

MEBS6016 Energy Performance of Buildings

<http://www.mech.hku.hk/bse/MEBS6016/>



Introduction



Dr. Sam C. M. Hui

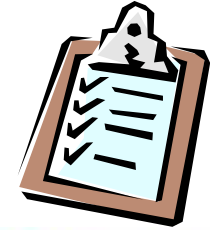
Department of Mechanical Engineering

The University of Hong Kong

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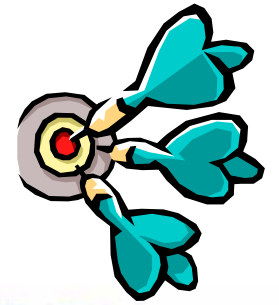
Dec 2012

Contents



- Course Overview ← Prepare you to study
- Energy Basics ← Things you should know
- Energy Use in Buildings ← Understand current status
- Energy Efficiency ← Some ideas to consider

Course Overview



- MEBS6016 Energy Performance of Buildings
- Lecturers:



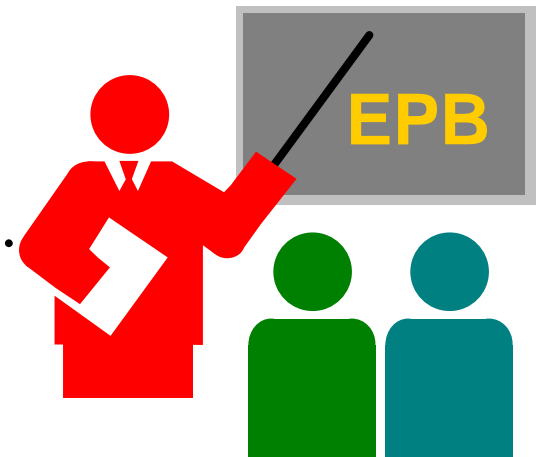
Dr. Sam C. M. Hui

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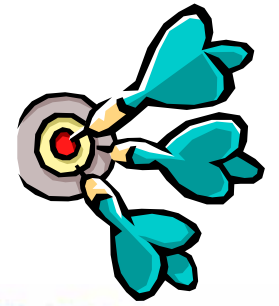


• *Dr. JIANG Wei*

- Email: jiangwei@gmail.com
- Associate Director, WSP Hong Kong Ltd.



Course Overview

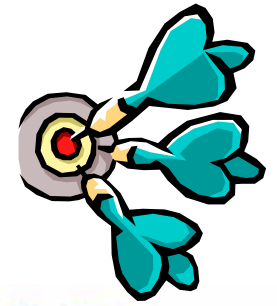


- *Dr. Sam C. M. Hui*



- 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, Association 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

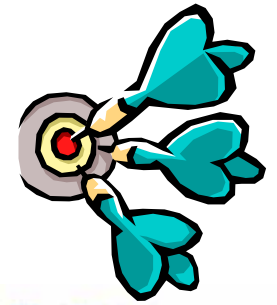


Course Overview



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

Course Overview



- Study Topics:

- 1) Introduction
- 2) Energy efficiency in buildings (I) & (II)
- 3) Energy information systems
- 4) Energy auditing of buildings
- 5) Economic and financial analysis

Dr. Sam Hui

-
- 6) Energy efficient technologies
 - 7) Building energy standards & codes
 - 8) Building energy simulation

Dr. JIANG Wei

Course Overview



- Learning Methods:
 - Lectures
 - Assigned Reading
 - Exercises
- Learning Resources:
 - References
 - Web Links
 - Course Website
 - Moodle



Course Overview

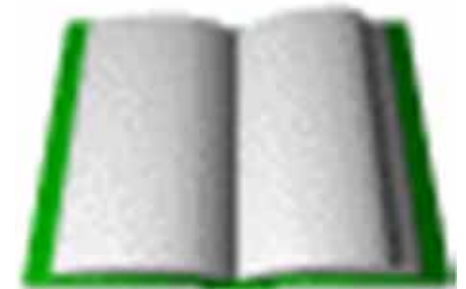


- Assessment Method

- 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

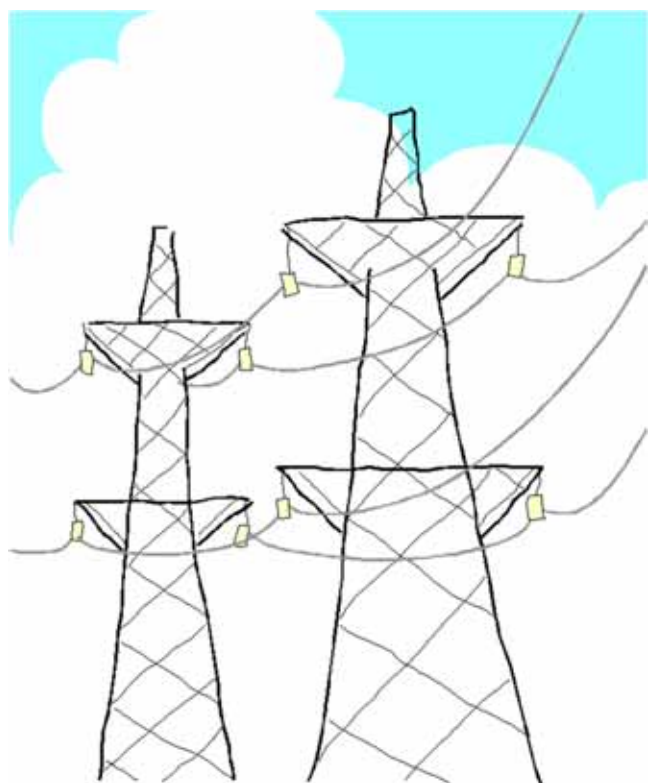


- Units of energy*
 - Kilowatt-hour (kWh), $1 \text{ kWh} = 3.6 \times 10^6 \text{ joule}$
 - $1 \text{ kWh} = 3.6 \text{ MJ} = 860 \text{ kcal} = 3412 \text{ Btu}$
 - Calorie (卡路里), $1 \text{ calorie (cal)} = 4.2 \times 10^3 \text{ J}$
 - British thermal unit (Btu), $1 \text{ Btu} = 1.055 \times 10^3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

(*See also <http://www.aps.org/policy/reports/popa-reports/energy/units.cfm>)



能源



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

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

Energy Basics

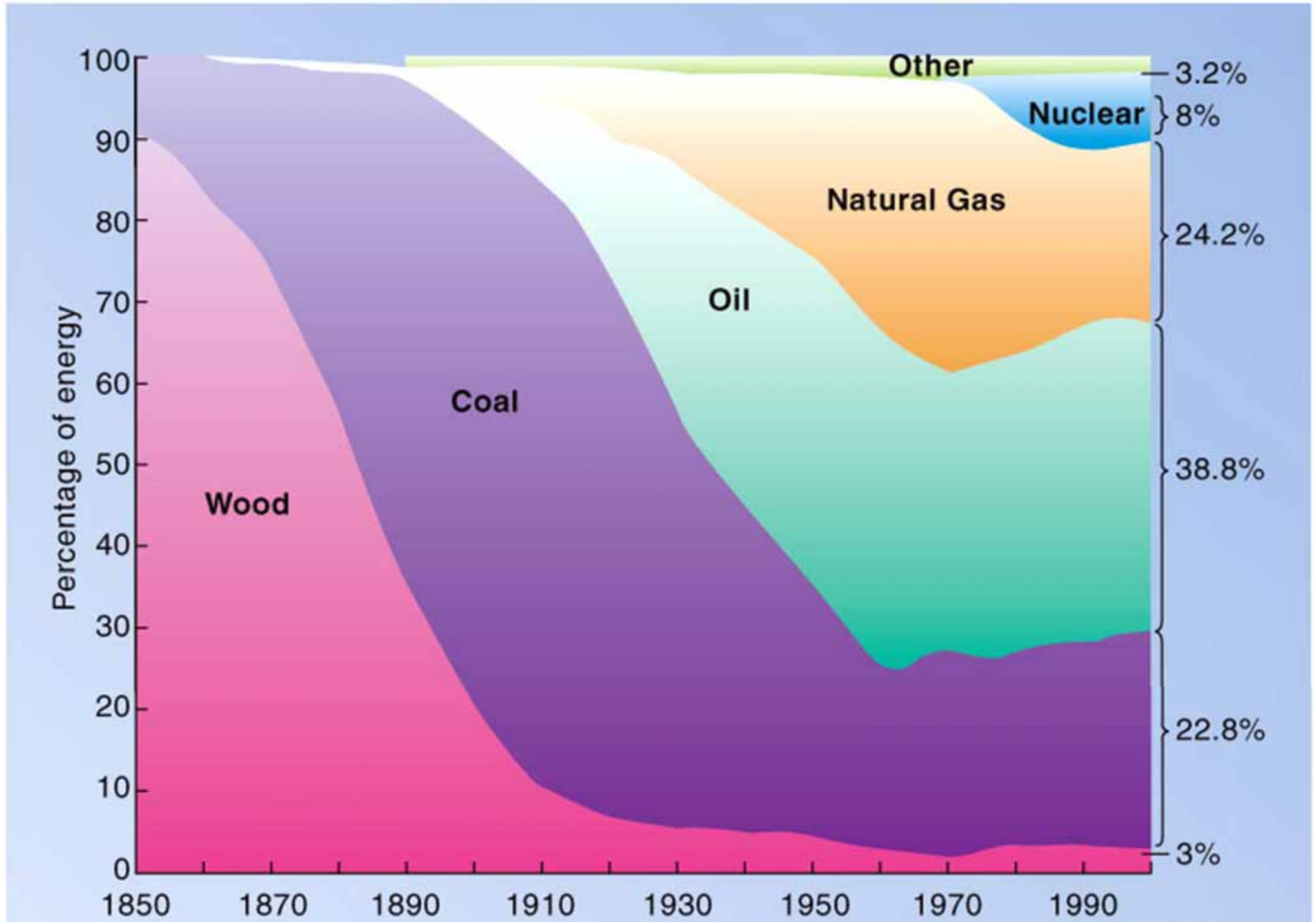


- Energy end-use: (*Demand side, final energy*)
 - Air-conditioning and ventilation
 - Lighting
 - Equipment
 - Hot water
 - Cooking
 - Industrial processes
 - Transportation



Changes in Energy Sources in Year 1850-2000

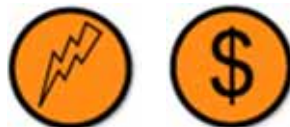
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Energy Basics



- **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

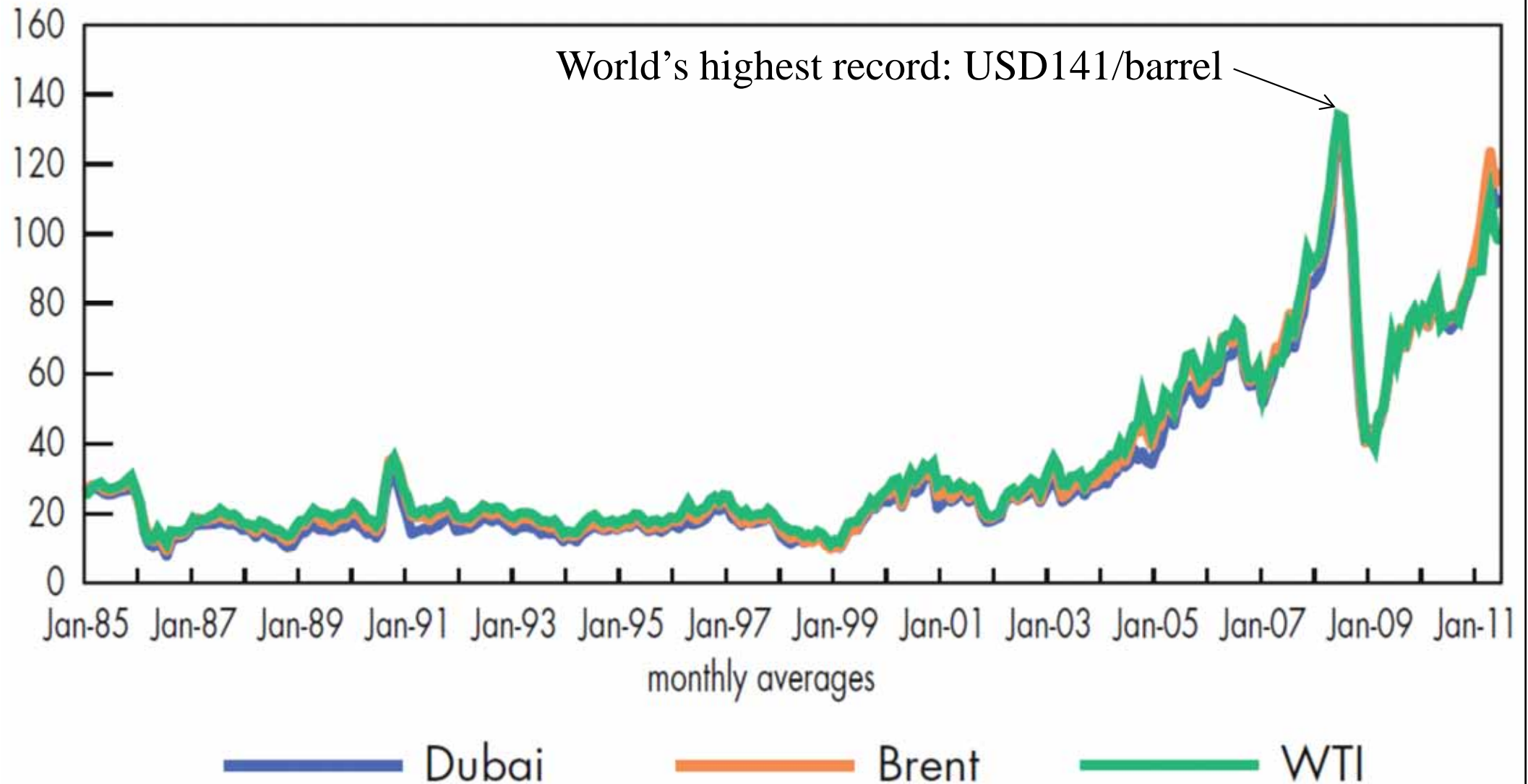


Energy Basics



- 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

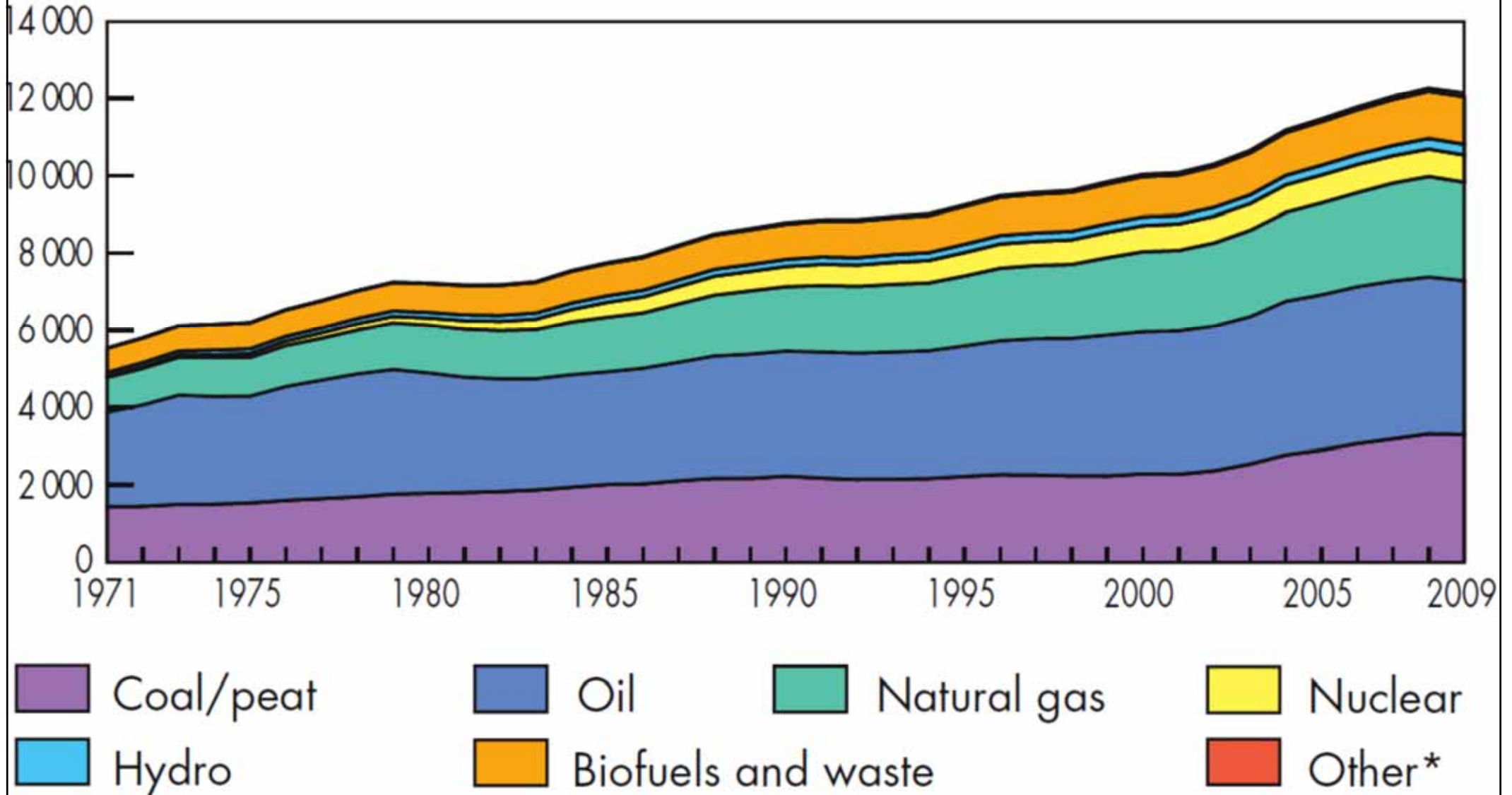
Key crude oil spot prices in USD/barrel



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

(TPES)

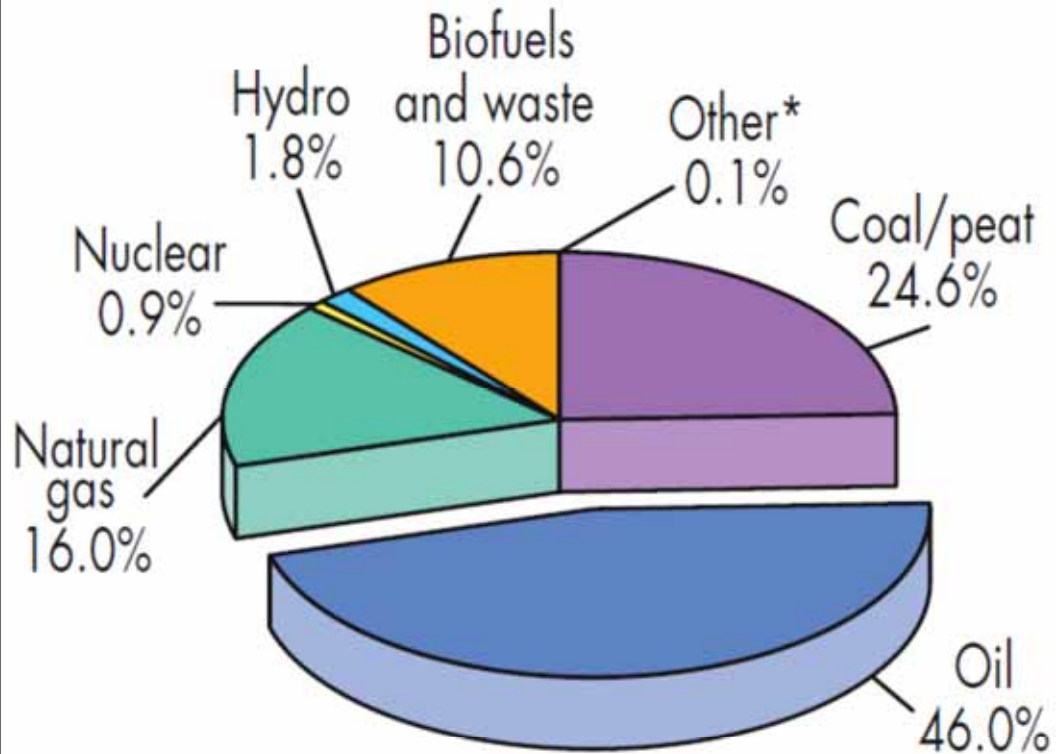
World total primary energy supply from 1971 to 2009 by fuel (Mtoe)



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

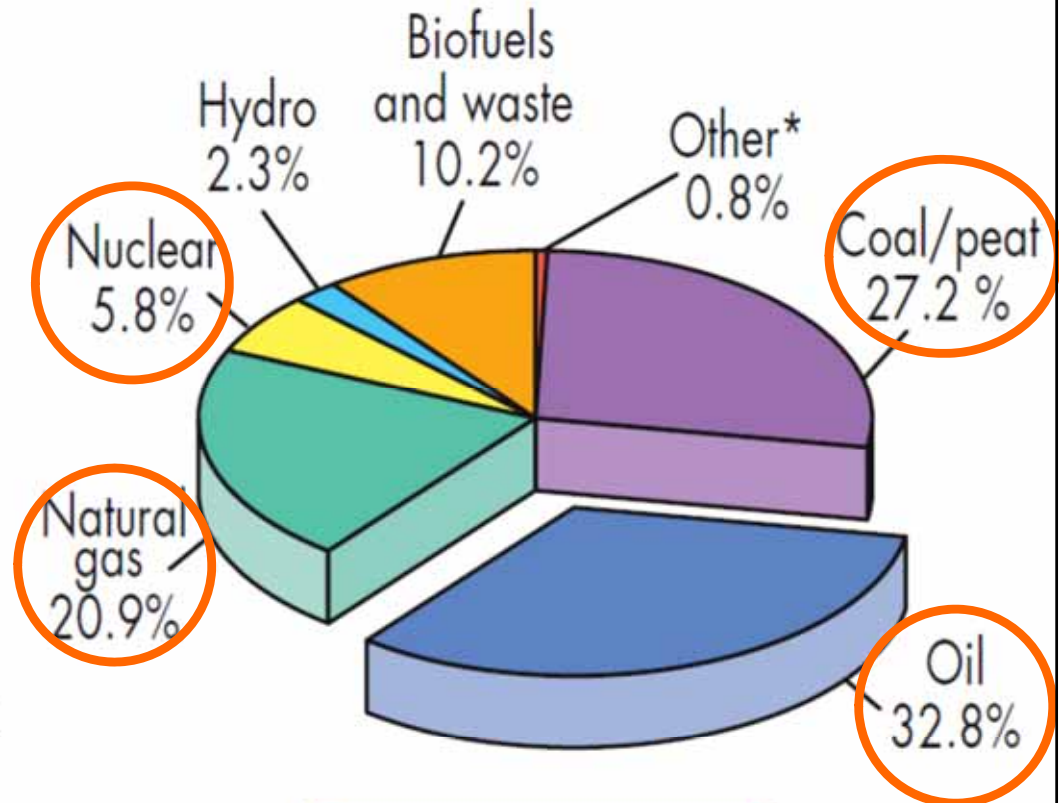
1973 and 2009 fuel shares of TPES

1973



6 111 Mtoe

2009

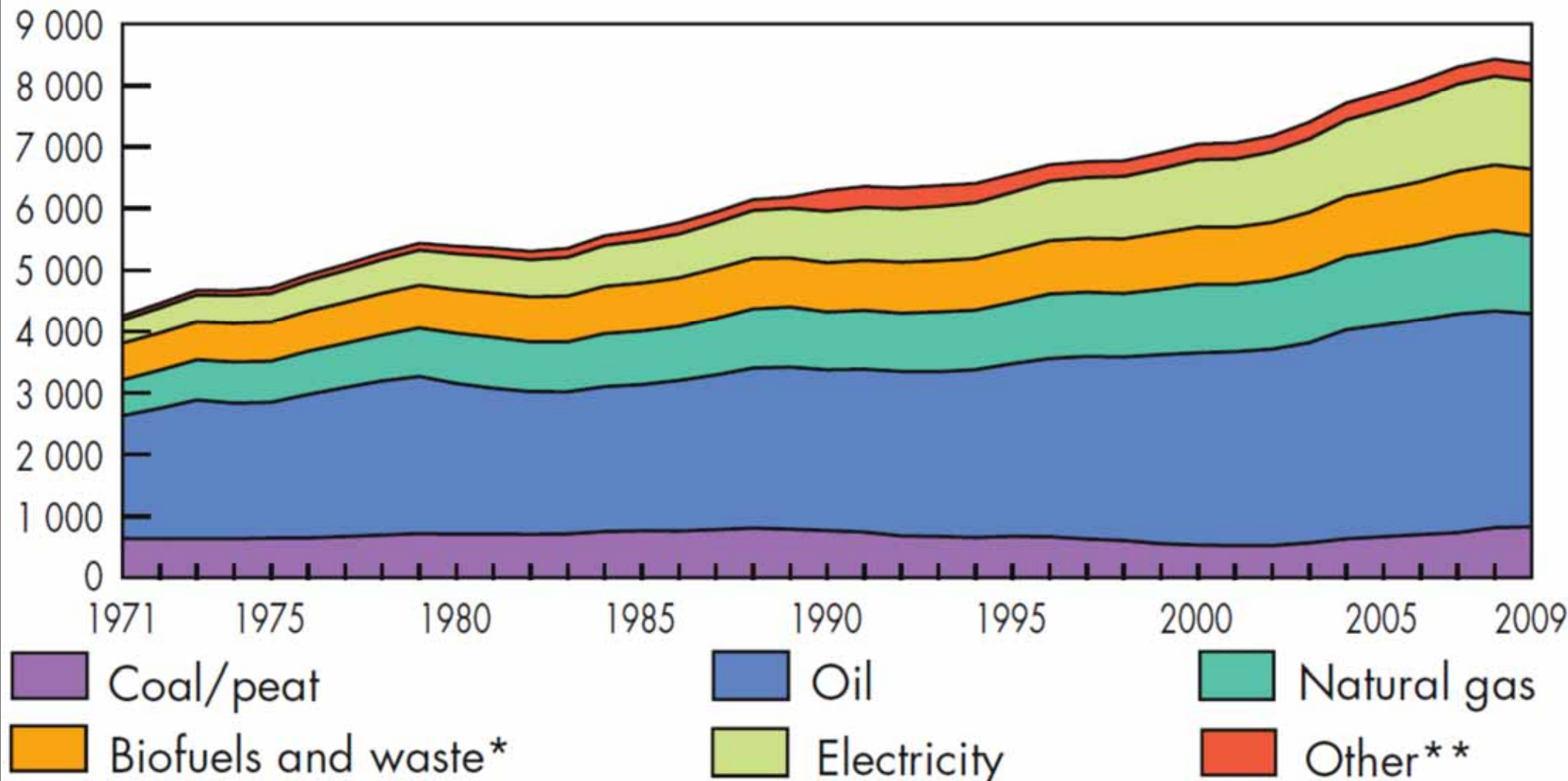


12 150 Mtoe

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

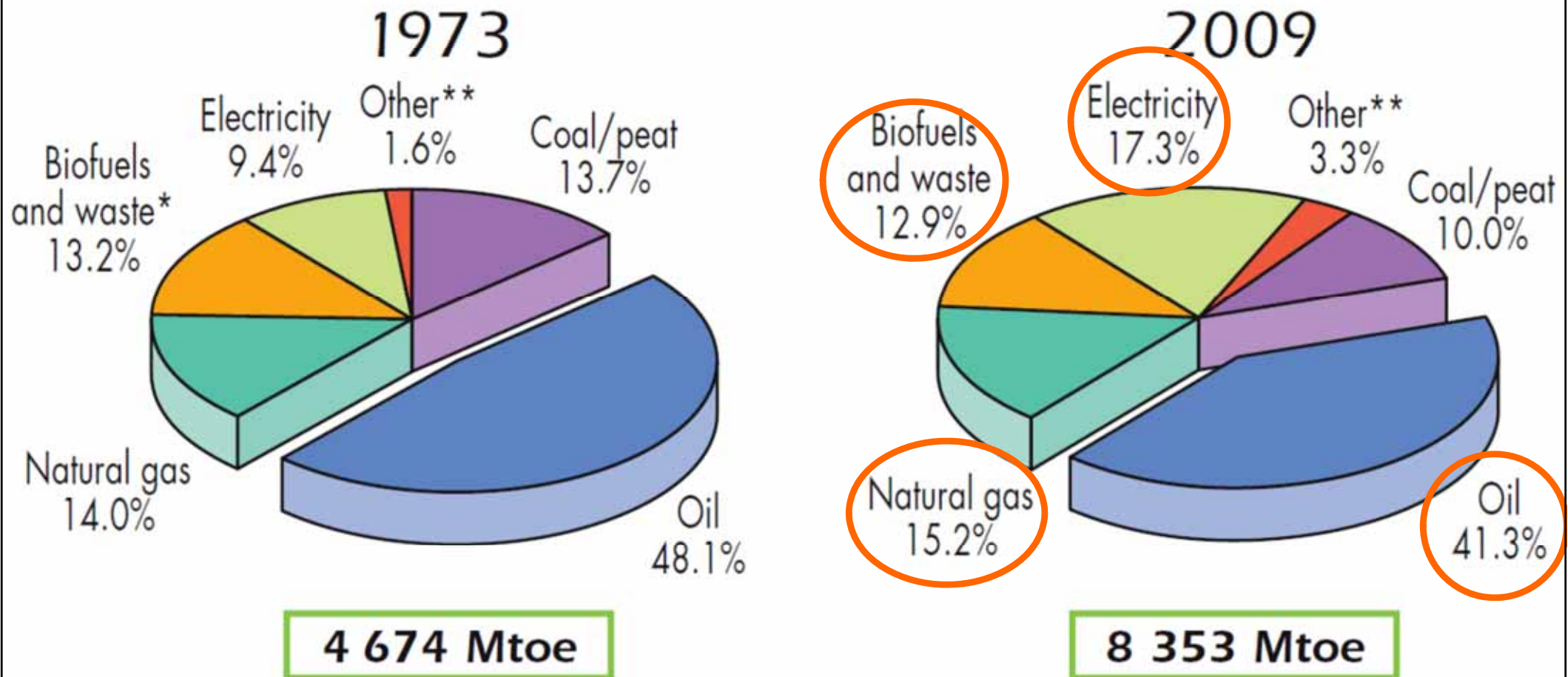
(* Source: IEA, 2011. *Key World Energy Statistics 2011*, International Energy Agency, Paris. Available at www.iea.org)

World total final consumption from 1971 to 2009 by fuel (Mtoe)



(* 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



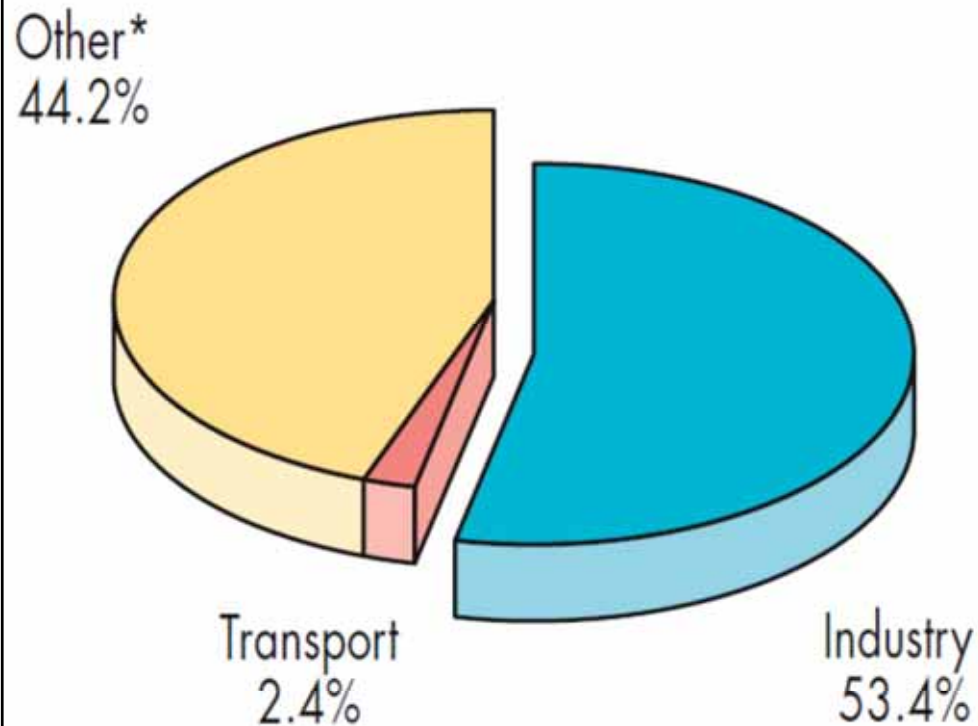
*Data prior to 1994 for biofuels and waste final consumption have been estimated.

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

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

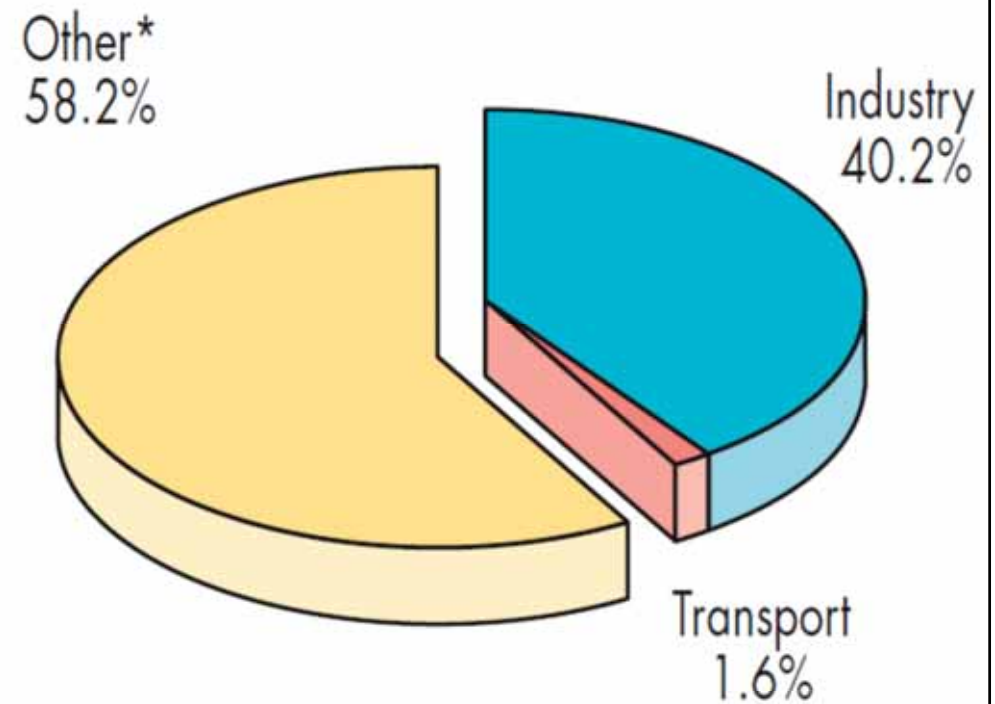
1973 and 2009 shares of world electricity consumption

1973



439 Mtoe

2009

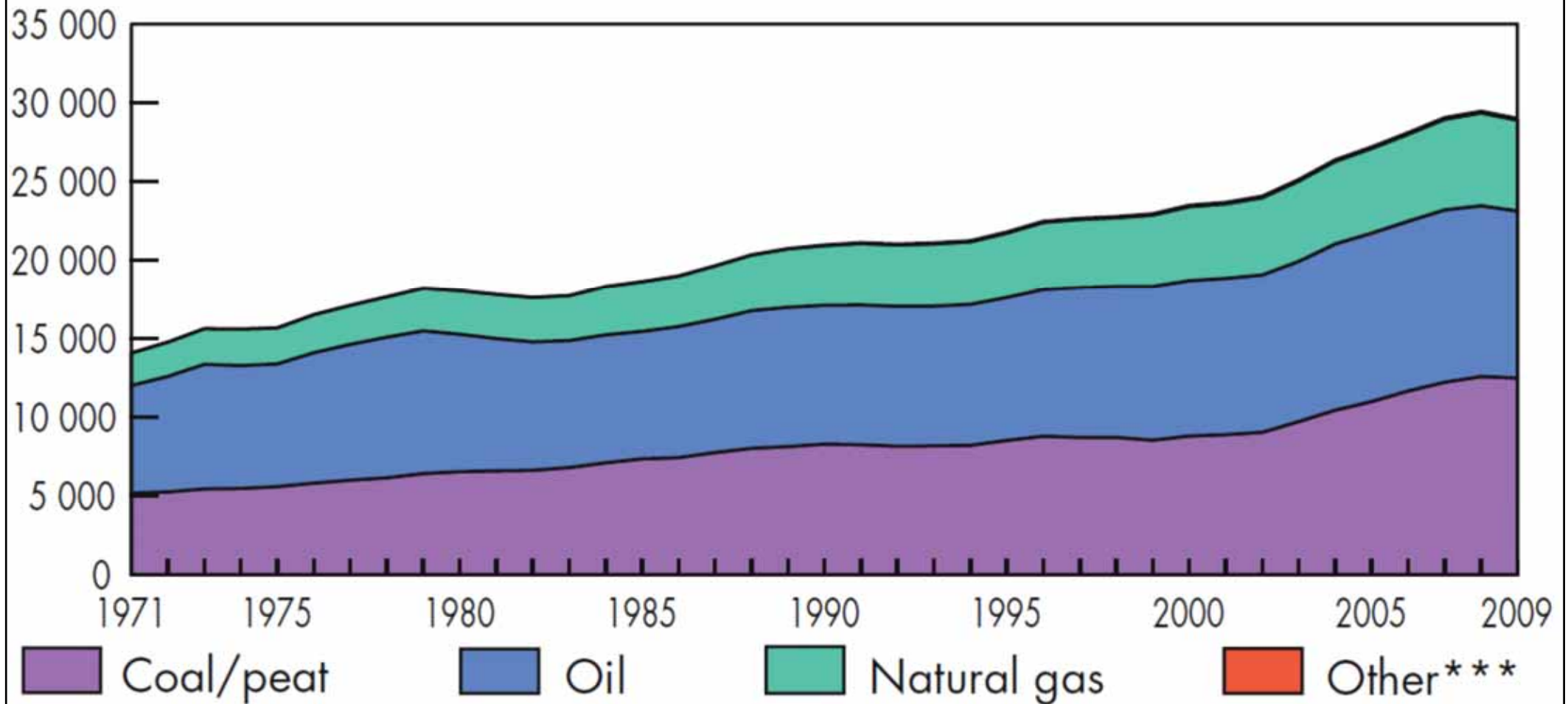


1 441 Mtoe

**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)

World* CO₂ emissions** from 1971 to 2009 by fuel (Mt of CO₂)



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

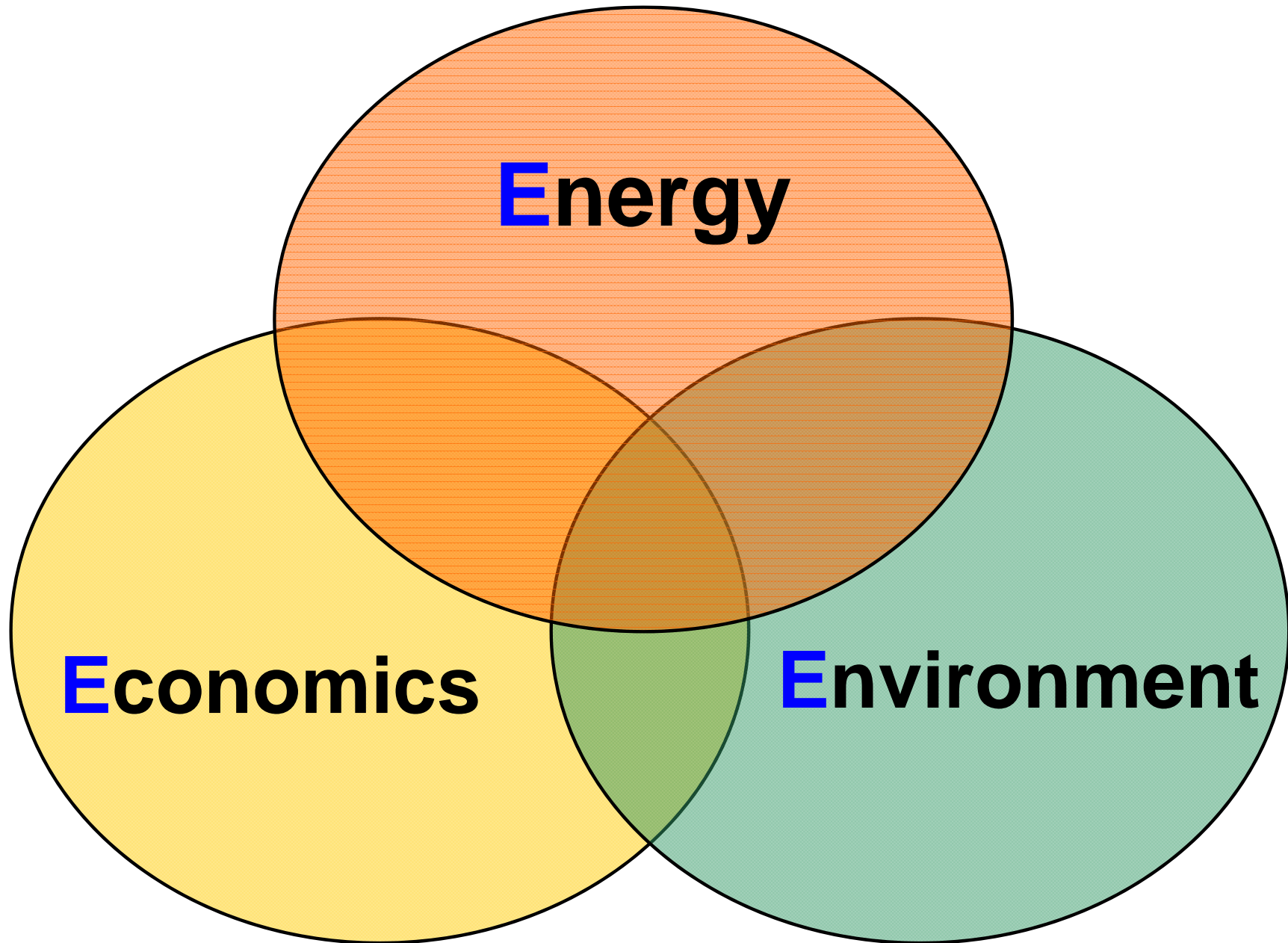
(* Source: IEA, 2011. *Key World Energy Statistics 2011*, International Energy Agency, Paris. Available at www.iea.org)

Energy indicators for 2009

Economy	Population (million)	GDP/pop (yr2000 USD)	TPES/pop (toe/ capita)	TPES/GDP (toe/yr2000 USD)	CO₂/pop (t CO₂/ capita)	CO₂/GDP (kg CO₂/ 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)

3 'E' Relationships



Energy Basics



- Significance of energy management

- Economics

- Energy costs and operating costs

- Energy security

- Energy supply (political and economic reasons)

- Environment

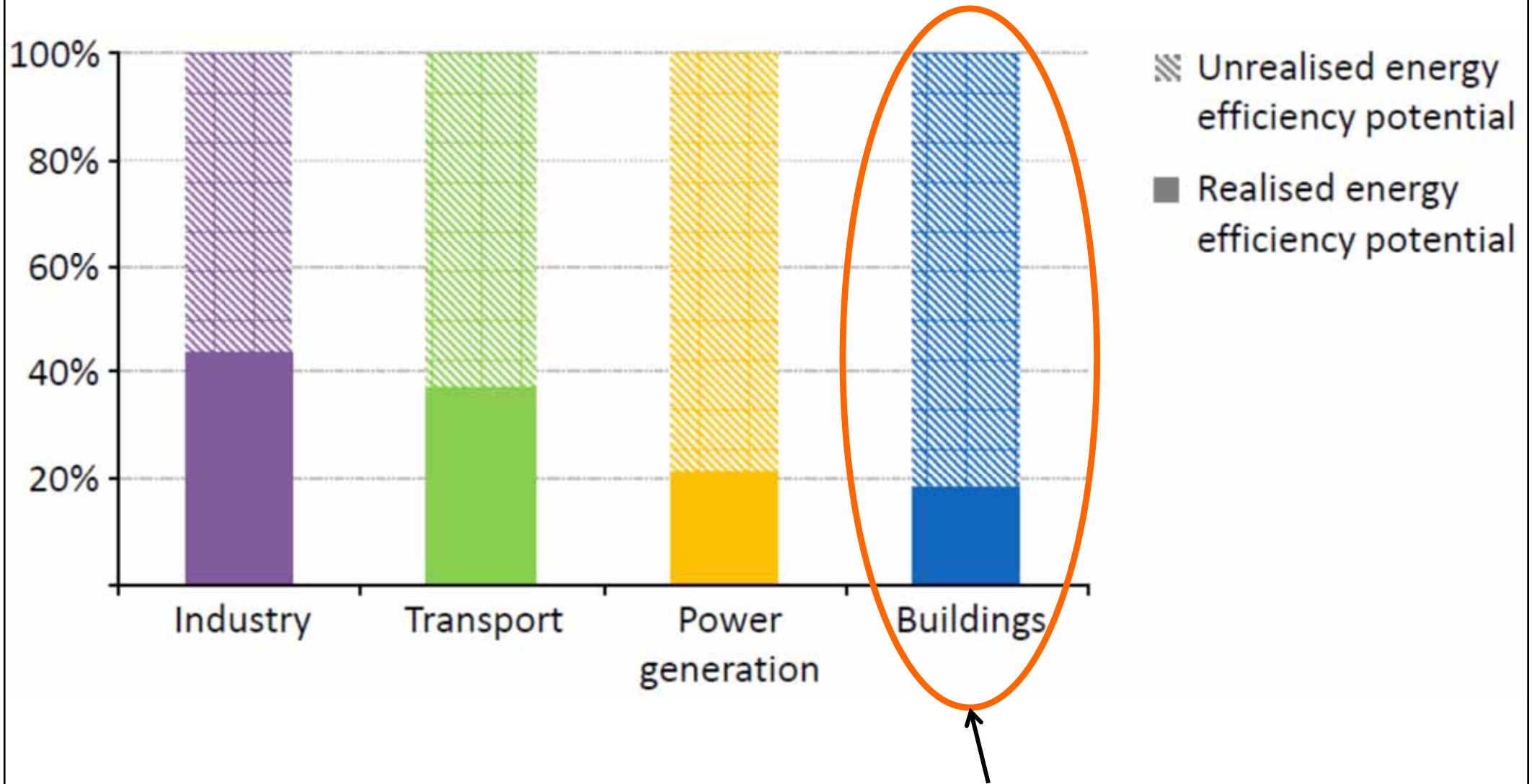
- Climate change, global warming, air pollution

- Resources depletion

- Oil, gas and coal will be used up



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



The building sector has the largest potential

Energy Use in Buildings

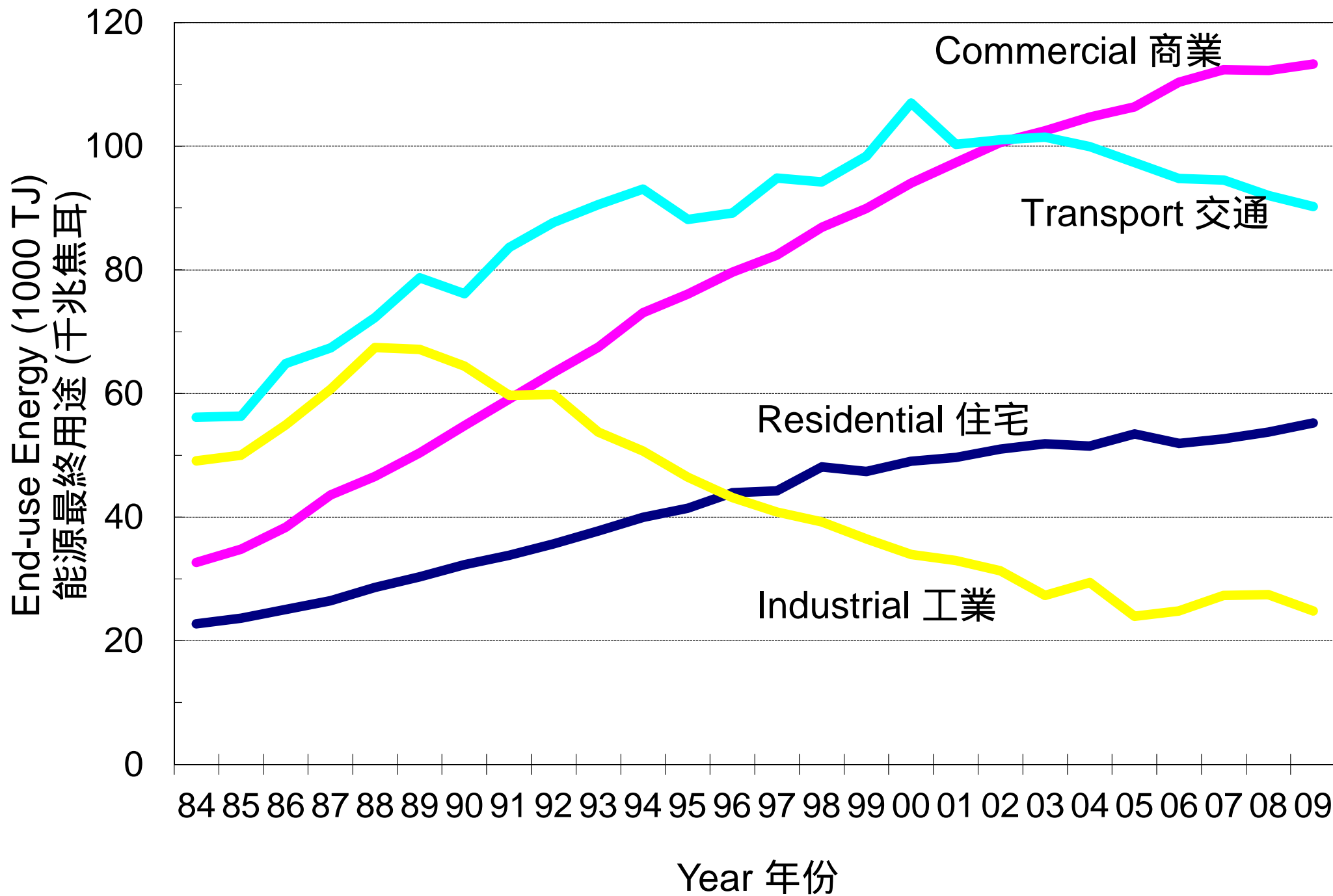


- About 90% of total electricity consumption in Hong Kong is contributed by buildings
- Buildings constitute 30-50% of energy needs
 - Residential + commercial + industrial
 - The potential for energy saving is large
- The real cost of energy
 - Energy price + Environmental costs (e.g. \$\$ for pollution control & “repairing” of environmental damages)

Energy Use in Buildings

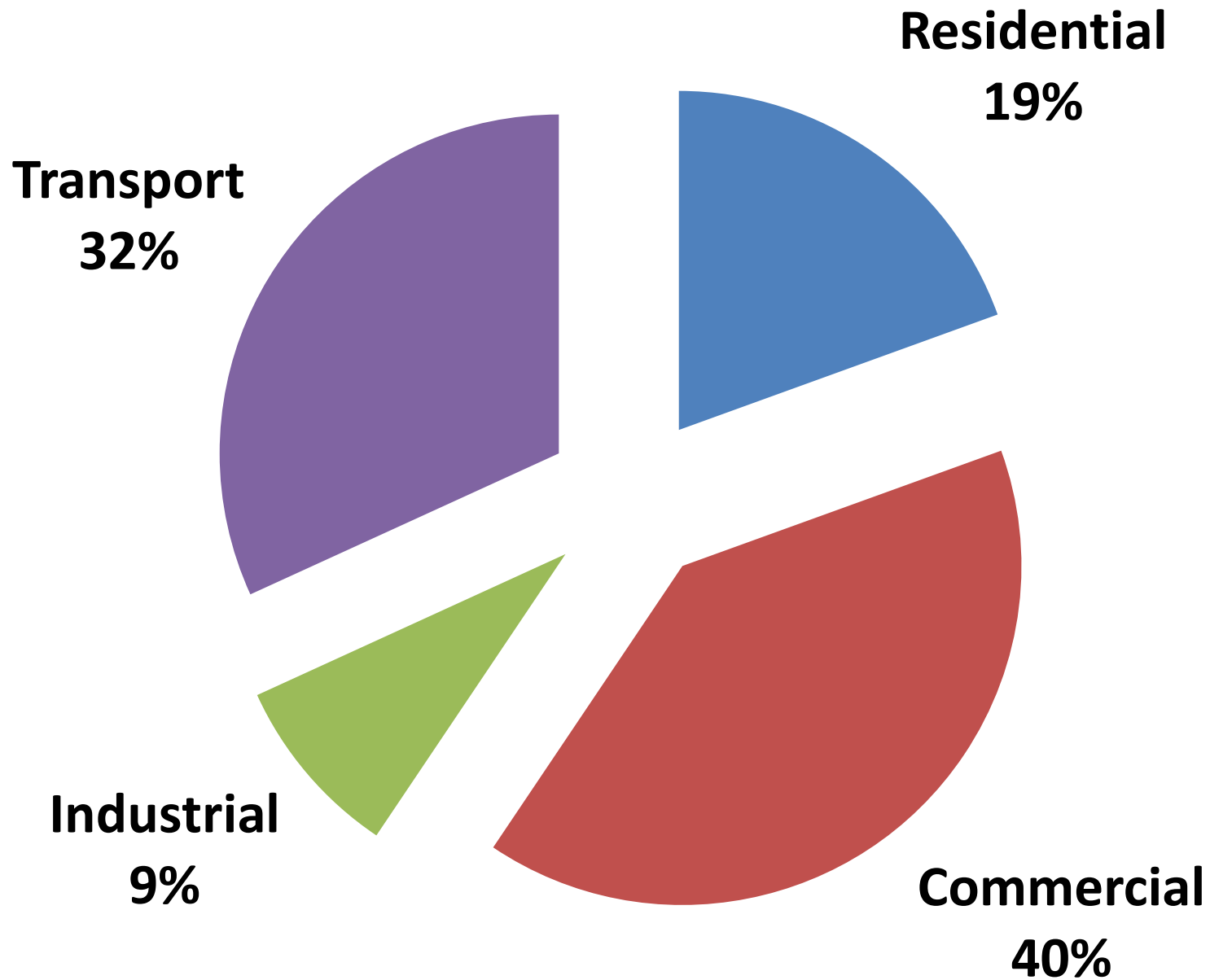


- Possible benefits from energy efficiency:
 - 1. Improved building design and operation
 - 2. Better working environments
 - 3. Life-cycle cost savings
 - 4. Added market value of buildings
 - 5. Reduced CO₂ emissions and consumption of finite fossil fuels
 - 6. Reduced capital cost by better integration of building fabric and systems



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

Energy end-use by sector (2009)



Energy end-use in Hong Kong

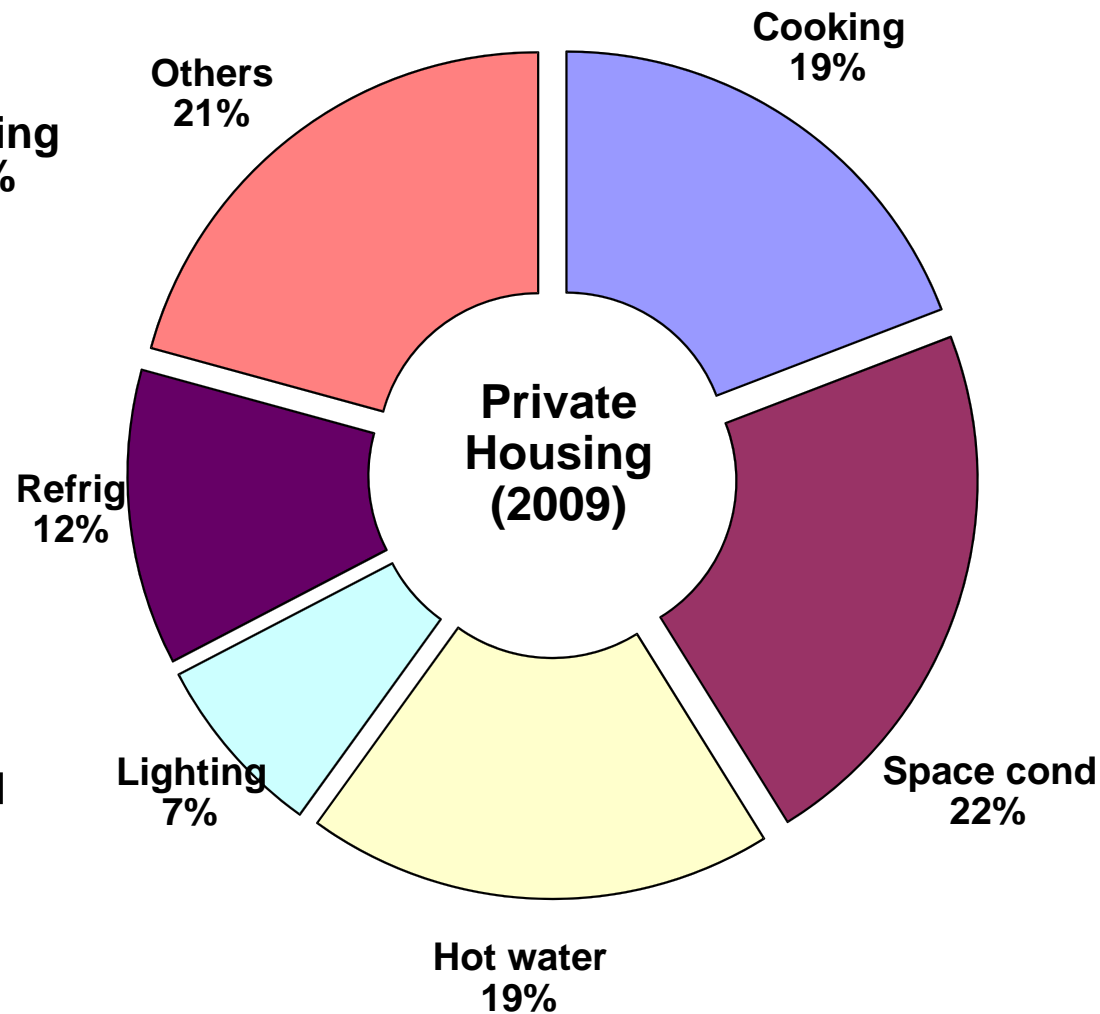
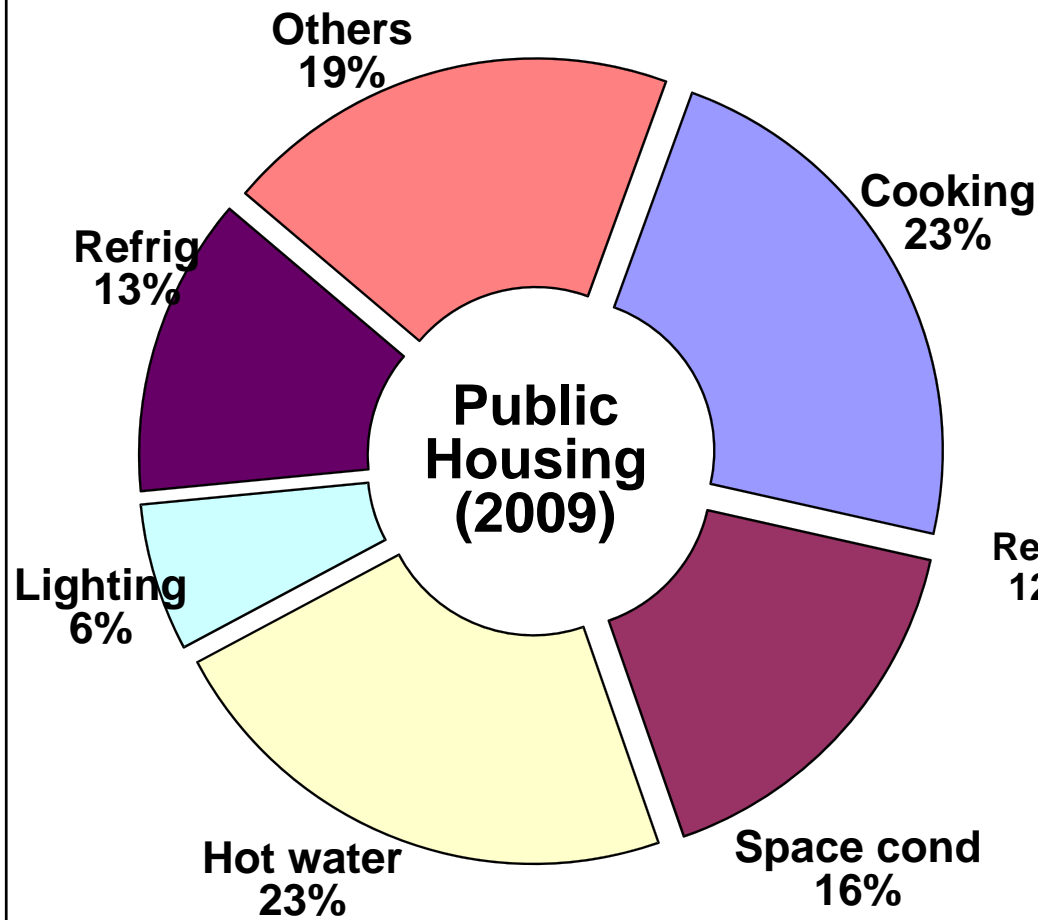
(Data source: EMSD)

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

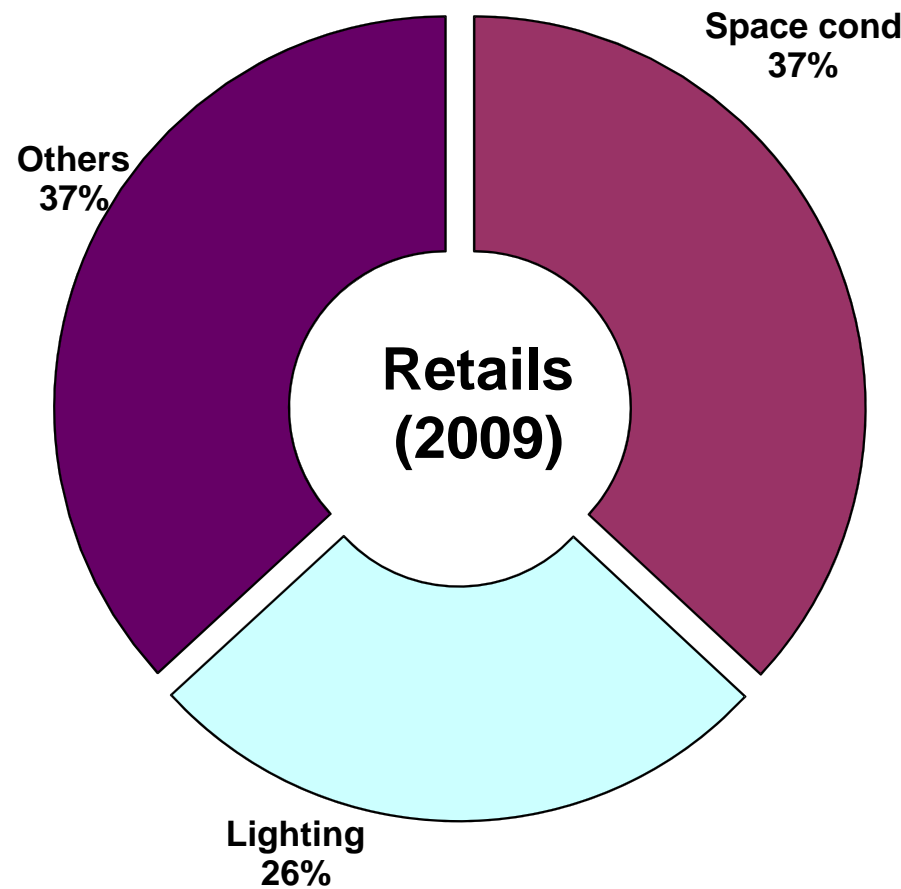
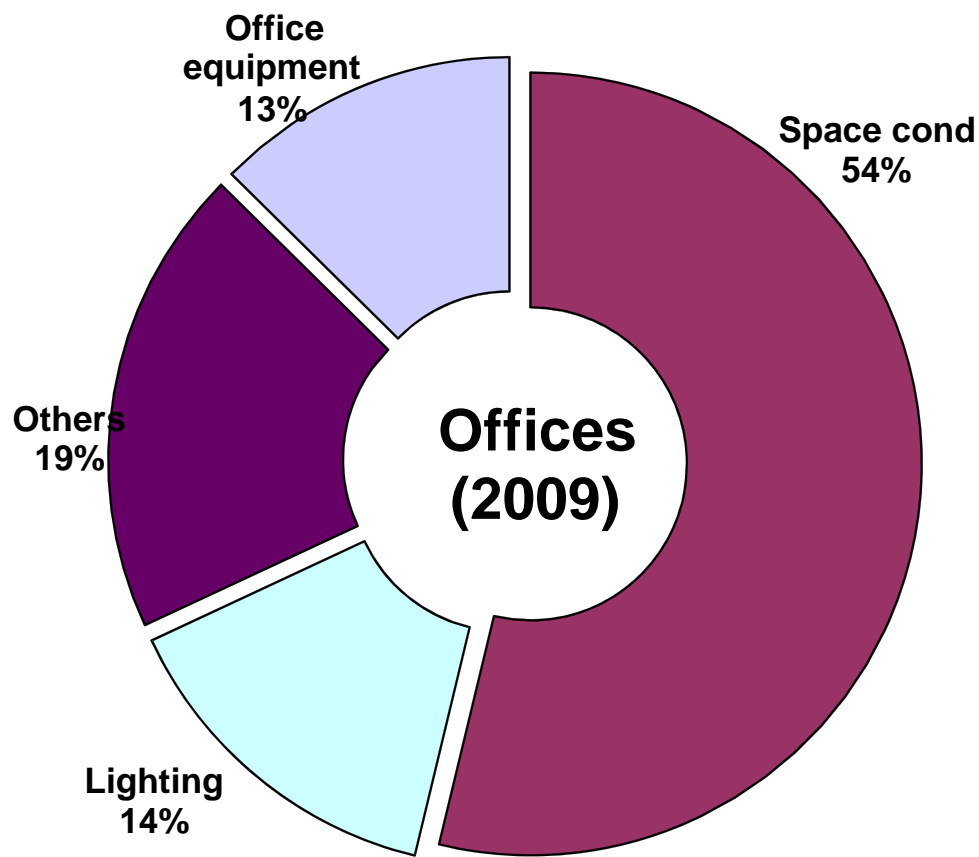
Unit: MJ	Commercial	Residential	Industrial	Total
Electricity	100 280 (67%)	39 344 (26%)	11 080 (7%)	150 705 (100%)
Town gas	11 389 (41%)	15 272 (55%)	917 (3%)	27 578 (100%)
Elec. + town gas	111 669	54 616	11 997	178 283
% in total FER	37.5%	18.4%	4.0%	59.9%

Total FER for 2010 = 297 488 TJ

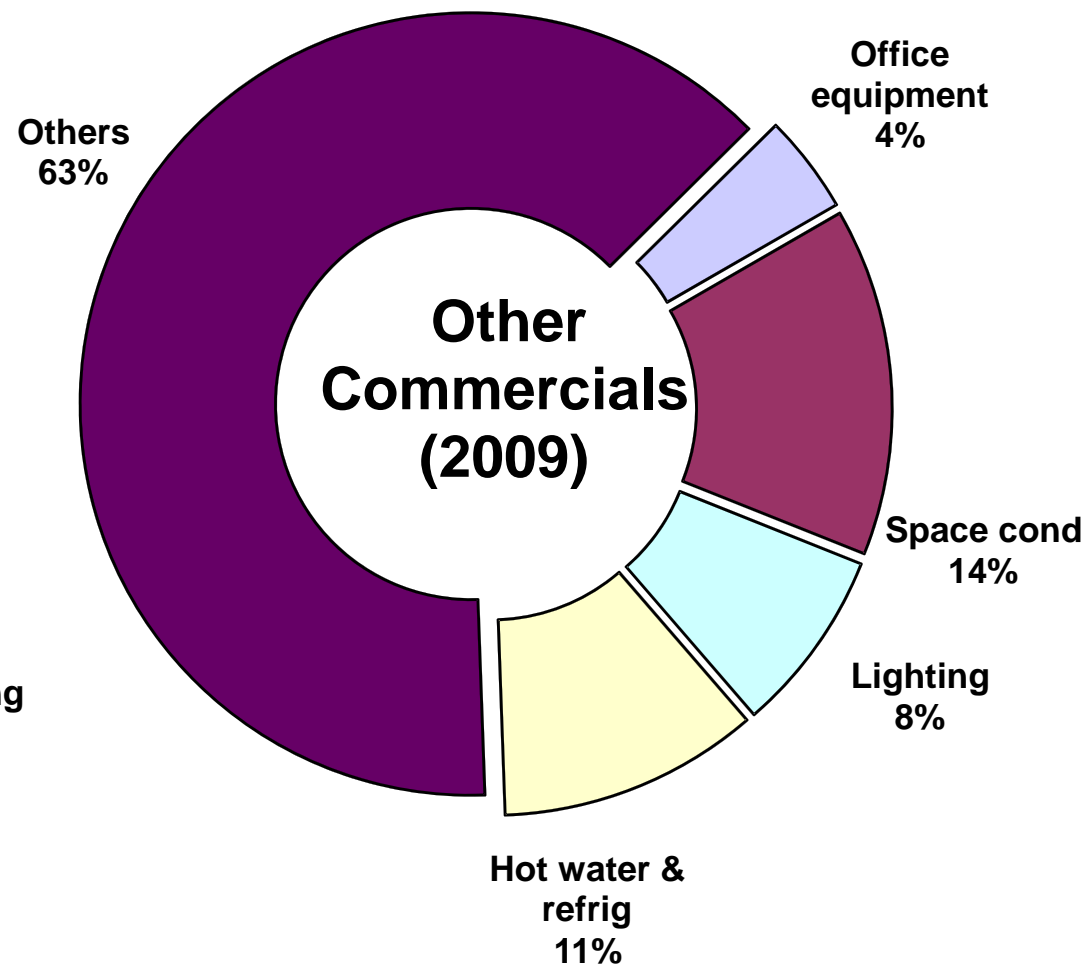
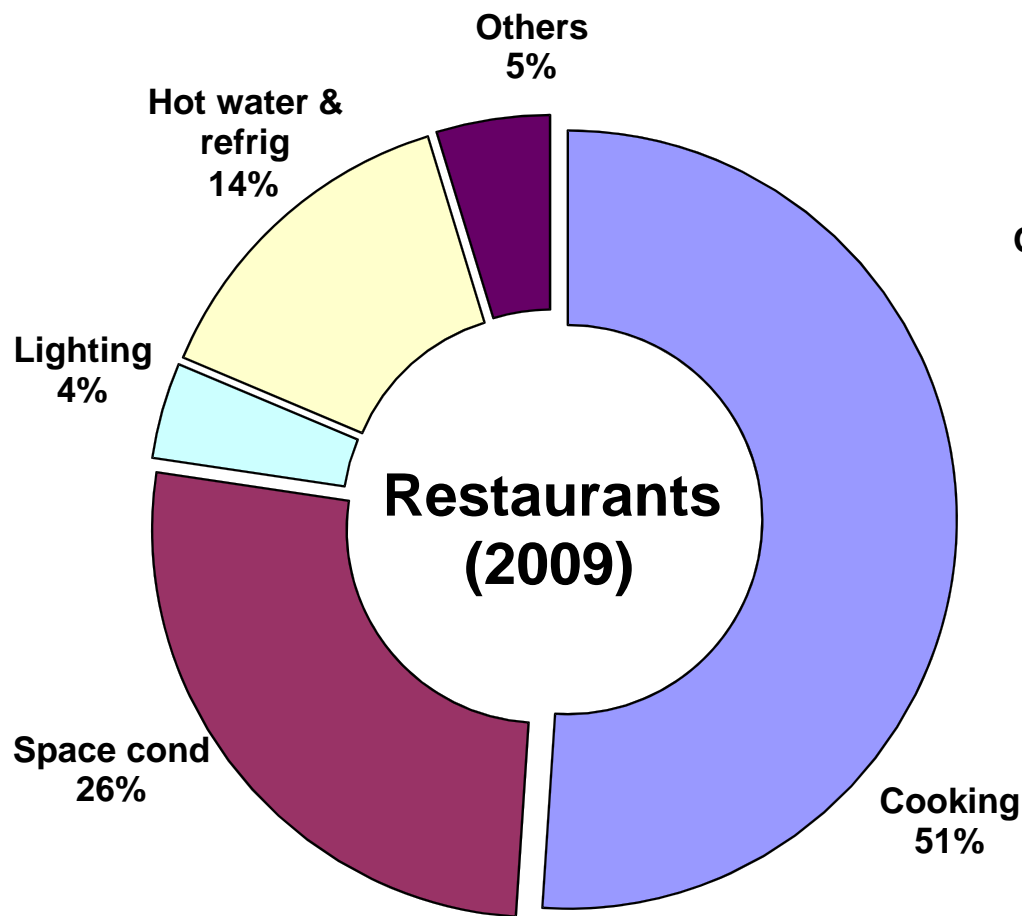
(* Data Source: *Hong Kong Energy Statistics 2010 Annual Report*)



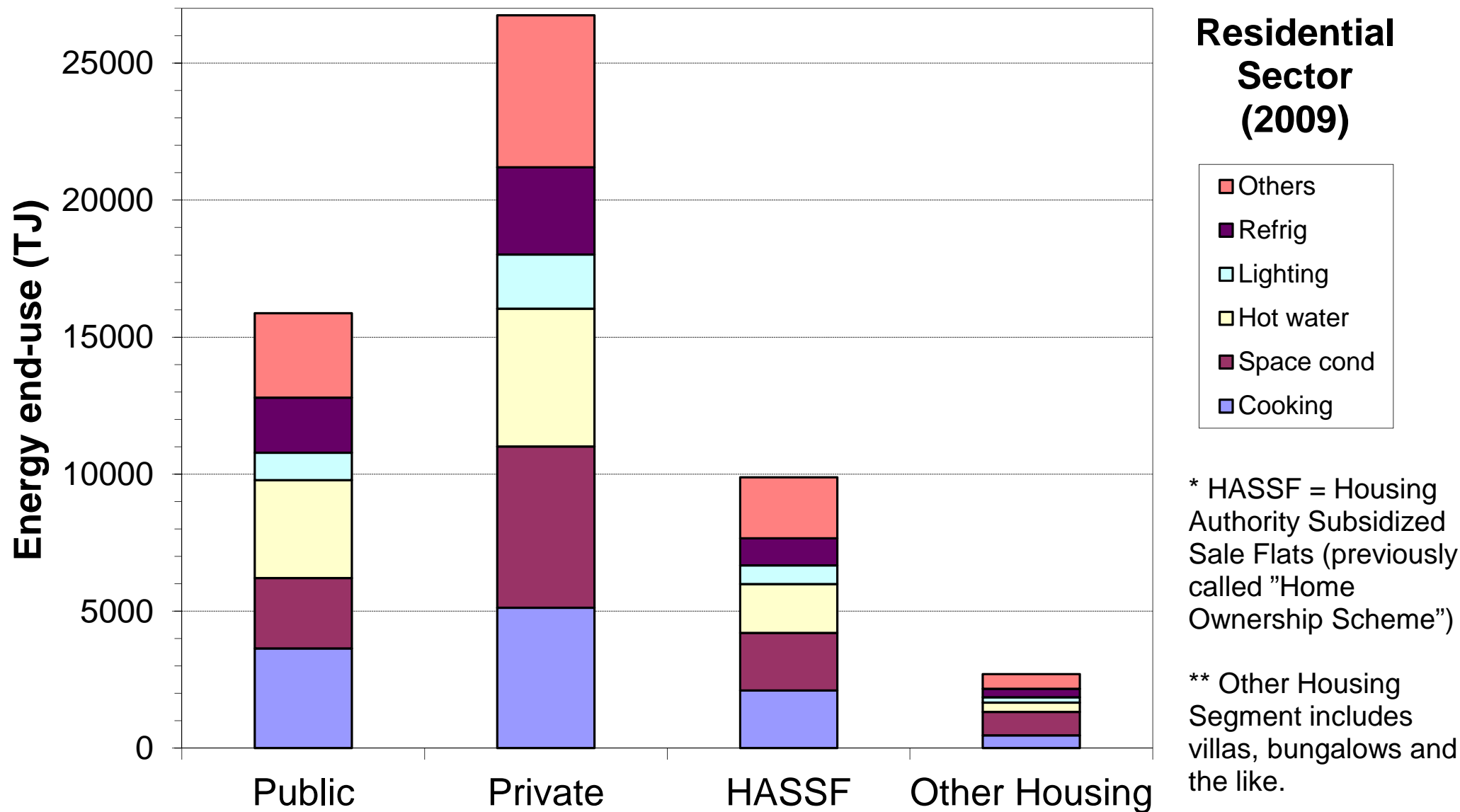
Energy consumption patterns in residential buildings
 (Data source: Energy Efficiency Office, HK)



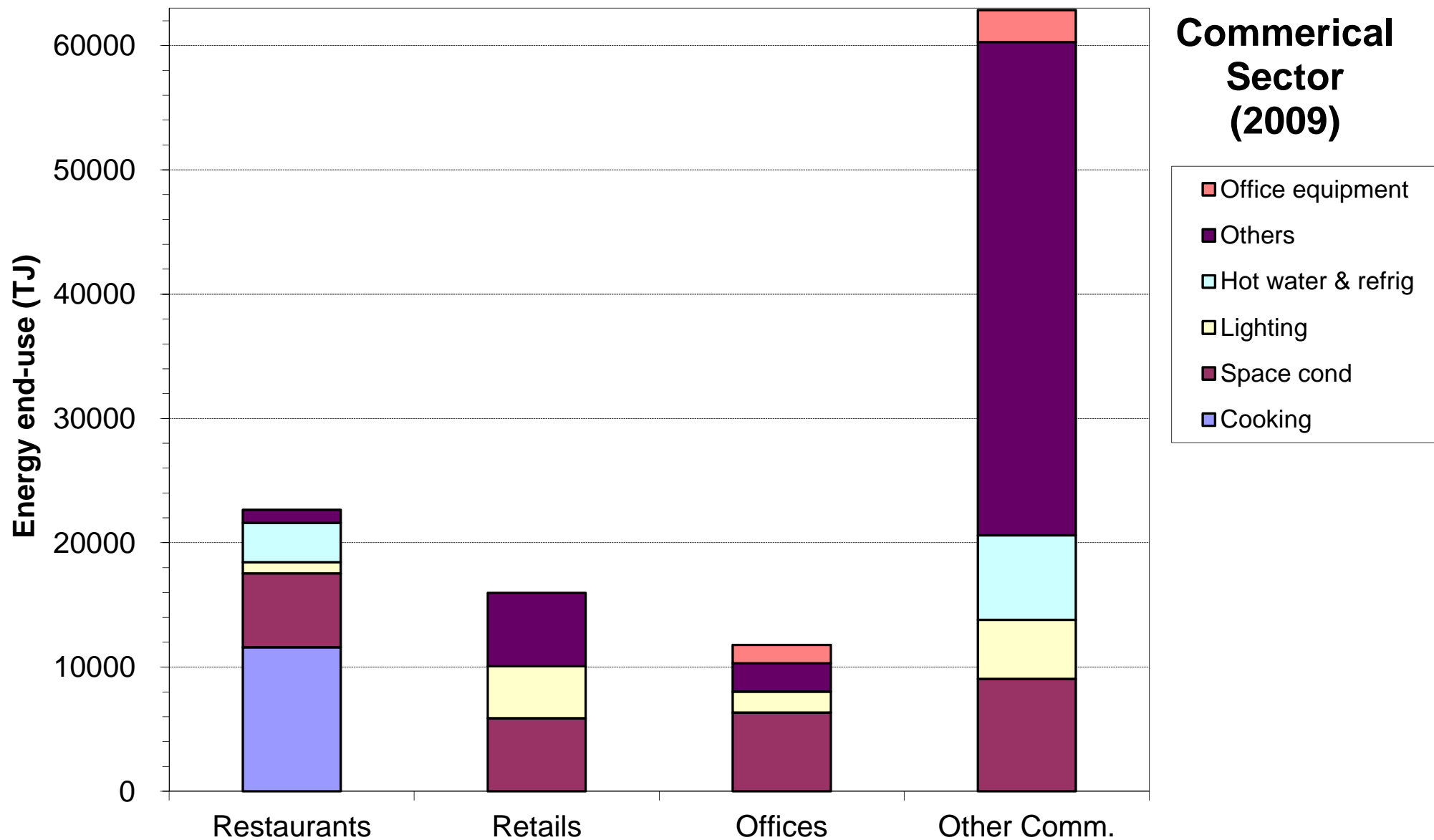
Energy consumption patterns in offices and retails
(Data source: Energy Efficiency Office, HK)



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)



機電工程署
EMSD



ENG

繁體

简体

《建築物能源效益條例》 The Buildings Energy Efficiency Ordinance



空調裝置
Air-conditioning installation



電力裝置
Electrical installation

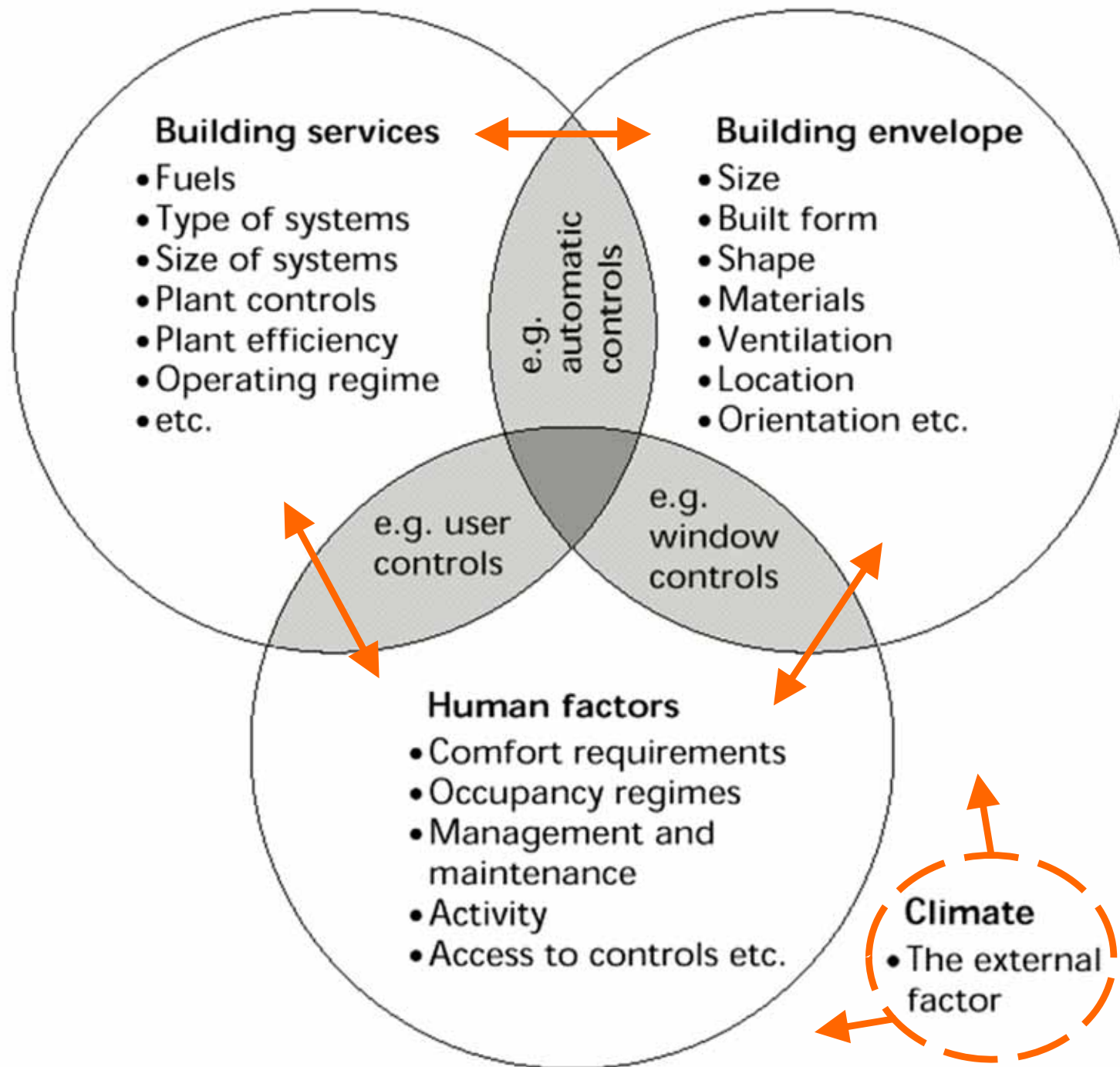


升降機及自動梯裝置
Lift & escalator installation



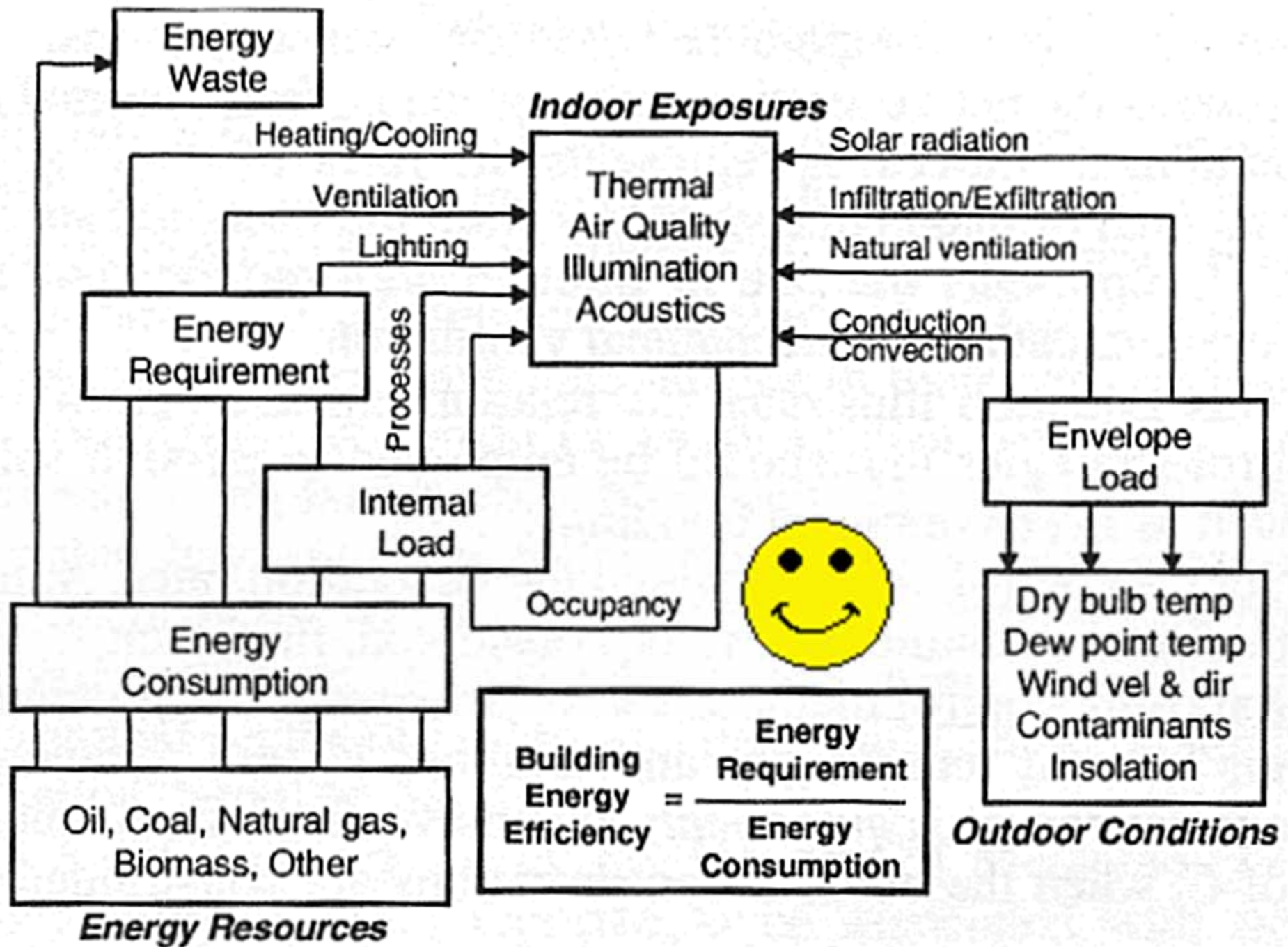
照明裝置
Lighting installation





Key factors influencing energy consumption

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



Energy flow and concept in buildings



Energy Efficiency

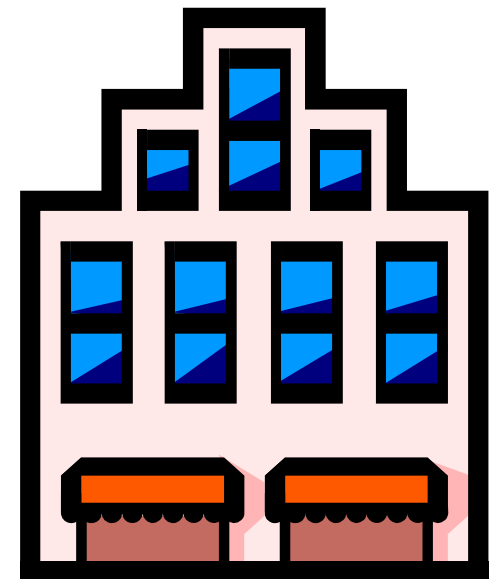
- Key persons in building energy efficiency
 - Building Developer or Owner (Client)
 - Architect
 - Building Services Engineer
 - Building/Facility Manager
 - End-Users





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



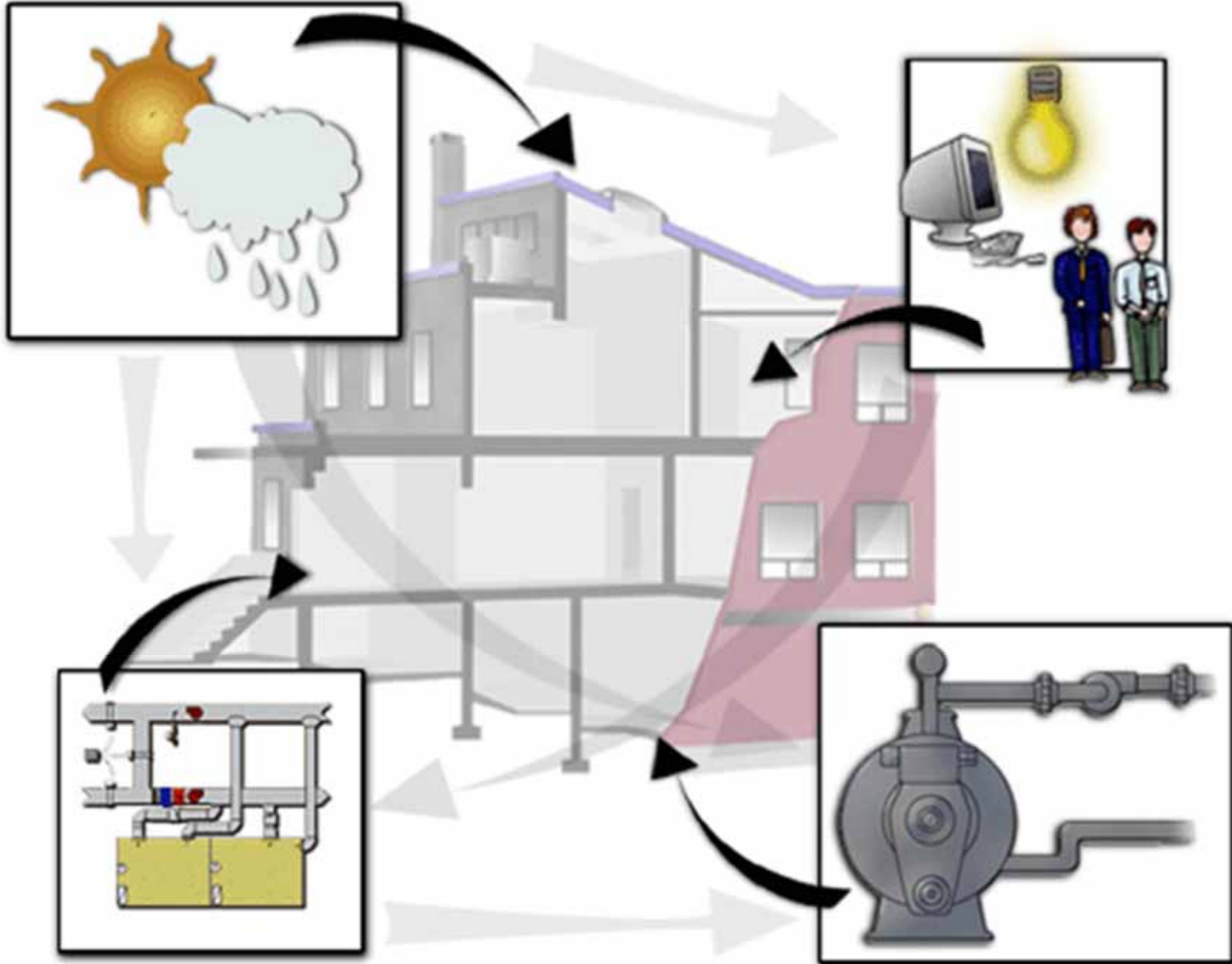


Energy Efficiency

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

External climate

Internal loads



Air-conditioning systems

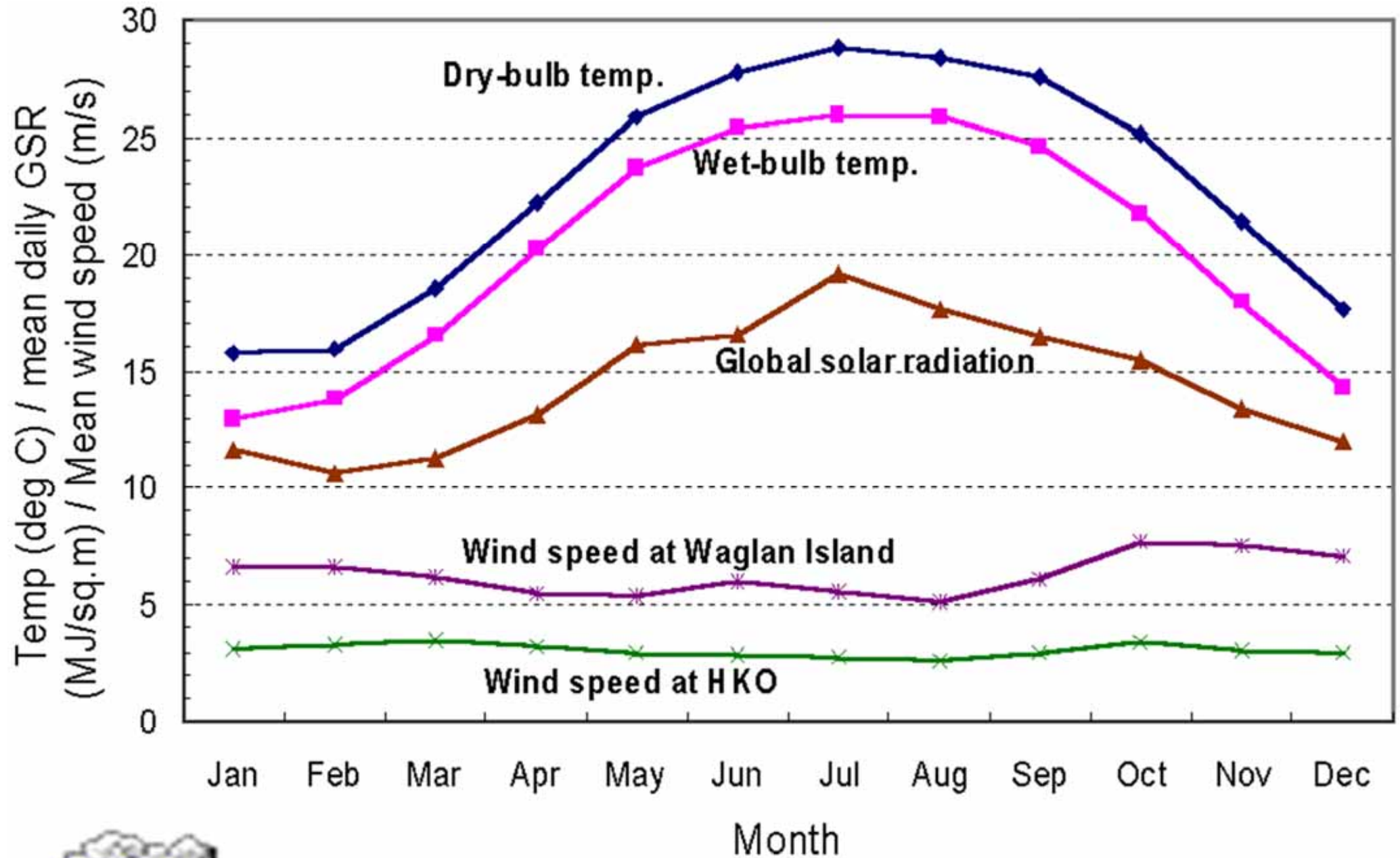
Chiller plants



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



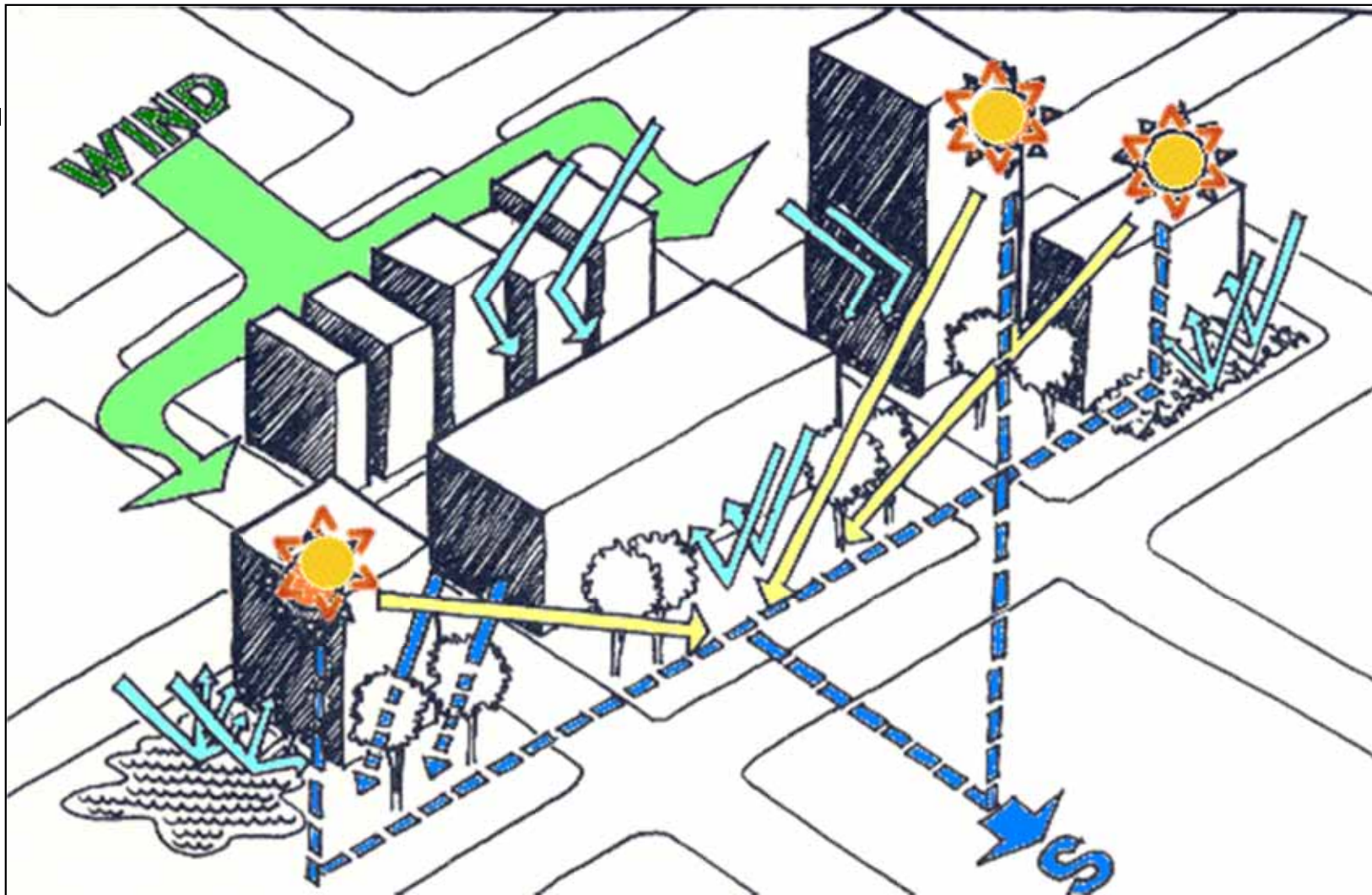
Building designer is like a “Feng Shui” master.

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)



* Face House, Kyoto, Japan

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

Main criteria:

- wall area
- window area
- thermal properties
- orientations
- thermal mass
- shading device



Energy Efficiency

- Major factors determining envelope heat flow:

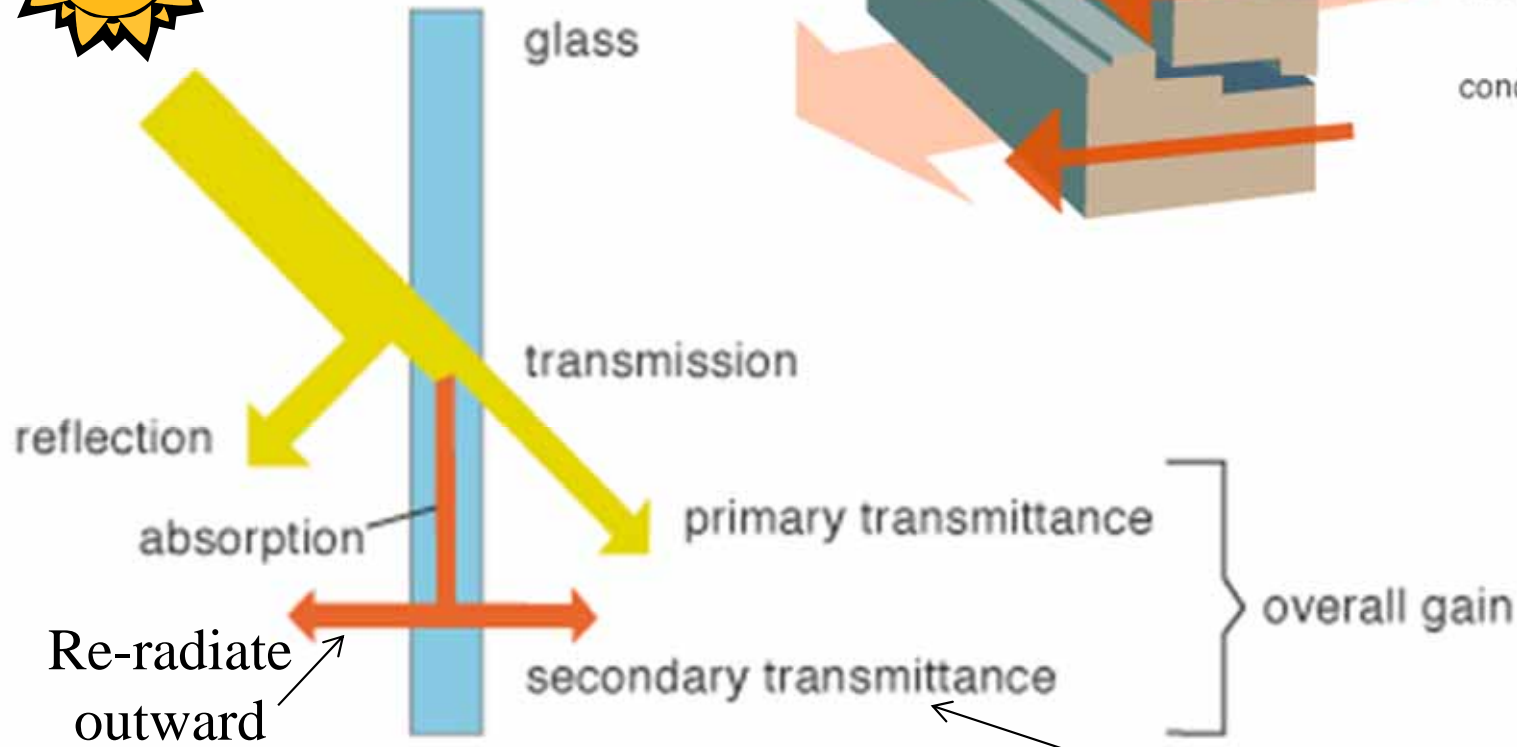
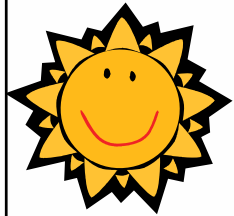
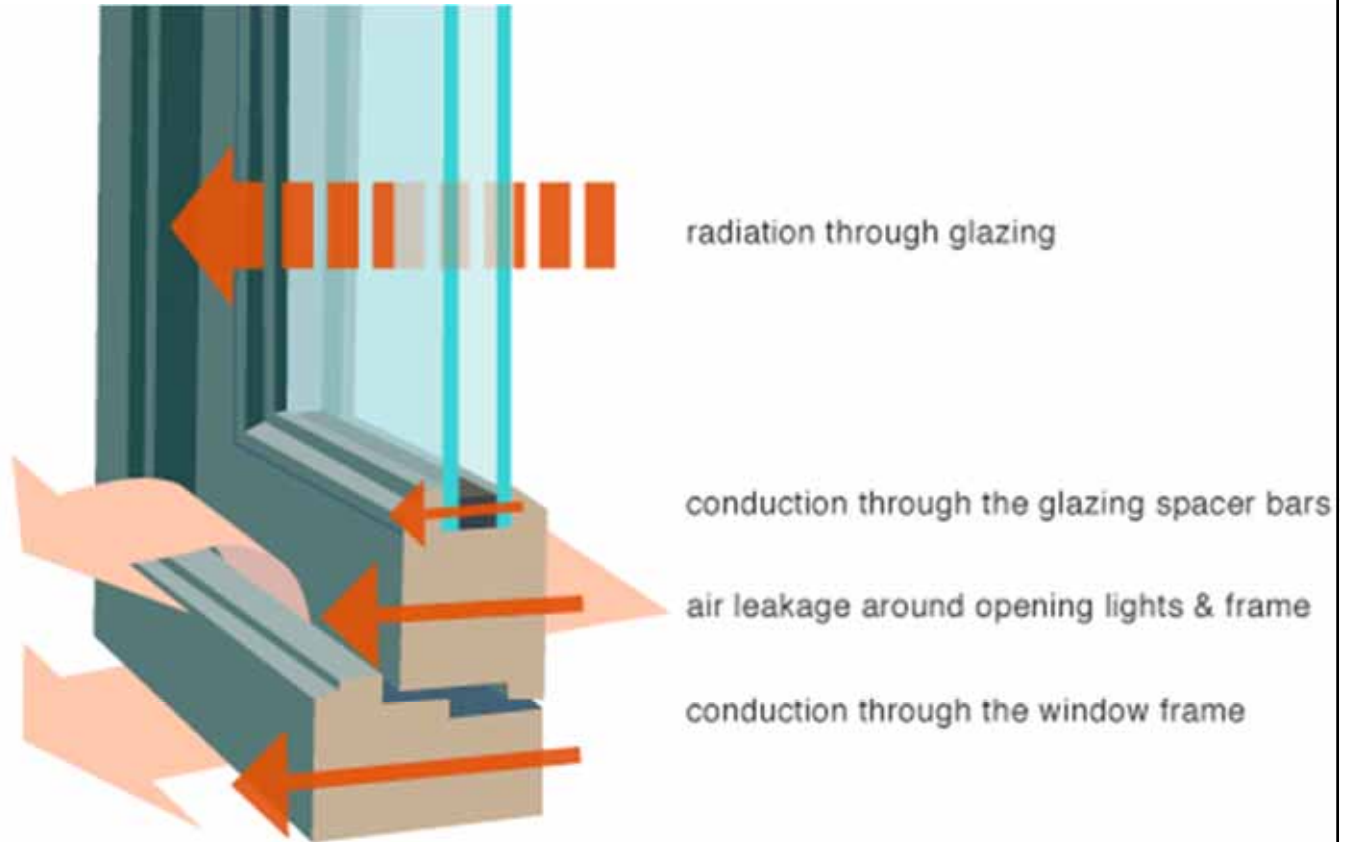
- Temperature differential, ΔT
- Area of exposed building surfaces, A
- Heat transmission properties, like U -value
- Thermal storage capacity
- Window-to-wall ratio (WWR)

$$Q = U A \Delta T$$

- Effect of thermal mass

- Delay heat transfer or act as a cooling source
- Important for intermittently cooled spaces

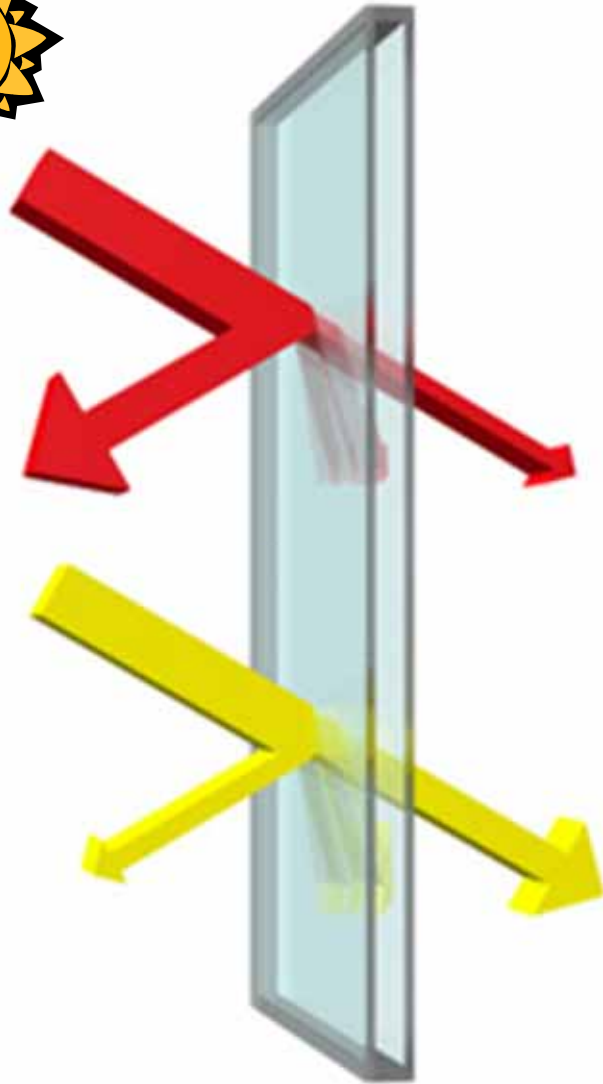
Solar heat gain and heat loss through window glass



(Source: www.greenspec.co.uk/windows.php)

Absorbed & re-radiate inward

Understanding window performance



U-factor = 0.25

U-factor (or U-value) = overall thermal transmittance ($\text{W}\cdot\text{m}^{-2}\cdot\text{K}^{-1}$)

SHGC = 0.39
39% of solar heat transmitted

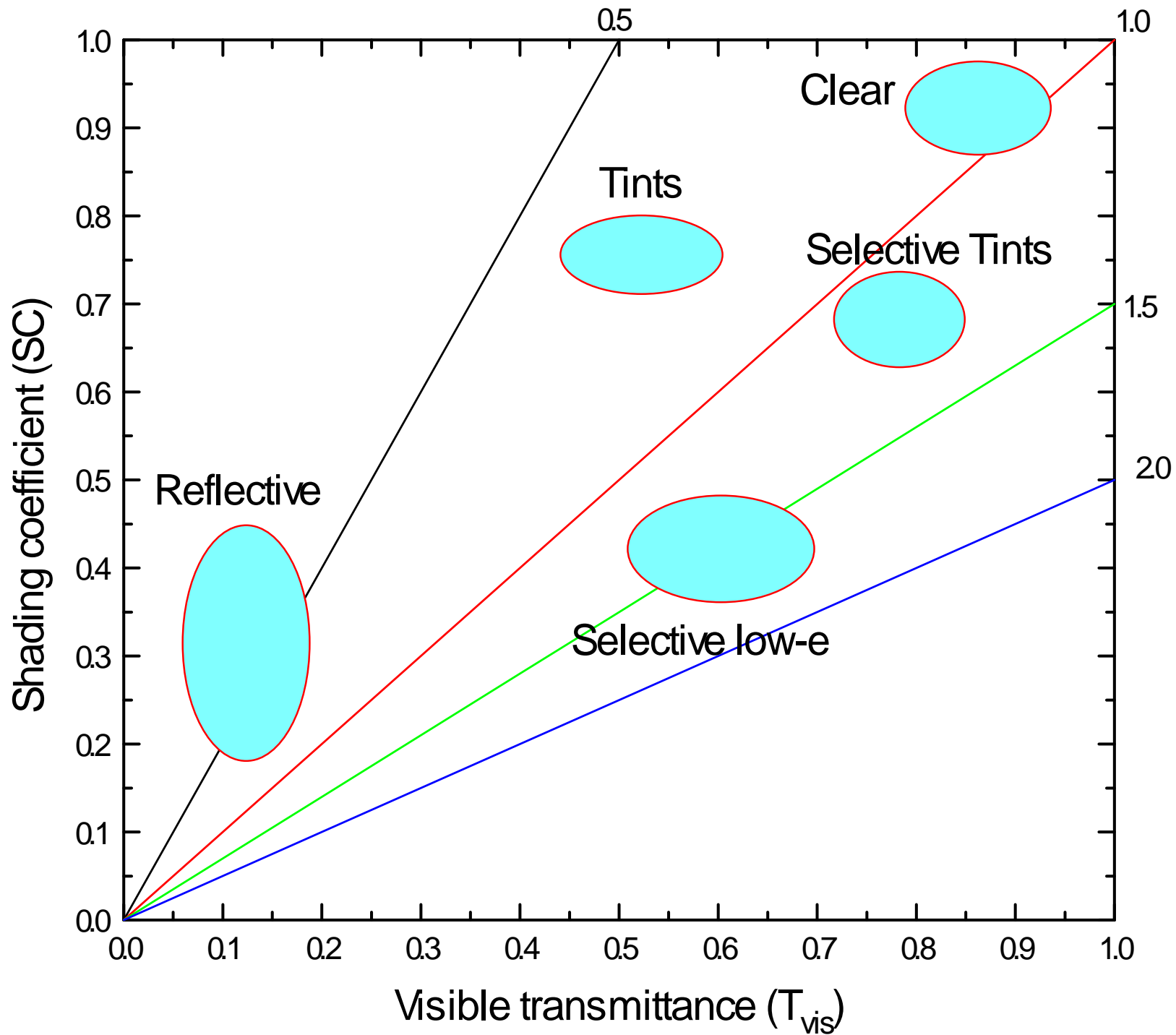
SHGC = solar heat gain coefficient

VT = 0.70
70% of visible light transmitted

VT = visible transmittance

$$\text{Shading Coefficient (SC)} = \frac{\text{Solar heat gain of the window glazing}}{\text{Solar heat gain of unshaded 3 mm clear float glass}}$$

Properties and selection of window glasses





Energy Efficiency

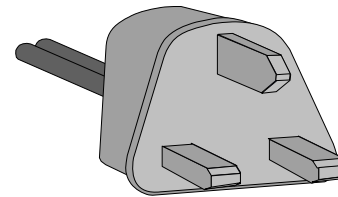
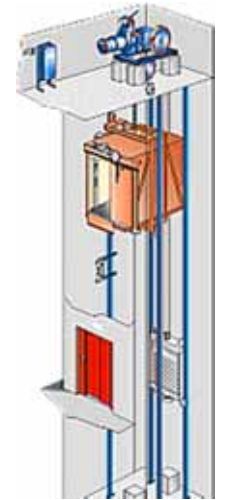
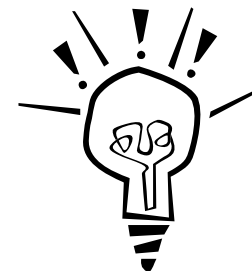
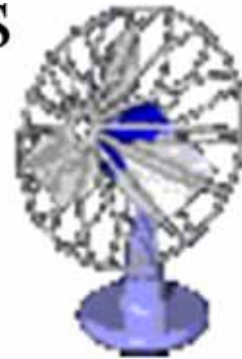
- Architects and Engineers work together to
 - Evaluate envelope performance at early stage
 - Select appropriate window design and materials
 - Design thermal insulation and building fabric
- Complicated issues with building envelope:
 - Dynamic behaviour of climate and building
 - Interaction of light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



Energy Efficiency



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



Energy efficiency labels in HK

ENERGY LABEL 能源標籤

more efficient 效益較高

1 2 3 4 5

less efficient 效益較低

Grade 1

Annual Electricity Consumption (kWh/yr)
每年耗電量 (千瓦小時/年)
Based on 1000 hours operation
以每年使用1000小時為基準

Cooling Capacity (kW) 製冷量 (千瓦) 1106

Refrigerant 製冷劑 R410A

Room Air Conditioner 空調機

Brand 品牌: ABC

Model 型號: HK1234

Reference Number / Year Information Provider 參考編號 / 年份資料提供者: C090123 / 2008 XYZ

機電工程署 EMSD

Grade 1 products are most efficient (green) and Grade 5 products are least efficient (red).

Annual electricity consumption. Use this number to estimate how much money you could save by choosing different models.

Cooling capacity of the model at full load.

ENERGY LABEL 能源標籤

more efficient 效益較高

1 2 3 4 5

less efficient 效益較低

1 級 Grade

Lamp luminous efficacy of the model. A higher number indicates that the product is more efficient.

53 Lumen/W (流明/瓦)

Ref/Yr 編號/年份: L080123 / 08

Compact Fluorescent Lamp 緊湊型熒光燈(慳電膽)

機電工程署 EMSD

This indicates the energy efficiency grading of the model. Grade 1 products are most efficient (green) and have an average lamp life of 8,000 hours or above. Grade 5 products have an average lamp life of below 6,000 hours (red).

Examples of mandatory energy efficiency labels in Hong Kong

ENERGY LABEL 能源標籤

Brand 牌子 ABC

Model 型號 某某牌

Annual Energy Consumption * kWh/yr
每年耗電量 1000

Energy Efficiency Grade*
能源效益級別 1

Room Cooler Category* 冷氣機類別 1

Cooling Capacity (kW) 製冷量 2.5

Refrigerant 製冷劑 RHC 123

REG. Registration Number
能源標籤登記號碼 C 98-0001

* The data are provided according to the Hong Kong Energy Efficiency Labeling Scheme for Room Coolers administered by the Electrical and Mechanical Services Department (EMSD), Government of the Hong Kong Special Administrative Region. The registration record can be found at the EMSD website at www.emsd.gov.hk.

機電工程署 EMSD

ENERGY LABEL 能源標籤

Reg. No. 登記號碼: RC11-0001

Electric Rice-Cookers (電飯煲)

機電工程署 EMSD

Examples of voluntary energy efficiency labels in Hong Kong

Comparing different grades of energy efficiency labels*

節省能源的百分比 Percentage of Energy Saving

	空調機 Room Air Conditioners	冷凍器具 Refrigerating Appliances	慳電膽 Compact Fluorescent Lamps	洗衣機 Washing Machines	抽濕機 Dehumidifiers
第1級比第3級 Grade 1 vs Grade 3	15%	35%	14%	25%	24%
第1級比第5級 Grade 1 vs Grade 5	29%	49%	18%	40%	42%

(*See also Energy Label Net, <http://www.energylabel.emsd.gov.hk>)

(Source: www.energylabel.emsd.gov.hk)



Energy Efficiency

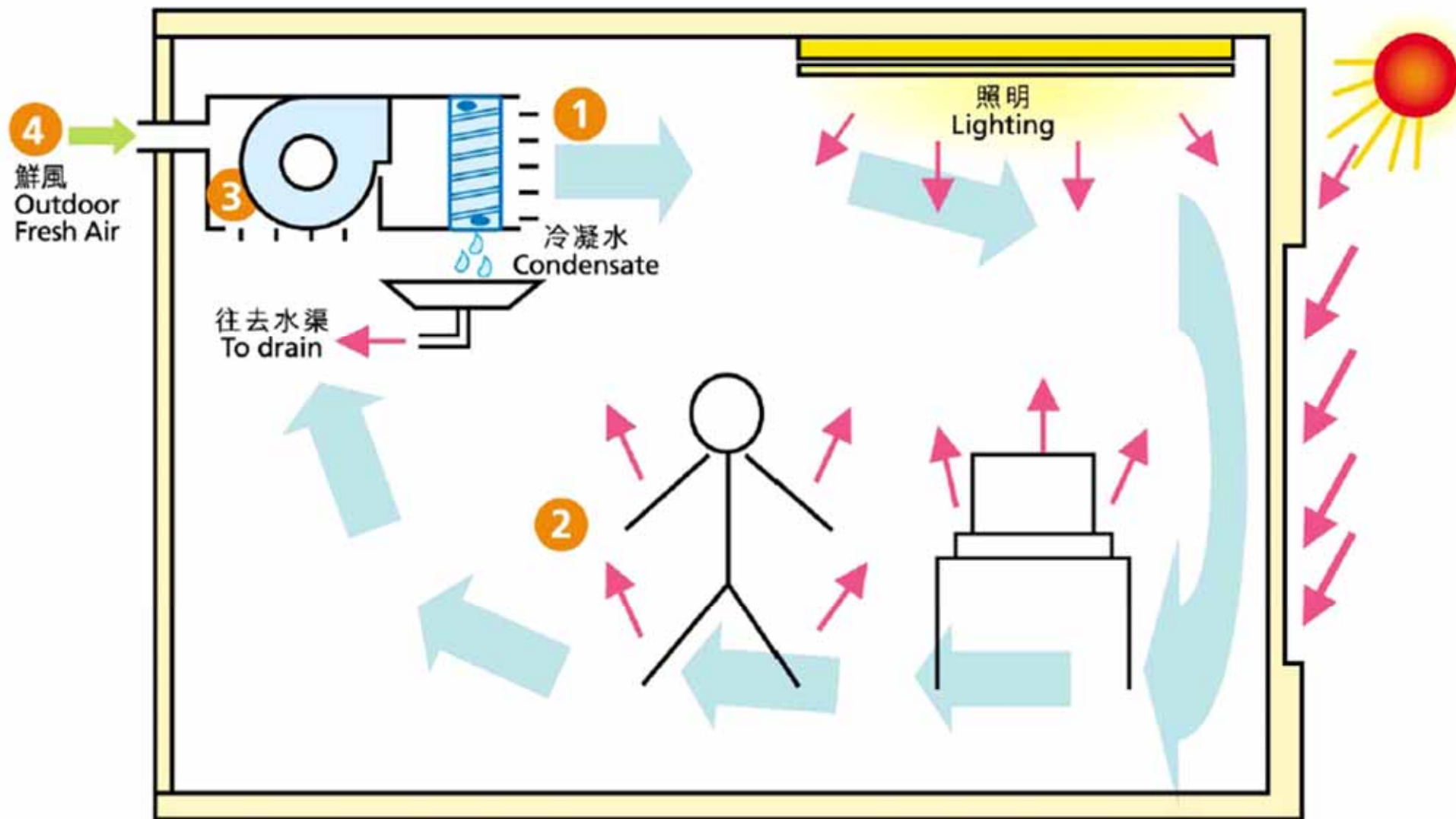
- Heating, ventilating & air-conditioning (HVAC) systems
 - Usually the most important energy users
 - Provide for occupant comfort, health and safety
 - HVAC design is affected by architectural features and occupant needs
- In Hong Kong, heating load is small and main focus is on air-conditioning or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



典型空調系統

Typical Air-conditioning Process

冷卻盤管具冷卻及抽濕功效
Cooling Coil for Cooling & Dehumidification



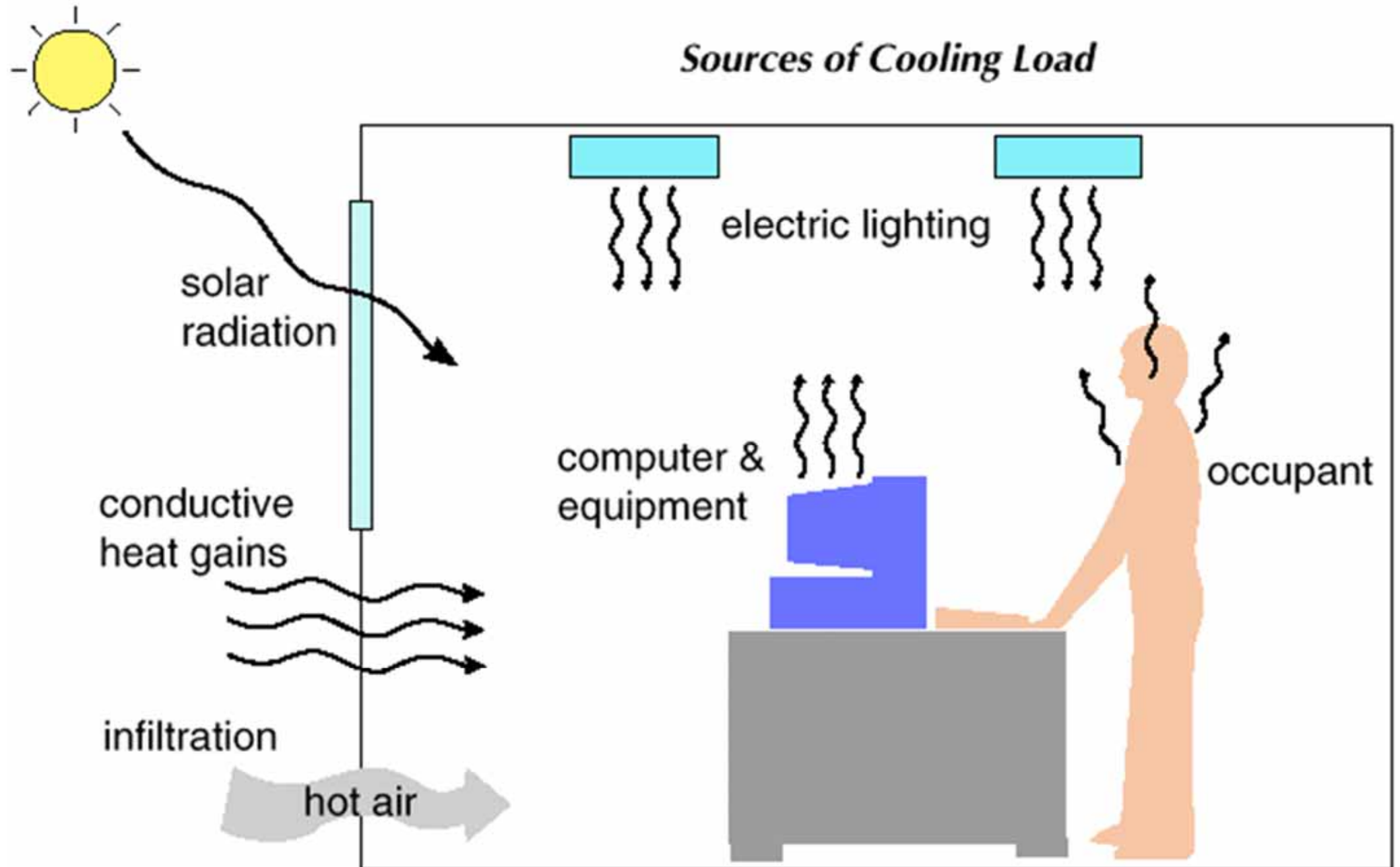
(Source: EnergyWitts newsletter, EMSD)



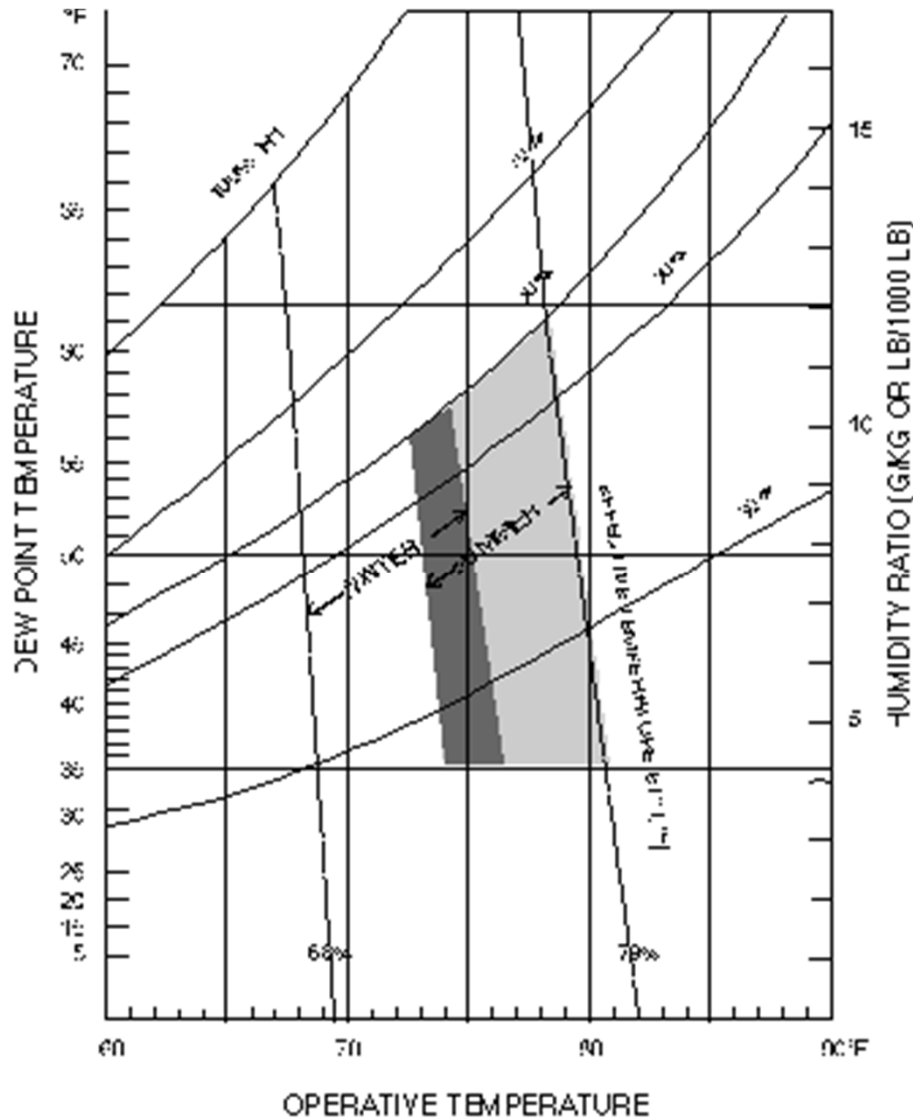
Energy Efficiency

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

Heat flow and sources of cooling load



Thermal comfort criteria and design



ASHRAE comfort envelope



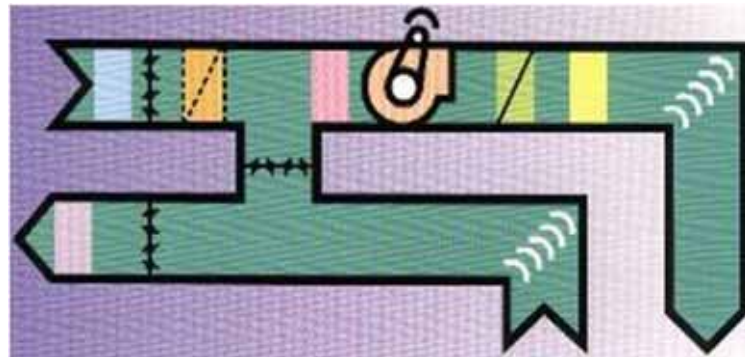
Thermal comfort & design conditions



Energy Efficiency

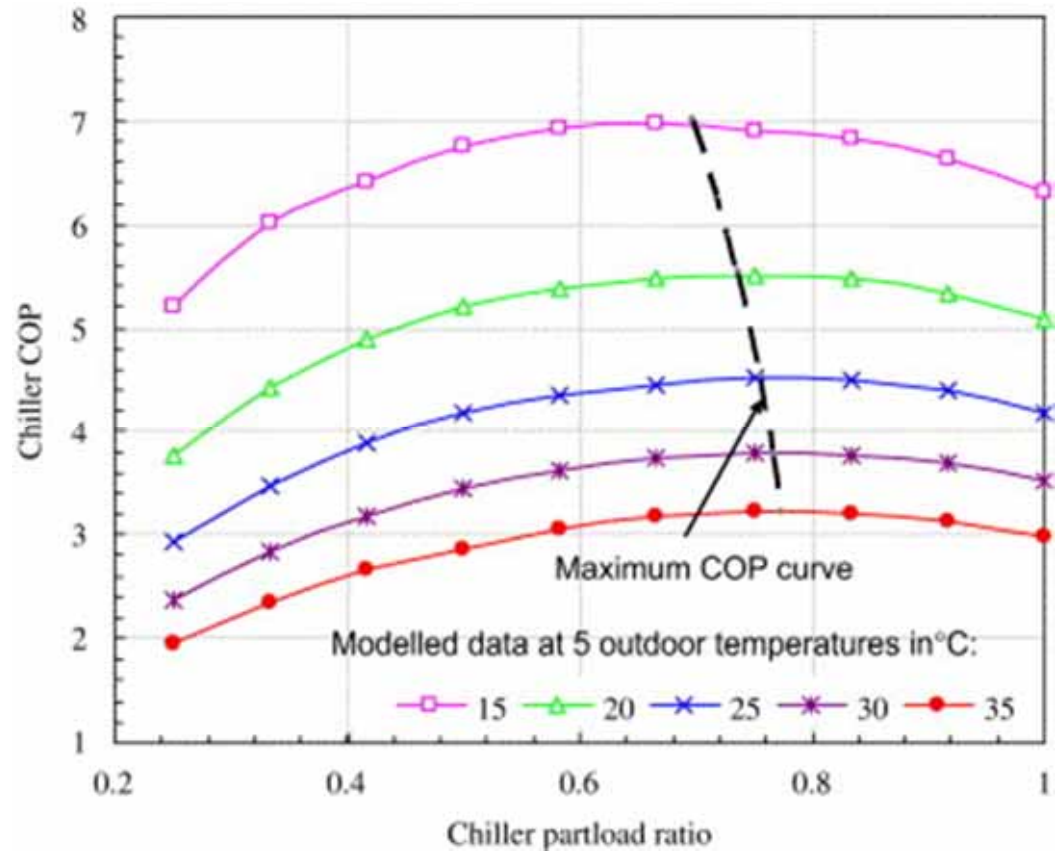
- HVAC system design and operation
 - System characteristics
 - Type of systems
 - Energy efficiency ratios
 - Coefficient of performance
 - System operation & control
 - Equipment and plant operation
 - Especially during partload conditions
 - Opportunity for heat recovery
 - District cooling or energy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

Partload efficiency of HVAC equipment and plant



HVAC system and plant

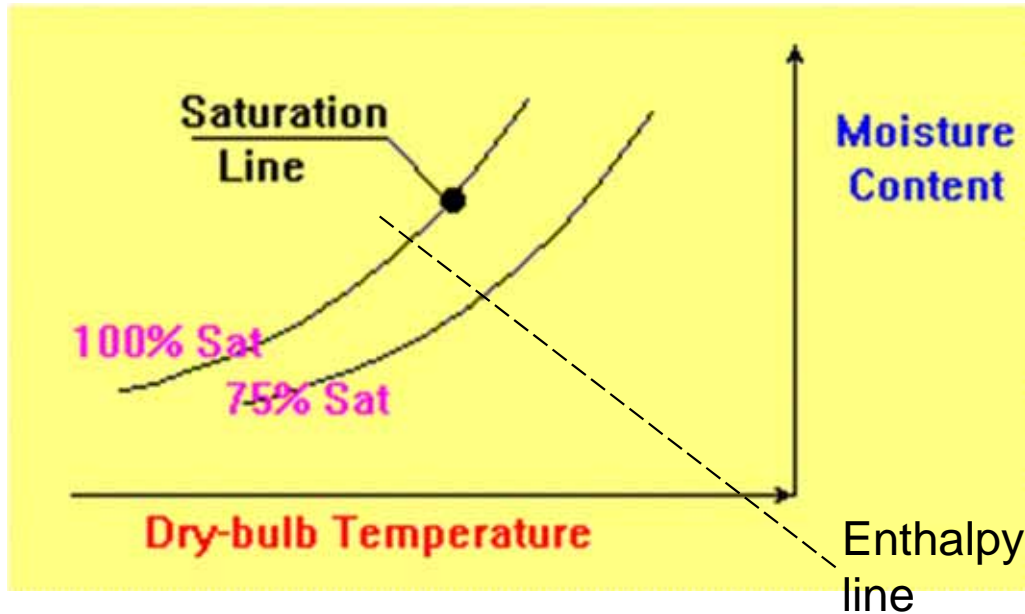
Highest efficiency at about 70%-90% partload ratio



Chiller partload ratio

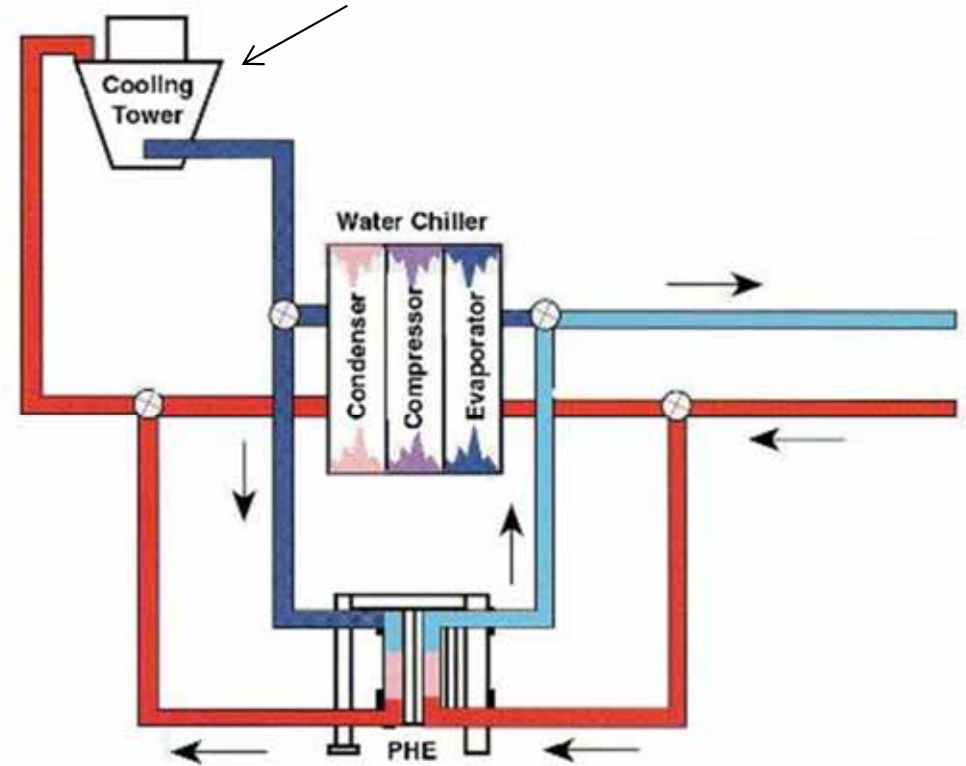
'Free' cooling methods in HVAC system

Analyse the outdoor air conditions on a psychrometric chart



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

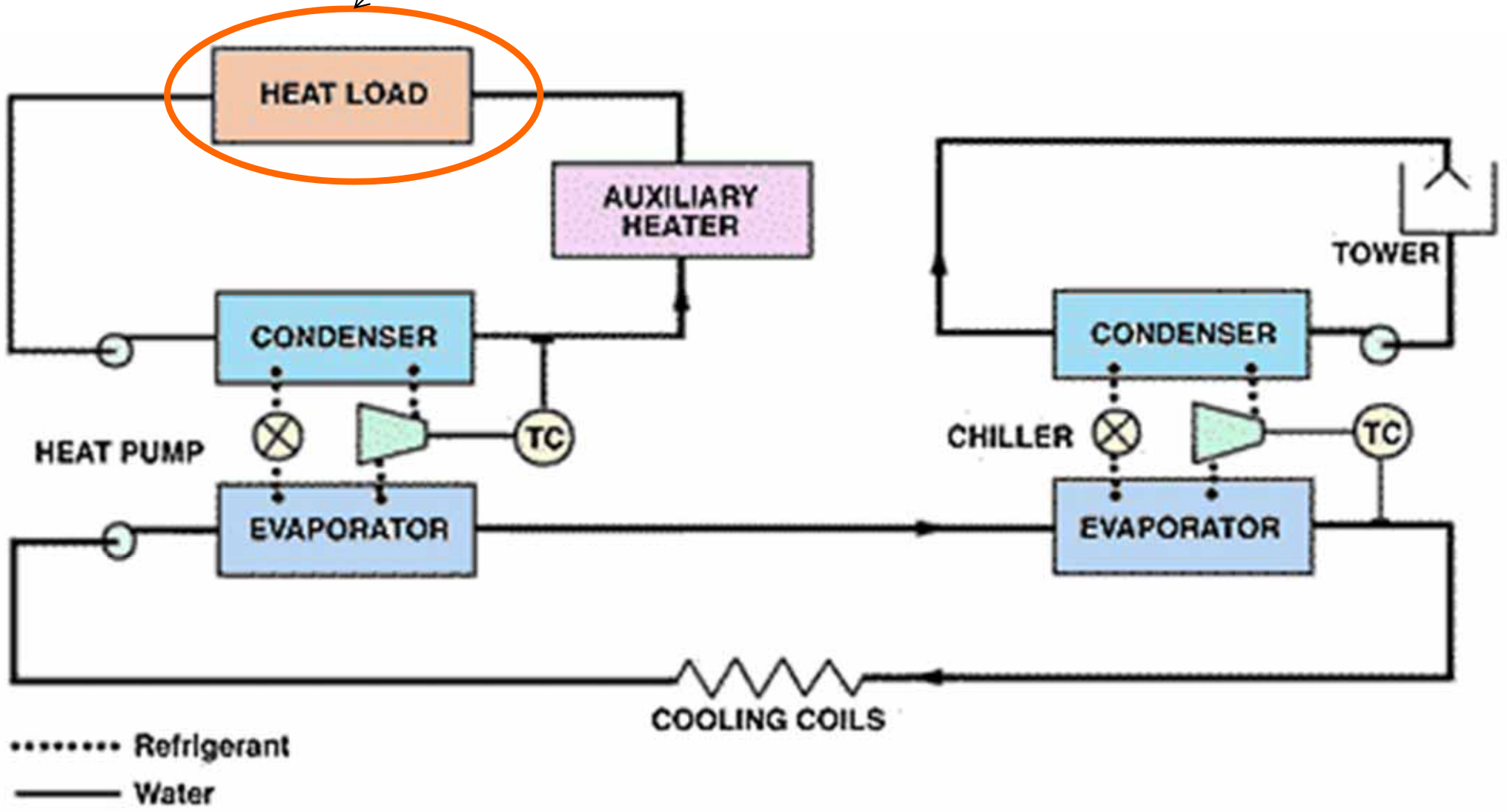
Use cooling tower alone to produce chilled water (chiller turned off)



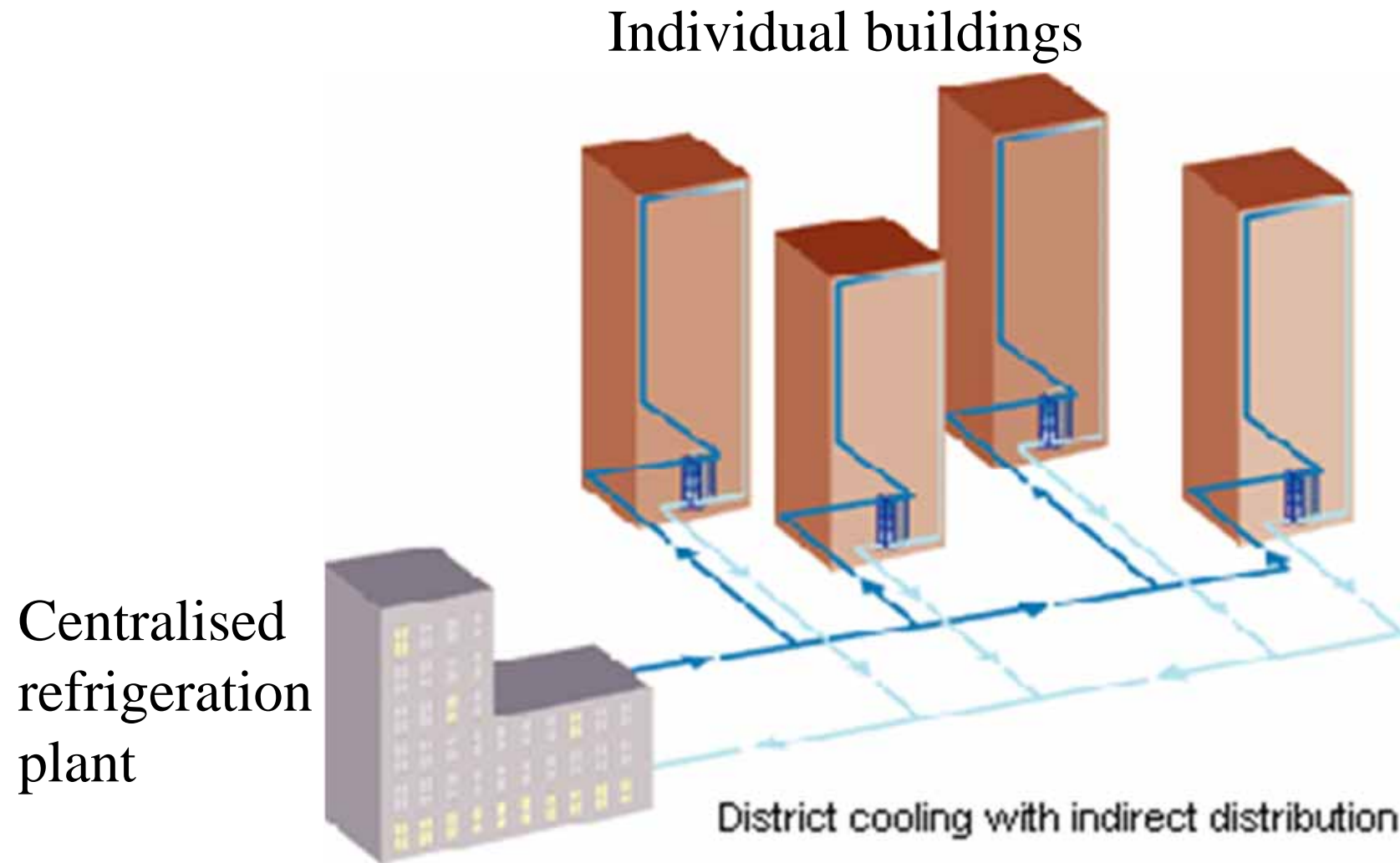
- (b) 'Free' refrigeration
- chiller bypass when the system can be cooled by ambient

Schematic diagram of waste heat recovery - heat pump + chiller

Using the waste heat for heating water or space air



Basic concept of district cooling system (DCS)



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



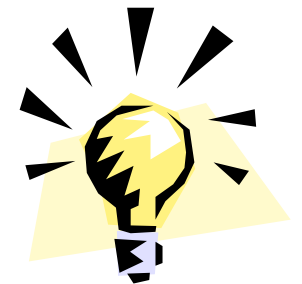
Energy Efficiency

- 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

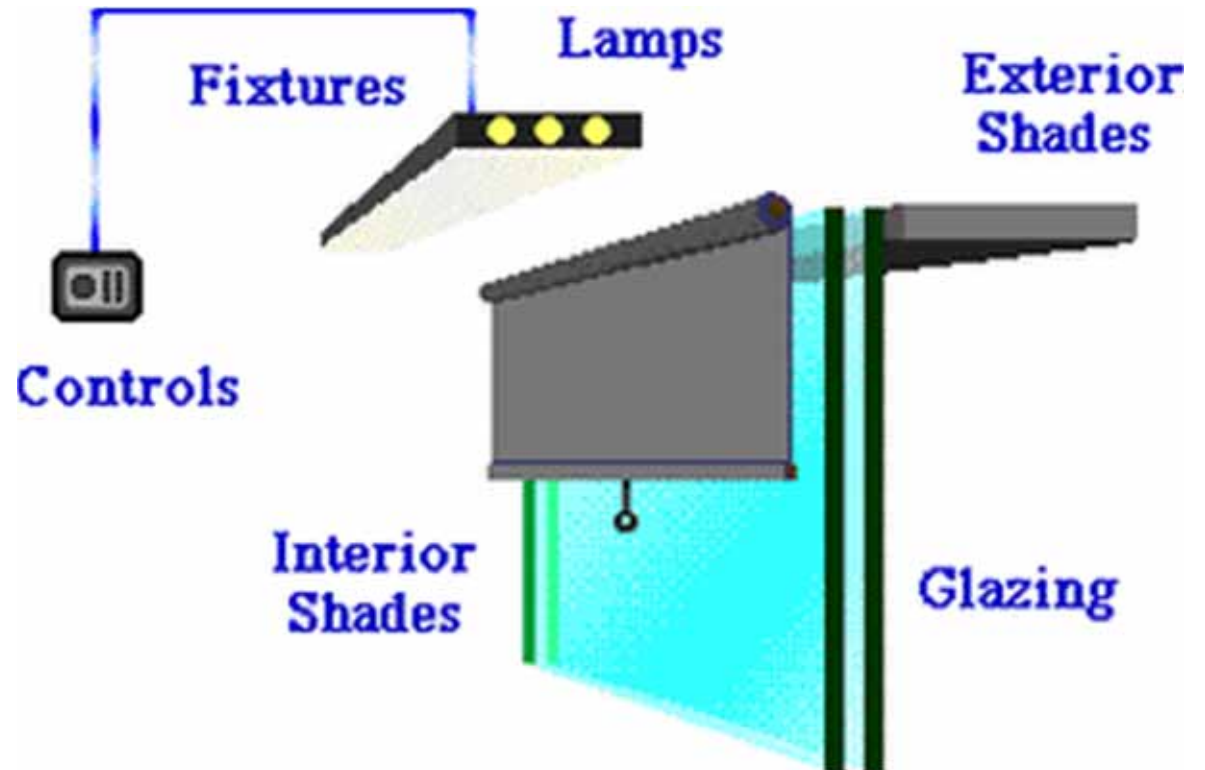


(*See also <http://www.wbdg.org/resources/efficientlighting.php> and <http://www.wbdg.org/resources/daylighting.php>)

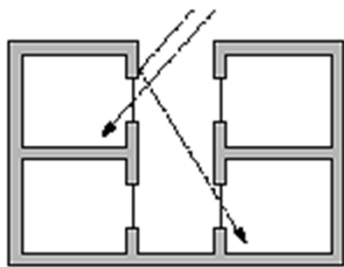
Energy efficient lighting design strategies



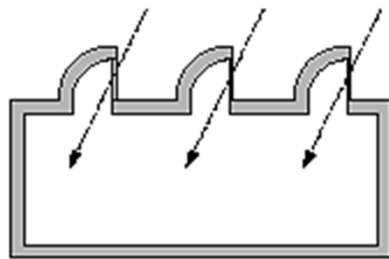
Energy efficient fittings (e.g. compact fluorescent lamps)



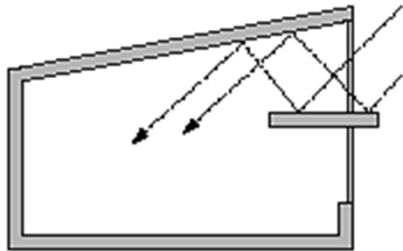
Lighting controls and interactions with windows



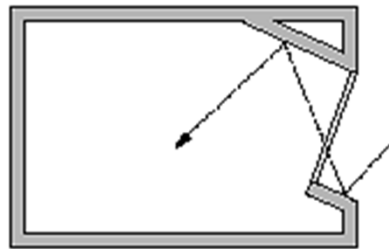
Light well



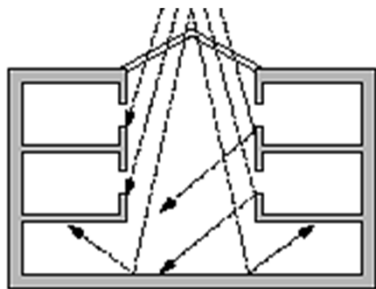
Roof monitor



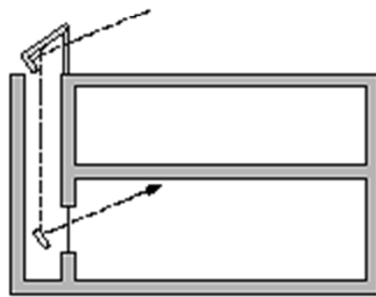
Light shelf



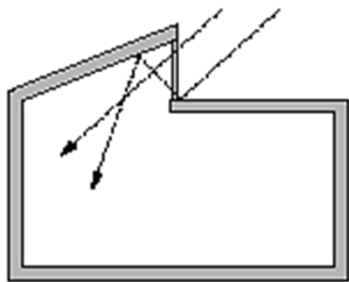
External reflectors



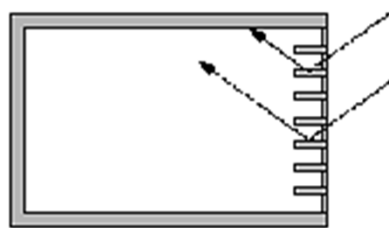
Atrium



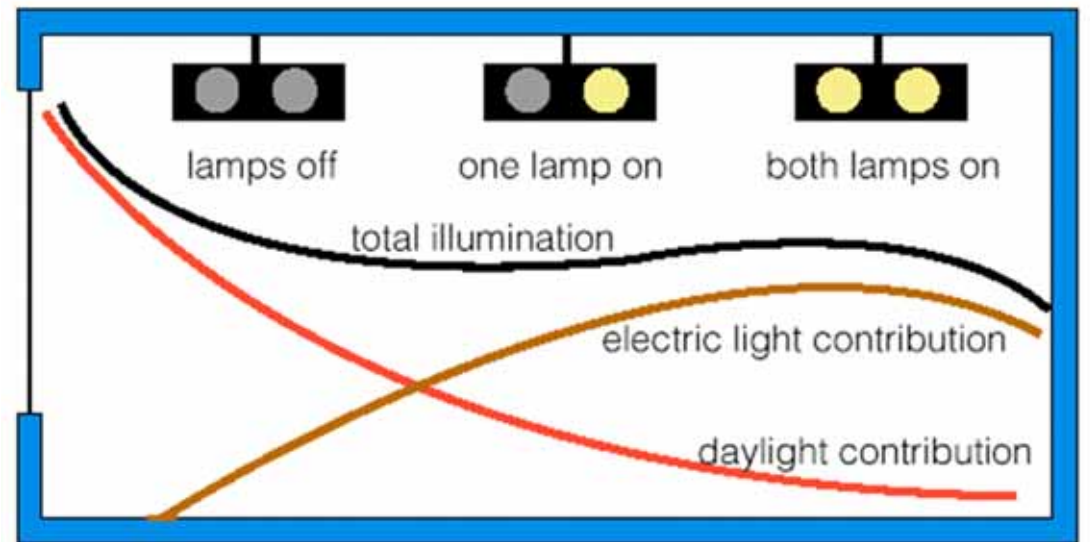
Light duct



Clerestory



Reflective blinds



Daylighting design and control

Integrated controls for lighting luminaires

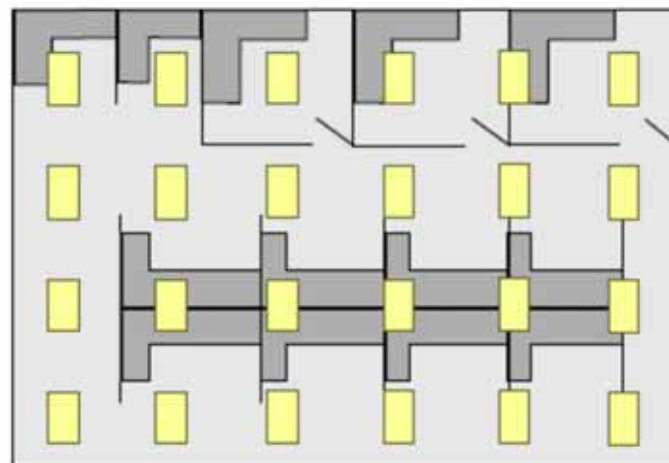
Vertically Integrated Design

Personal Control Features:

- Direct/ Indirect Pendant Luminaire
- Task light: 2T8-PS Dimmable EB (64W)/ 100%-5%
- Ambient light: 1T8-PS EB (31W)/ ON/OFF only
- Photocell Sensor built in
- Occupancy Sensor built in

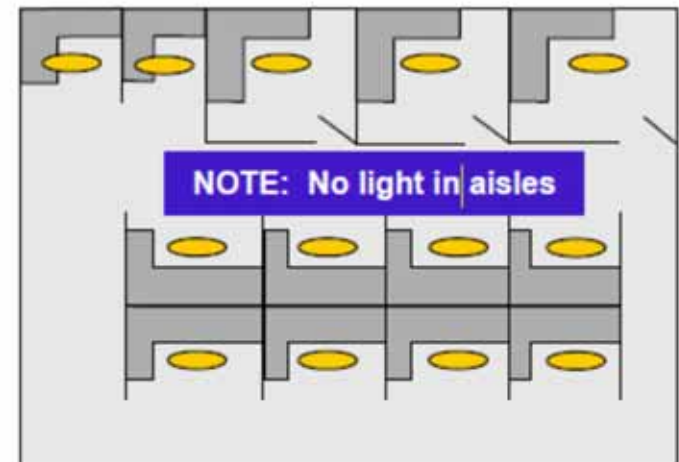


Comparison to a Standard Troffer Layout:



- 2x4 Parabolics
- **24 Luminaires**
- 72 lamps
- ~2300 watts

- Direct Indirect
- **13 Luminaires**
- 39 lamps
- ~1250 watts





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

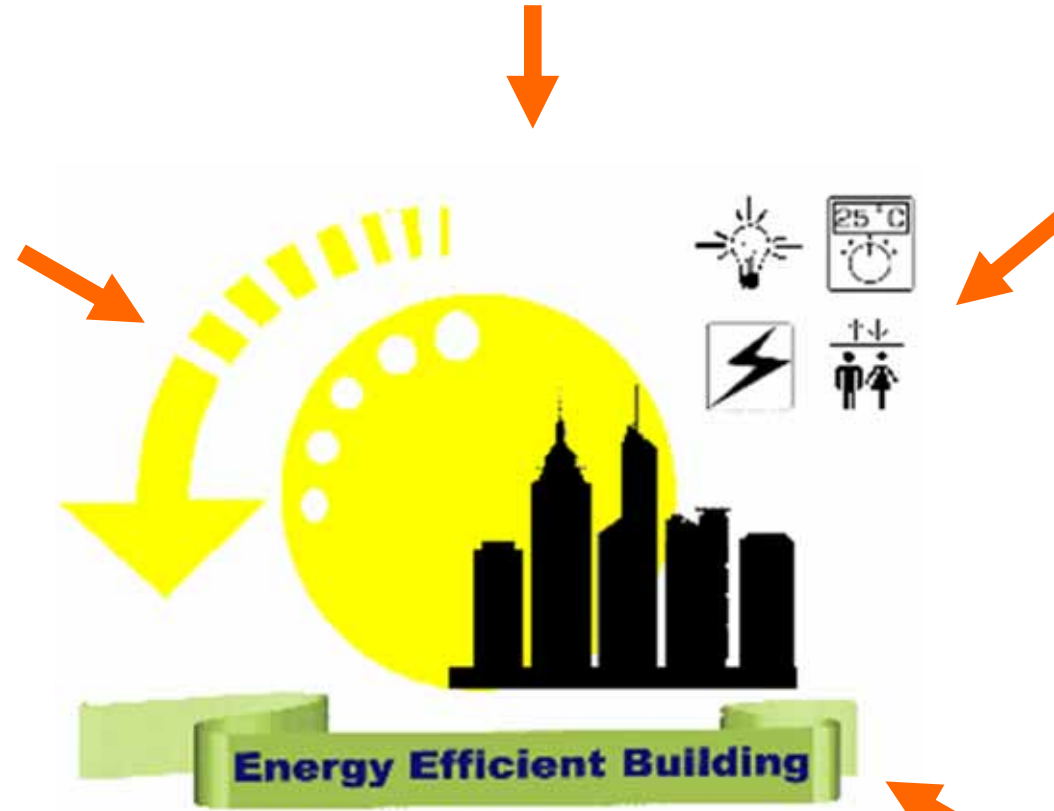
- Human factors
 - Comfort requirements
 - Thermal comfort
 - Visual comfort
 - Noise control
 - Occupant behaviours*
 - Patterns of use
 - Periods of occupation
- Management issues
 - Building use, operation & maintenance



Good design practices

Integrated & total energy approach

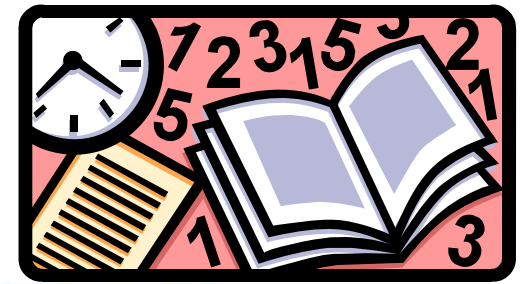
Efficient systems



Good house-keeping

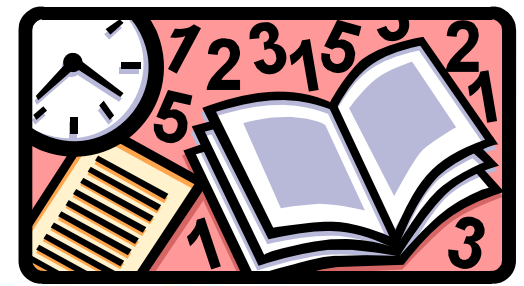
User education & awareness

Efficient operation



Further Reading

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



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
- Website: EnergyLand, EMSD
 - <http://www.energyland.emsd.gov.hk/>