Energy Efficient Technologies

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Contents

- Building Envelope
- HVAC
- Hot Water
- Lighting
- Electrical Services
- Lifts & Escalators
- Building Management System

Examples of energy saving technologies for buildings*

Lighting:

Compact fluorescent lamp
Electronic ballast
T5 fluorescent lamp
Digital Addressable Lighting Interface (DALI) lighting control
Lighting retrofit – Light level abatement
Light reflector for redirection
Lighting retrofit – Plug and enhance
LED & self-luminous exit signs
LED MR16 spot light
Ceramic metal halide MR16 spot light
Central/group dimmer for general lighting
Occupancy/photo sensor

Lifts & escalators:

Lift regeneration
Service-on-demand escalator
Energy optimisers for escalator motor drives

HVAC:

Variable speed drive
Water cooled air conditioning
District cooling system
Brushless DC motor fan coil unit
Predictive curve secondary chilled water pump control
Condensing water pump control
Chiller with oil free magnetic bearing compressor
Reduced static pressure reset for VAV system
Heat pump water heaters
High temperature heat pump

Electrical services:

High efficiency motor
Reduce standby power use

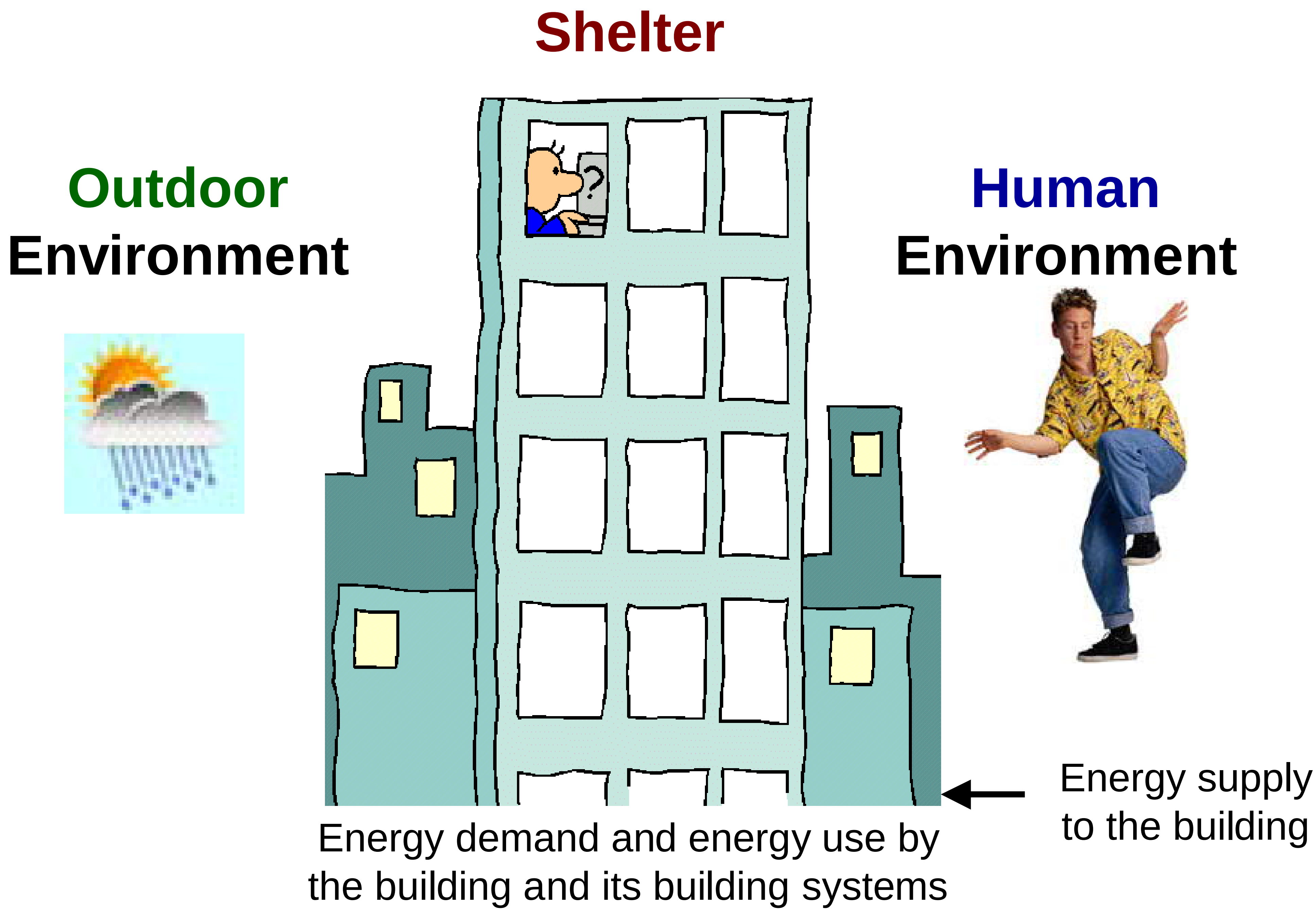
Others:

Solar control window firms
Grey water heat recovery

Which one do you know?

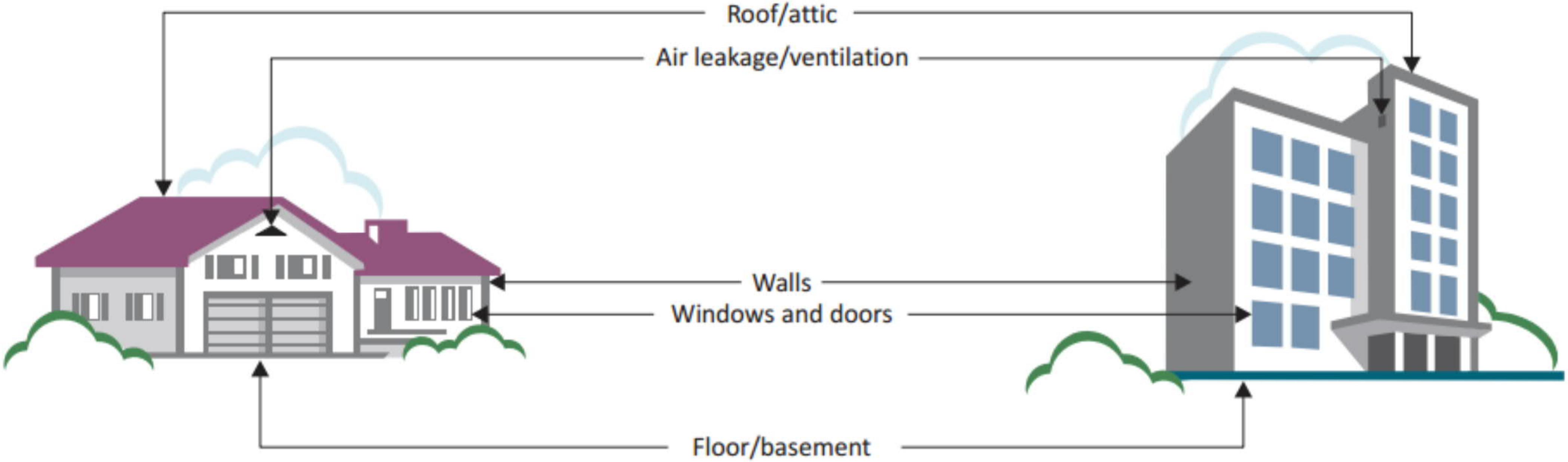
(*Further Reading: http://www.emsd.gov.hk/emsd/eng/pee/aest.shtml)

Building envelope as the "Shelter":
the primary thermal barrier between interior and exterior



Building Envelope

- Building envelope components
  - Roof, walls, windows, skylights, doors, floor, basement; Related issues: air leakage, ventilation



(Source of image: 2013 IEA Technology Roadmap -- Energy efficient building envelopes)

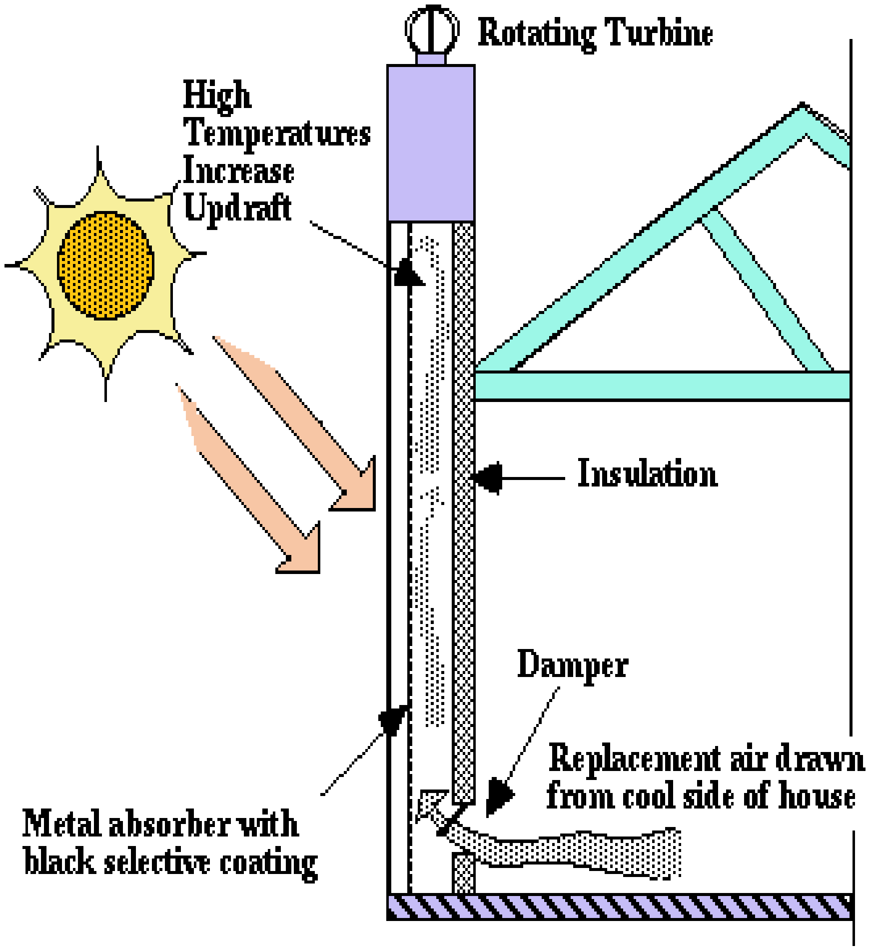
Building Envelope

- Building envelopes today
  - Old techniques: local materials for local climate
  - Passive design and natural ventilation
  - Insulation
  - Air sealing
  - Windows
  - Reflective surfaces
- Energy-efficient building materials

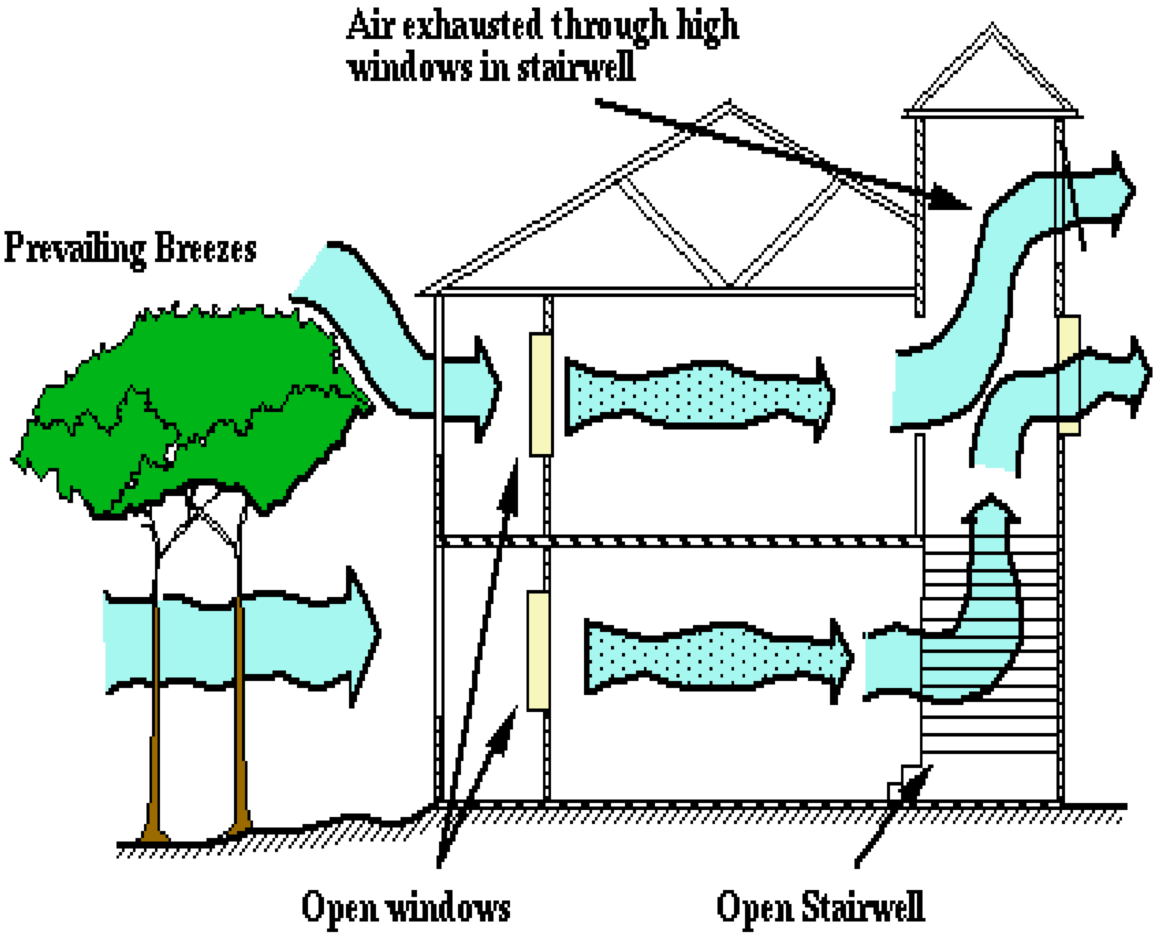
New buildings: advanced design & codes
Existing buildings: How to upgrade the building envelopes?

Examples of passive cooling designs

(promote passive & natural cooling => reduce mechanical energy)



Thermal chimney

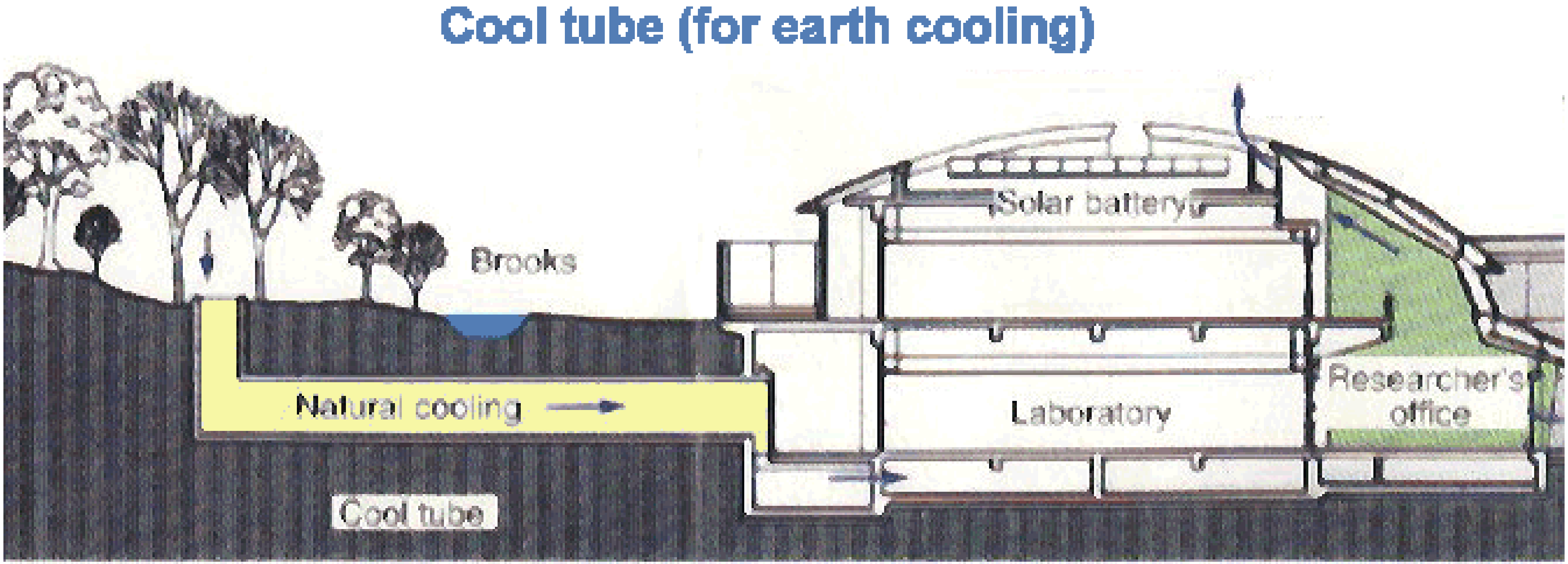


Natural ventilation

(*Examples for tropical climate, http://www.arch.hku.hk/research/BEER/passcool/cool.html)

Examples of passive cooling designs – earth tube cooling

(outdoor fresh air cooled by the earth before entering the building)



Earth tube cooling (Japan)

(Source: http://www.mech.hku.hk/sbe/case_study/case/jap/RITE_Building/energy.html)

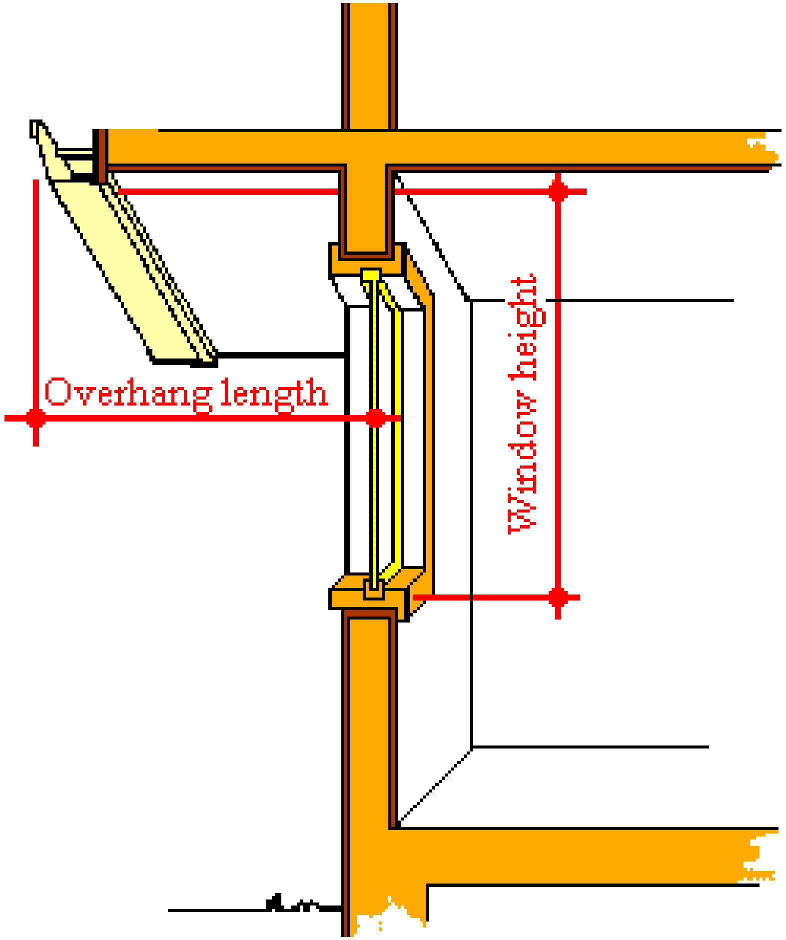
Building Envelope

- Examples of current envelope technologies:*
  - Double-glazed low-e (emissivity) glass
  - Window films (solar control)
  - Window attachments (e.g. shutters, shades)
  - Highly insulating windows (e.g. triple-glazed)
  - Typical insulation and exterior insulation
  - Advanced insulation (e.g. aerogel)
  - Air sealing
  - Cool roofs, advanced roofs, green roofs

(*See also: http://energydesignresources.com/technology/building-envelope-design.aspx)

Shading devices (external and internal) for sun control

(reduce direct sun light => reduce cooling energy & glare)



Overhang

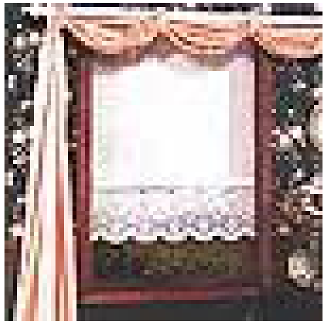

Louvers


Awnings


Shutters

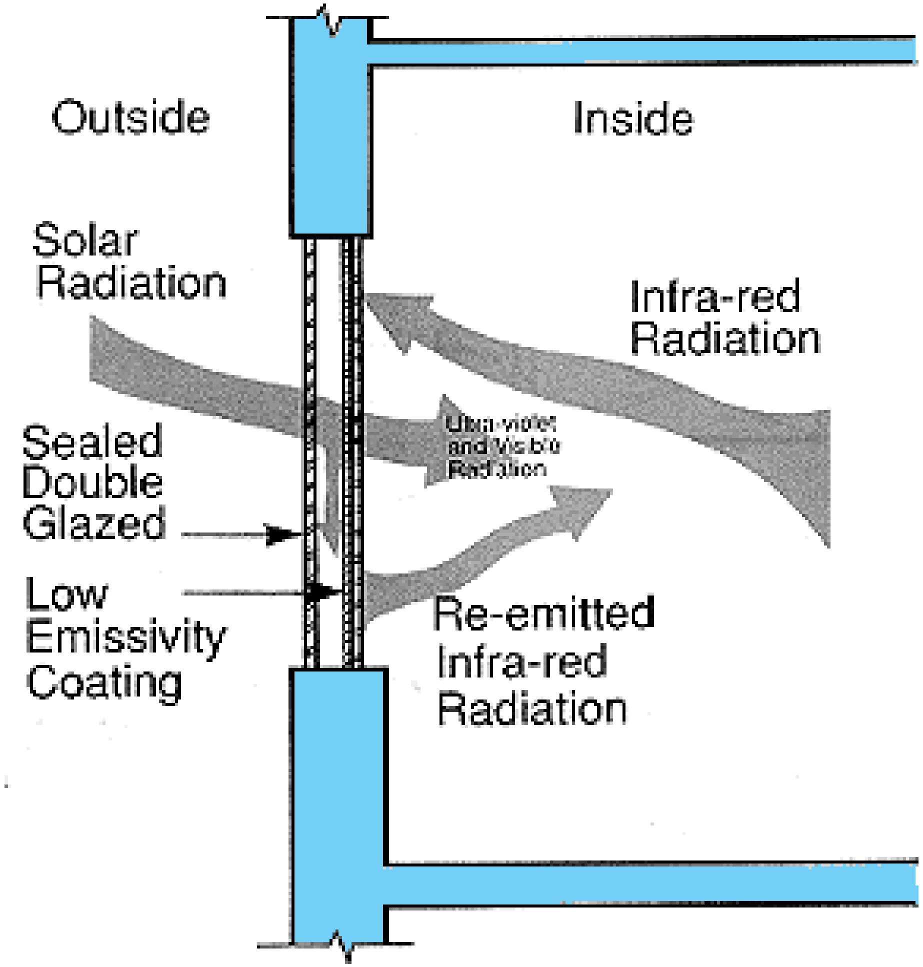

Drapes and curtains


Venetian blinds


Roller shades

Advanced window and insulation technology

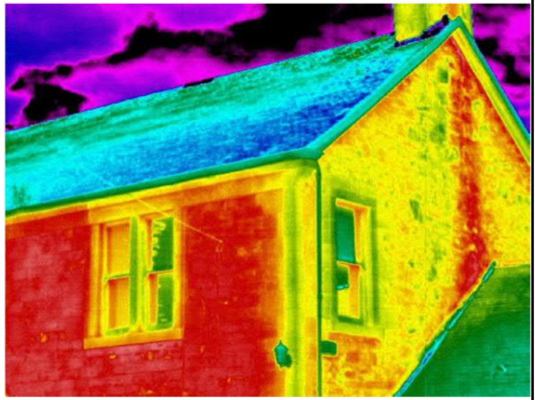
(reduce solar heat gain => reduce cooling energy)



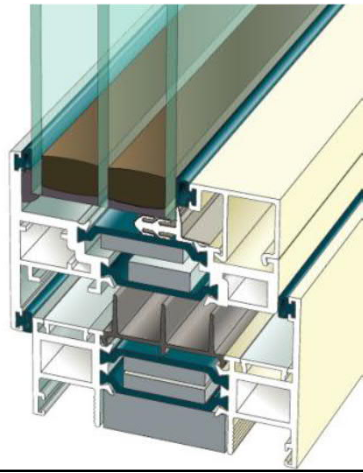
Low-e (emissivity) glazing

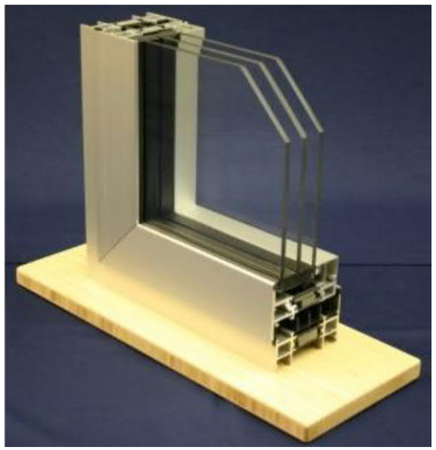
Gas filled panel (high performance insulation)

Building Envelope



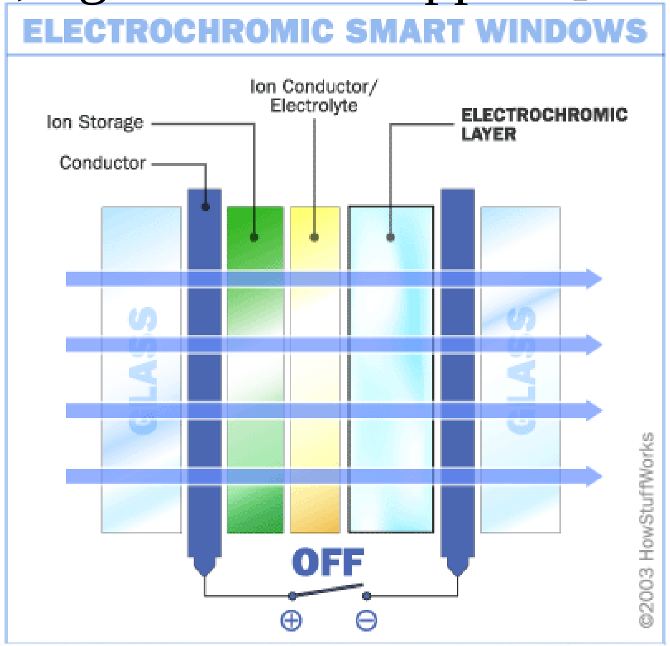
- Advanced/emerging technologies
  - Highly insulating windows
  - Building envelope material
  - Air-sealing technologies (systems-level approach)
  - Dynamic windows and window films
  - Visible light redirection
  - Highly insulating roofs
  - Double-skin/active façades
- More R&D are needed





Smart windows or switchable windows

[Changes light transmission properties when voltage, light or heat is applied]

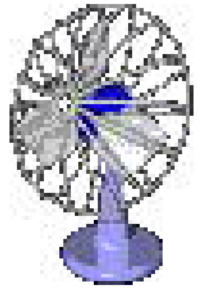


Smart glass technologies include electrochromic, photochromic, thermochromic, suspended particle, micro-blind and liquid crystal devices (http://en.wikipedia.org/wiki/Smart_glass)

Large-scale demonstration of electrochromic glazing at Chabot College, California:

(Source: Source: Sage (Sage Electrochromics) (2013), "Portfolio - Chabot College, Hayward, California" http://sageglass.com/portfolio/chabot-college/)

HVAC



- A primary goal when designing high performance energy efficient buildings is to eliminate or reduce the need for cooling or heating equipment
- This may not be possible in severe cold or hot climates, but should still be a key design aim
- Ventilation design strategy for HVAC:
  - Passive design approach, before mechanical systems are applied

Ventilation design hierarchy

Is it feasible to use
Natural Ventilation?

If situation prevents this,
is it feasible to use
Mechanical Ventilation?

If situation prevents this,
is it feasible to use
Hybrid/Mixed Mode Ventilation?

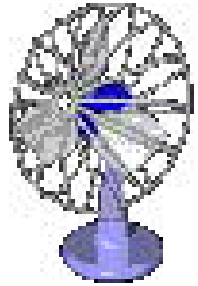
If situation prevents this,
is it feasible to use
Cooling and Heating (without humidity control)?

If situation prevents this,
is it feasible to use
Full Air Conditioning (with humidity control)?

Increasing:

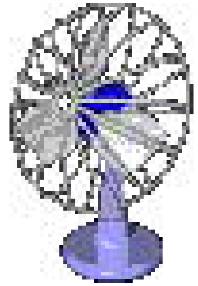
- energy consumption
- capital cost
- running costs
- maintenance
- complexity

HVAC



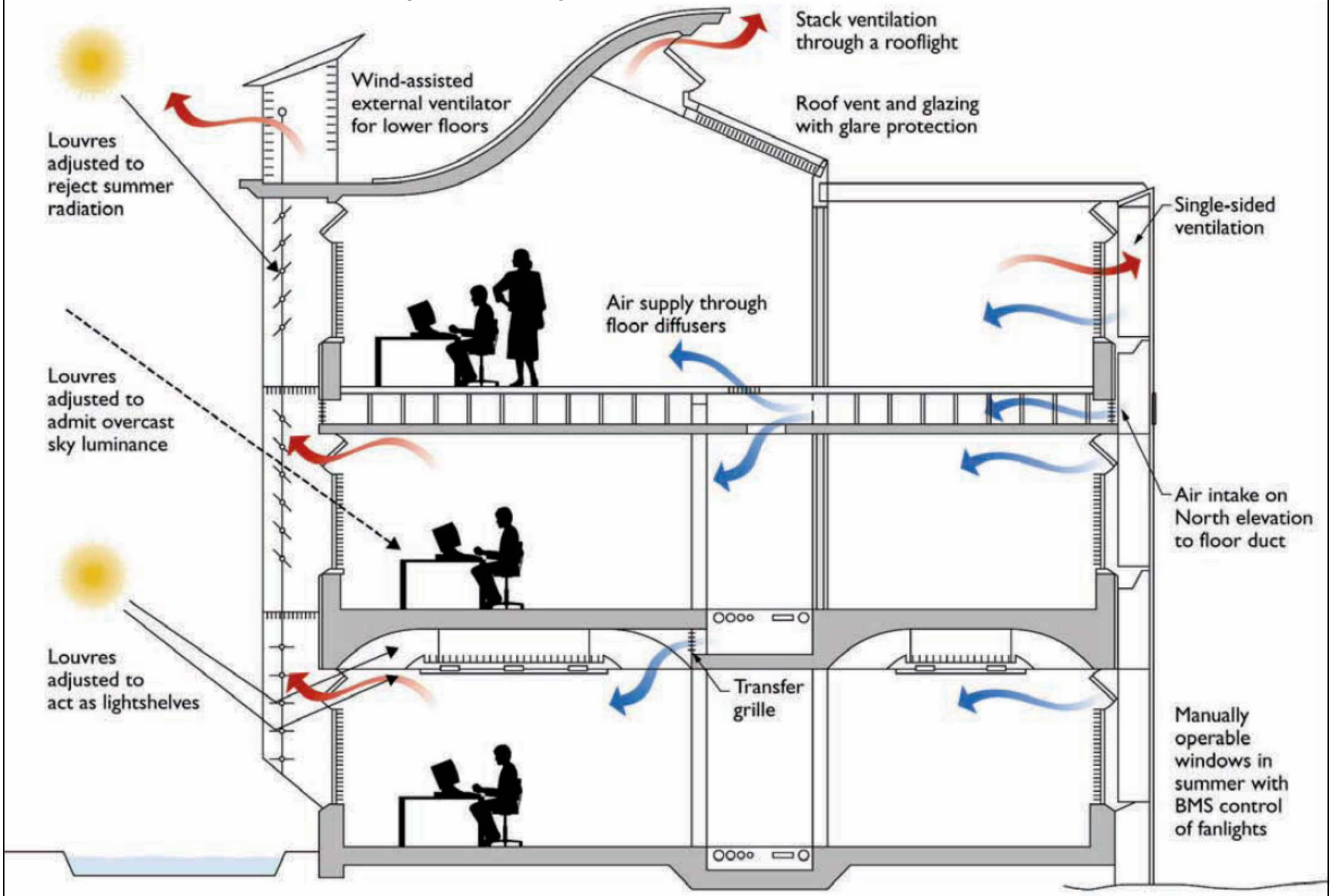
- Benefits of **natural ventilation**
  - Can save substantial energy by decreasing or eliminating the need for HVAC
  - May improve indoor air quality if outdoor air quality is good and air exchange rate is high
  - Buildings with well-designed natural ventilation systems often provide very comfortable and pleasant environments for the occupants
  - People may increase their work productivity when they can open and close windows and vary the natural ventilation rate in their workspace

HVAC

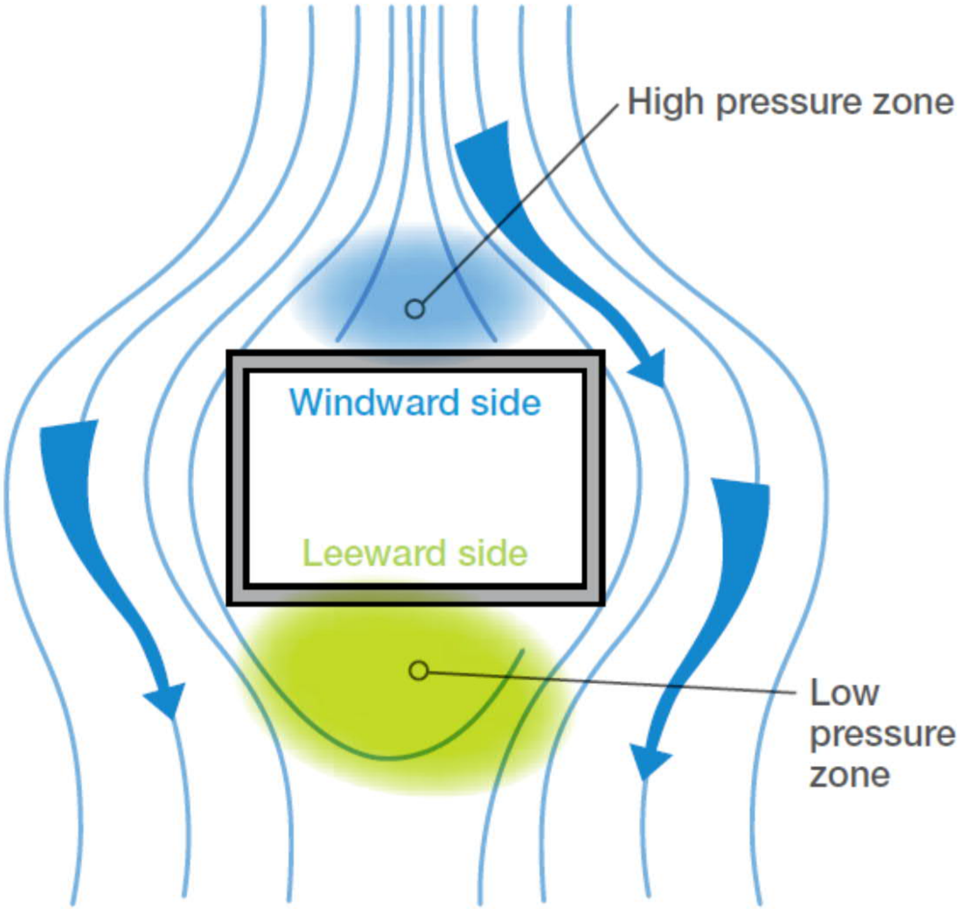


- Key factors affecting natural ventilation:
  - Depth of space related to ventilation openings
  - Ceiling height
  - Thermal mass exposed to the air
  - Location of building and possible air pollutants
  - Heat gain
  - Climate, e.g. outdoor temperature or wind velocity
- Can achieve passive cooling effect
  - Technologies or design features used to cool buildings without power consumption

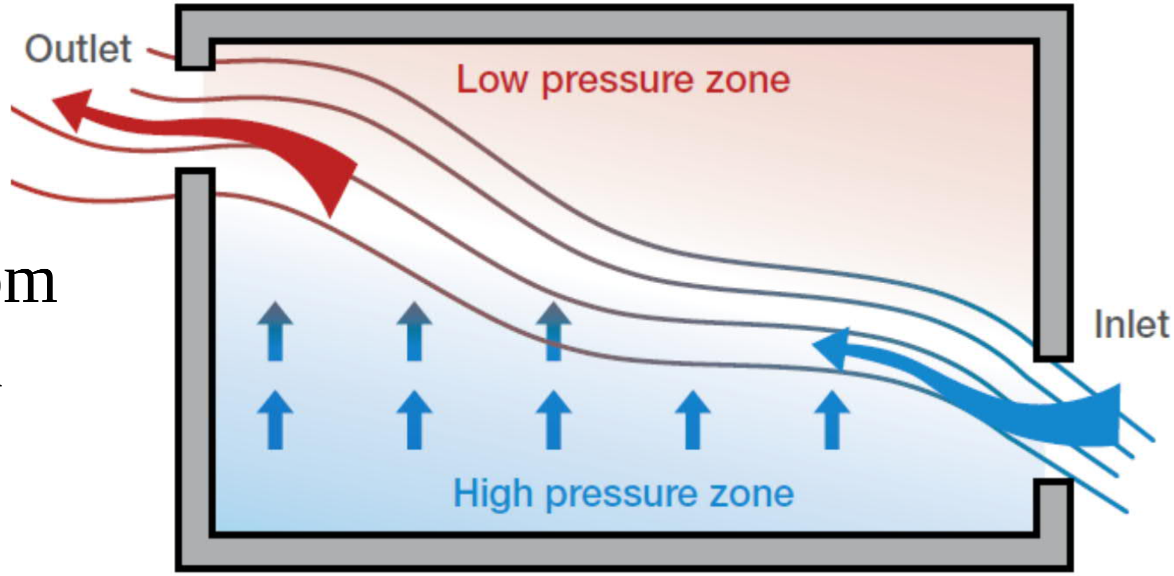
Design strategies of natural ventilation



(Source: Pennycook, K., 2009. *The Illustrated Guide to Ventilation*)



Pressure effect from wind



Pressure effect from stack ventilation

Stack Ventilation Analysis

Stack ventilation rate q_B through two openings is:

$$q_B = c_d A^* \sqrt{2\left(\frac{T_i - T_o}{T_o}\right) gH}$$

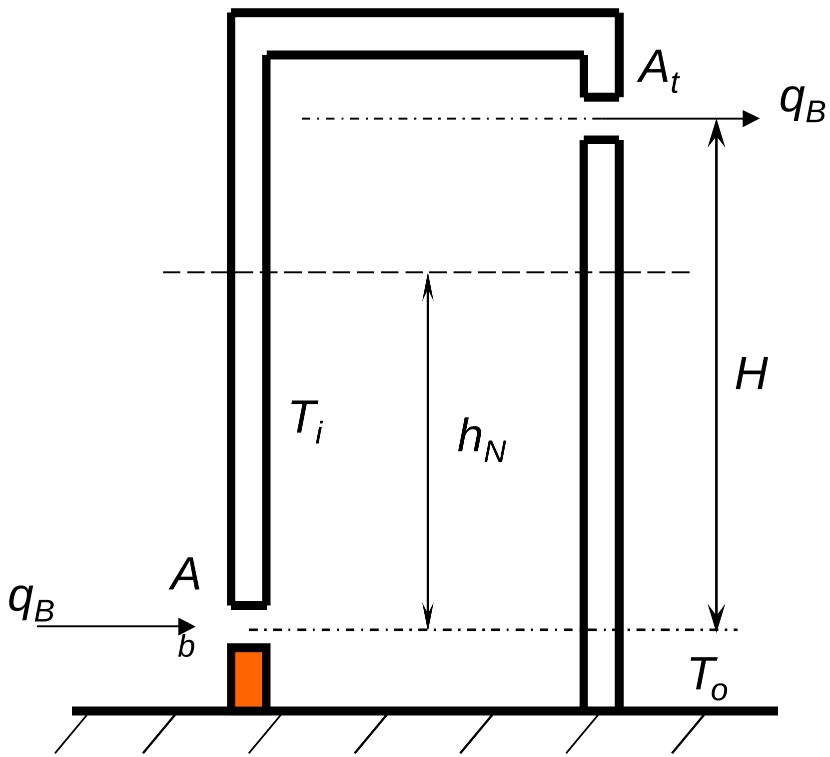
where

$$1/A^{*2} = 1/A_b^{\,2} + 1/A_t^{\,2}$$

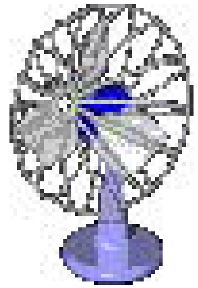
the Neutral Plane Level h_N is:

$$h_N = \frac{A_t^2}{A_b^2 + A_t^2} H$$

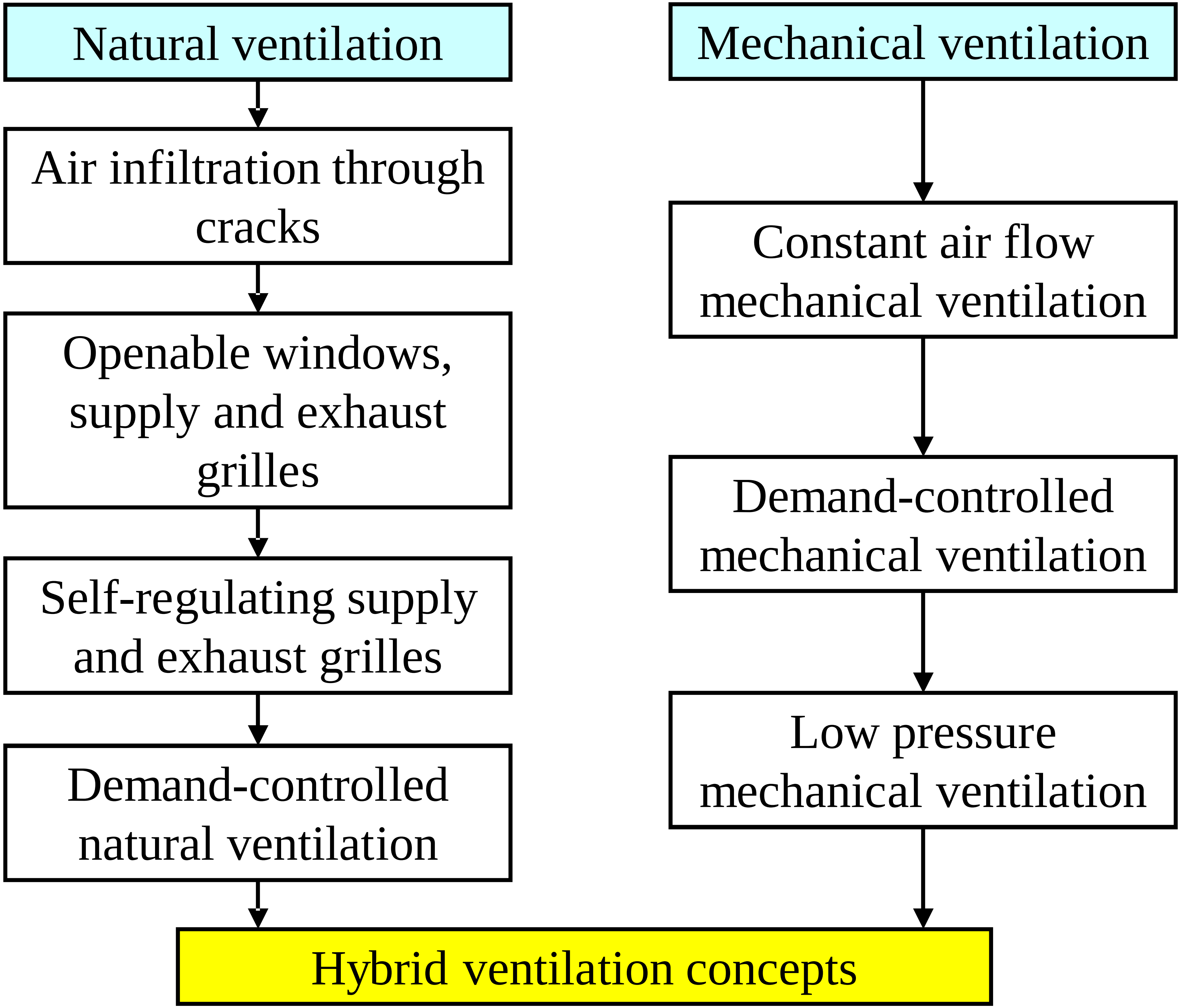
and C_d = discharge coefficient for opening, C_d = 0.61 for sharp-edge orifice.



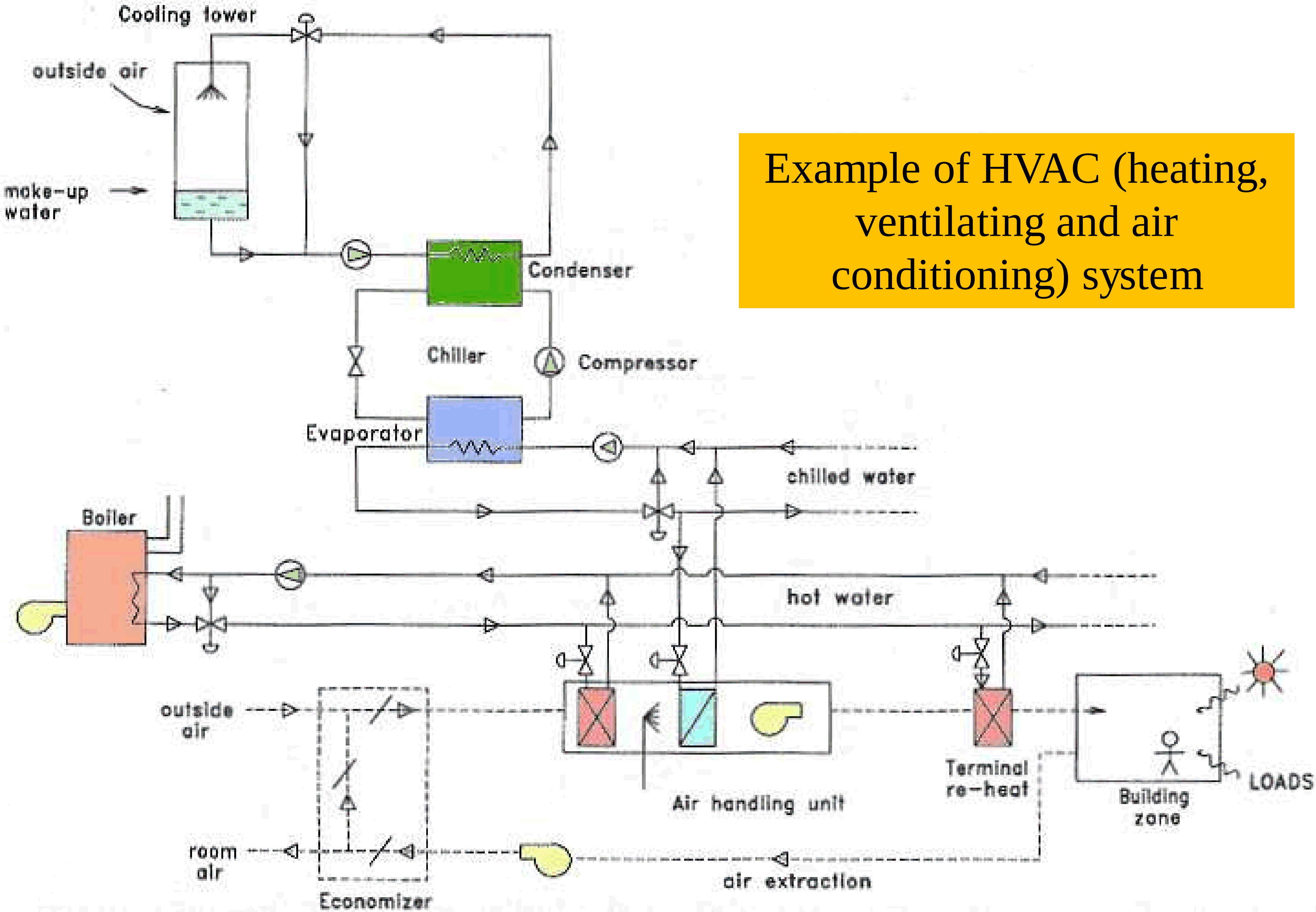
HVAC

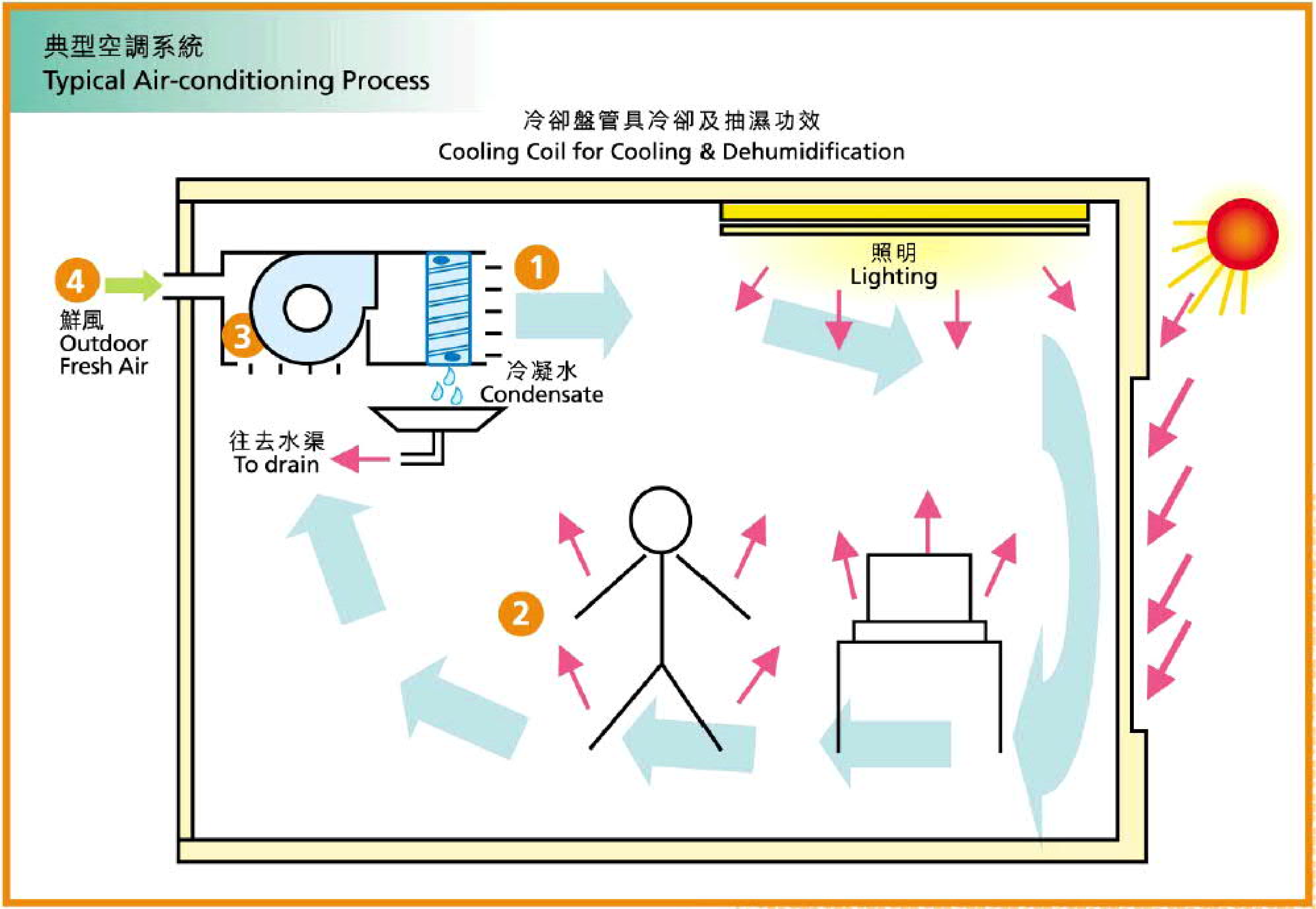


- Hybrid ventilation (mixed mode ventilation)
  - = Natural ventilation + Mechanical ventilation (and/or full air conditioning)
  - Use them at different time of the day or seasons of the year
  - Usually have a control system to switch between natural and mechanical modes
  - Combine the advantages of both to satisfy the actual ventilation needs and minimise energy consumption


Natural ventilation
Mechanical ventilation
Air infiltration through cracks
Constant air flow mechanical ventilation
Openable windows, supply and exhaust grilles
Demand-controlled mechanical ventilation
Self-regulating supply and exhaust grilles
Low pressure mechanical ventilation
Demand-controlled natural ventilation
Hybrid ventilation concepts

Example of HVAC (heating, ventilating and air conditioning) system





(Source: EnergyWitts newsletter, EMSD)

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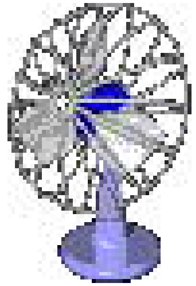
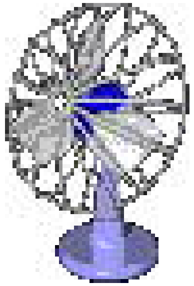
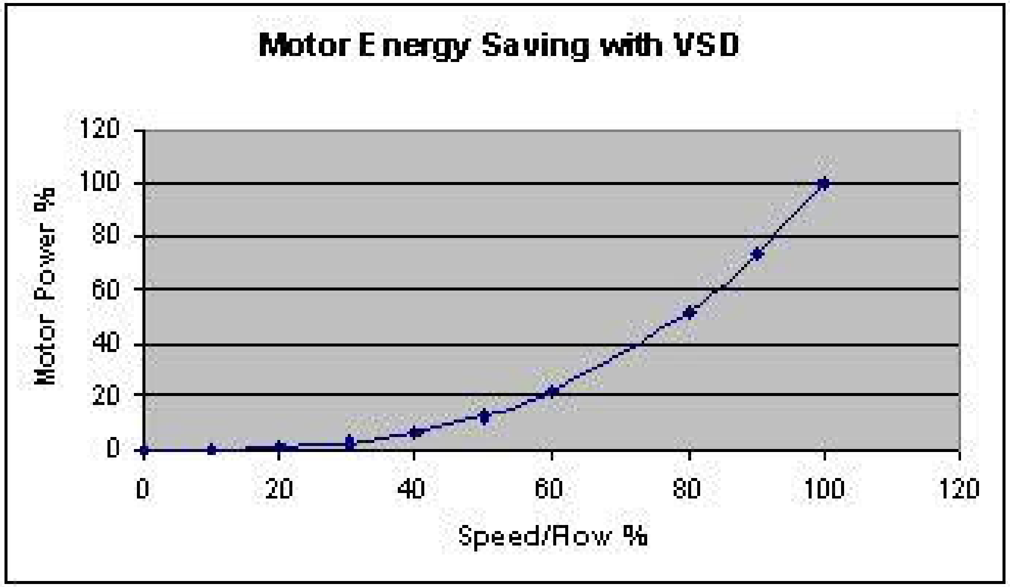


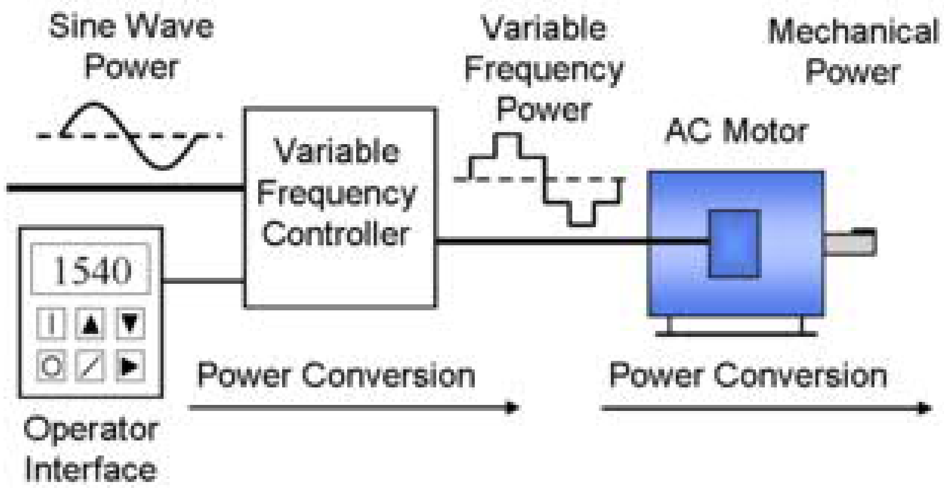
- HK EE Net: Air Conditioning System
  - http://ee.emsd.gov.hk/english/air/air_intro/air_intro.html
  - Air-side systems/equipment
  - Water-side systems/equipment
  - Control system
  - Other EE air-conditioning technologies
  - Emerging EE air-conditioning technologies

HVAC



- Variable speed drives (VSD)
  - More efficient means of achieving flow control by reducing the speed of the fan or pump motor
  - Using power semiconductors & microprocessors*





(*See also: http://en.wikipedia.org/wiki/Variable-frequency_drive)

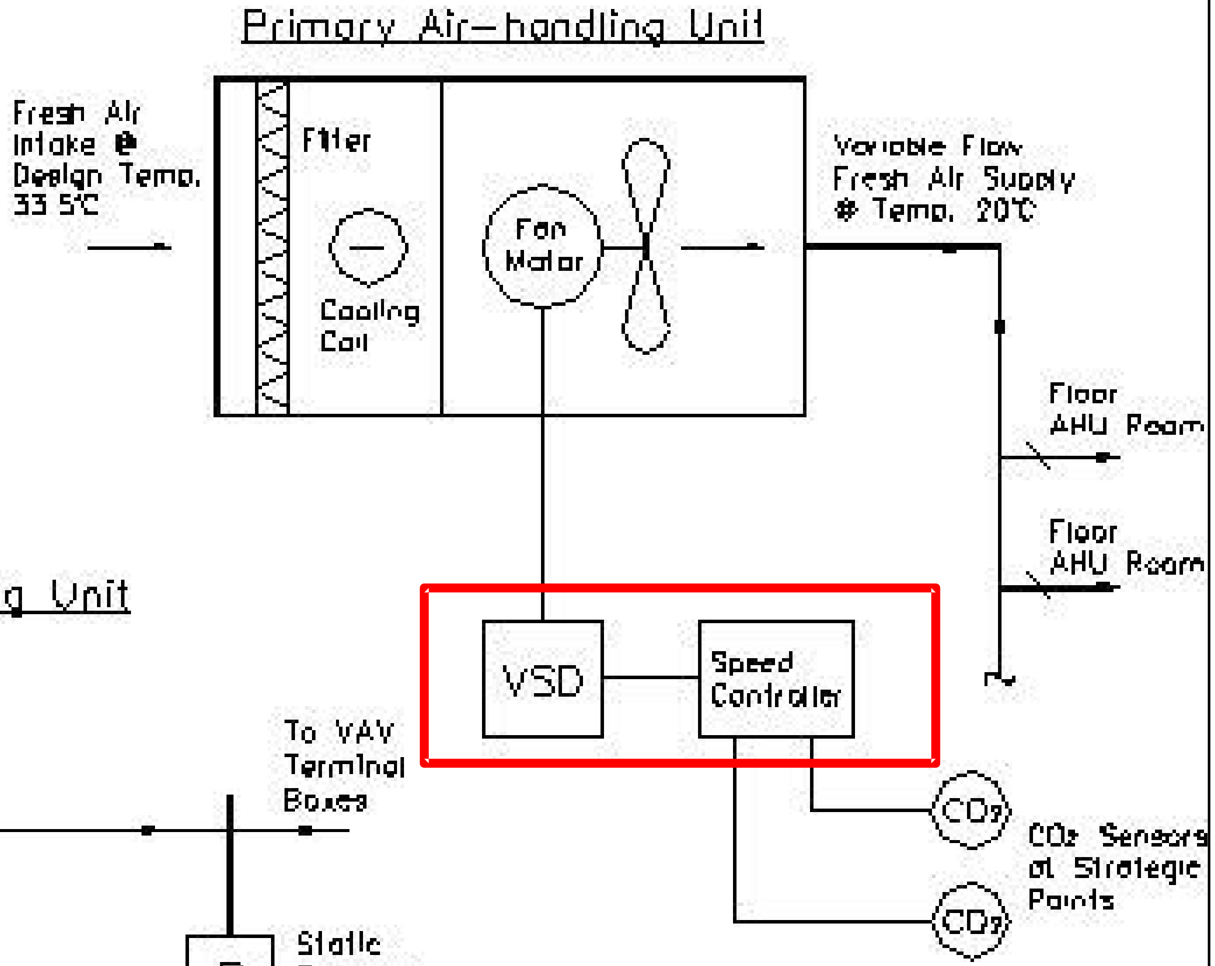
Applications of variable speed drives (VSD): HVAC air side

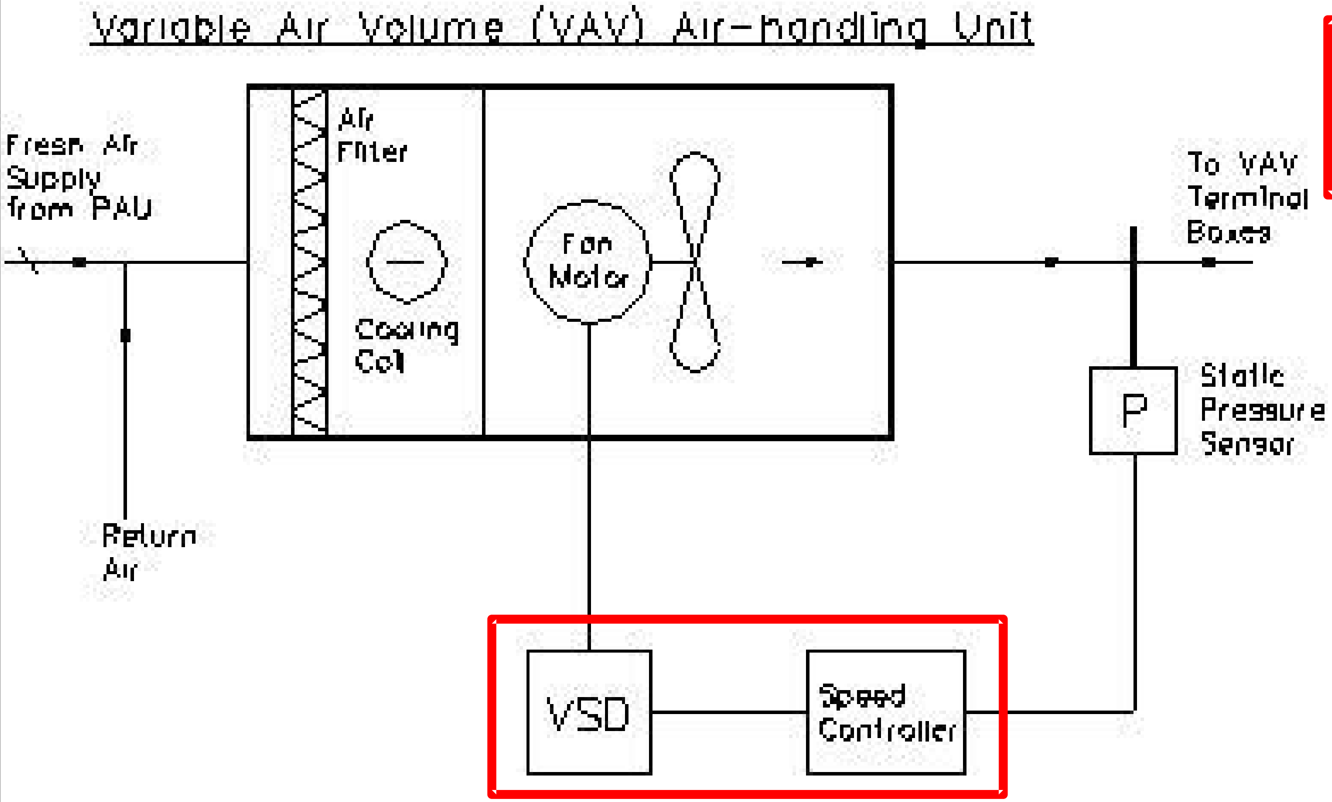
Fan Laws:

$$\mathring{V}_2/\mathring{V}_1 = n_2/n_1$$

$$\Delta p_{t2}/\Delta p_{t1} = (n_2/n_1)^2(\rho_2/\rho_1)$$

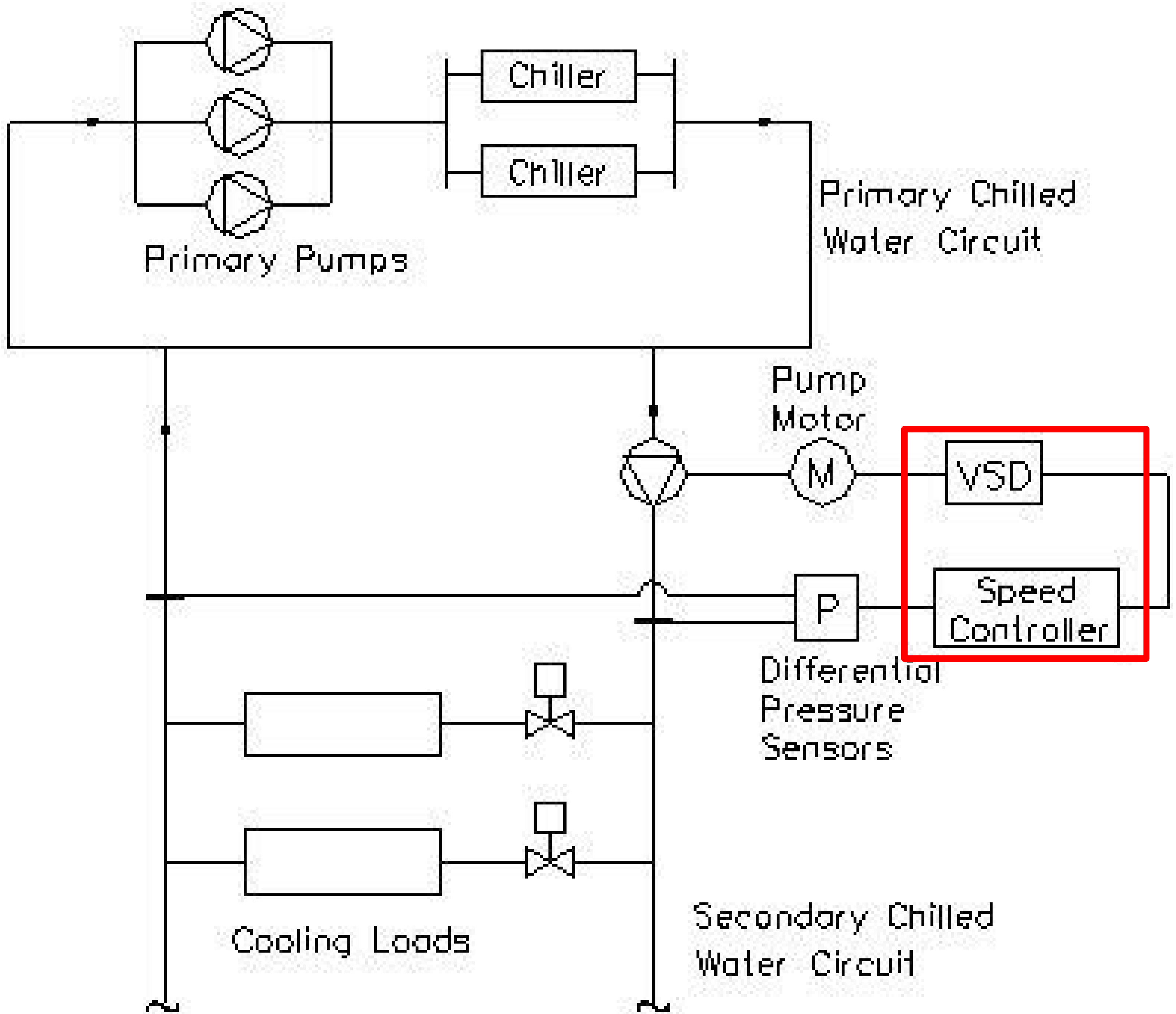
$$P_2/P_1 = (n_2/n_1)^3(\rho_2/\rho_1)$$





(Source: http://www.emsd.gov.hk/emsd/eng/pee/em_pub_2.shtml)

Applications of variable speed drives (VSD): chilled water side



(Source: http://www.emsd.gov.hk/emsd/eng/pee/em_pub_2.shtml)

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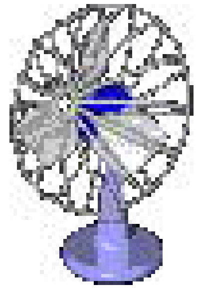
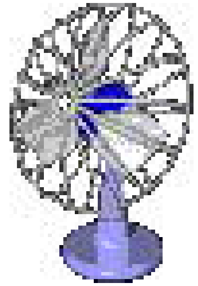


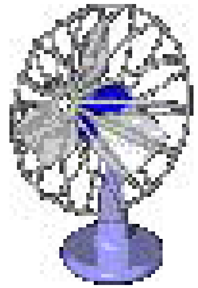
- Advanced Energy Saving Technologies (EMSD)
  - Application Guide to Variable Speed Drives (VSD)
    - http://www.emsd.gov.hk/emsd/eng/pee/em_pub_2.shtml
  - Application of Physical Scale Prevention Technologies for Chiller Condenser
    - http://www.emsd.gov.hk/emsd/e_download/pee/Physcl-Scl-Prvntn-Tchnlg.pdf
  - Predictive System Curve Control for Secondary Chilled Water Pumps
    - http://www.emsd.gov.hk/emsd/e_download/pee/EMS_Water_Pumps(low-res).pdf

HVAC

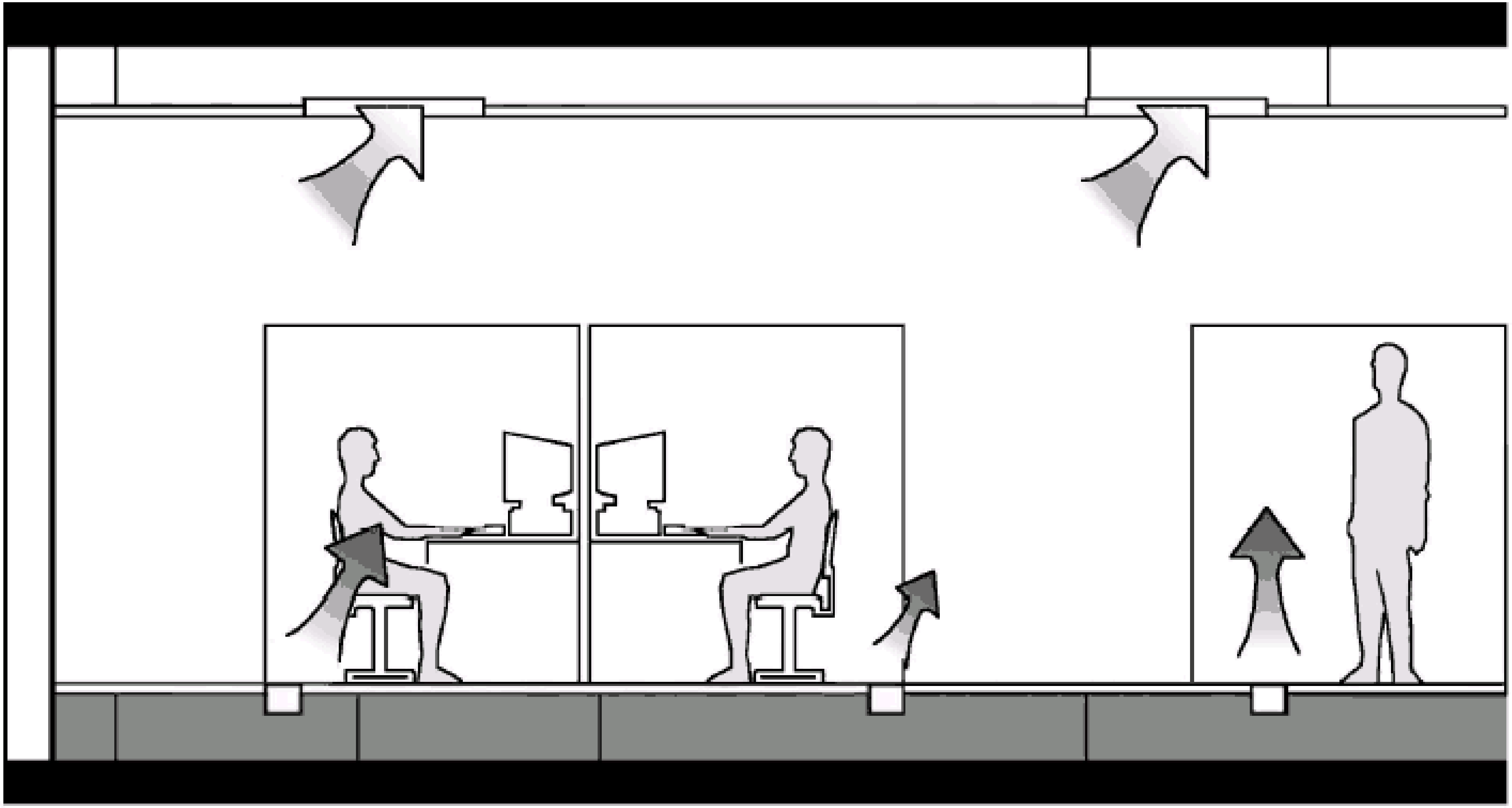


- Advanced Energy Saving Technologies (EMSD)
  - Total Hydronic Balancing in Chilled Water System
    - http://www.emsd.gov.hk/emsd/e_download/pee/THB_CHW.pdf
  - Variable Flow Control for Condensing Water Pumps
    - http://www.emsd.gov.hk/emsd/e_download/pee/Conds-water-pump.pdf
  - VAV System Static Pressure Reset Control
    - http://www.emsd.gov.hk/emsd/e_download/pee/VAV-SPRC.pdf

HVAC

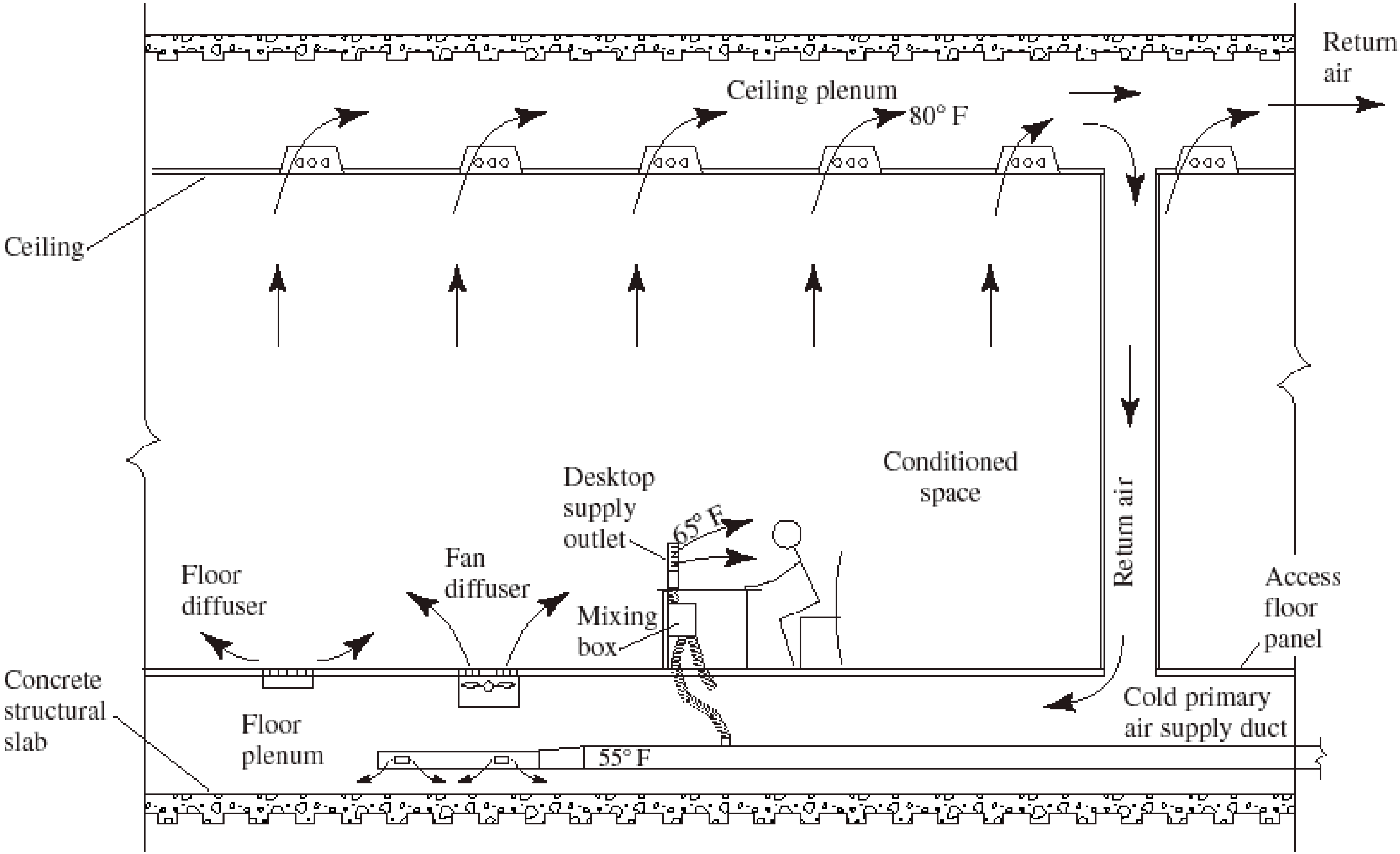


- Some new HVAC systems have the potential to be highly energy efficient
  - May apply when appropriate
  - Must understand their merits and limitations
- Examples of innovative HVAC systems:
  - Underfloor air distribution (UFAD)
  - Chilled ceiling and chilled beam (CC+CB)
  - Variable refrigerant flow (VRF)

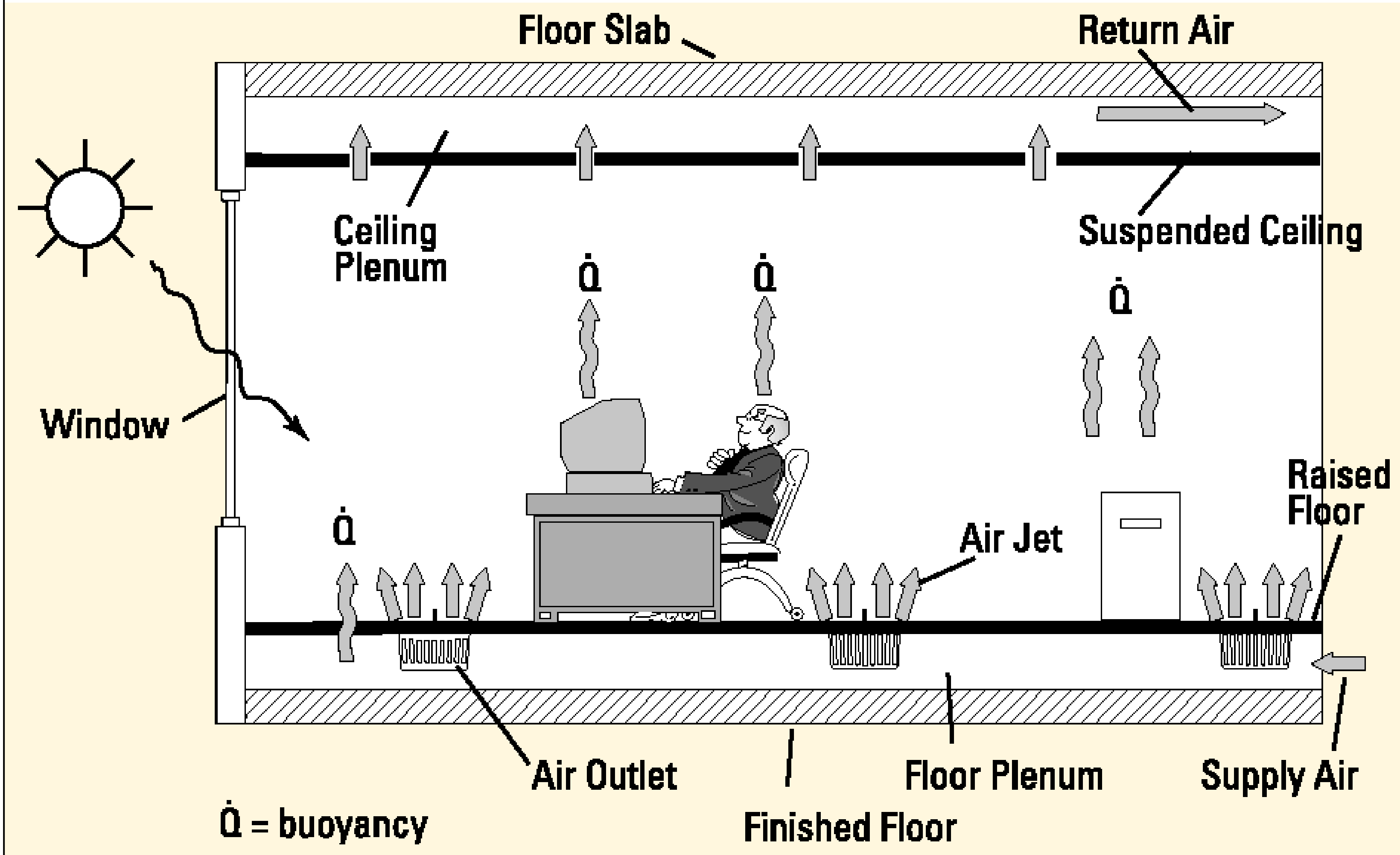


Underfloor air distribution system

(Source: *ASHRAE Underfloor Air Distribution Design Guide*)

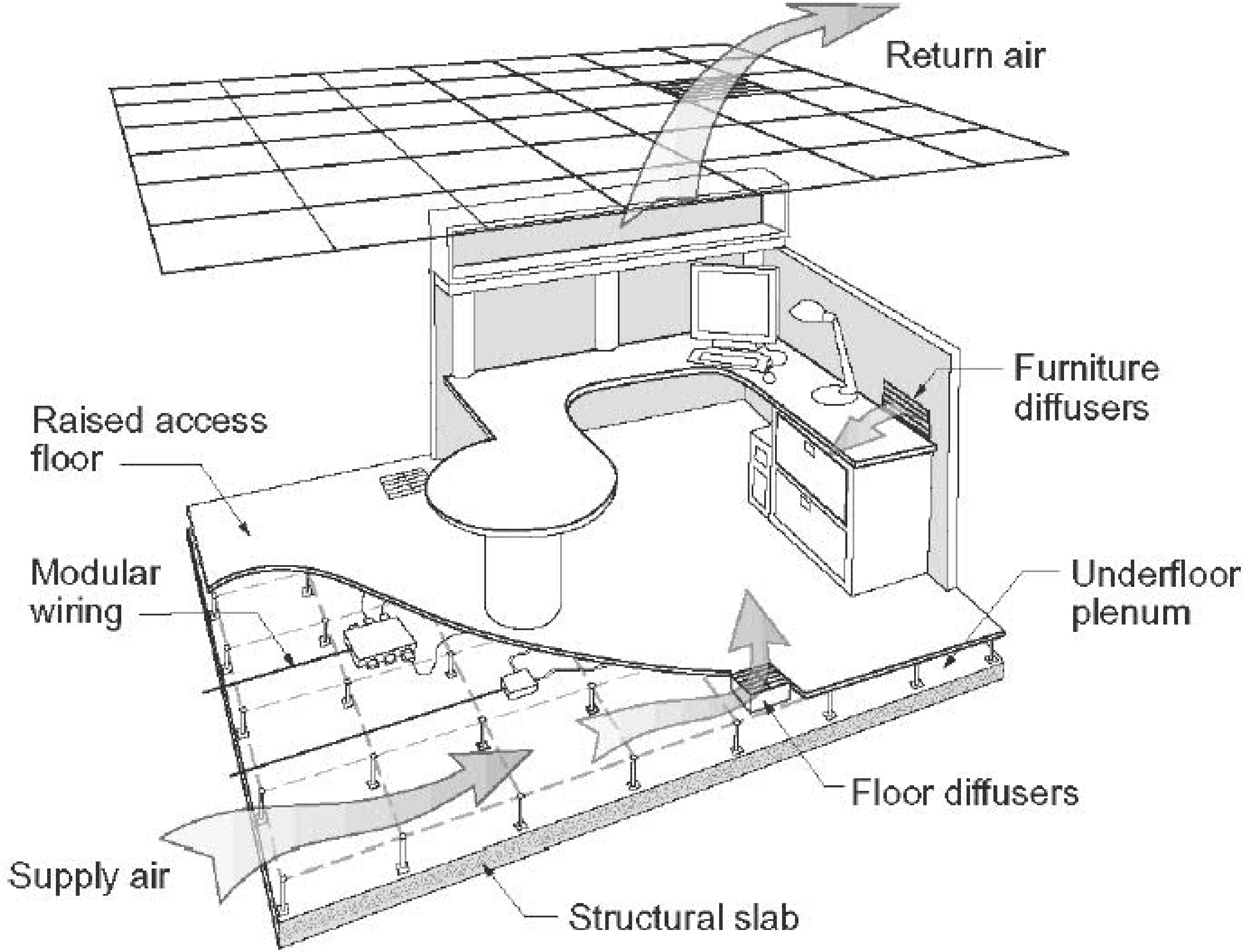


Upward flow underfloor air distribution system



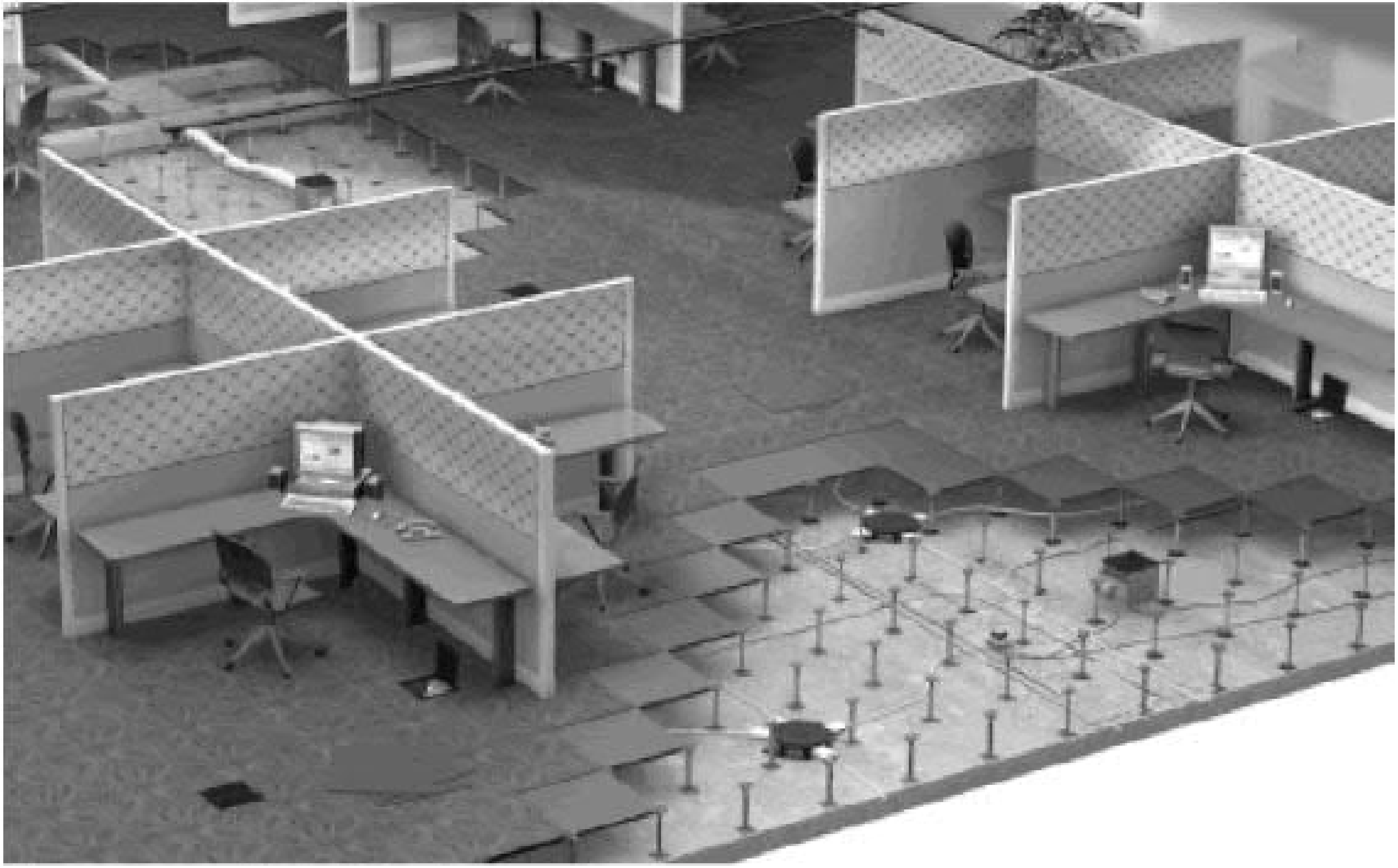
Underfloor air supply

(Source: http://www.price-hvac.com)



Office space with underfloor air distribution & task air-conditioning

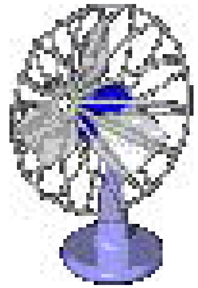
(Source: *ASHRAE Underfloor Air Distribution Design Guide*)



Installation of raised floor system in open plan office

(Source: *ASHRAE Underfloor Air Distribution Design Guide*)

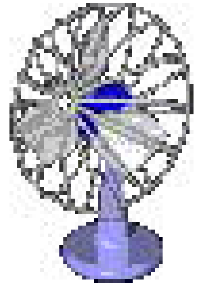
HVAC



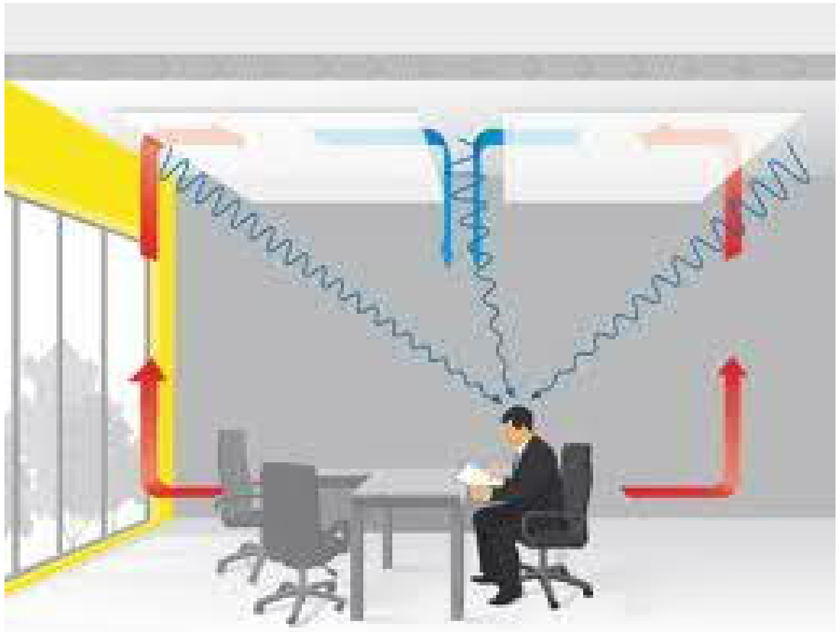
- Advantages of underfloor air distribution (UFAD):
  - Integrated well with raised floor plenum
  - Can be very flexible for future changes/relocations
  - Conditioned air is supplied directly to occupants
  - Stagnant air can be reduced (if ceiling return)
  - Upward flow lifts some unneutralised heat
  - It can utilise thermal mass of access floor & slab to reduce peak demands
- Disadvantages of UFAD:
  - Higher initial costs
  - Need for raised floor system & floor diffusers

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

HVAC

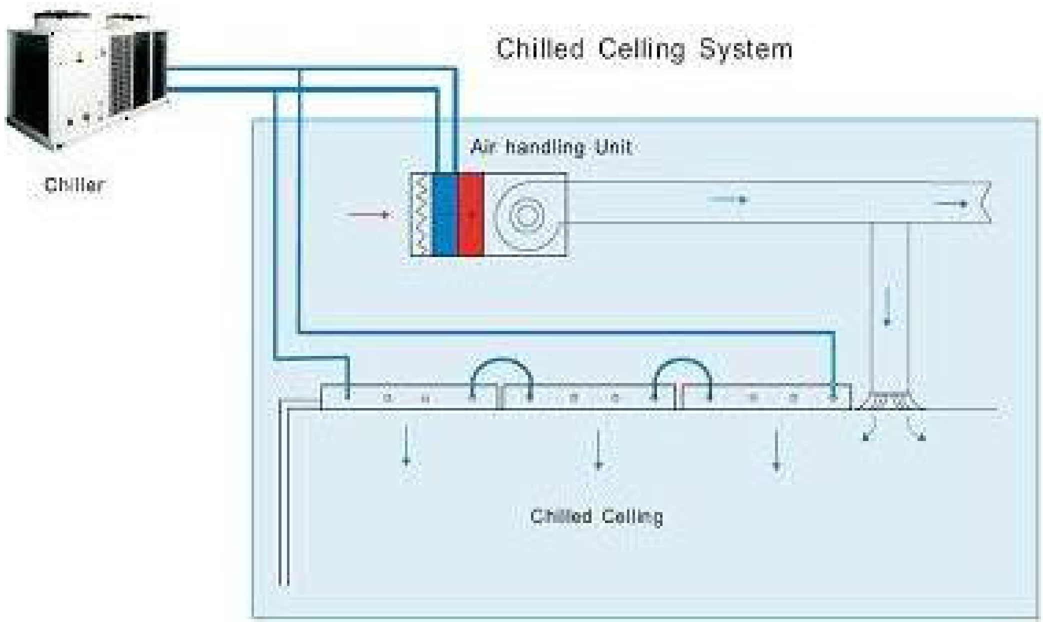


- Chilled ceiling and chilled beam (CC+CB)
  - Used in Europe since mid-80s; Become popular in other countries
  - Potential benefits
    - Better thermal comfort
    - Lower energy consumption
    - Smaller air flow rate
    - Low sound level
    - Green building credits



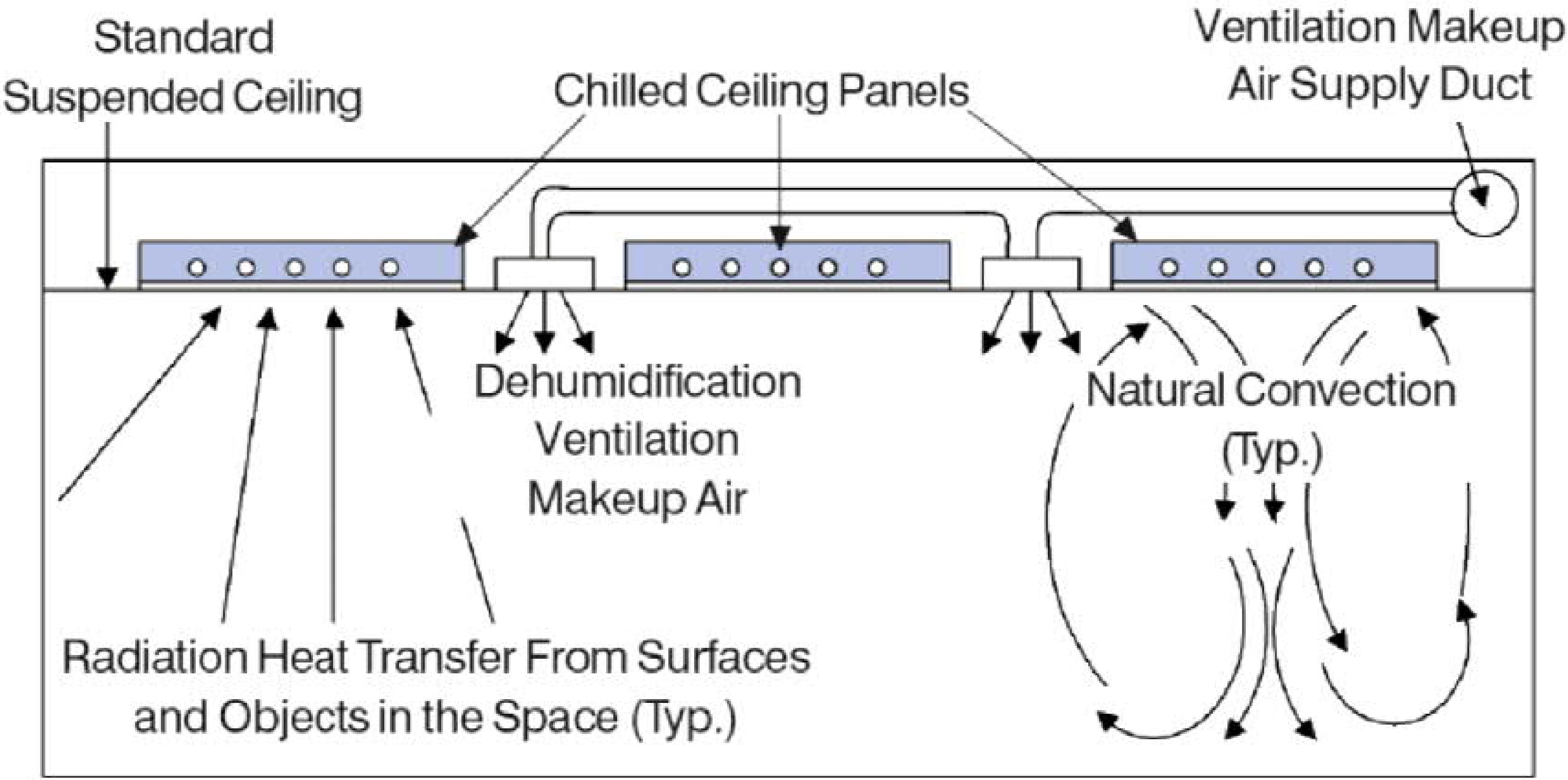
(*See also: http://archtoolbox.com/materials-systems/hvac/120-chilled-beam-ceiling.html)

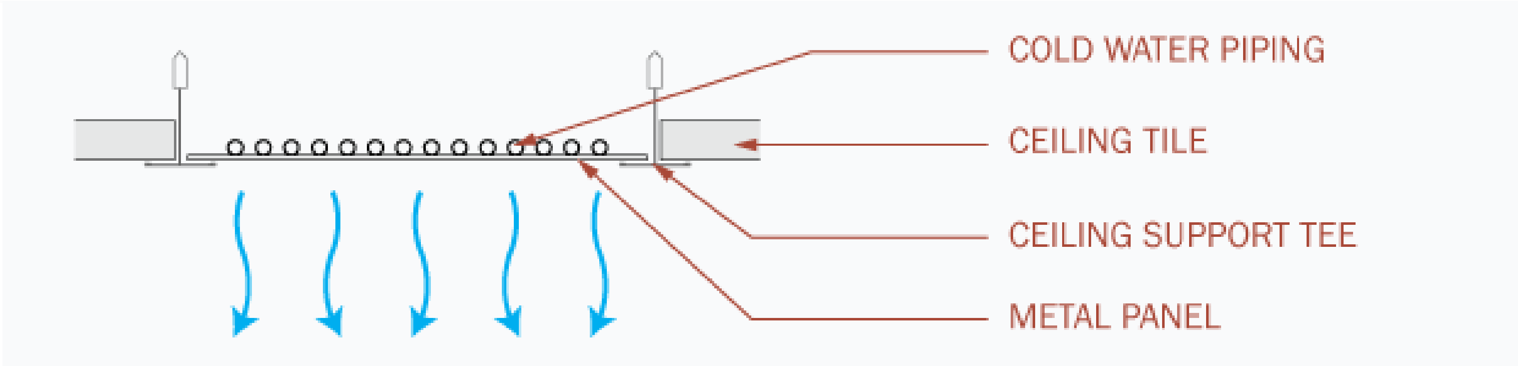
Examples of chilled ceiling panels



(Source of images: www.kuehldecken.de and www.sasint.co.uk and www.barcolair.cn)

Operating principle of chilled ceiling systems

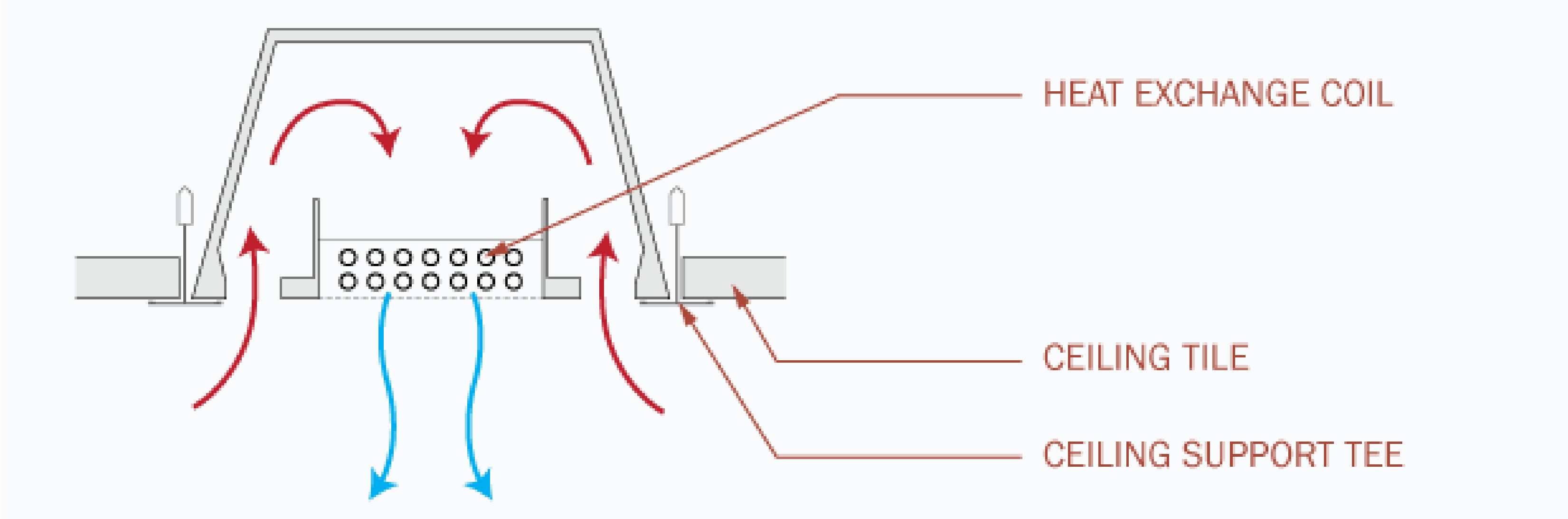




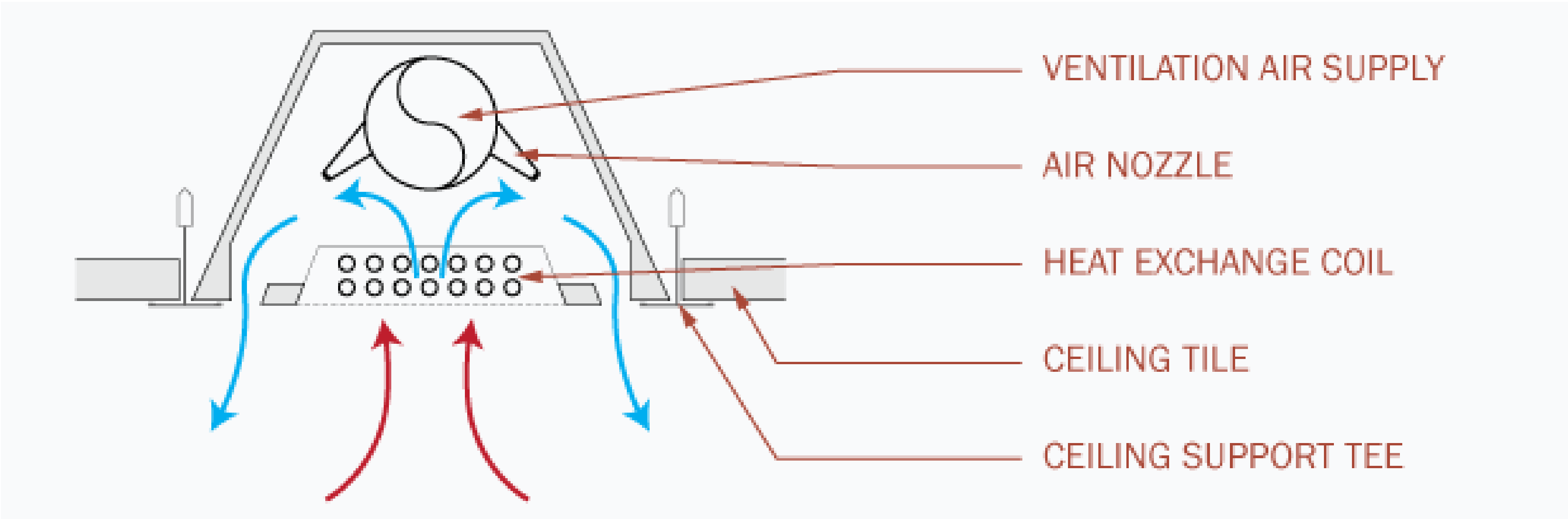
(Source: Dieckmann and Brodrick, 2004; http://archtoolbox.com/materials-systems/hvac/120-chilled-beam-ceiling.html)

Types of chilled beam systems

Passive chilled beams

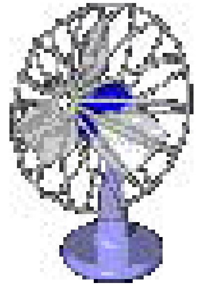


Active chilled beams



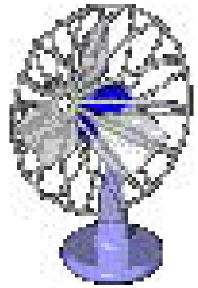
(Source: http://archtoolbox.com/materials-systems/hvac/120-chilled-beam-ceiling.html)

HVAC



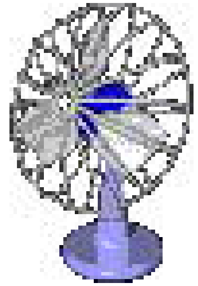
- Chilled ceiling system: Water-based cooling
  - Ceiling-based radiant cooling panels coupled with chilled water pipes or coils (14-17 $^{\circ}$C)
  - A combination of natural convection & radiation
  - A separate dedicated outdoor air system (DOAS) is used to dehumidify the outdoor air
- Thermal comfort
  - Supply air flow rate is lower => draft is reduced
  - Small temperature difference between room air and chilled ceiling surface

HVAC



- Chilled ceiling: Thermal comfort (cont’d)
  - Higher indoor temperature can be used => decrease cooling loads and energy use
- Energy performance
  - Higher chilled water temp
    - => Higher chiller evaporative temp
    - => Chiller energy saving
  - Supply air flow rate is lower
    - => Fan energy saving
  - Radiation w/ mixed convection heat transfer

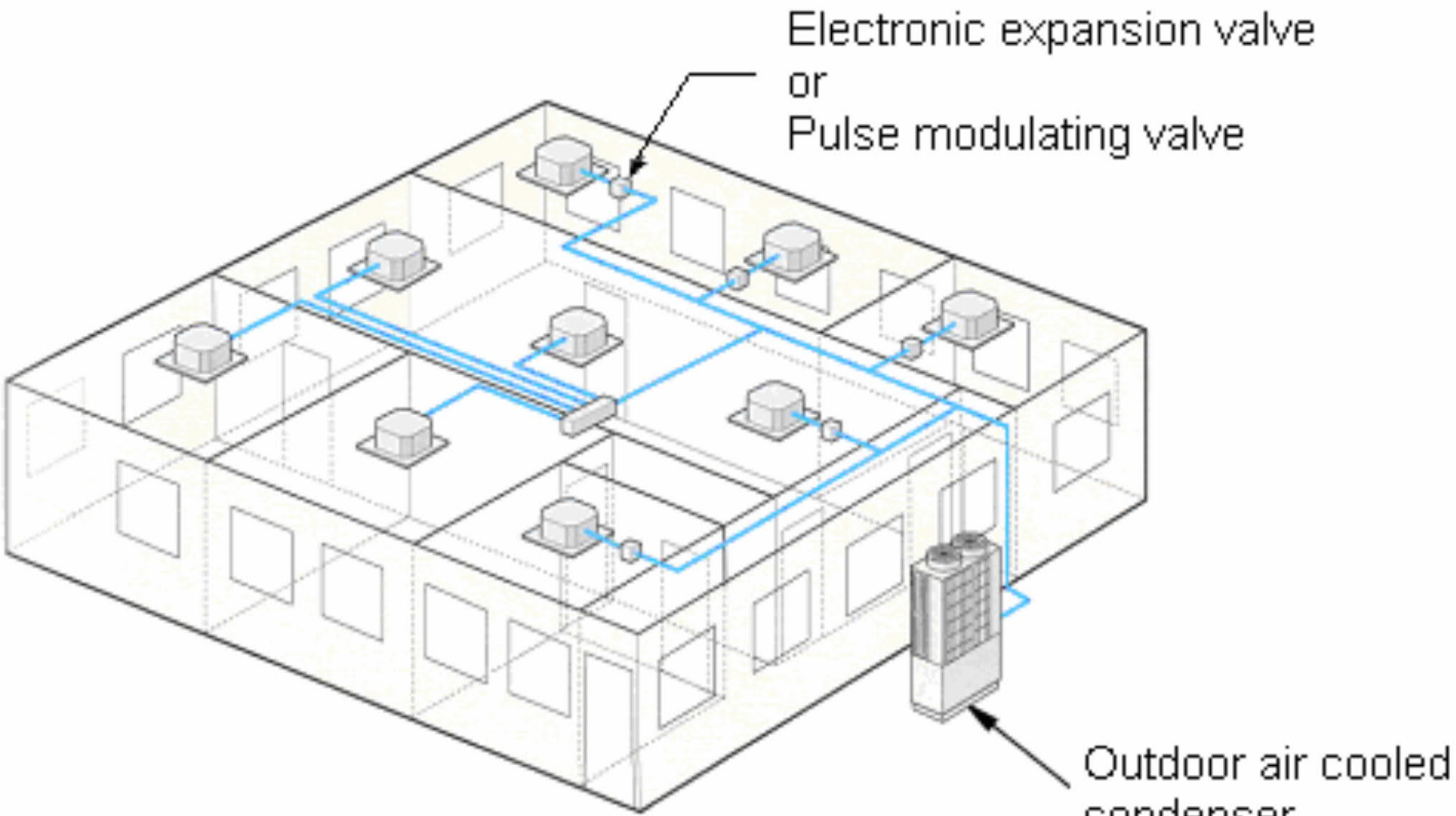
HVAC



- Variable refrigerant flow (VRF) systems*
  - Direct expansion (DX), similar to multi-split systems; widely used in Japan and Europe
  - Able to control the amount of refrigerant flowing to the multiple evaporators (indoor units), enabling the use of many evaporators of differing capacities and configurations connected to a single condensing unit
  - Provides an individualized comfort control, and simultaneous heating & cooling in different zones

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

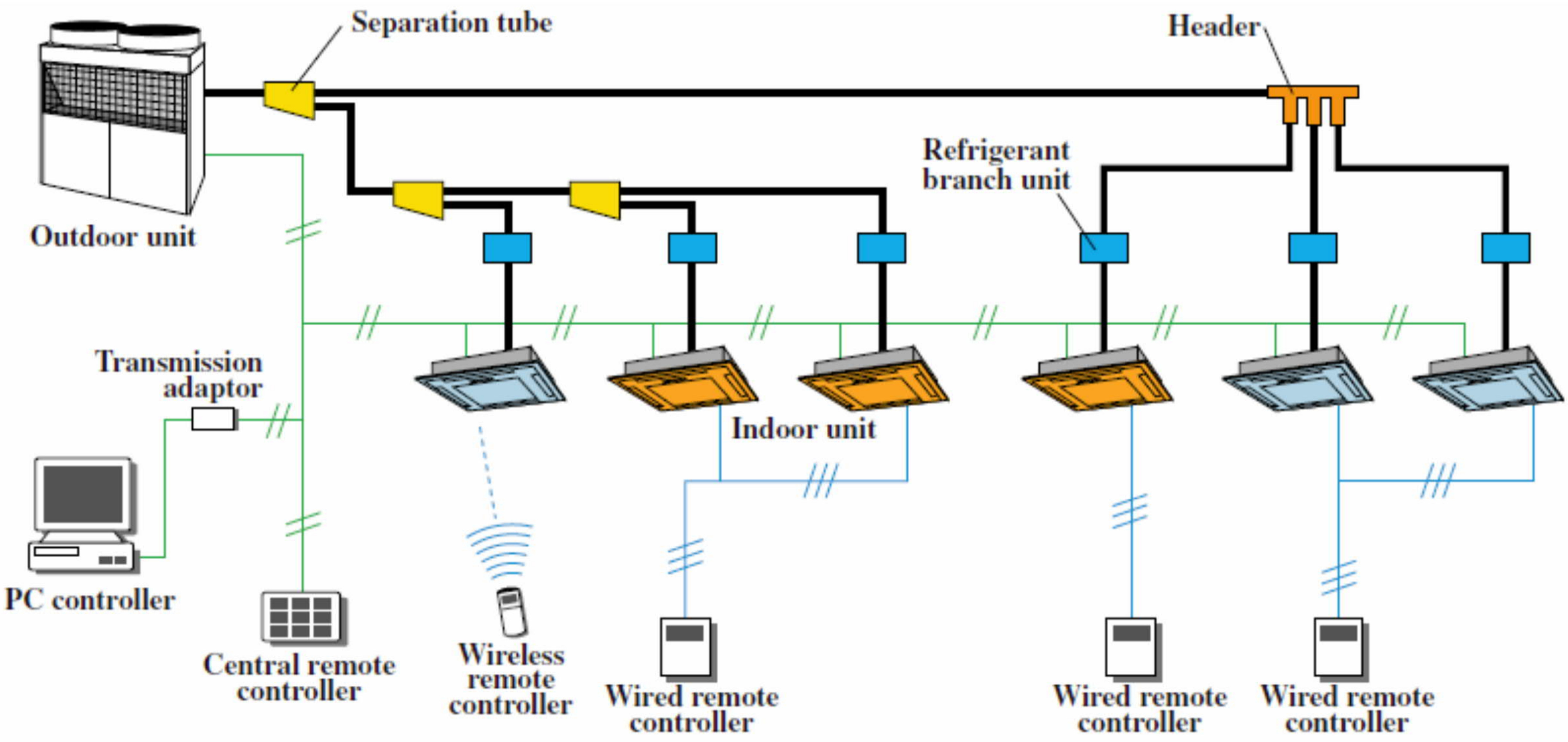
Variable refrigerant flow (VRF) system



VRF System with Multiple Indoor Evaporator Units

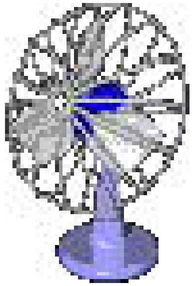
(Source: Fujitsu)

Variable refrigerant flow (VRF) system



(Source: Fujitsu)

HVAC



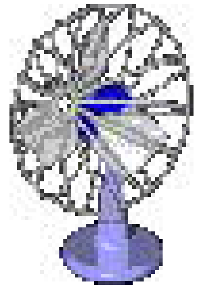
- Energy performance of VRF systems
  - Linear step control in conjunction with inverter and constant speed compressor combination
    - Adjust compressor speed to its optimal energy usage
  - Allows more precise control of the necessary refrigerant circulation amount required according to the system load (smooth capacity control)
    - High part-load and seasonal efficiency
  - Minimizes or eliminates ductwork completely
    - Reduce duct losses and fan energy

(*See also: Variable Refrigerant Flow (US GSA) http://www.gsa.gov/portal/content/163491)

HVAC

- Other benefits of VRF systems
  - Can bring rooms to desired temperature quickly and keep temperature fluctuations to minimum
  - Capable of simultaneous cooling and heating
  - Modular design and zoning flexibility
  - Energy sub-metering is relatively simple
  - Commissioning/maintenance are not complicated
- Limitations of VRF:
  - Piping distance, oil management, fresh air intake

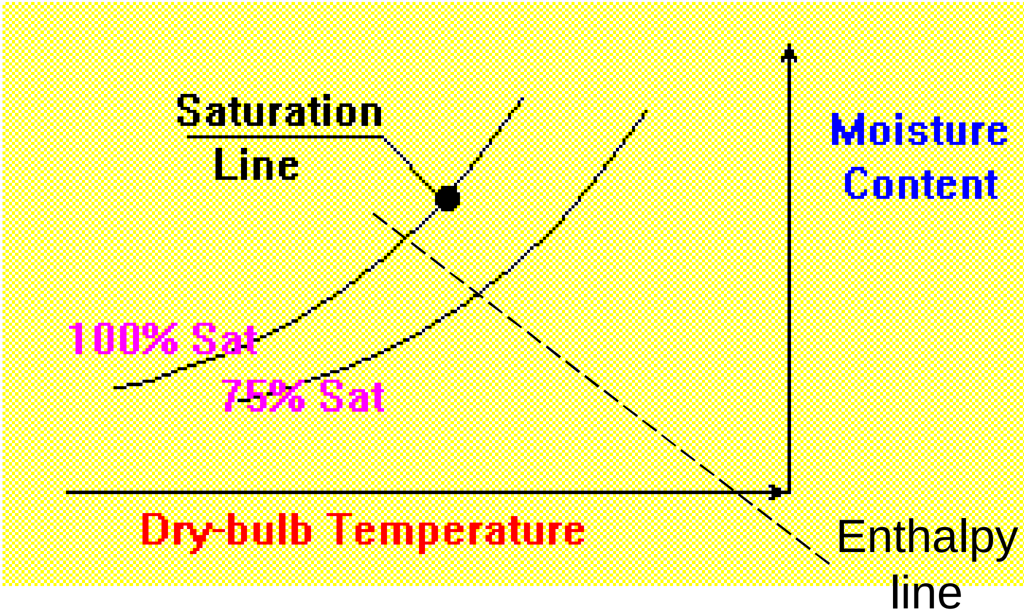
HVAC

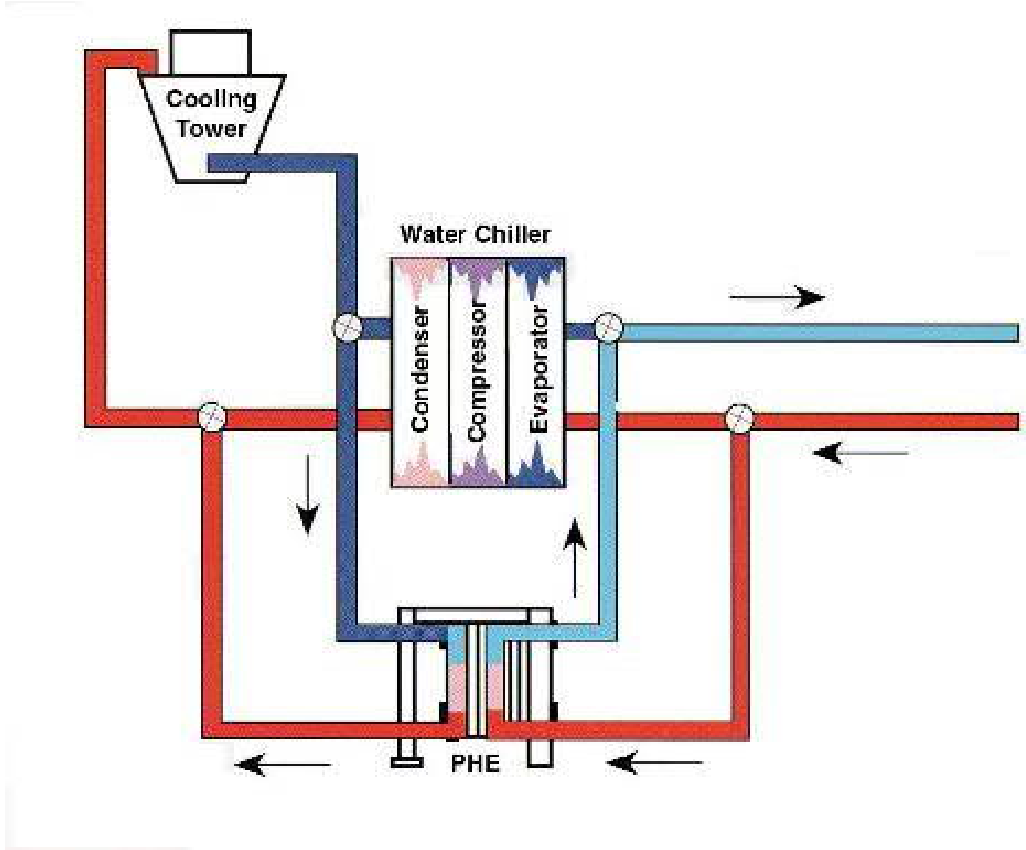


- Free cooling methods*
  - An economical method of using low external air temperatures to assist in cooling or chilling water
  - Also called economizer cycles
    - 1) Air-side economizer
    - 2) Water-side economizer (free refrigeration)
  - Free cooling for data centres and computer server
- Waste heat recovery
  - Such as using heat recovery chiller

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

‘Free’ cooling methods in HVAC system*





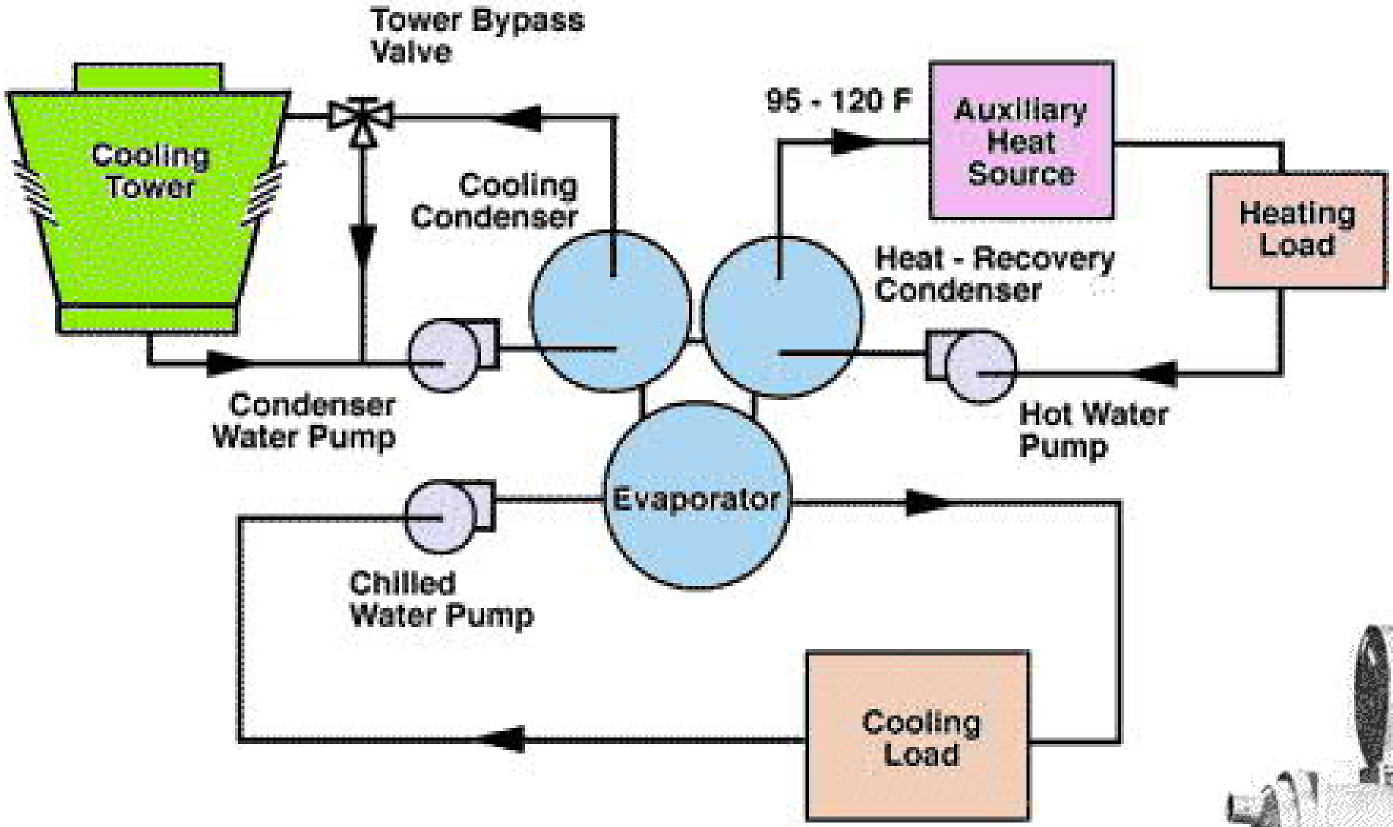
(a) Air-side free cooling/economiser cycle
- intake more outdoor air when its enthalpy (energy content) is lower than indoor air
- save energy in cooling systems

(b) Water-side free cooling or ‘free’ refrigeration
- chiller bypass when the system water can be cooled by ambient
- save energy in refrigeration or chiller plant

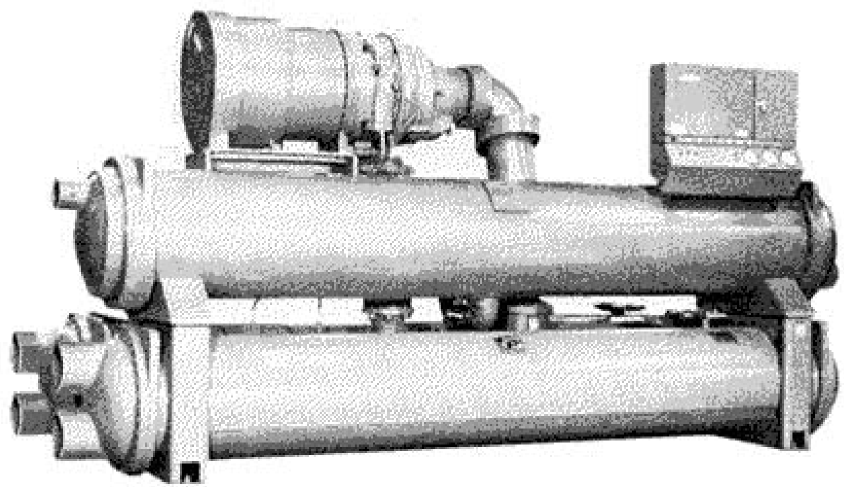
(*See also: http://en.wikipedia.org/wiki/Free_cooling)

Waste heat recovery – e.g. double bundle heat recovery chiller

Strategy: use of heat recovery



Make use of waste heat from condenser to produce warm/hot water or for heating the space.

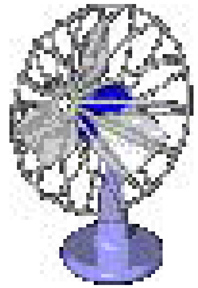


Double bundle heat recovery chiller

- Waste heat = "dumped" heat that can still be reused
- Waste heat recovery saves fuel

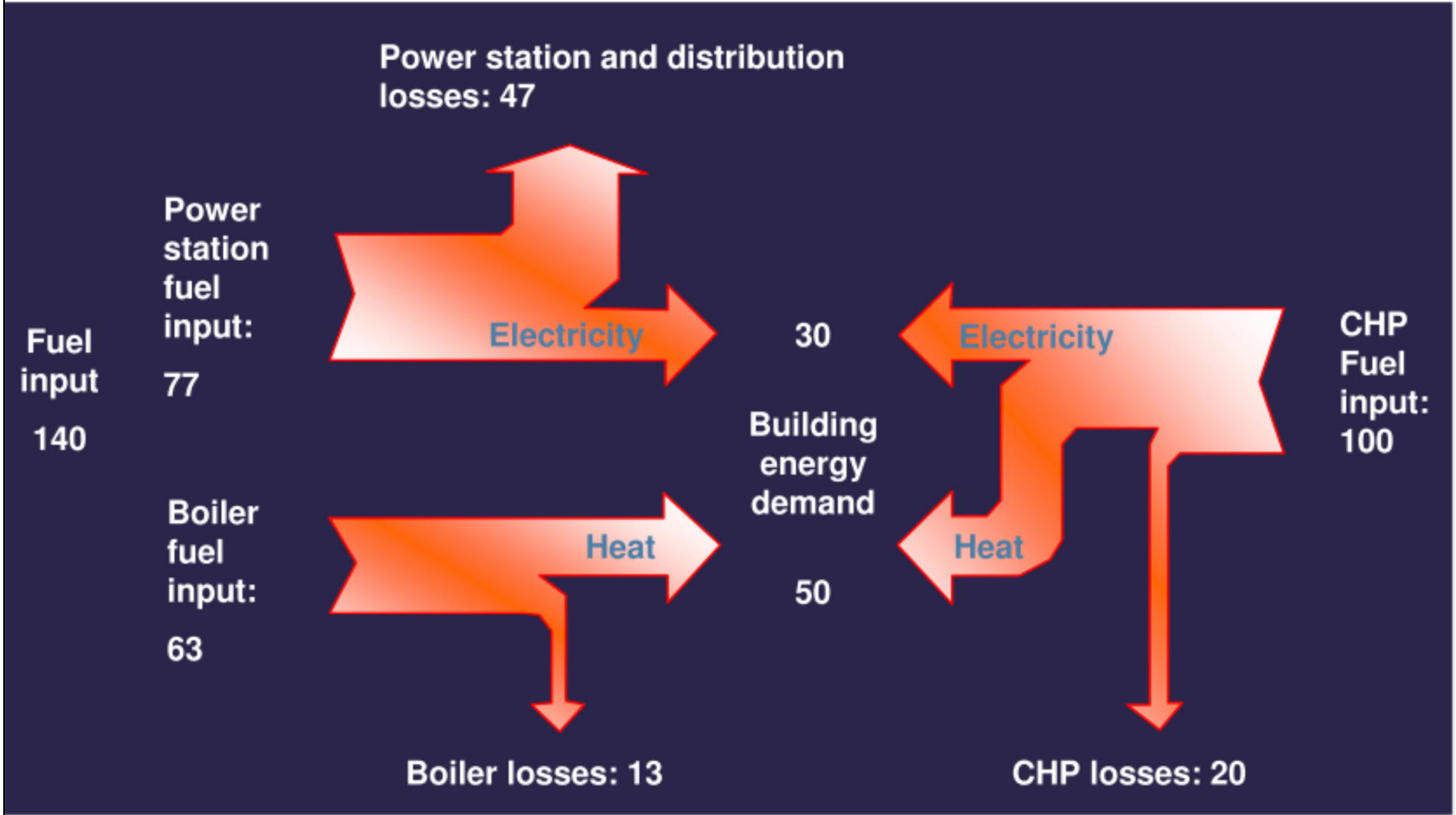
(*See also: http://www.energyefficiencyasia.org/energyequipment/ee_ts_wasteheatrecovery.html)

HVAC



- Cogeneration or combined heat and power (CHP) 熱電聯供 is the use of a heat engine or power station to simultaneously generate electricity and useful heat
- Trigeneration or combined cooling, heat and power (CCHP) 三聯供 refers to the simultaneous generation of electricity and useful heating and cooling from the combustion of a fuel or a solar heat collector

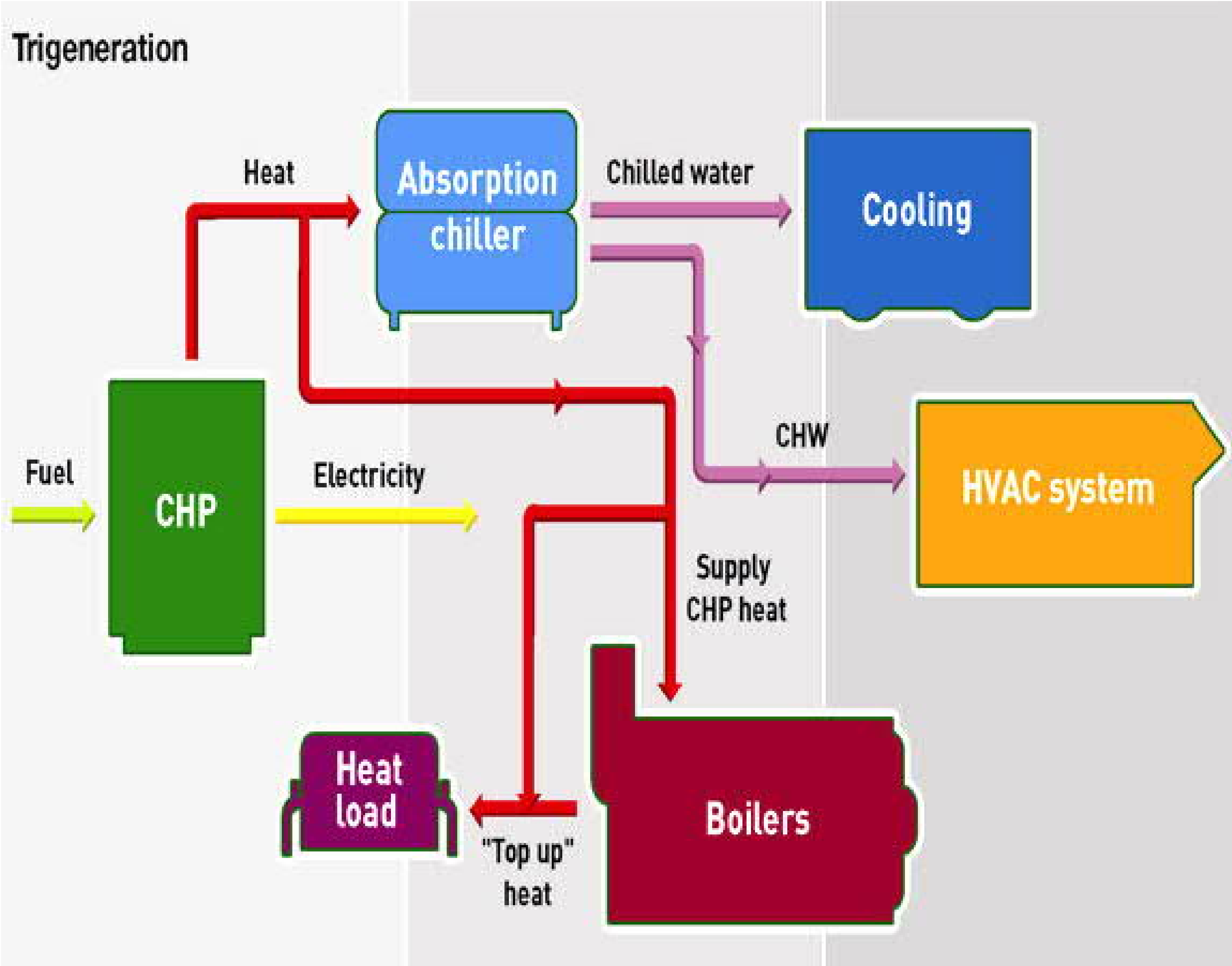
Combined heat and power (CHP), also known as cogeneration, reduces energy use by 30%



Further information: http://en.wikipedia.org/wiki/Cogeneration

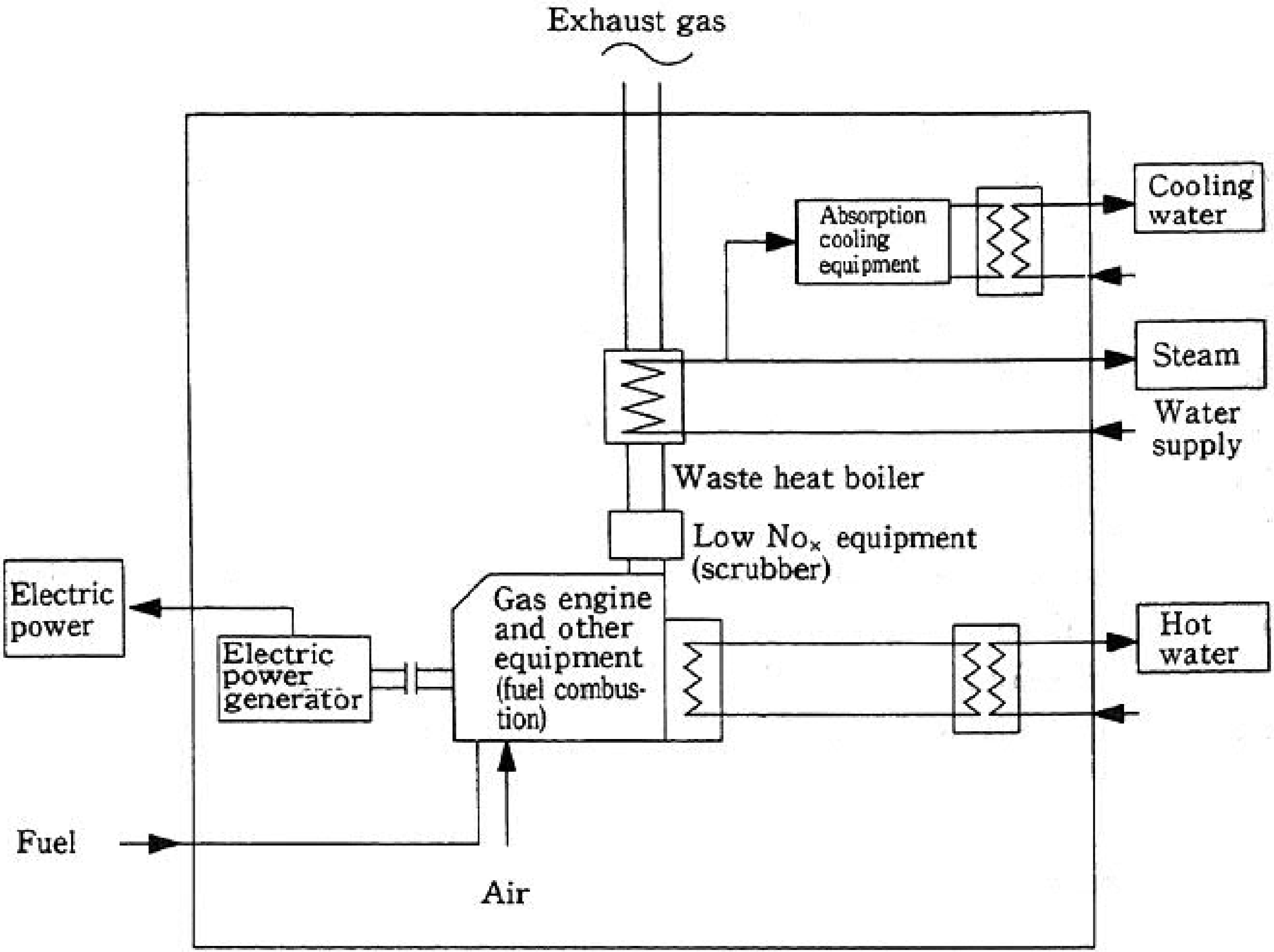
(Source: www.revival-eu.net)

Basic concept of trigeneration: heat, cool, electricity (三聯供)



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

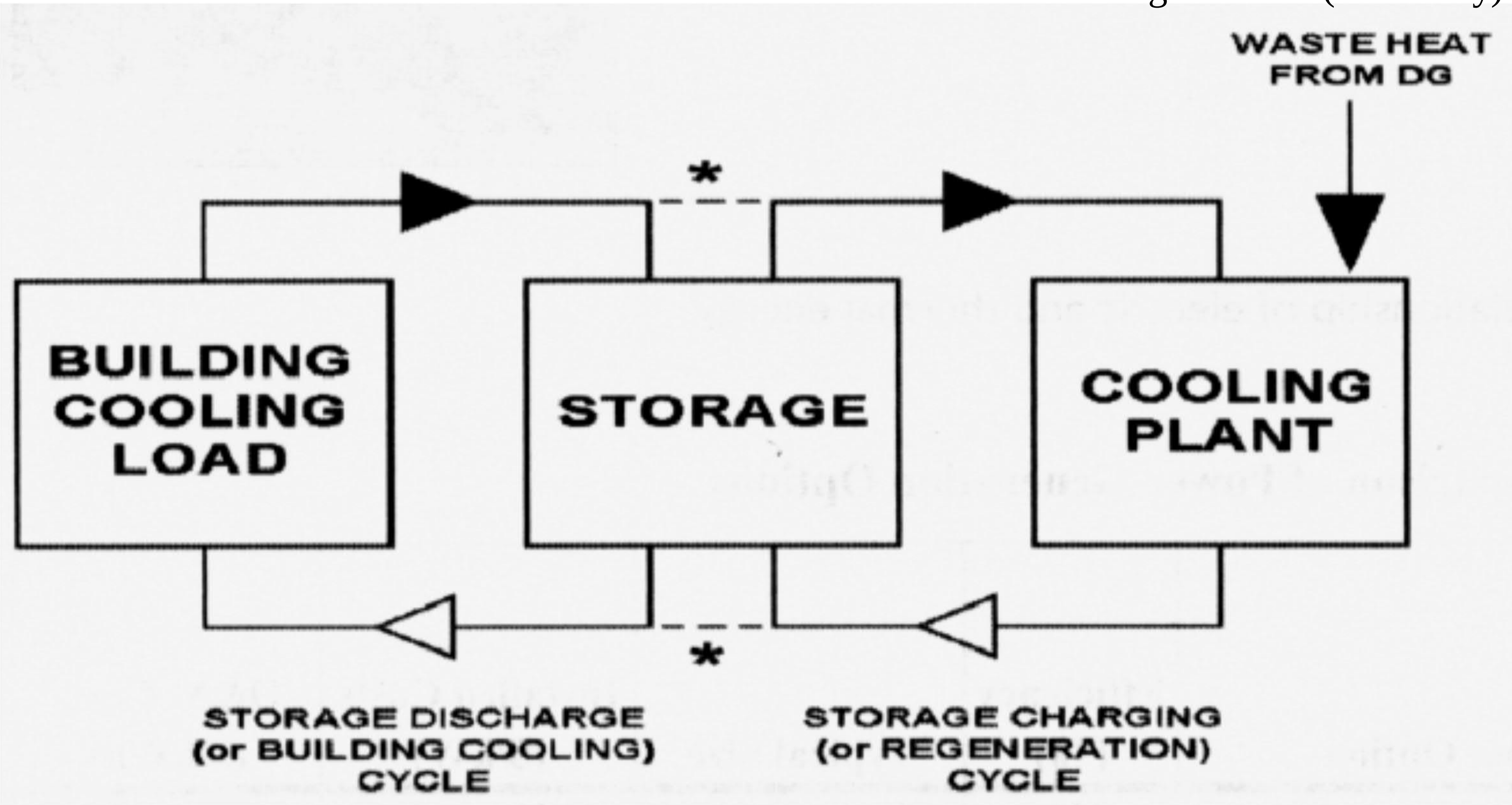
A typical trigeneration system (in Japan)



(Source: www.env.go.jp)

Thermal uses of waste heat by energy storage

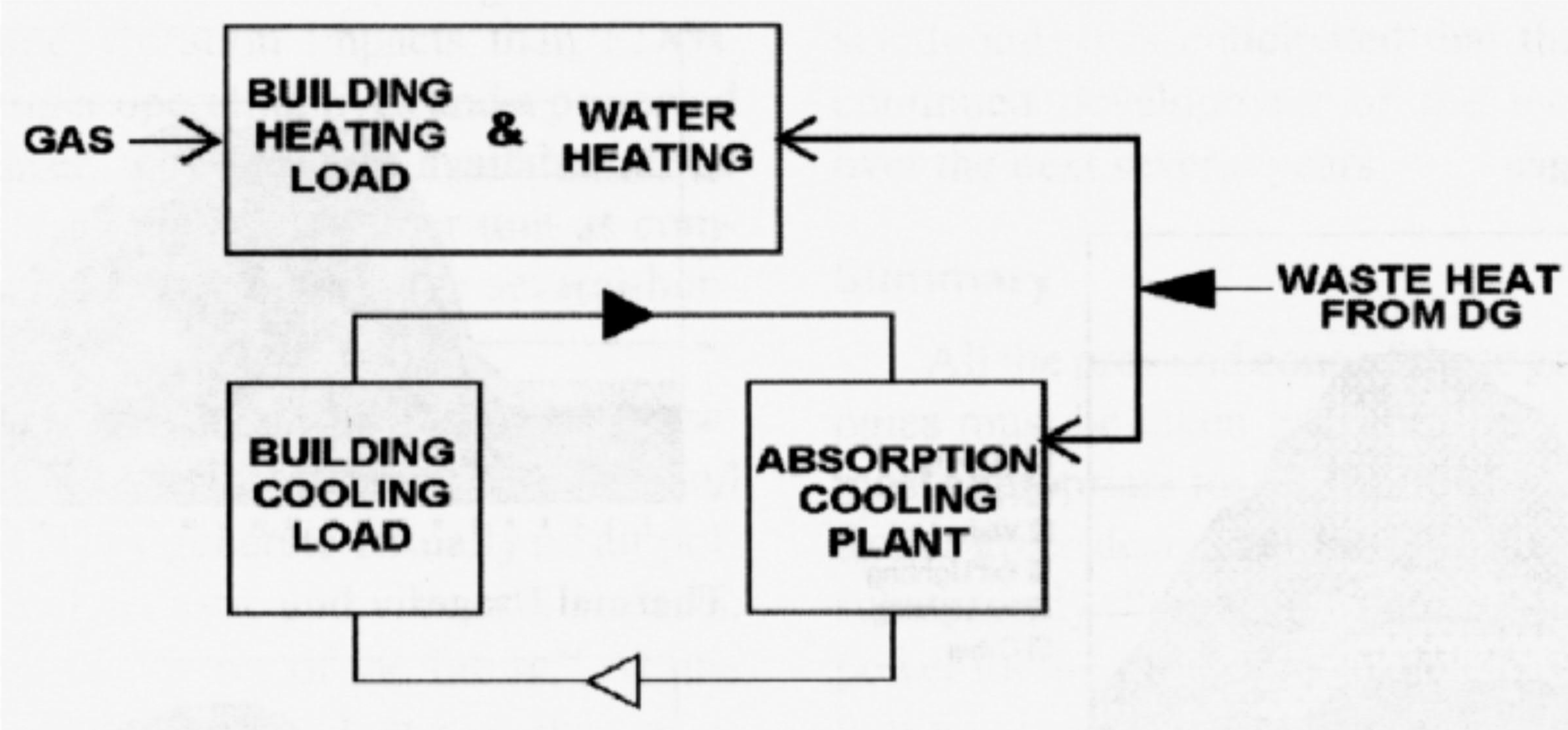
* DG = distributed generation (electricity)



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

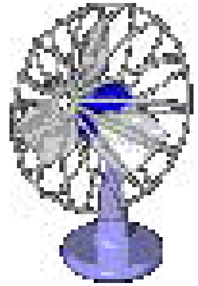
Thermal energy storage and waste heat usage

* DG = distributed generation (electricity)



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

HVAC

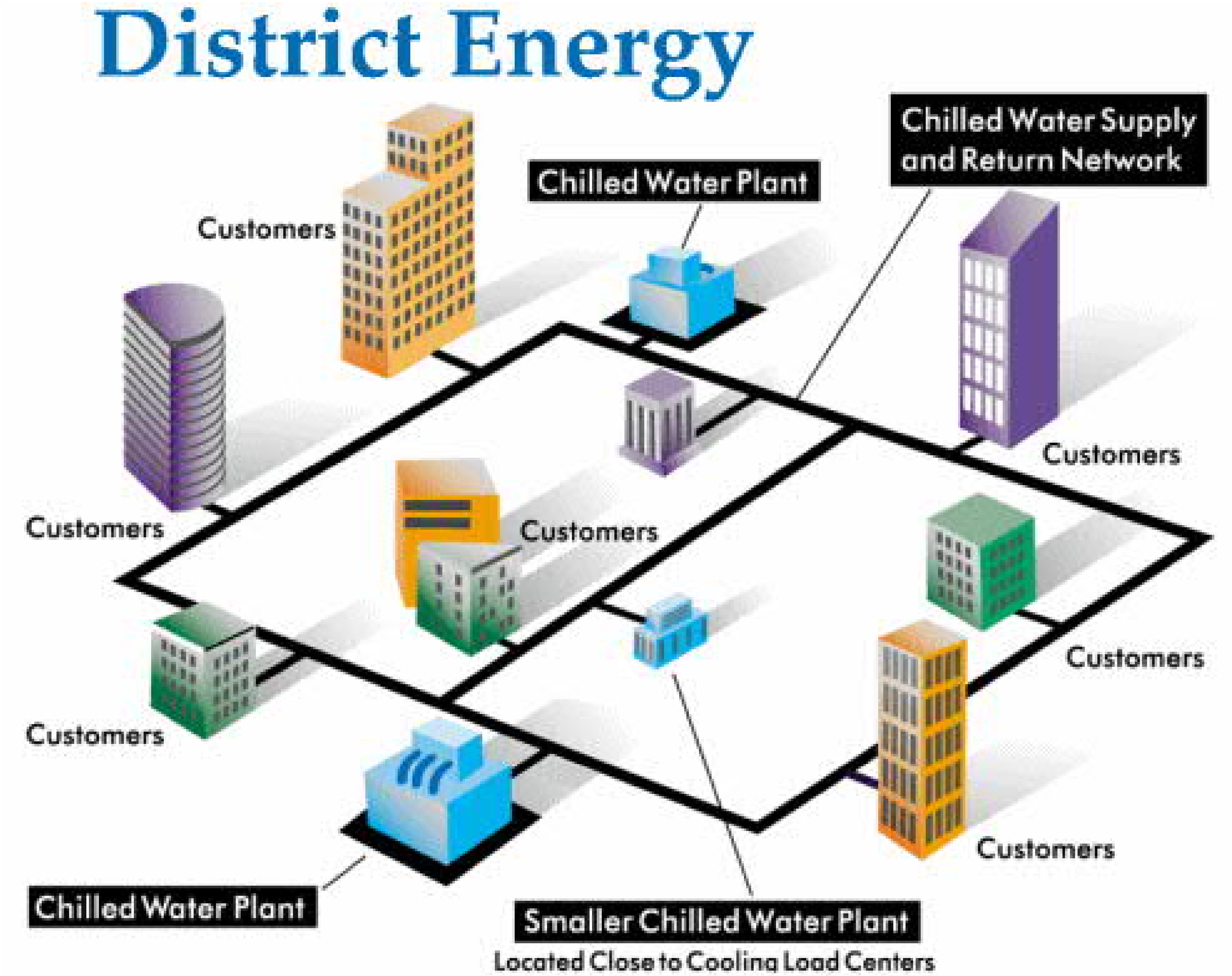


- District Cooling System (DCS)*
  - A centralized cooling system which provides chilled water to the air-conditioning system of user buildings for cooling purpose
  - The central chiller plant supplies chilled water and conveys it to the user buildings via underground chilled water pipe network
- District heating/cooling with combined heat and power => District energy system

(*Video: District Cooling System (5:58) http://www.youtube.com/watch?v=DDY32Chx6Gg)

District cooling system (DCS)

Strategy: total energy approach



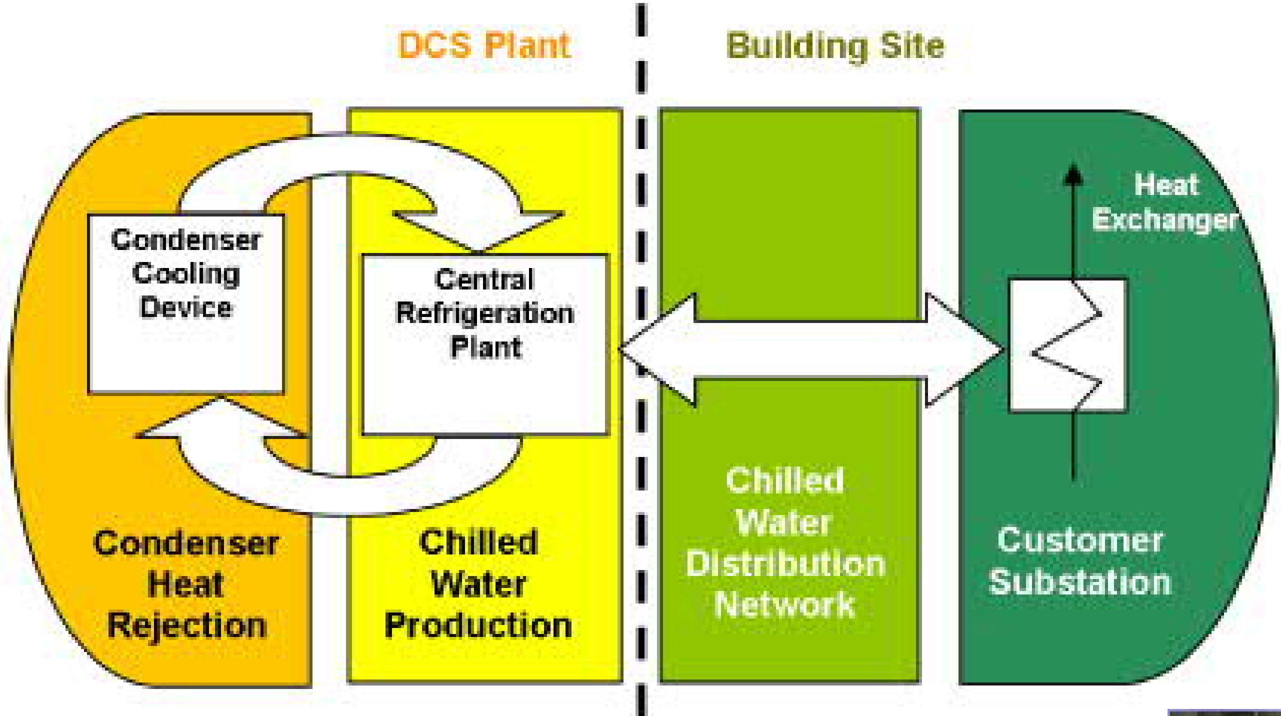
(Source: www.entergy-thermal.com/district_energy)

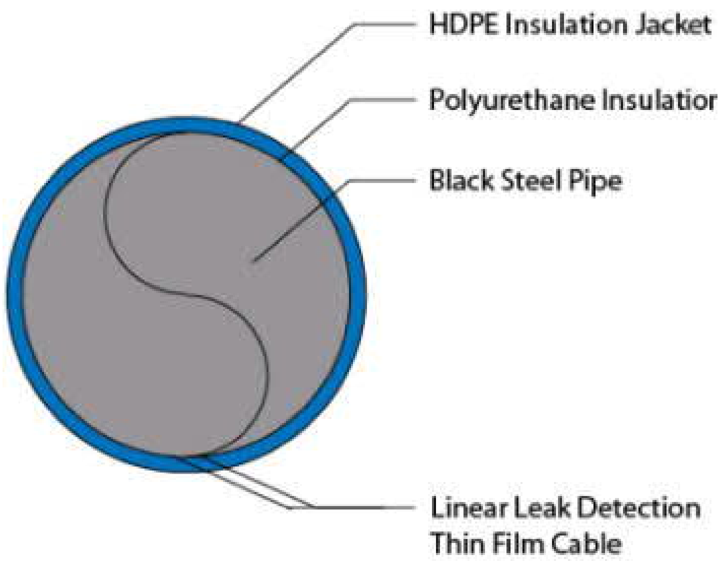
District cooling system (DCS): potential benefits

Benefits to Society	Benefits to End-users
(a) Highly energy-efficient feature of DCS enables energy saving up to 35% compared with conventional air-cooled air-conditioning systems. (b) Environmentally friendly system as it consumes less electrical energy and hence produces less greenhouse gases and contaminants to the environment. Other environmental problems caused by the chillers, such as noise, vibration, and thermal plume are also resolved as no chiller plant is required in the end-user building. (c) Architectural benefits such as more freedom in architectural and facilities design, can be achieved from elimination of roof top chiller plant, resulting in roof space available for installation of sky garden or PV panels.	(a) Reliability and quality are superior to conventional air-conditioning. With a team of professional engineers and supporting staff, DCS's computerized Central Chiller Plant ensures stable cooling supply to the end-user building at all time. (b) Save plant room space with an average of 70% for end-user building. (c) Flexible design to meet growth of cooling demand and extended service hours easily. (d) Save initial cost as no need to build its own chiller plant. (e) Save maintenance and operation cost due to less serviceable equipment and higher efficiency.

(Source: http://www.emsd.gov.hk/emsd/eng/pee/wacs.shtml)

District cooling system (DCS) at Kai Tak Development

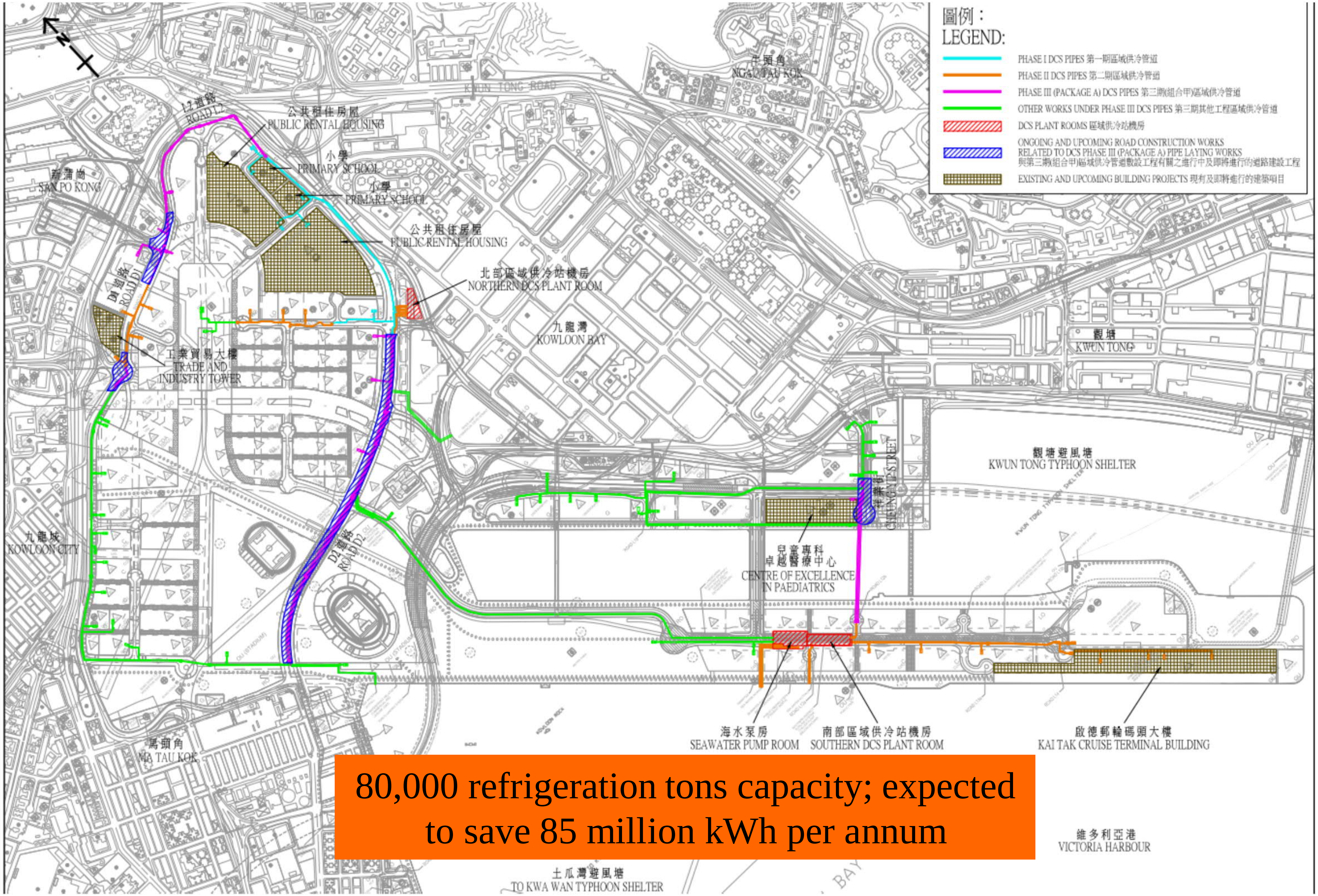




Pre-Insulated Pipe Configuration

(Image sources: www.ekeo.gov.hk, www6.cityu.edu.hk/bst/, http://aqutek.asia & www.epd.gov.hk)

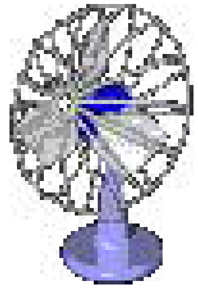
District cooling system (DCS) at Kai Tak Development



80,000 refrigeration tons capacity; expected to save 85 million kWh per annum

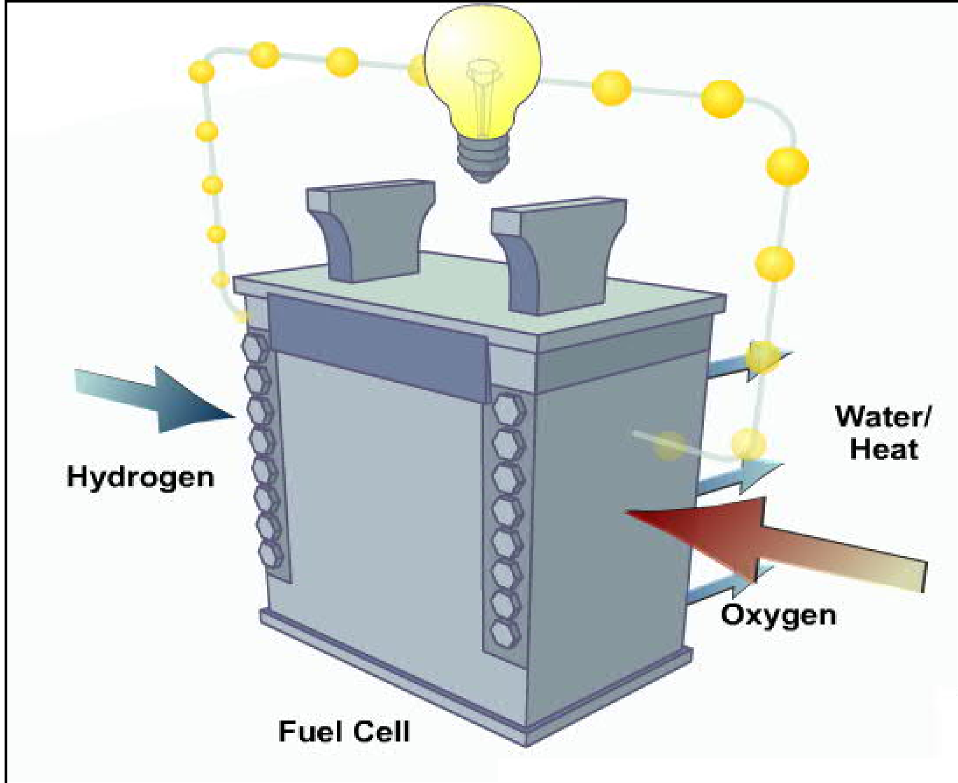
(Image source: http://www.legco.gov.hk/yr12-13/english/panels/dev/papers/dev0122cb1-428-6-e.pdf)

HVAC

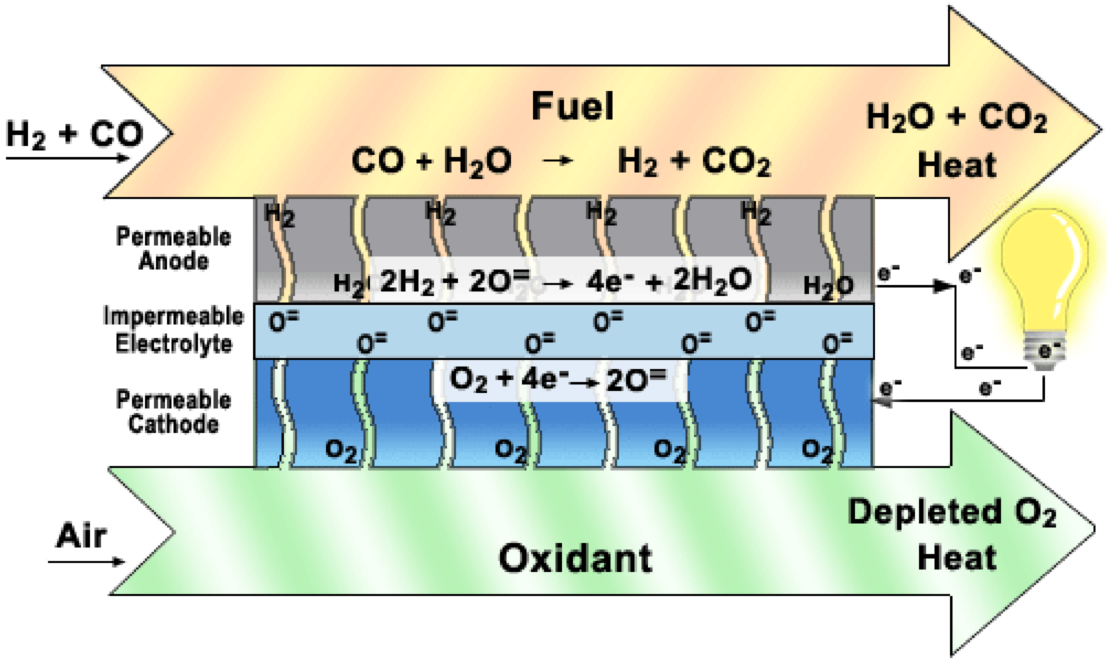


- Fuel cells: An electrochemical cell that produces electricity from a fuel tank*
  - Converts the chemicals hydrogen and oxygen into water, and in the process it produces electricity.
    - Anode side: $2H_2$ => 4H+ + 4e-
    - Cathode side: O_2 + 4H+ + 4e- => $2H_2O$
    - Net reaction: $2H_2 + O_2$ => $2H_2O$
  - Can be integrated with the energy systems in buildings or vehicles

(*See also: Fuel Cell Basics http://americanhistory.si.edu/fuelcells/basics.htm)

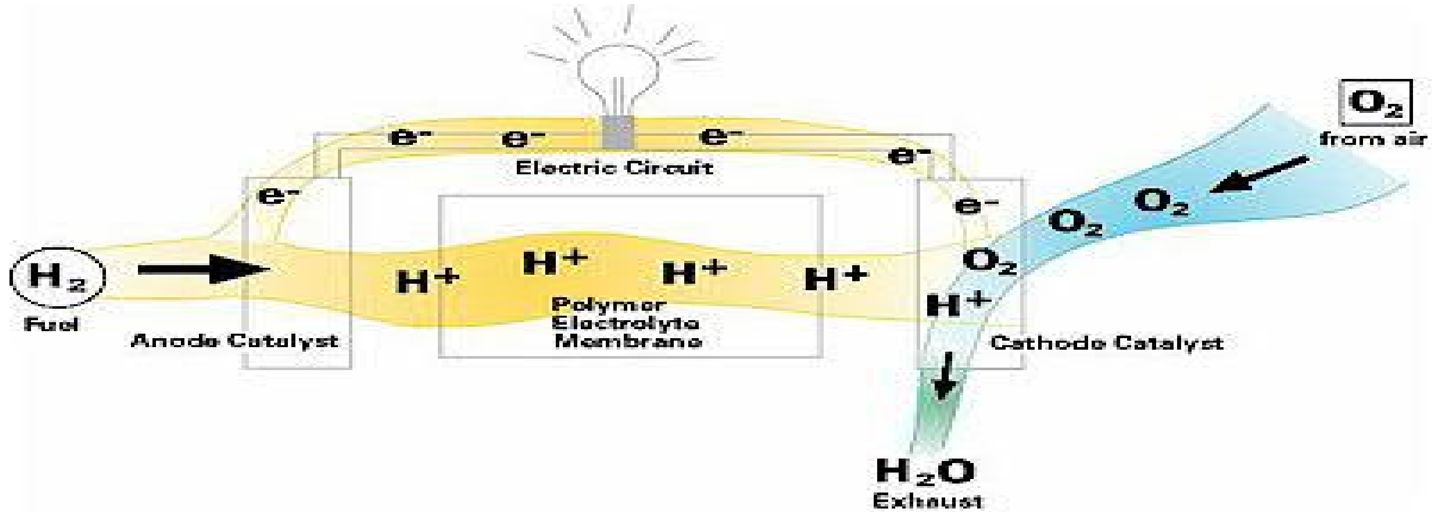


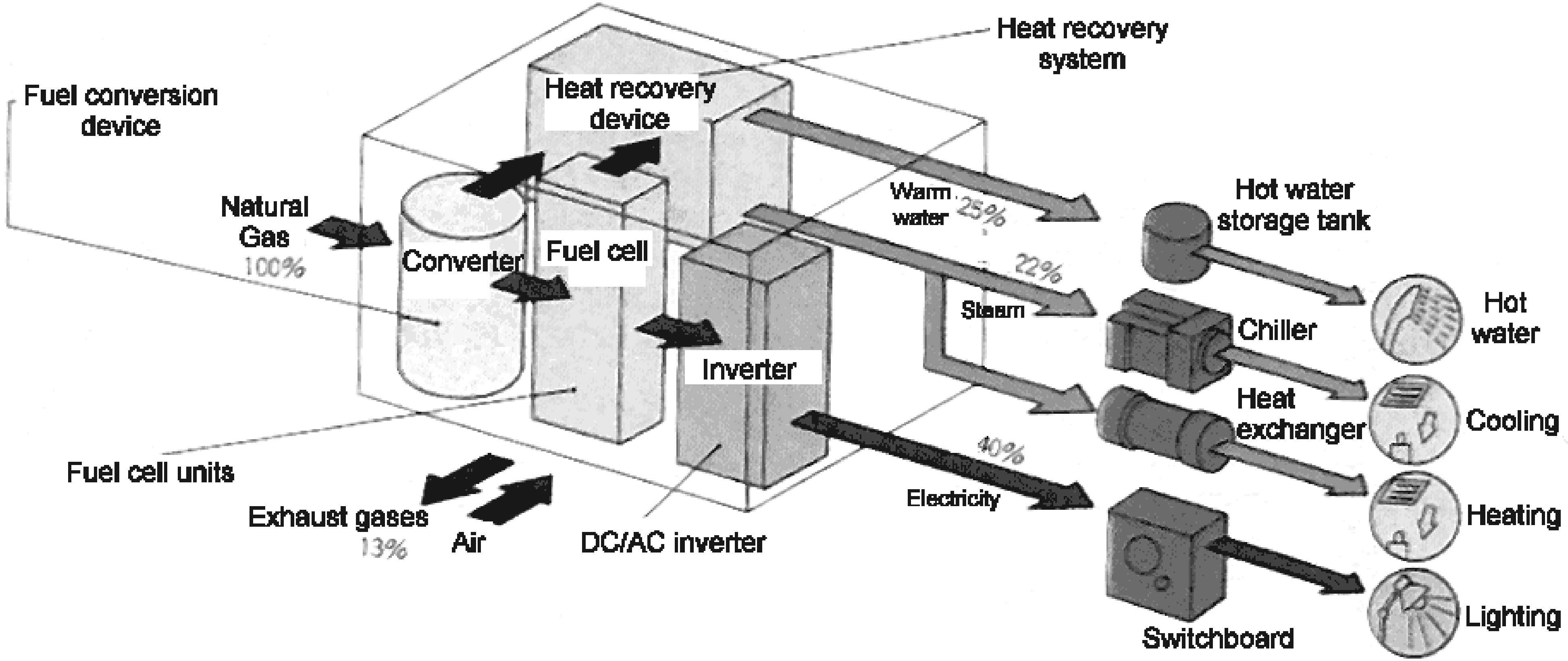
Solid Oxide Fuel Cell



(*Video: How Fuel Cells Work (3:17) http://auto.howstuffworks.com/fuel-efficiency/4836-how-fuel-cells-work-video.htm)

Fuel cell principle and application in buildings*





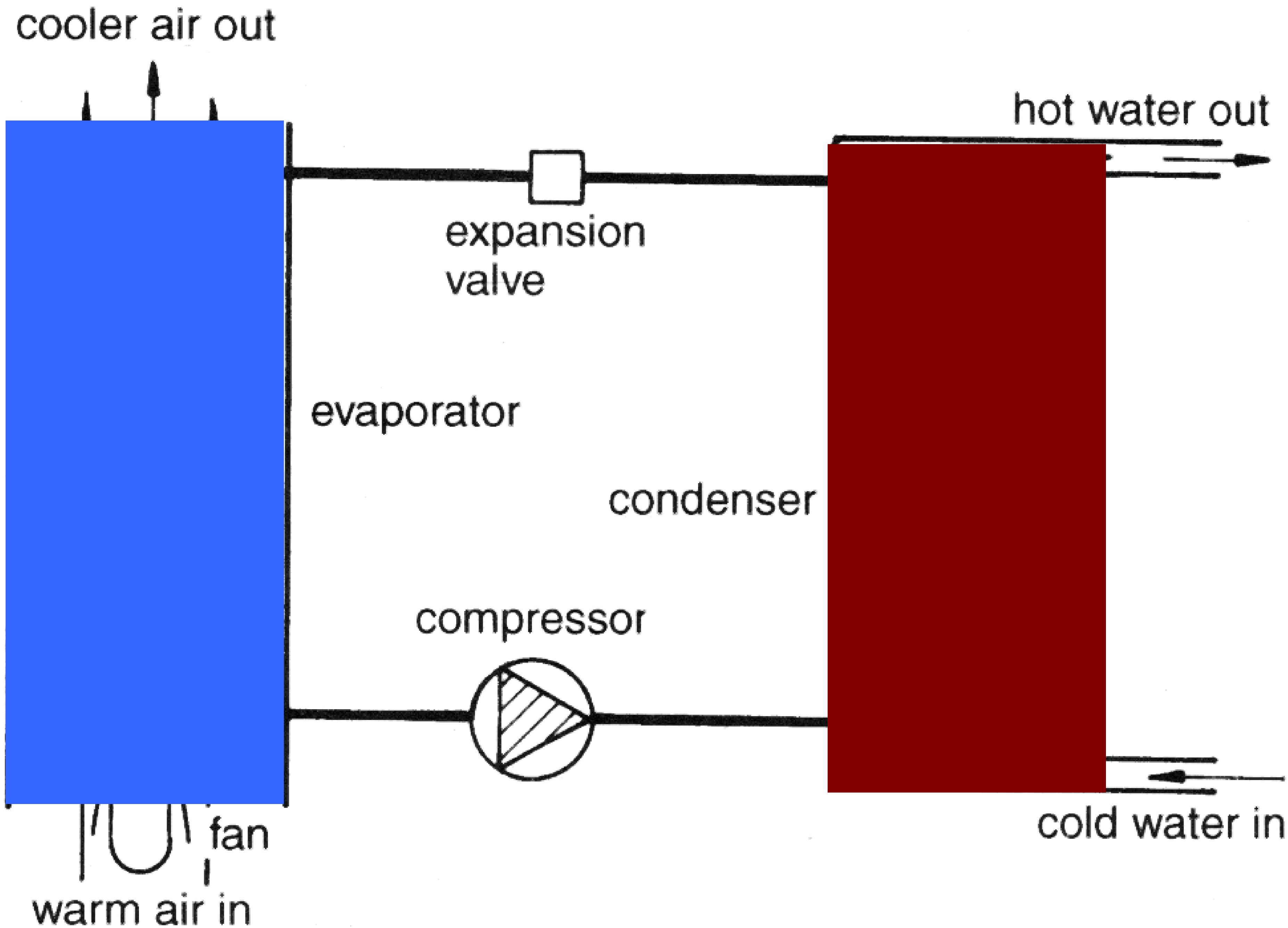
System Operation of a Fuel Cell

(* See also http://www.mech.hku.hk/sbe/case_study/case/jap/next21/next21-index.html)

Hot Water

- Heat pumps*
  - An effective tool to produce hot water or warm air
  - Extract energy from ground, water, or ambient air
  - Typical applications:
    - To preheat conventional hot water systems
    - To augment existing systems
    - To supply full hot water or warm air
  - Reverse of the normal refrigeration cycle
    - e.g. reverse cycle heat pump air conditioners

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

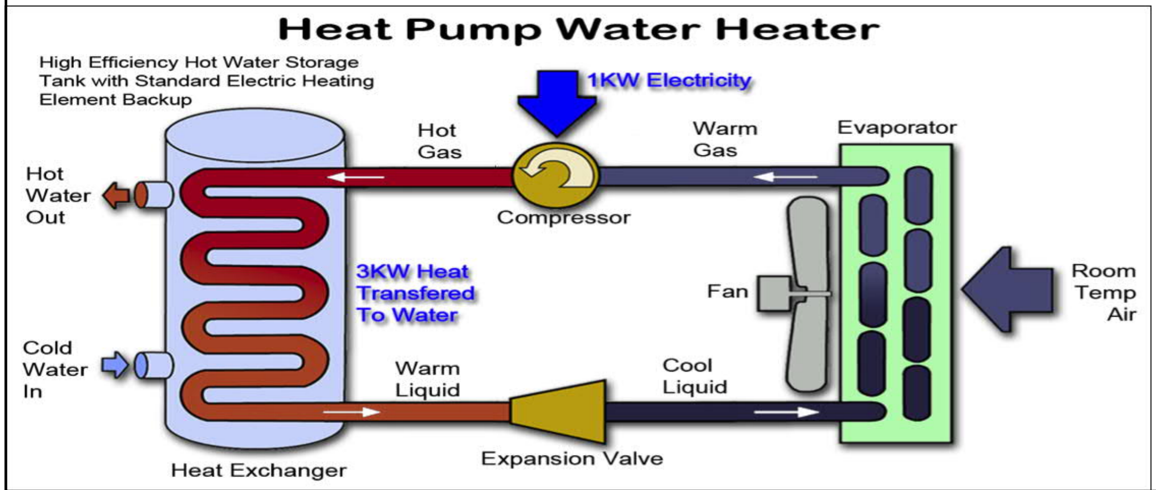


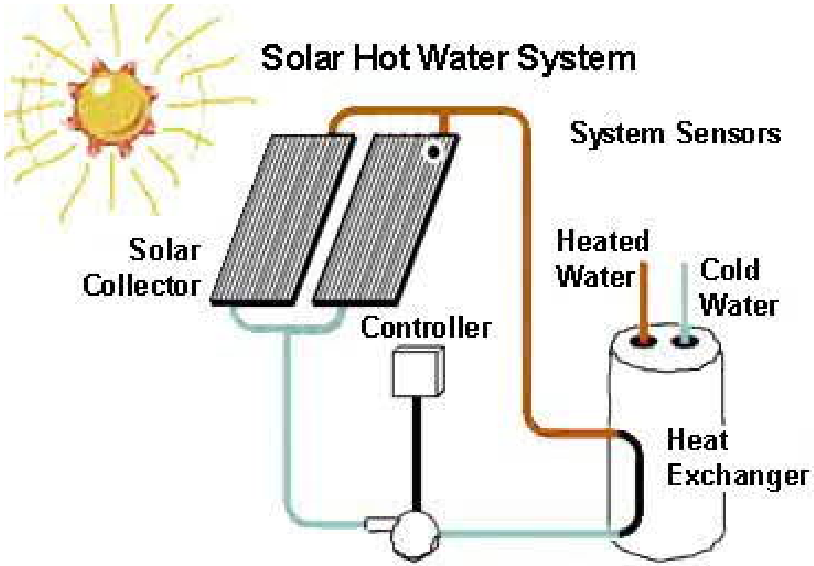
Basic principles of heat pump

(Source: Garrett, R. H., 2008. *Hot and Cold Water Supply*)

Hot Water

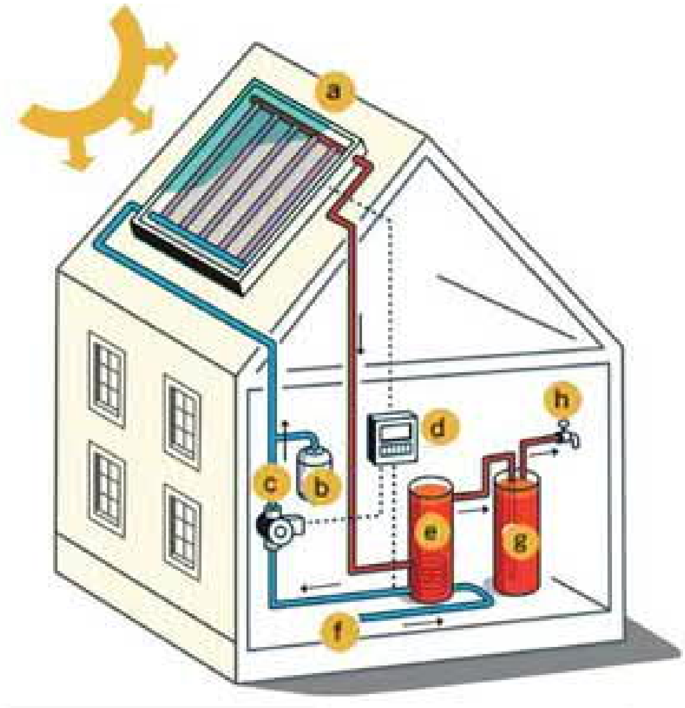
- Advanced Energy Saving Technologies (EMSD)
  - Heat Pump Water Heaters
    - http://www.emsd.gov.hk/emsd/e_download/pee/HeatPumpPamphlet.pdf
  - Solar Thermal Collectors for Water Heating
    - http://www.emsd.gov.hk/emsd/e_download/pee/EMS8313_waterheating(low-res).pdf





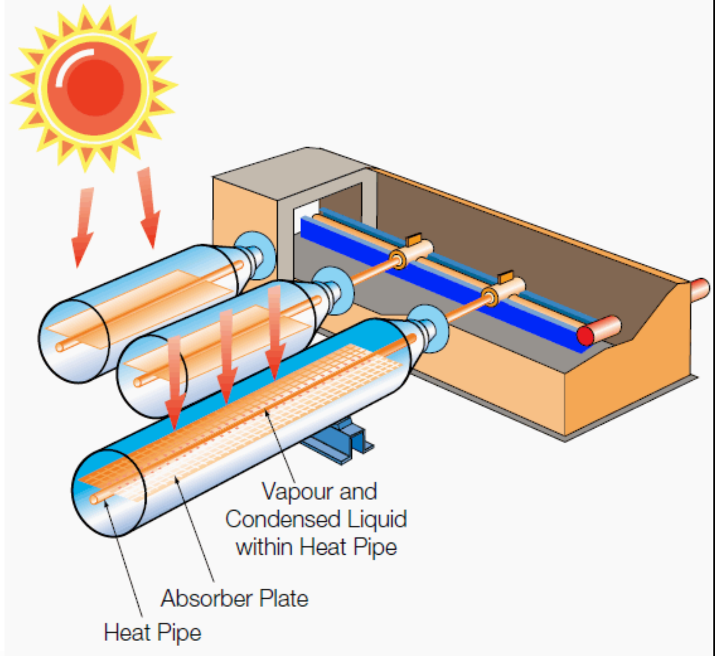
Hot Water

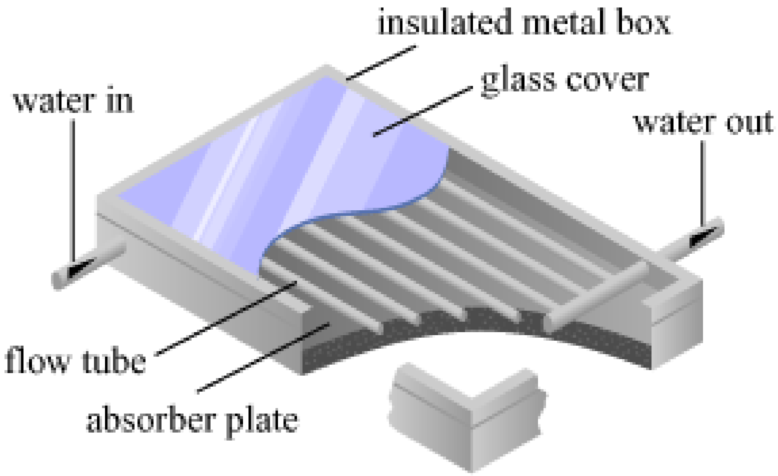
- Solar water heating
  - ‘Renewable’ or green energy
  - Simple system (e.g. domestic):
    - Solar collector + direct feed gravity
- Types of solar collectors:
  - Formed plastic
  - Flat plate
  - Evacuated tube (heat pipe)



Examples of solar thermal systems

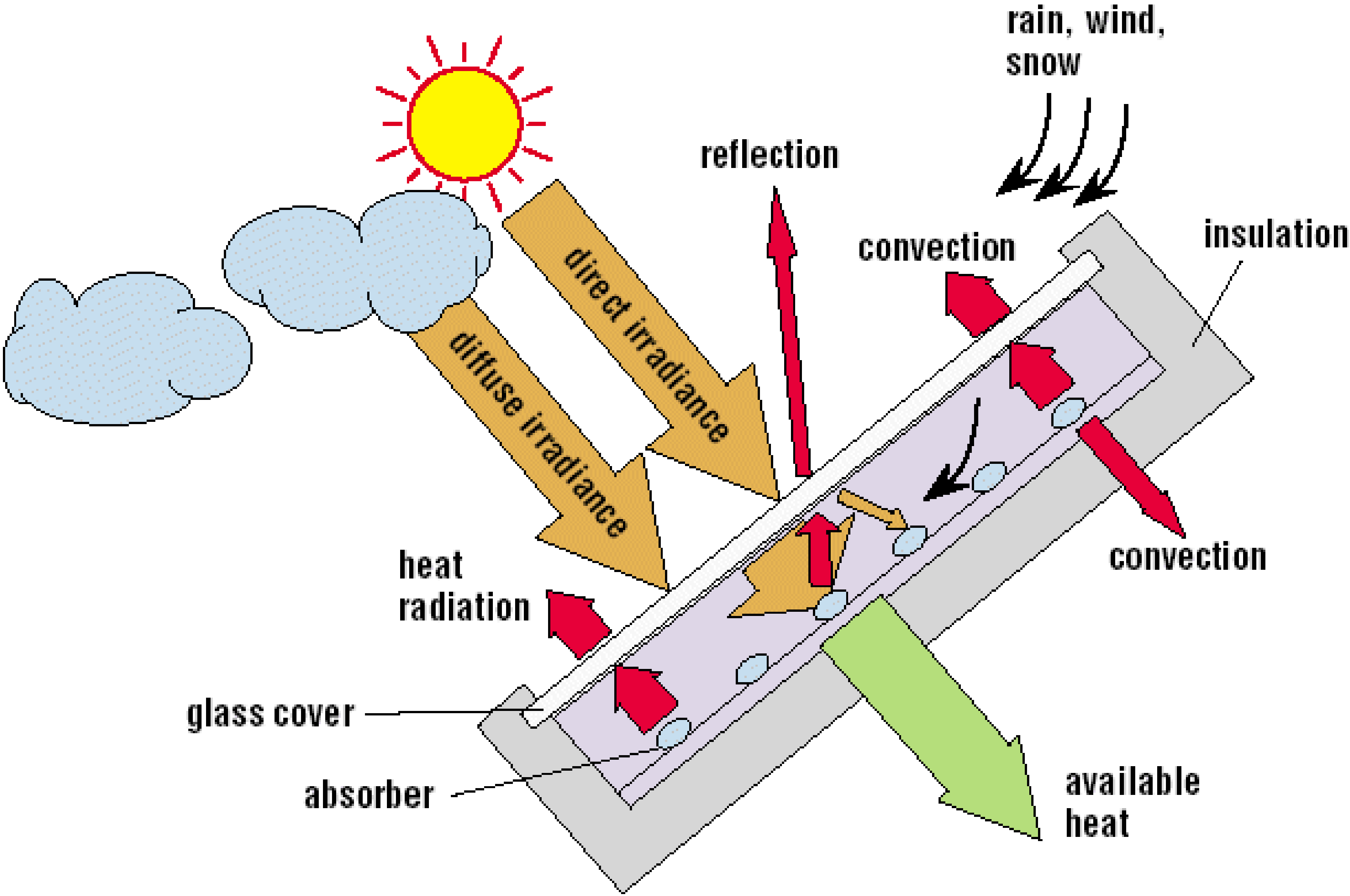
Flat-plate solar collector



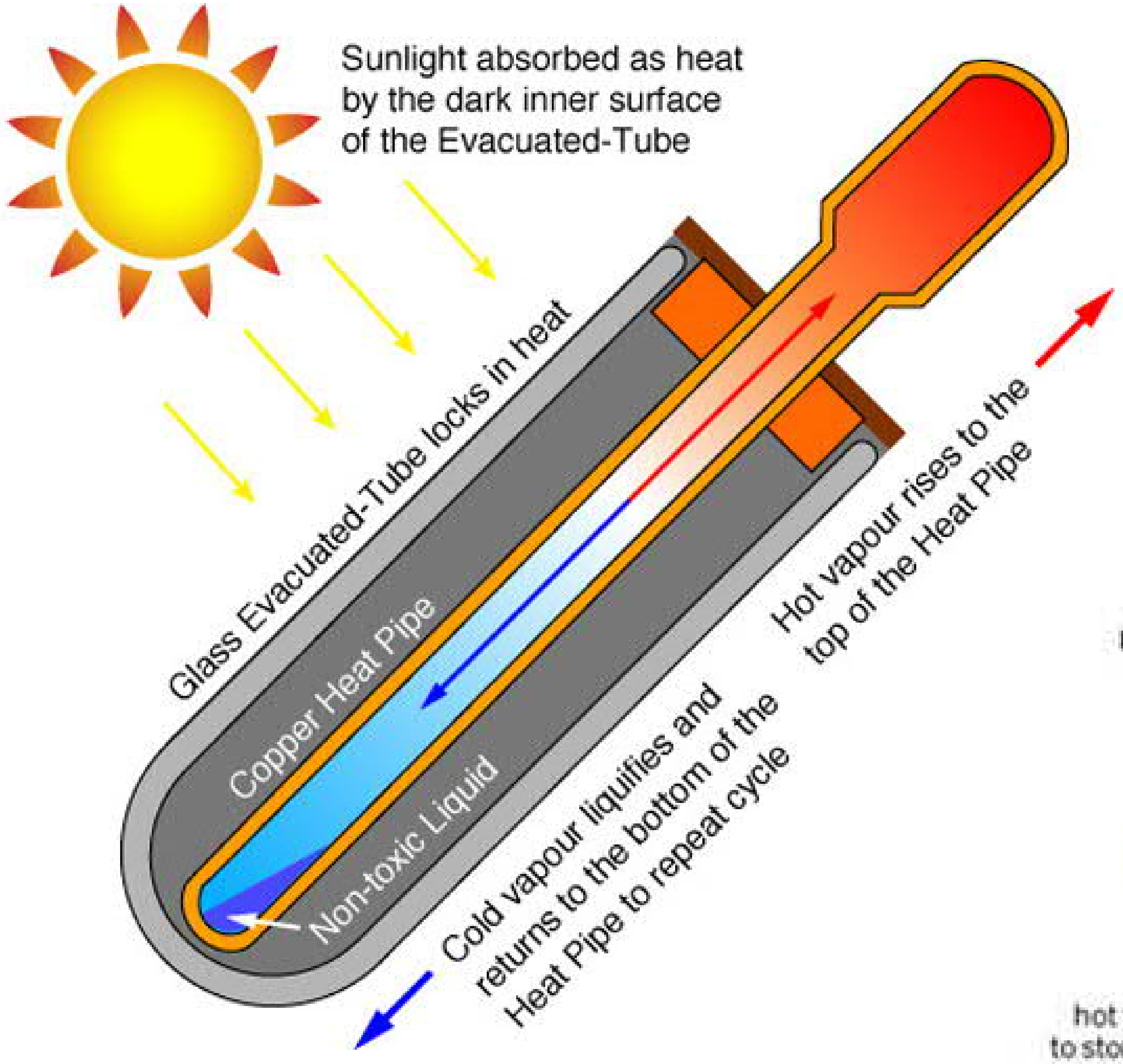


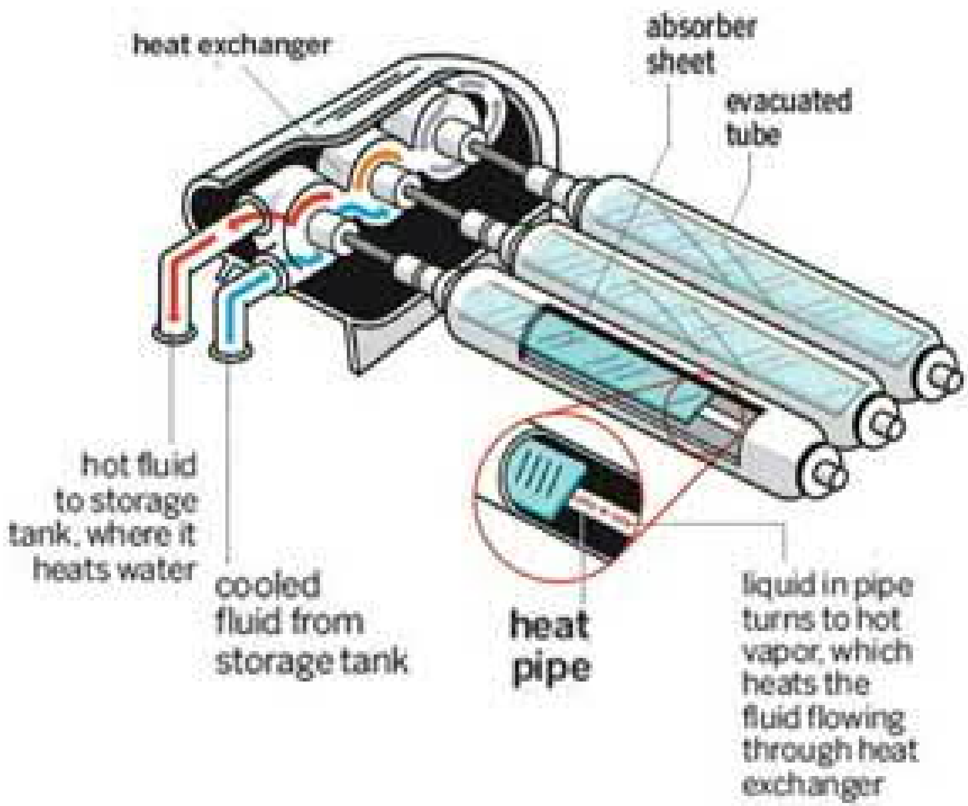
Evacuated-tube solar collector

Heat transfer processes at a flat-plate solar collector

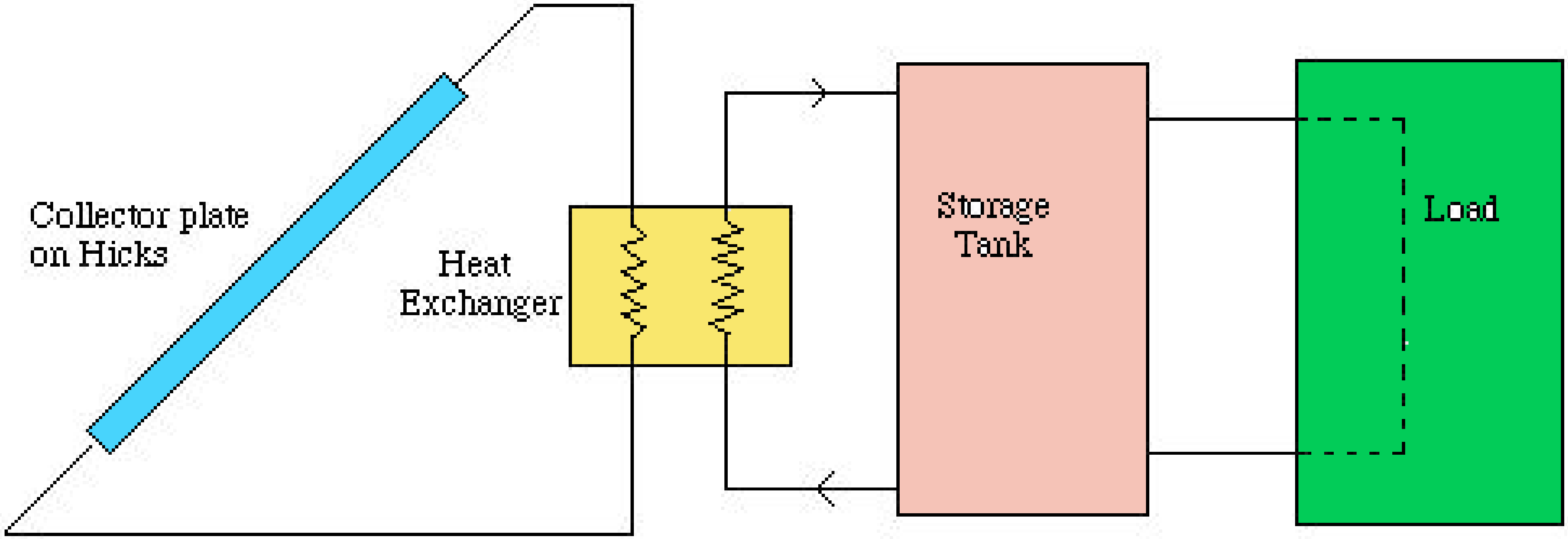


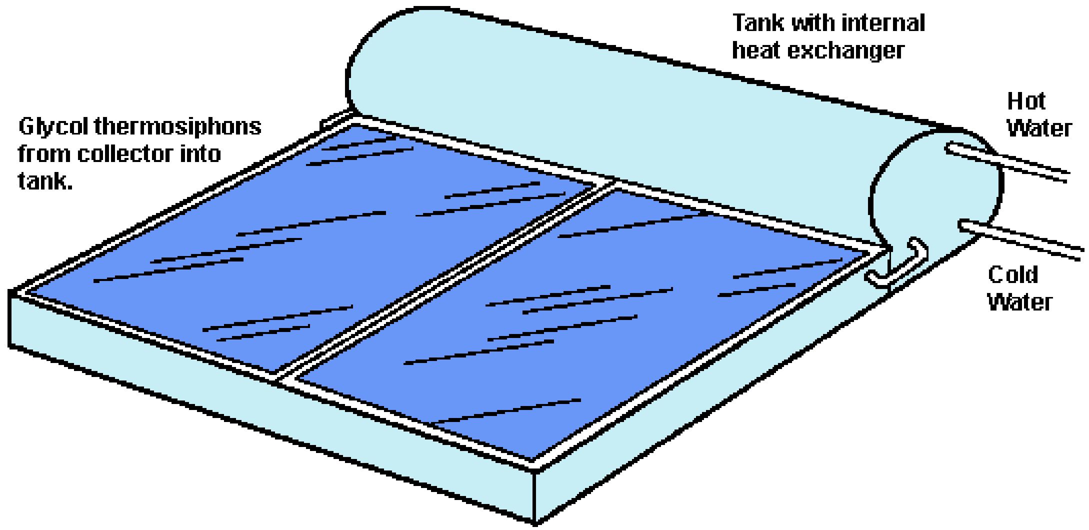
(Source: http://www.volker-quaschning.de/articles/fundamentals4/index.php)





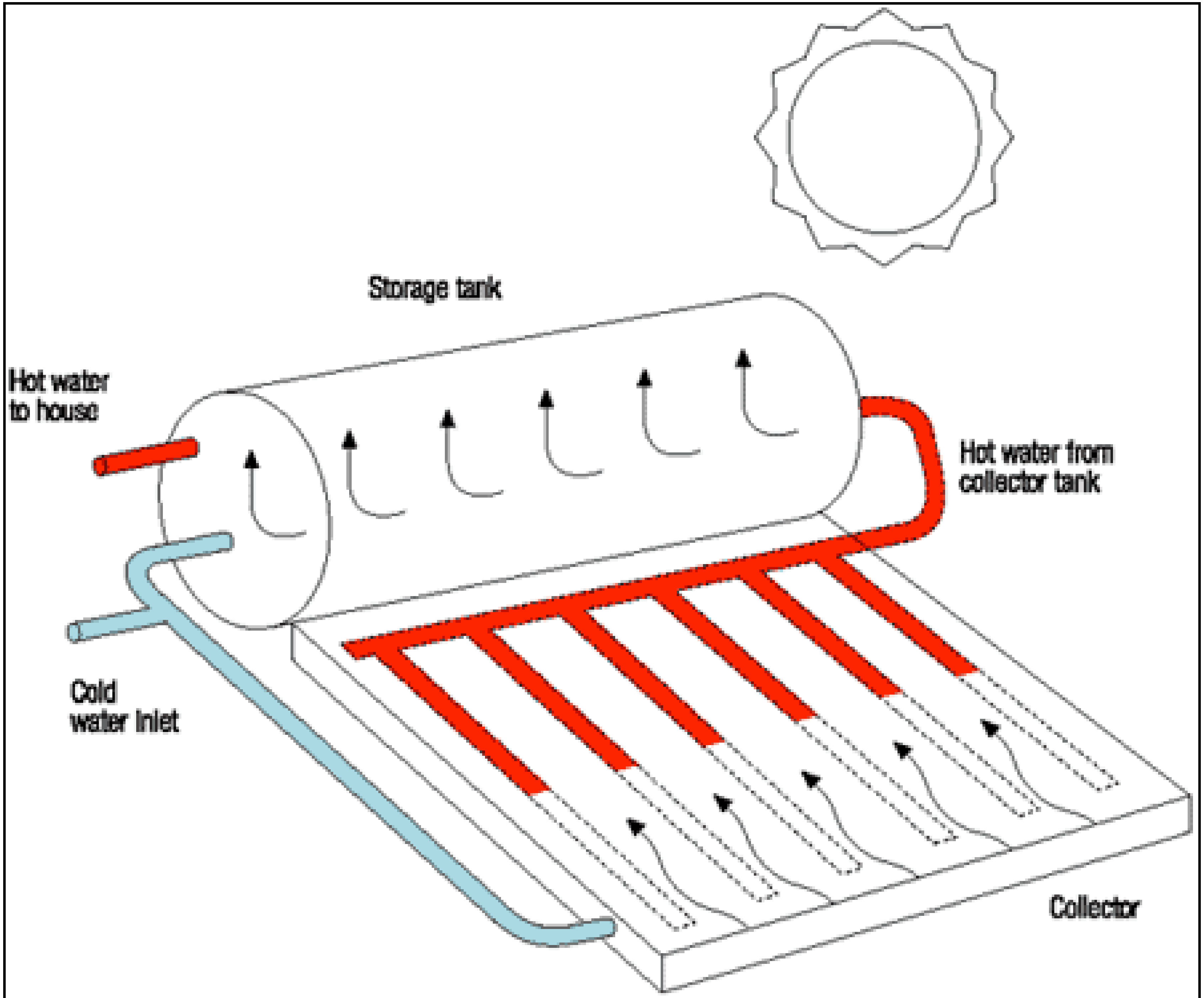
Heat pipe evacuated-tube solar collector





Simple domestic system
(with integral storage tank)

Solar hot water systems



Thermosyphon Flow

Comparison of flate-plate and evacuated-type collectors

	Pros	Cons
Flate-plate collectors 平板式太陽能集熱器	• capable to deliver moderate temperature hot water • lower cost compared with evacuated tube	• heavier weight • larger wind load • more susceptible to pipe blockage & leakage • more complications in maintenance
Evacuated-type collectors 真空管太陽能集熱器	• lower heat loss to surrounding • capable to deliver moderate to high temperature water (60-80 ºC) • lighter support structure • simplicity in maintenance	• higher capital cost compared with flat plate

(Source: EMSD, www.emsd.gov.hk)

Lighting

- Lighting consumes a great share of energy use in buildings
  - Consumption of electricity
  - Indirectly affect the cooling systems (due to heat)
  - Operating & maintenance costs
- The need to manage the lighting energy
  - Prevent energy wastage & save energy costs
  - Ensure good quality visual environment

Lighting

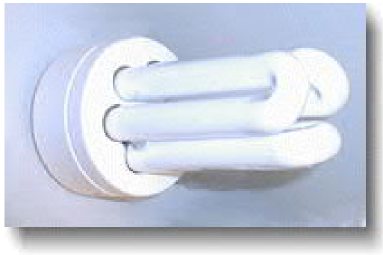
- HK building energy codes (by EMSD)*
  - Code of Practice for Energy Efficiency of Building Services Installations (2012)
  - Code of Practice for Energy Efficiency of Lighting Installations (2007)
  - Guidelines on Energy Efficiency of Lighting Installations (2007)
- Energy Efficiency Labelling Scheme (HK)*
  - Compact fluorescent lamps, LED

(* See also www.beeo.emsd.gov.hk and www.energylabel.emsd.gov.hk)

Lighting

- **EMSD lighting code requirements *****
  - Minimum allowable luminous efficacy
    - Choose appropriate type of lamps
  - Maximum allowable lamp controlgear loss
    - Energy efficient ballast for fluorescent lamps
  - Maximum allowable lighting power density (LPD)
    - Design suitable amount and type of lighting systems
  - Interior lighting controls (switching)
    - Number of control points (to facilitate effective operation)

Lighting



- Lighting efficiency
  - Lighting hardware efficiency
    - Includes light source, control gear, optical system, luminaire housing, etc.
  - Lighting installation efficiency
    - Largely dependent on the choice, location, and setting up (e.g. aiming) of the lighting hardware
  - Usage efficiency
    - Depends largely on the type of lighting controls

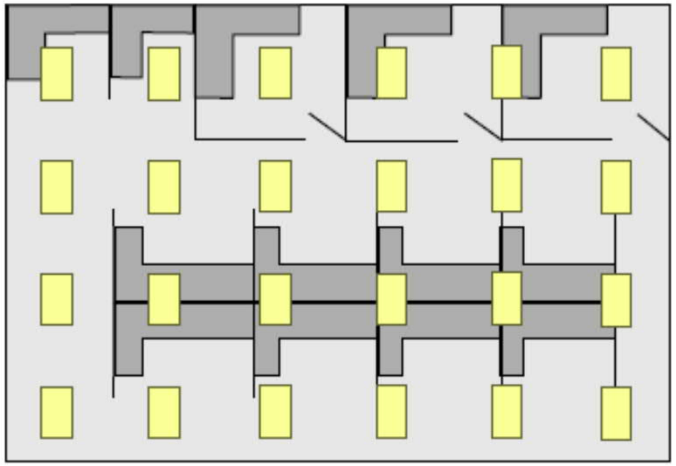
Integrated controls for lighting luminaires

Vertically Integrated Design

Personal Control Features:

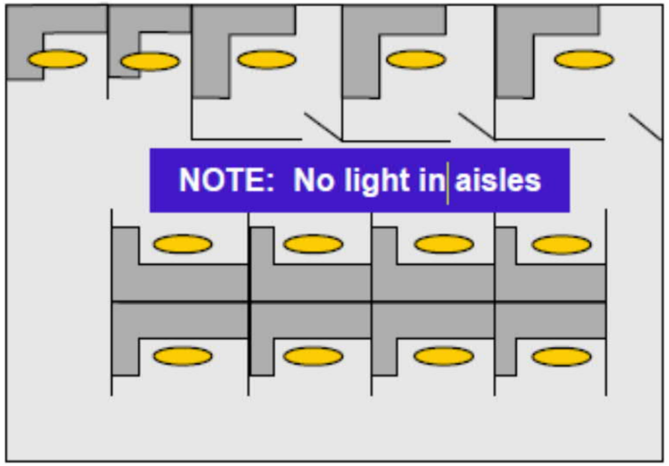
- Direct/ Indirect Pendant Luminaire
- Task light: 2T8-PS Dimmable EB (64W)/ 100%-5%
- Ambient light: 1T8-PS EB (31W)/ ON/OFF only
- Photocell Sensor built in
- Occupancy Sensor built in

Comparison to a Standard Troffer Layout:



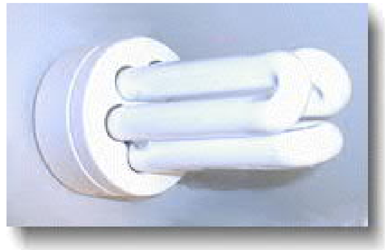
- 2x4 Parabolics
- **24 Luminaires**
- 72 lamps
- **~2300 watts**

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



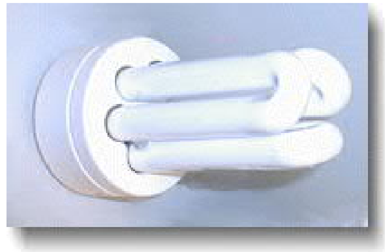
(Source: http://lightingdesignlab.com)

Lighting



- Lighting economics & system life cycle costs
  - Initial costs
    - Equipment, installation, wiring, HVAC
  - Energy costs
    - Direct lighting costs
      - Energy use (kWh) = lighting power (kW) x operating time (hr)
    - Lighting-related HVAC (indirect) costs
      - Lighting heats up the space & require cooling
    - Total cost savings = energy costs + demand costs
  - Maintenance costs

Lighting



- Potential lighting energy saving measures
  - Fluorescent upgrades
  - Delamping
  - Incandescent upgrades
  - HID upgrades
  - Control upgrades
  - Daylight compensation

- Three major areas of lighting improvement
  - Replace incandescent lamps with fluorescent or CFL/LED
  - Upgrade fluorescent fixtures with improved components
  - Install lighting controls to minimise energy costs

Lighting

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

- Ballasts* (e.g. electromagnetic and electronic ballasts)
  - For operation of gas discharge lamps (e.g. fluorescent, HID)
  - Provide several functions:
    - Deliver proper voltage to start or ignite the lamp(s)
    - Current limiting (to safely sustain operation)
    - Compensate for variations in line voltage
    - May offer electrode preheat, dimming or power quality adjustment

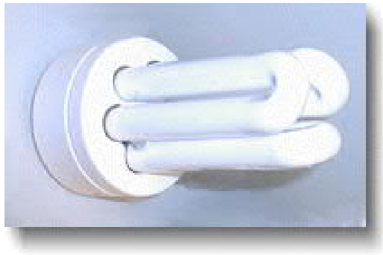
  - Consume power & reduce overall lumens per watt rating
  - Ballast factor (BF) (range from 0.7 to 1.2)
    - It is a measure of actual lumen output for a specific *lamp-ballast* system relative to the rated lumen output measured with a reference ballast under test conditions

Electromagnetic vs. Electronic Ballasts

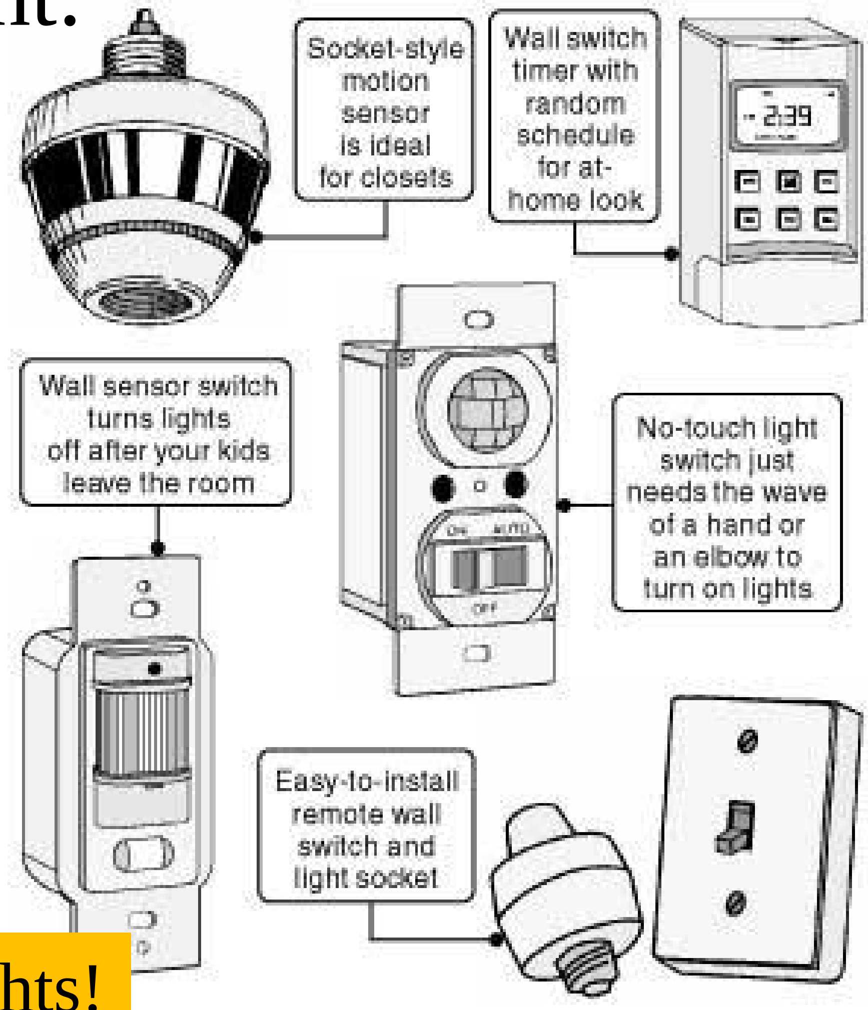
	Electromagnetic Ballast	**Electronic Ballast**
Heat	Generates about 30 deg. C more heat than electronic	Internal losses are less than 8 watts
Light Flicker	60 Hz frequency causes light flicker levels of 30% or higher	20,000-25,000Hz frequency produces virtually no detectable flicker
Noise	Vibrations induced by electromagnetic field causes humming noise	No audible noise
Weight	Heavy components coated in heavy protective material	Weighs about half as much as electro-magnetic type

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

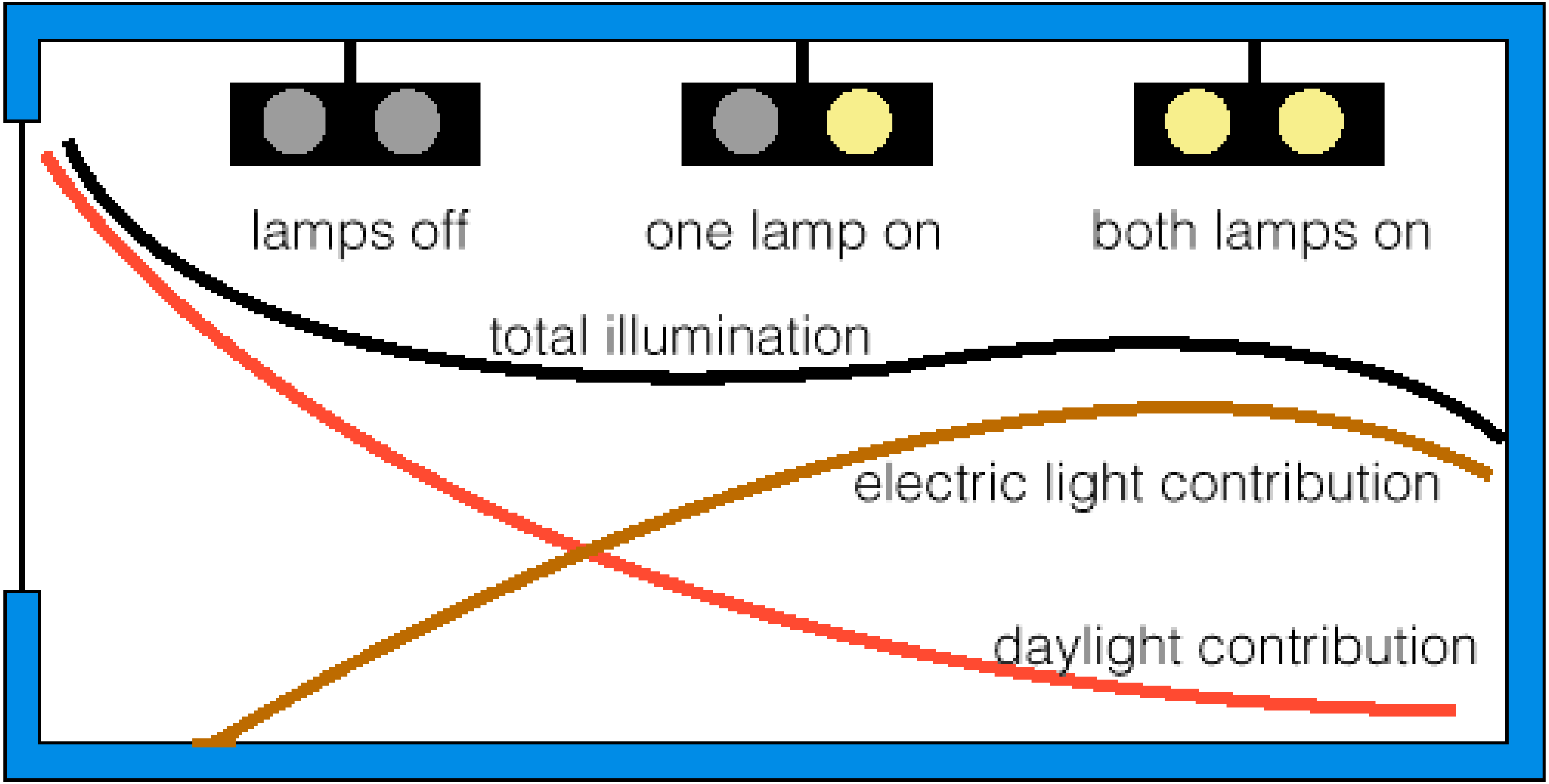
Lighting



- Lighting control equipment:
  - Switches
  - Occupancy sensing
  - Scheduling (timeclocks)
  - Daylight dimming
  - Tuning
  - Preset dimming
  - Wireless controls

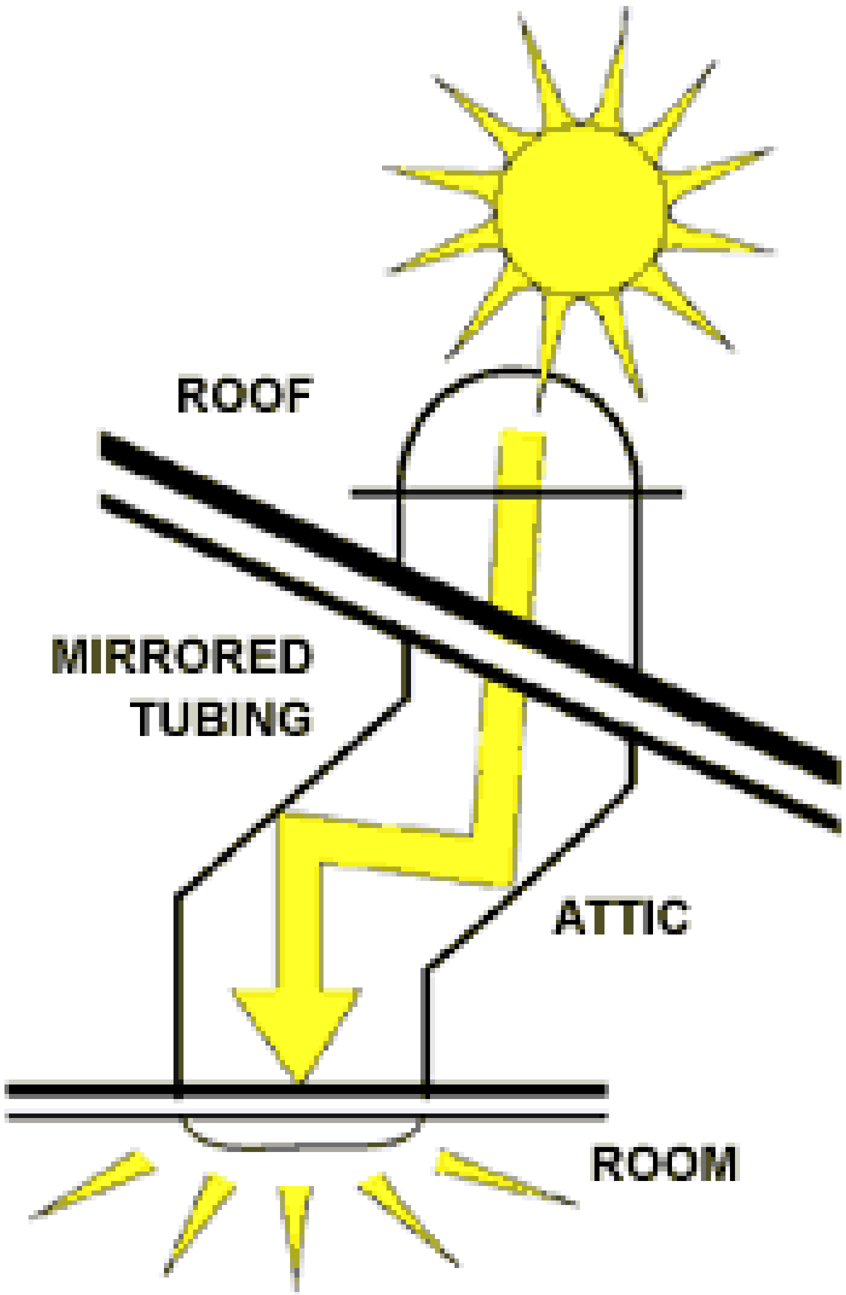


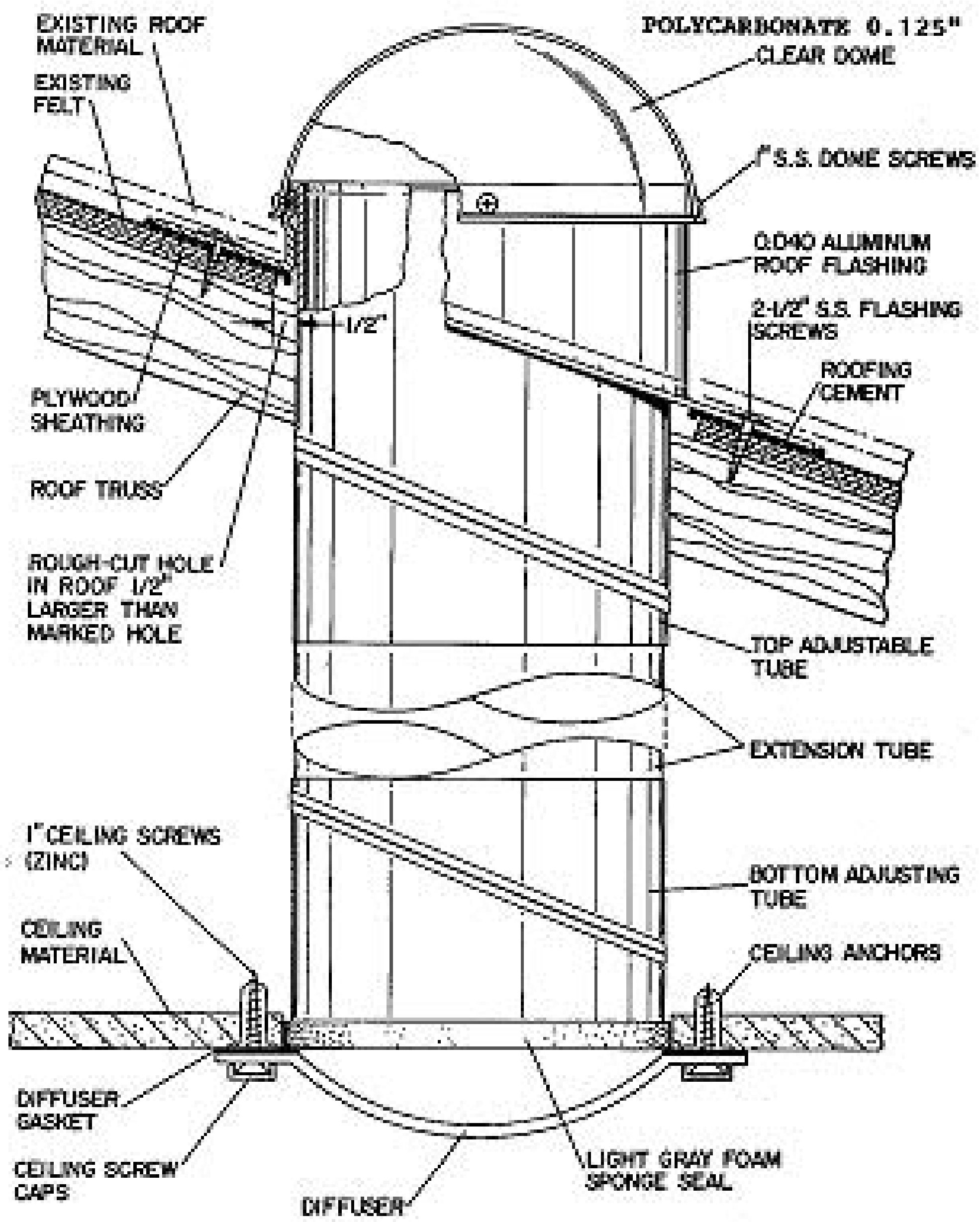
Remember: switch off unnecessary lights!



Daylight contribution and lamps control

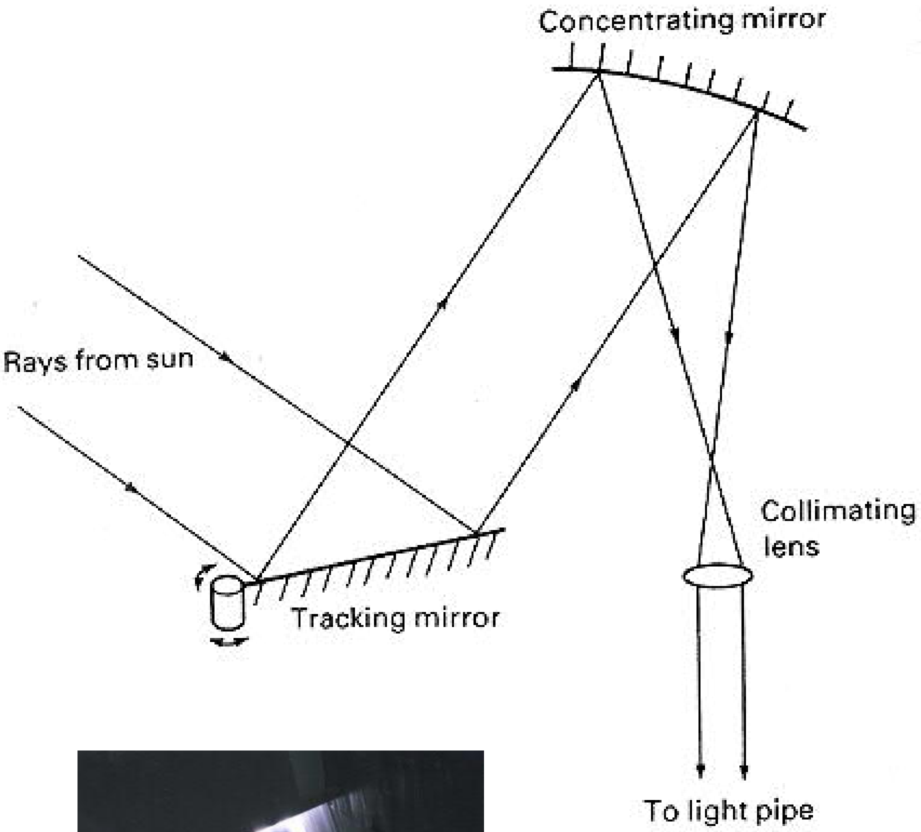
Light tube system

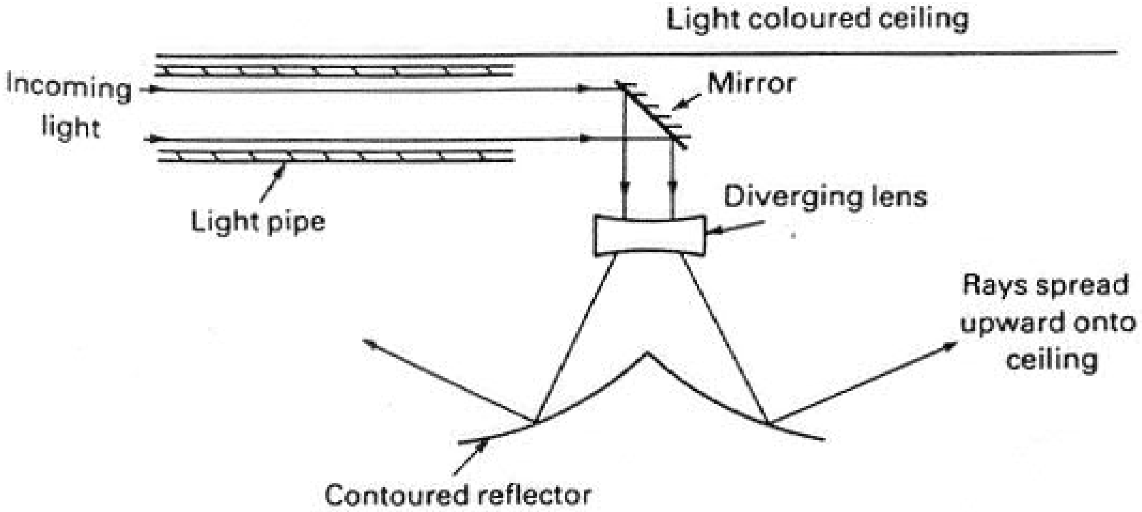




This can help to direct daylight into building interior

Light pipe system





Vertical light pipe

Horizontal light pipe

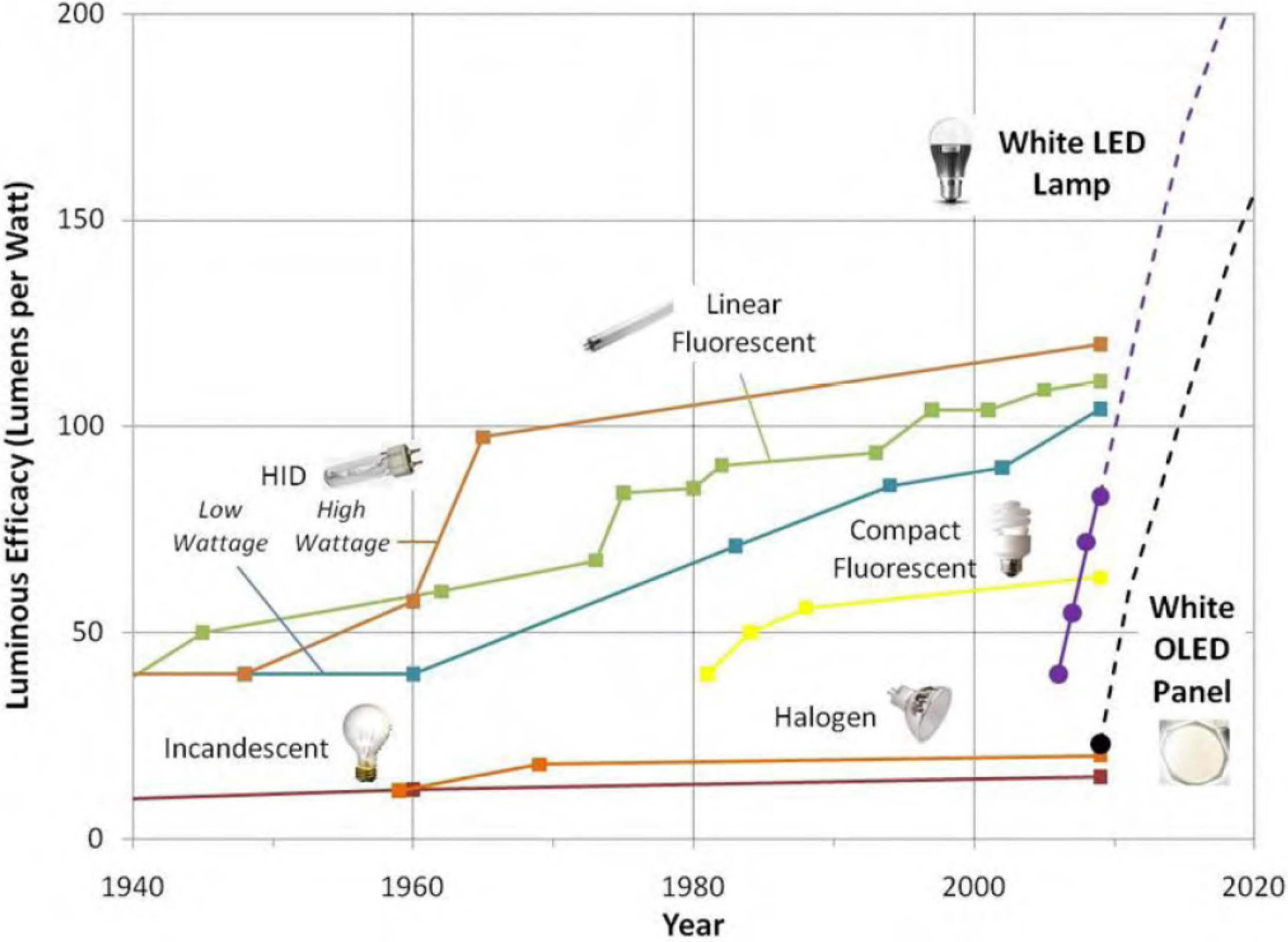
Evolution of light bulbs

Edison lamp

Incandescent lamp

Compact fluorescent lamp

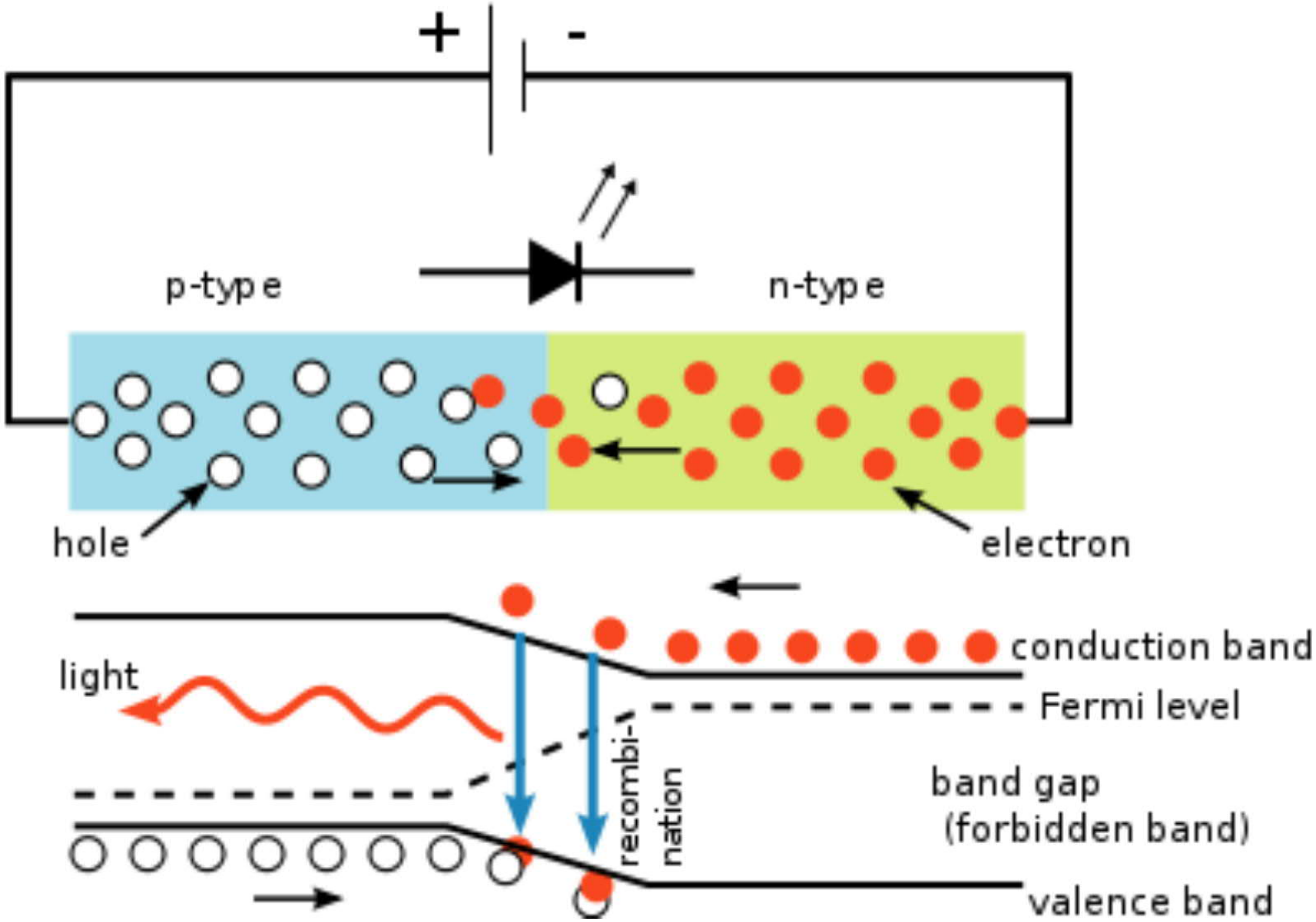
LED lamp

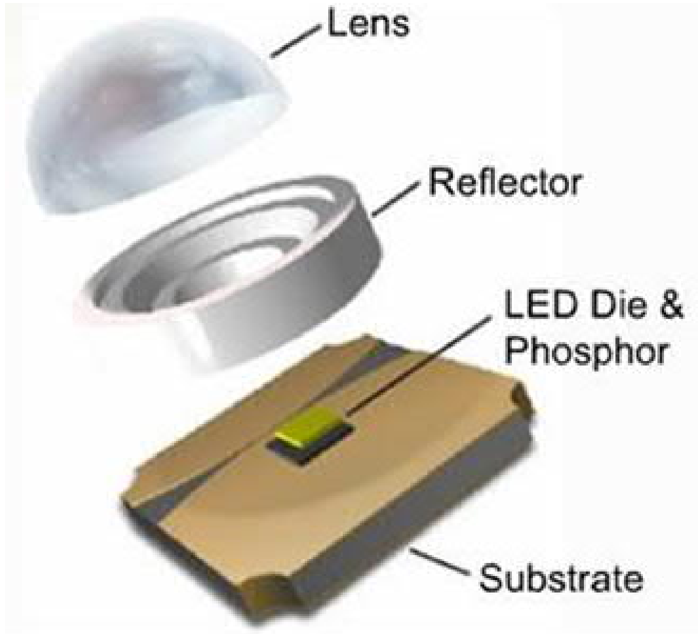


Historical and predicted efficacy of light sources

(Source: US Department of Energy)

Principle of LED and structure of high power white LED*





Structure of high power white LED

(* See How LED Works, http://www.omslighting.com/ledacademy/)

Examples of LED lamp application

Lighting

- Light emitting diode (LED)
  - Advantages
    - Low power consumption
    - Long lasting (long useful life)
    - Durable (withstand impact & vibration)
    - Cool (little heat produced)
    - Modular design & compact size
    - Controllability (colour balance & intensity)
    - Instant on, frequent switching
    - No annoying flicker
    - Low cost of manufacture
    - No ultraviolet & infrared radiation
    - Mercury free
  - Disadvantages
    - Focused, directional light
    - Need different optics design
    - May need heat sink (thermal management)

LED candles

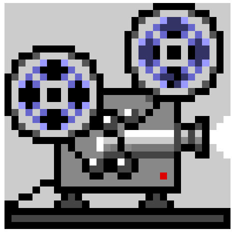
Lighting

- Solid state lighting (SSL)
  - Emits light from semi-conductor (solid)
    - Light emitting diode (LED)
    - Organic light-emitting diodes (OLED)
    - Polymer light-emitting diodes (PLED)

  - Advantages:
    - Low power consumption
    - Reduced heat generation
    - Greater resistance to shock, vibration, and wear
  - LED retrofits (not ideal), versus LED luminaires

Lighting

- Video: A new light on energy efficiency (OLED) (8:31)



  - http://youtu.be/yRU8ui9c9lY
  - OLED100.eu project (http://oled100.eu)
    - Develop technologies to produce efficient OLED products for exploitation
  - Research project at Gent University, Belgium
    - Organic light-emitting diodes (OLED) lighting
    - Can be made transparent

Lighting

- HK EE Net: Lighting
  - http://ee.emsd.gov.hk/english/lighting/light_intro/light_intro.html
  - Lamp & luminaire
  - Ballast
  - Control systems
  - Other EE lighting systems
  - Emerging EE lighting technologies

Lighting

- Advanced Energy Saving Technologies (EMSD)
  - Application Guide to Electronic Ballasts
    - http://www.emsd.gov.hk/emsd/eng/pee/em_pub_1.shtml
  - Digital and Addressable Lighting Control at Kowloon Bay Indoor Games Hall
    - http://www.emsd.gov.hk/emsd/e_download/pee/digital_lighting_control_at_kbigh.pdf
  - Guidelines on T5 Fluorescent Lamps
    - http://www.emsd.gov.hk/emsd/e_download/pee/t5guide.pdf
  - LED – a kind of Unconventional Lamp
    - http://www.emsd.gov.hk/emsd/e_download/pee/LED1.pdf

Lighting

- Advanced Energy Saving Technologies (EMSD)
  - Retrofit w/ Energy Efficient Fluorescent Lighting System
    - http://www.emsd.gov.hk/emsd/e_download/pee/lighting_retrofit.pdf
  - Self-Luminous EXIT Signs Testing and Application Report
    - http://www.emsd.gov.hk/emsd/e_download/pee/selfluminousexitsign.pdf
  - T5 Lamp Testing and Application Report
    - http://www.emsd.gov.hk/emsd/e_download/pee/t5lampe.pdf
  - Task Lighting Design
    - http://www.emsd.gov.hk/emsd/e_download/pee/Task_Lighting_Design.pdf

Electrical Services

- General approach*
  - Minimise copper losses in power distribution
  - Reduce equipment losses and energy wastage
  - Reduce losses related to power quality problems
  - Appropriate metering and monitoring facilities
- Building energy code requirements
  - Max. total harmonic distortion (THD) of current
  - Reduce unbalanced distortion of 3-phase loads
  - Metering & monitoring facilities

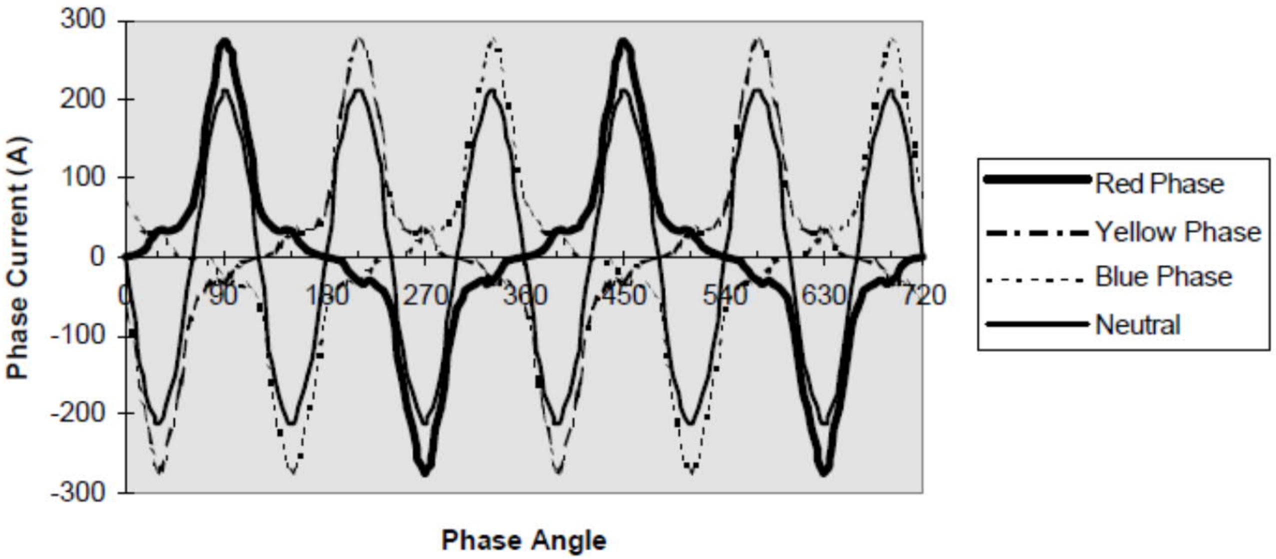
(* See also http://www.emsd.gov.hk/emsd/e_download/pee/EEC&harmonic.pdf)

Total harmonic distortion (THD) of current

Maximum THD of current in percentage of fundamental

Circuit Current at Rated Load Condition 'I' at 380V/220V	Maximum Total Harmonic Distortion (THD) of Current
I < 40A	20%
40A ≤ I < 400A	15%
400A ≤ I < 800A	12%
800A ≤ I < 2000A	8%
I ≥ 2000A	5%

Fig.2 Distored Phase Currents (I1=100A, I3=50A, I5=30A & I7=15A) A Typical Modern Office Floor with PC's



$$THD = \frac{\sqrt{\sum_{h=2}^{\infty}(I_h)^2}}{I_1}$$

(Source: http://www.emsd.gov.hk/emsd/e_download/pee/EEC&harmonic.pdf)

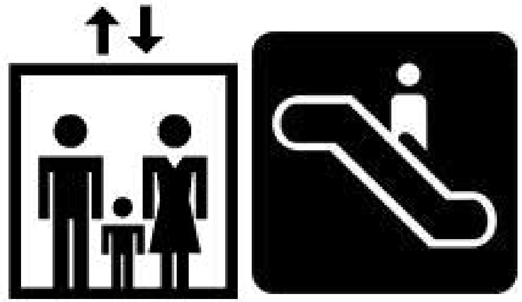
Electrical Services

- Problems with harmonics:
  - Power quality, overheating transformers, motors, phase & neutral conductors, causing unacceptable neutral-to-earth voltage, voltage distortion, electromagnetic interference (EMI), etc.
- Reasons for harmonics:
  - Non-linear loads e.g. variable speed motor drives, electronic ballasts and switch-mode power supplies in computers and other electronic office equipment

Electrical Services

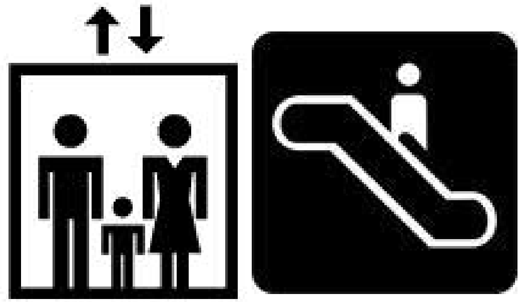
- Advanced Energy Saving Technologies (EMSD)
  - High Efficiency Motor
    - http://www.emsd.gov.hk/emsd/e_download/pee/ems_bk_low-res.pdf
  - Standards of Power Quality with reference to the Code of Practice for Energy Efficiency of Electrical Installations (by Ir. Martin Wu, EMSD)
    - http://www.emsd.gov.hk/emsd/e_download/pee/EEC&harmonic.pdf
- HK EE Net: Other EE Technologies
  - http://ee.emsd.gov.hk/english/other/oth_tech/oth_tech.html
  - Power factor improvement device, Harmonics filter

Lifts & Escalators

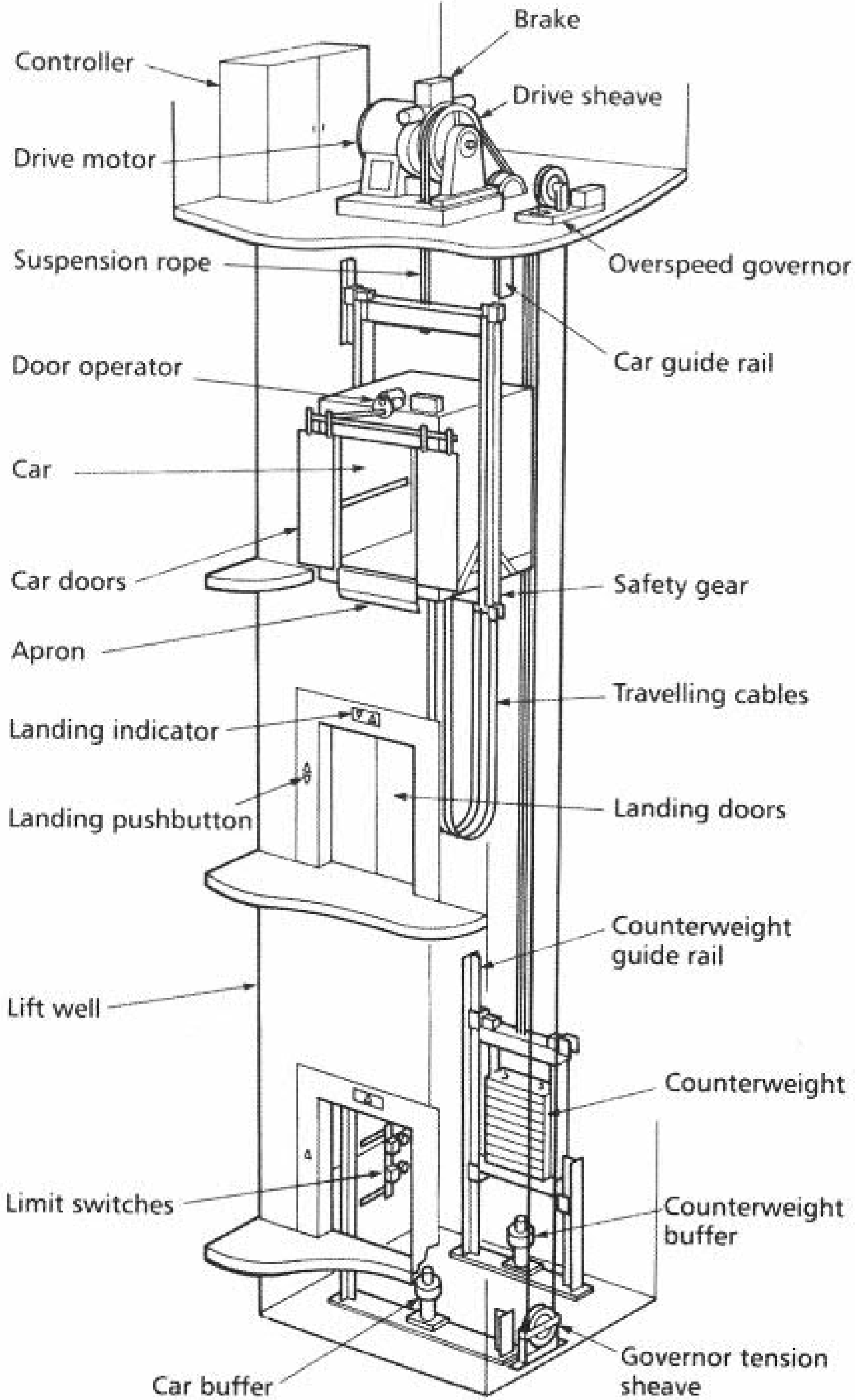


- Lifts & escalators are a major energy consumer in modern buildings
  - Typically consists 5-15% of electricity in high-rise commercial buildings
  - Also affects peak energy demand & power factor
- EMSD building energy code & guidelines:
  - Code of Practice for Energy Efficiency of Lift and Escalator Installations
  - Guidelines on Energy Efficiency of Lift and Escalator Installations

Lifts & Escalators



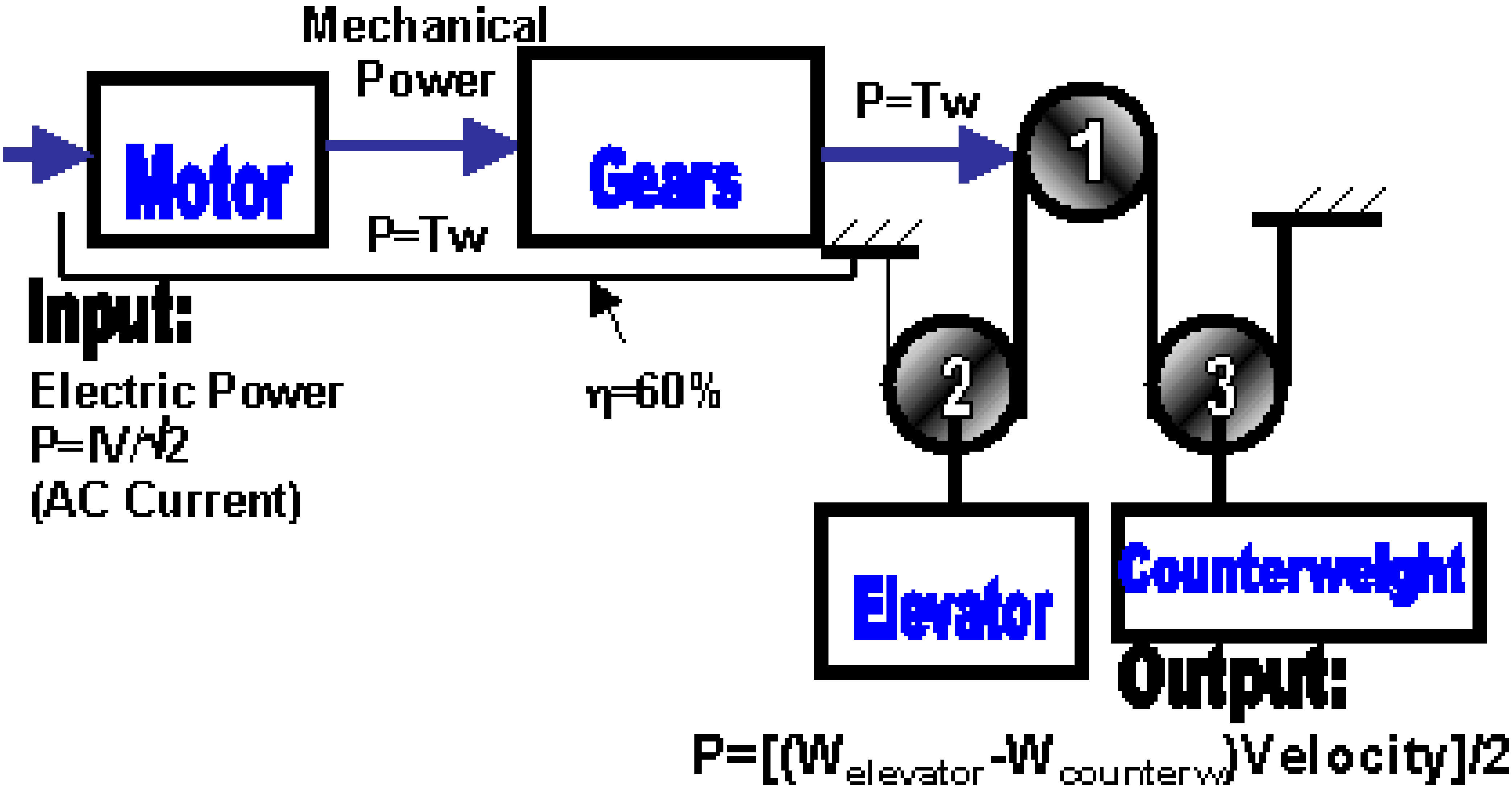
- Requirements on lifts & escalators
  - Maximum allowable electrical power
  - Energy management of lift cars or escalators
  - Total harmonic distortion (motor drive)
  - Total power factor (motor drive)
- Recommendations on lifts
  - Handling capacity
  - Lift traffic design



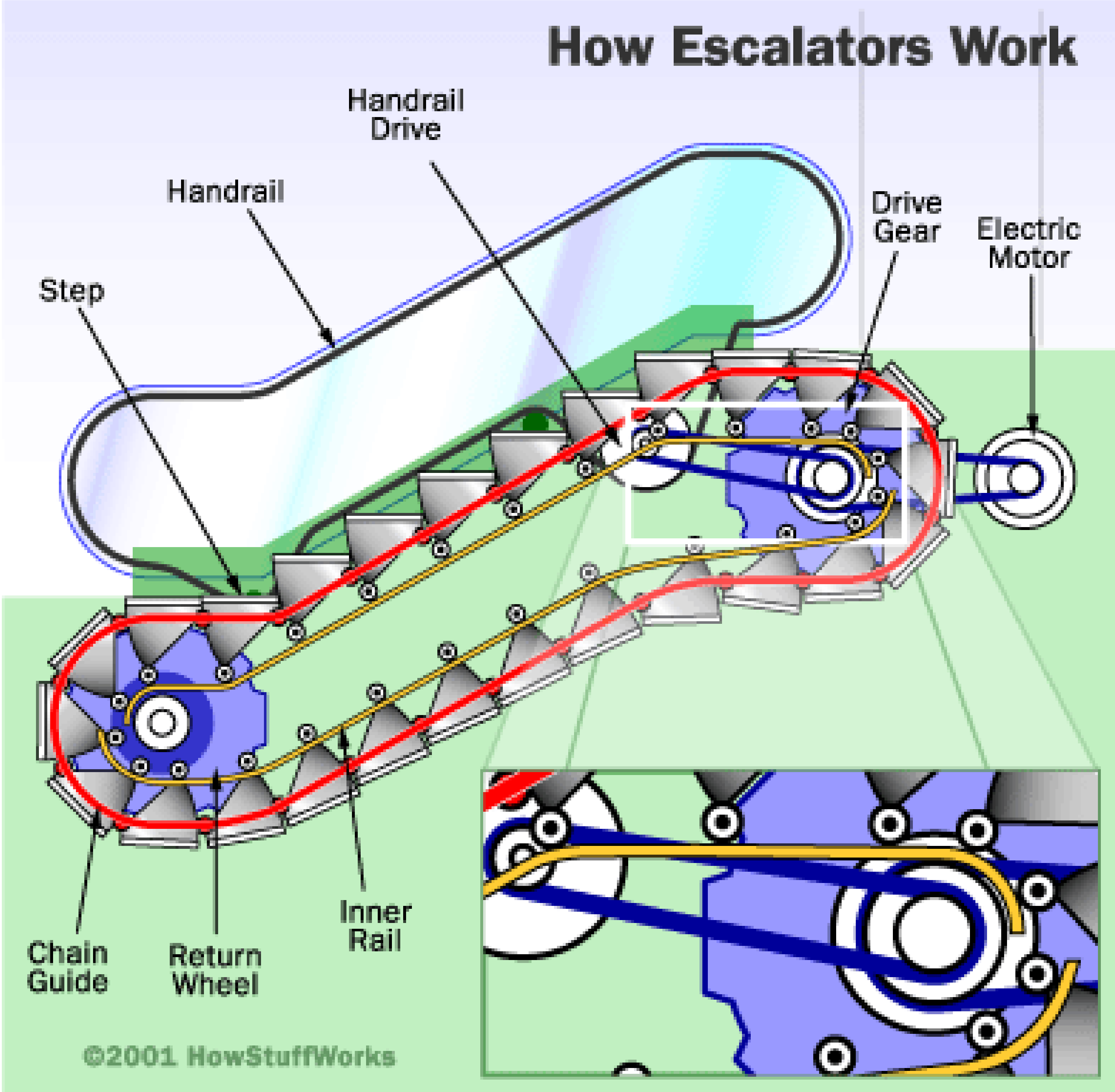
An electric traction passenger lift [source: CIBSE Guide D]

Video: how elevator work (How Machines Work)(4:16), http://youtu.be/GPxEPfTD454

Power flow through a typical elevator



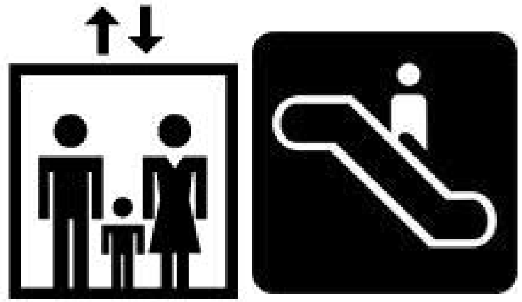
[Source: How an elevator works
http://web.mit.edu/2.972/www/reports/elevator/elevator.html]



Video: 完全機械手冊 - 扶手電梯 (5:23), http://www.youtu.be/i7s1ZOJ42ig

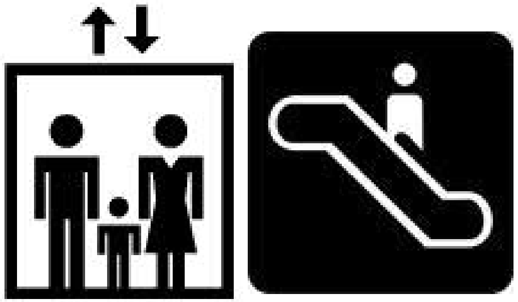
[Source: http://www.howstuffworks.com/]

Lifts & Escalators

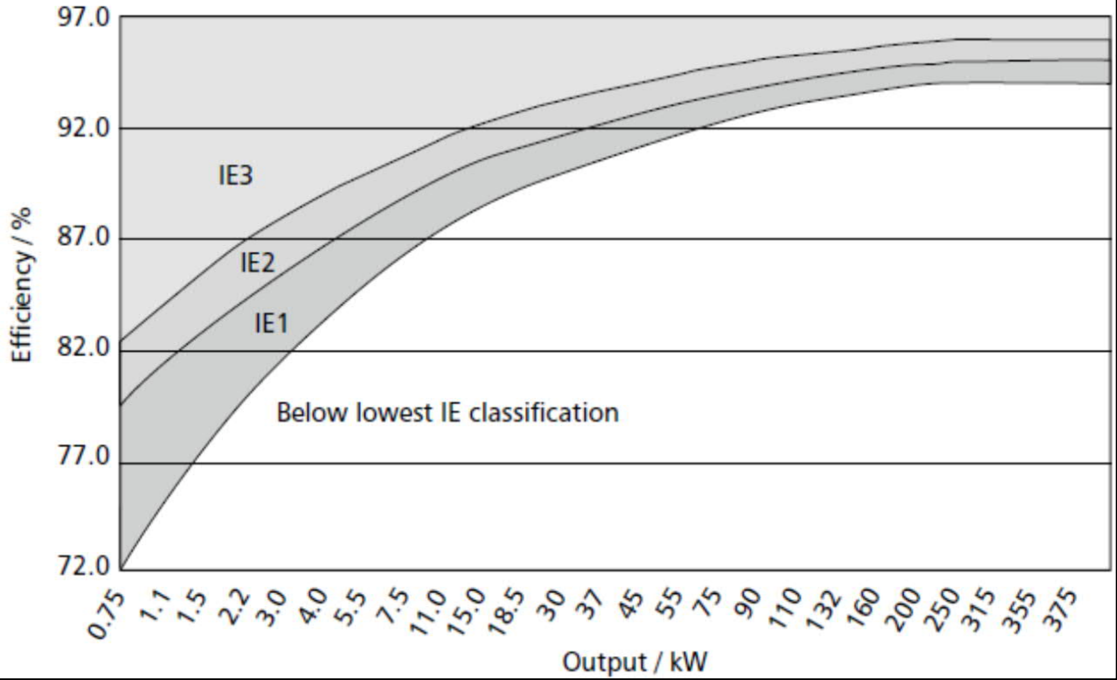


- Energy efficient strategy
  - Minimising the motor load
  - Motor sizing and selection
    - Correct sizing, high efficient motors
  - Motor drives (e.g. belt drives)
  - Controlling the motor load
    - Variable speed drives for efficient system regulation
    - Demand based control, duty cycle
  - Building transportation systems
    - Lift/escalator design, regenerative lift systems

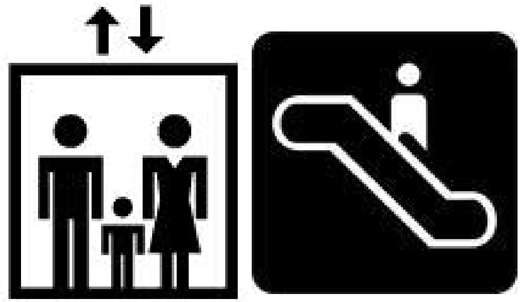
Lifts & Escalators



- Electric motors & drivers
  - Energy efficient motors: IEC 60034-30 international efficiency (IE) classes
    - IE1 = standard
    - IE2 = high
    - IE3 = premium
    - IE4 = super premium

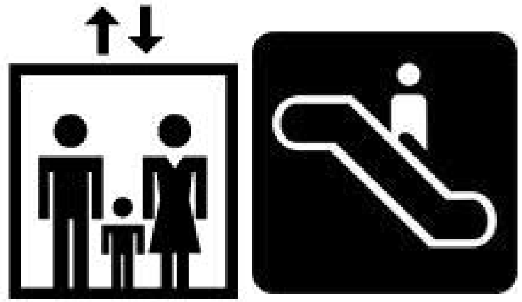


Lifts & Escalators

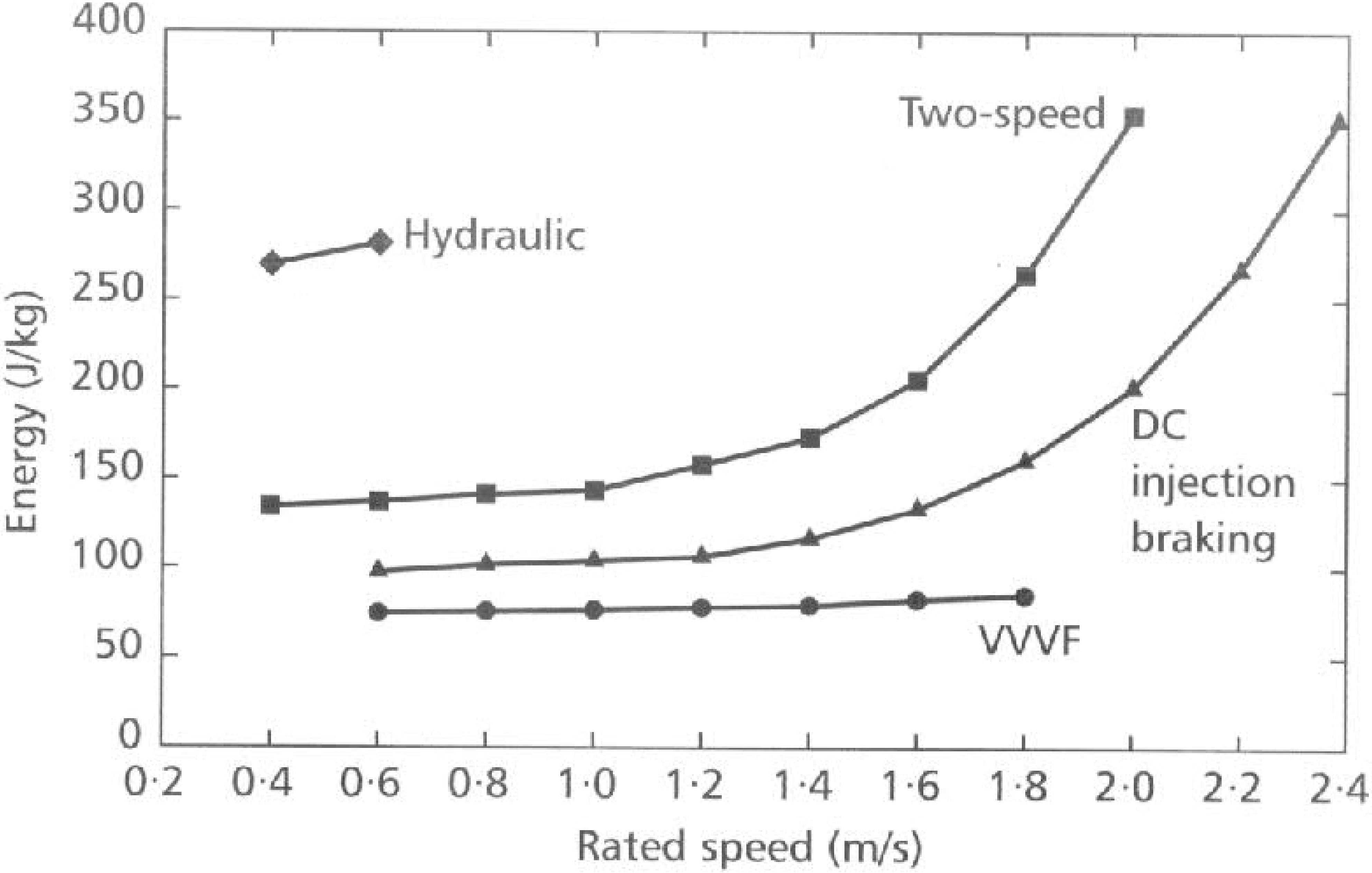


- General approach for lifts & escalators
  - Minimise friction losses & dynamic losses
  - Possible regeneration into the supply system
- General principles to energy efficiency
  - Specify energy efficiency equipment
  - Do not over design the system
  - Suitable zoning arrangement
  - Suitable control and energy management
  - Use light weight materials for lift car decoration
  - Good house keeping

Lifts & Escalators



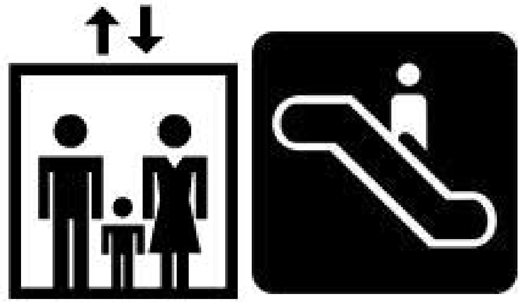
- Factors affecting energy consumption
  - Type of drive (hydraulic, two-speed, etc.)
  - Mechanical design (e.g. gearbox)
  - Efficiency of various components
  - Reduction of inertia (e.g. flywheel)
  - Type of gearing (if applicable)
  - Possibility of electricity regeneration
  - Running power factor
  - Loading (level of usage)



Energy consumption of various types of drives

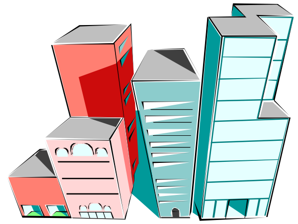
[Source: CIBSE Guide D]

Lifts & Escalators

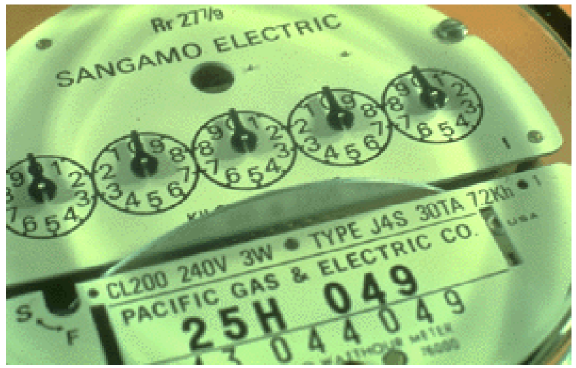


- HK EE Net: Lifts & Escalators
  - http://ee.emsd.gov.hk/english/lift/lift_tech/lift_tech.html
  - Variable Voltage Variable Frequency (VVVF) controller
  - Energy optimizer for lift and escalator
  - Service-on-demand escalator
  - Other energy saving measures

Building Management System



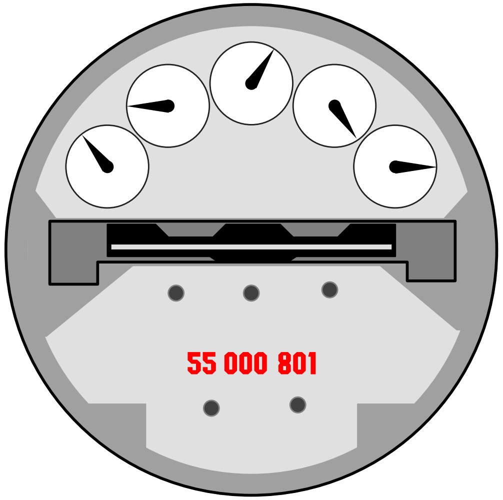
- Building management system (BMS):
  - Improve operating efficiency of equipment
  - Reduce operating costs through
    - Flexible scheduling
    - Limiting operation
    - Altering set points
    - Utilising natural or free cooling



- Reduce electrical consumption & demand
  - Energy (consumption) charge (kWh)
  - Demand charge (peak KW or KVA)

Building Energy Management System

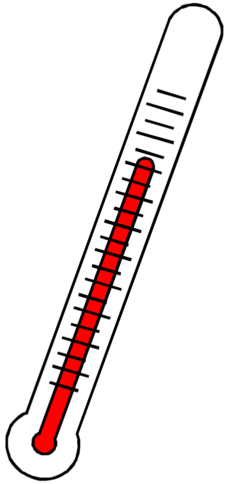
Lower energy cost

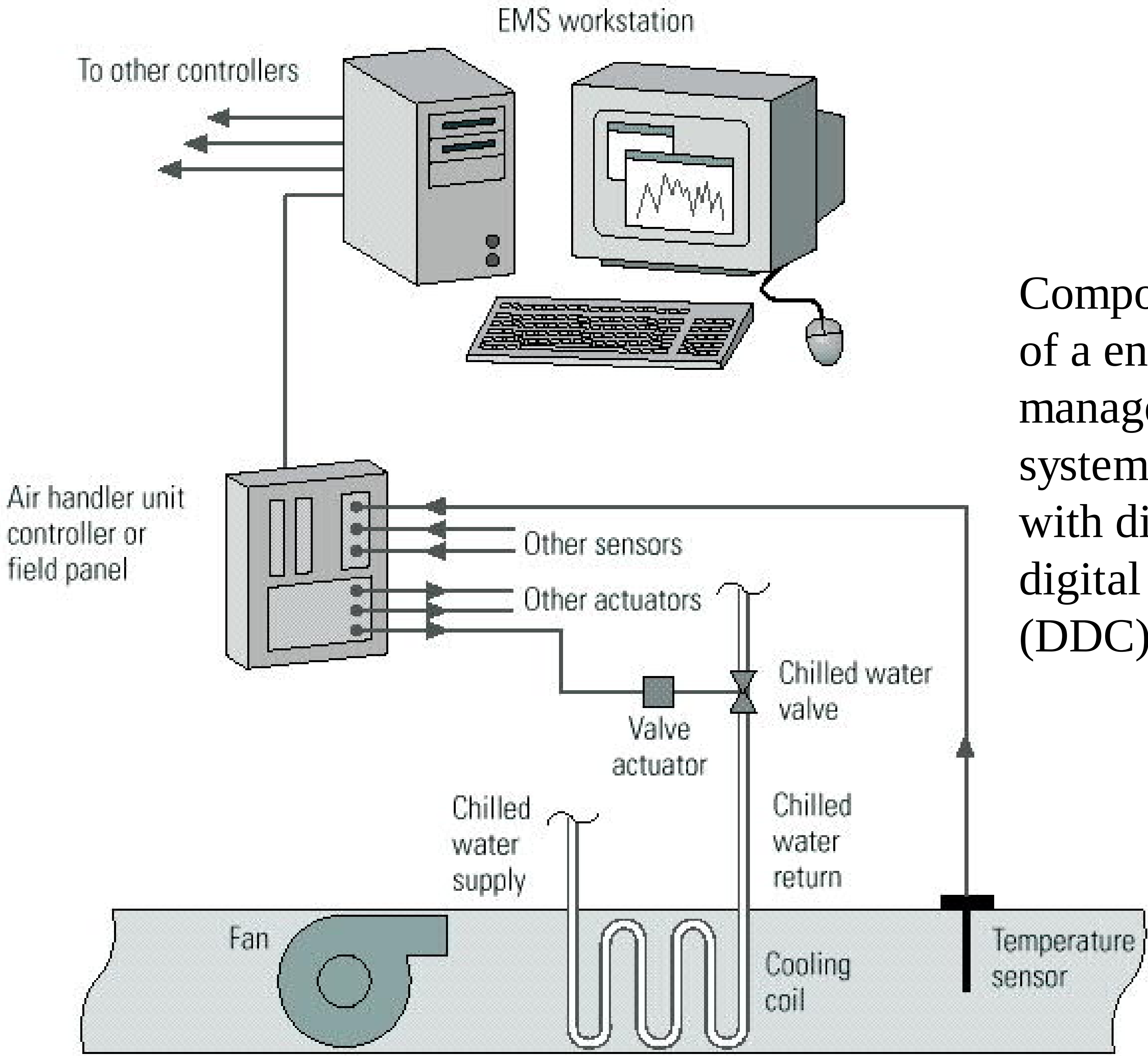


Lower operations cost

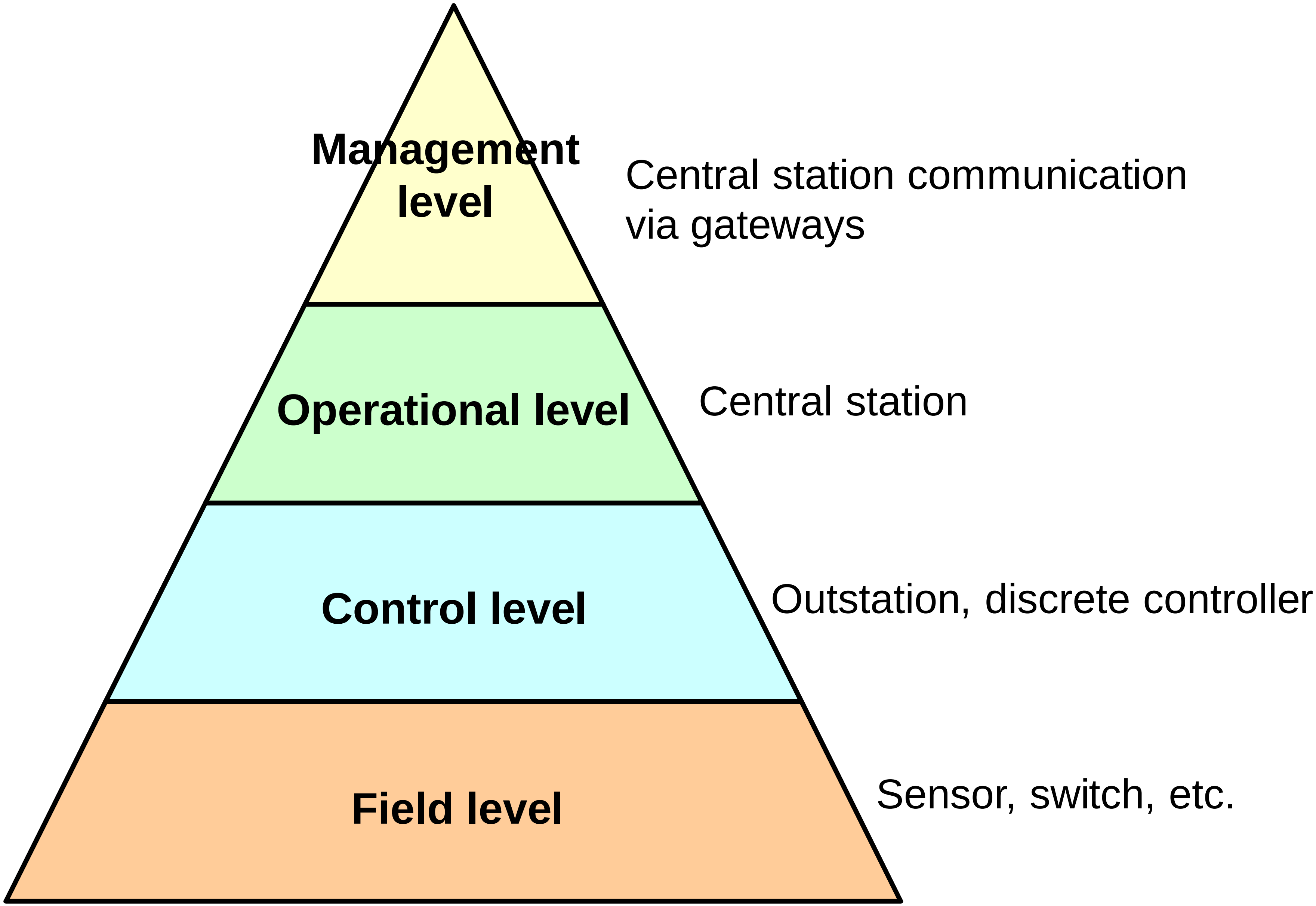
Increase flexibility

Ensure quality building environment

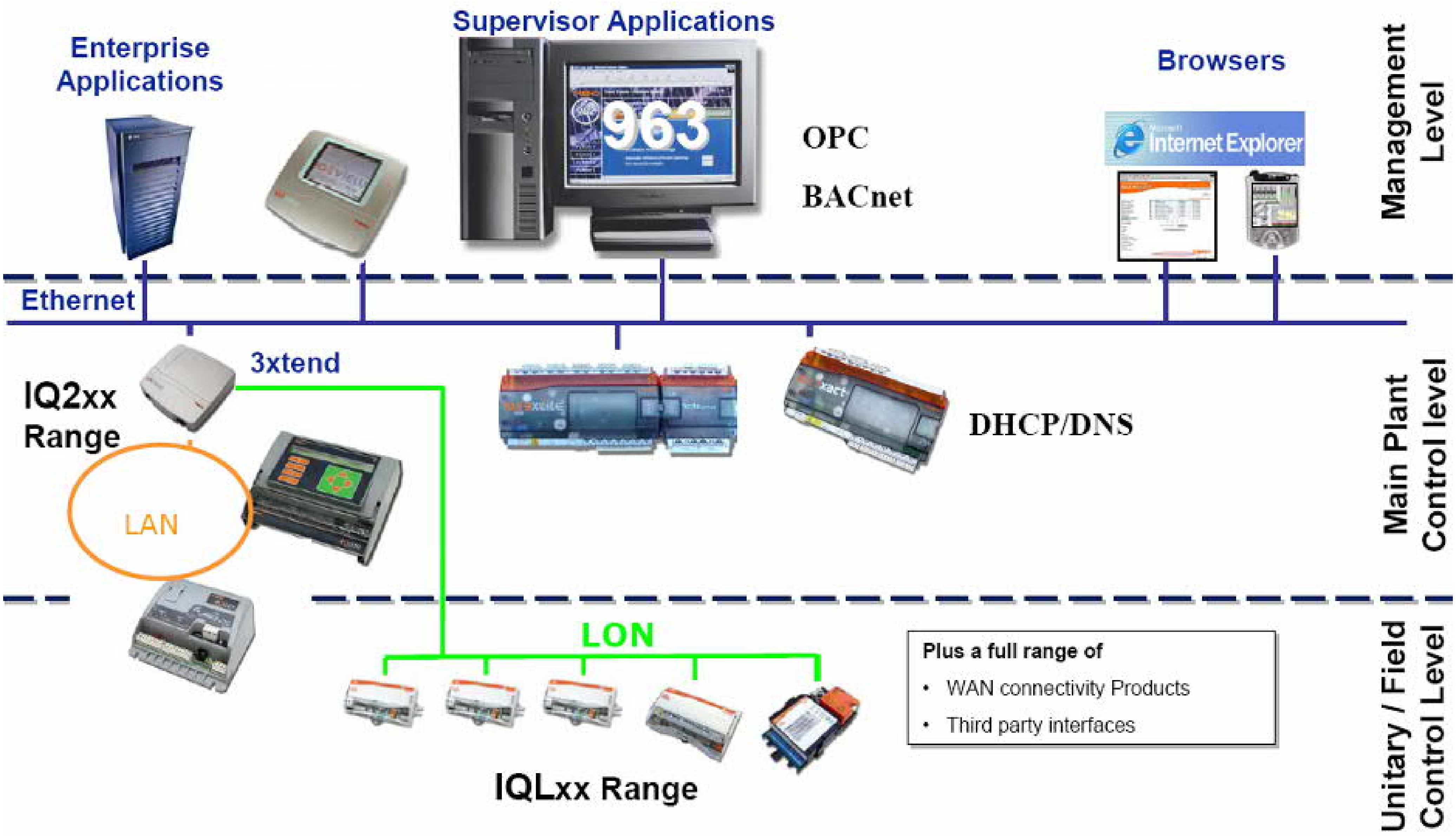




Components of a energy management system (EMS) with direct digital control (DDC)

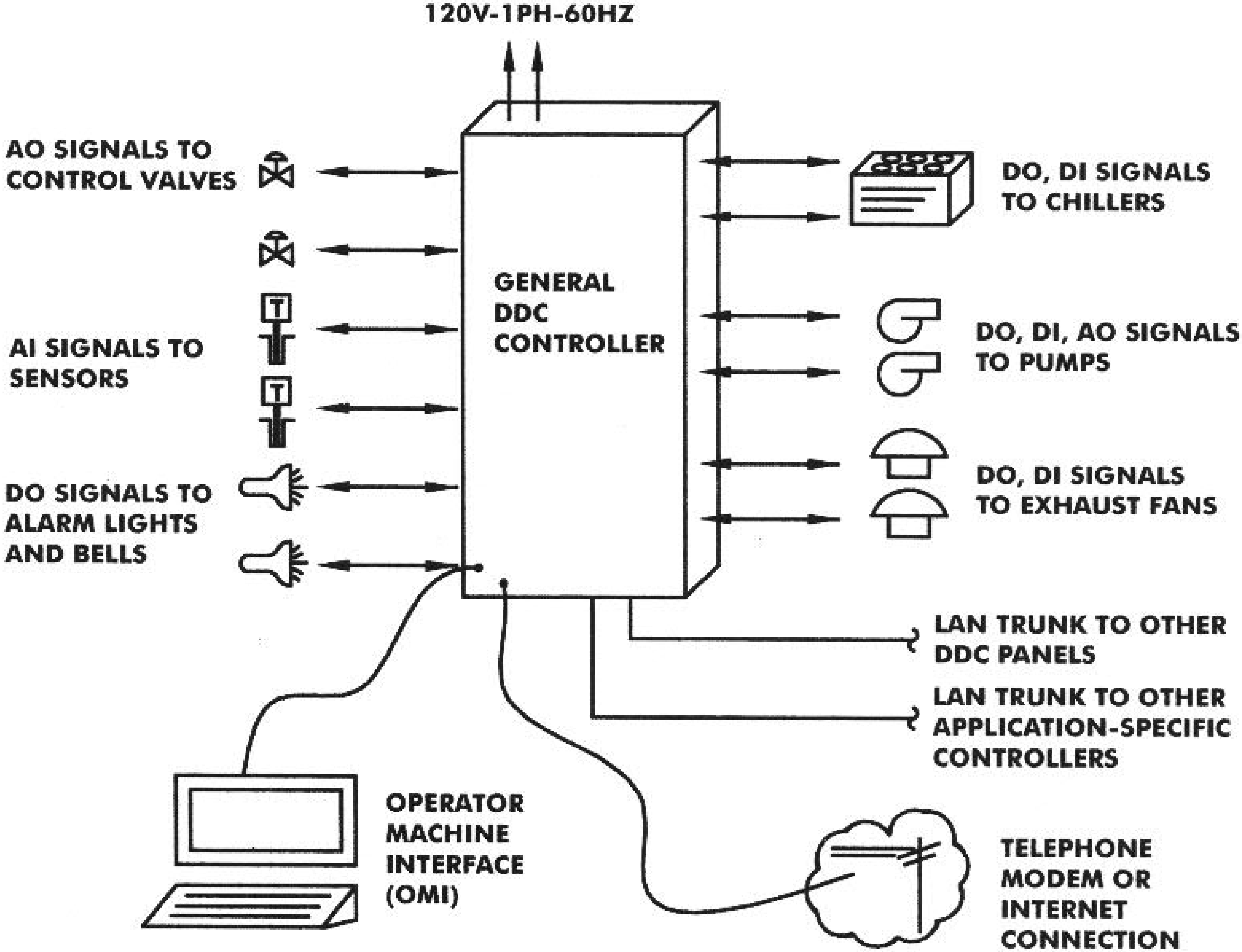


Levels of control in building energy management system



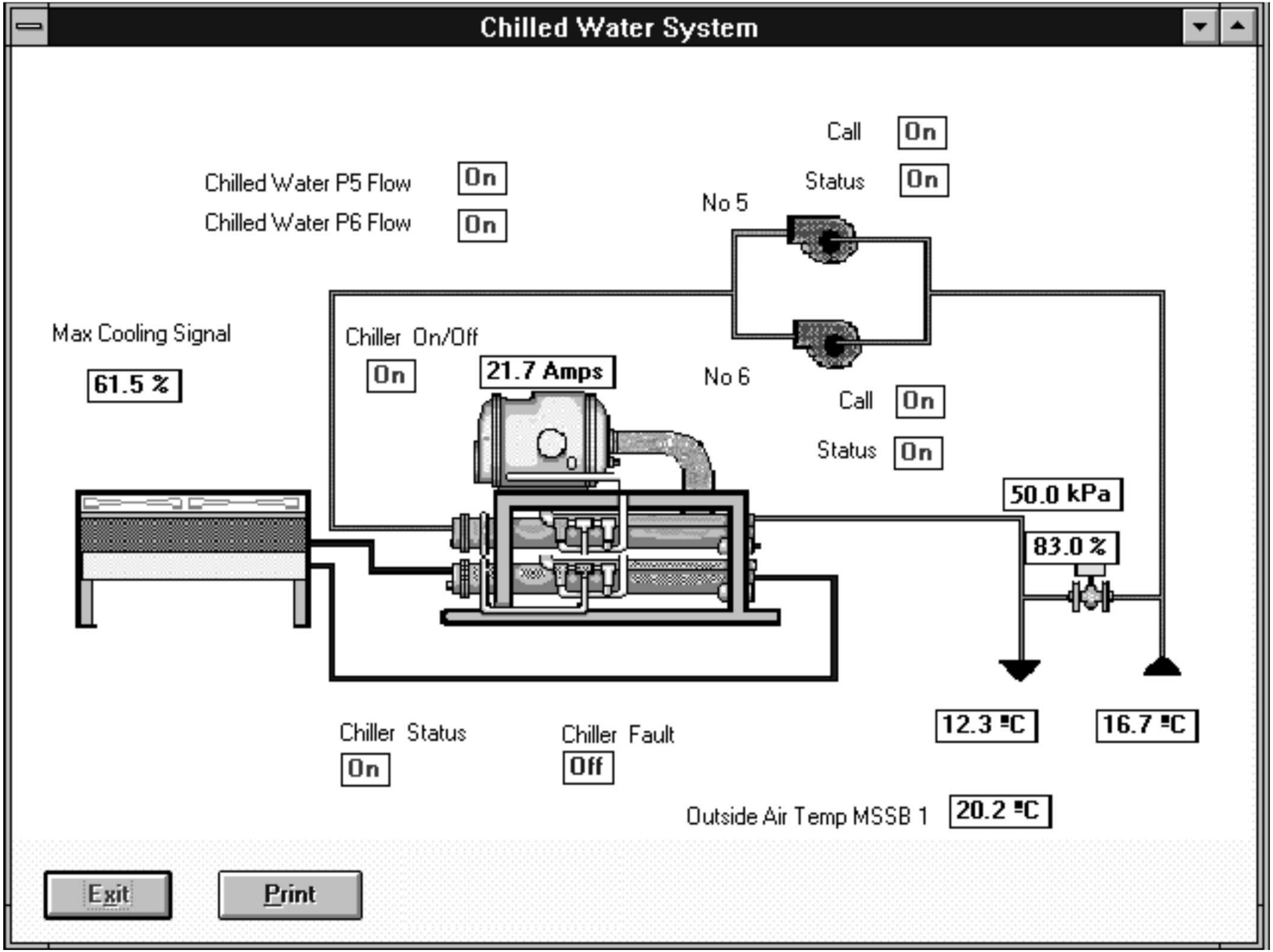
Example of system architecture for building management system

[Source: Trend Control Systems]



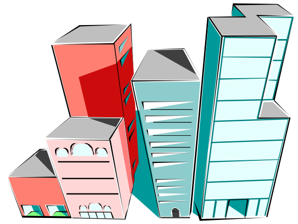
General purpose DDC controller

Building management software for HVAC control & monitoring

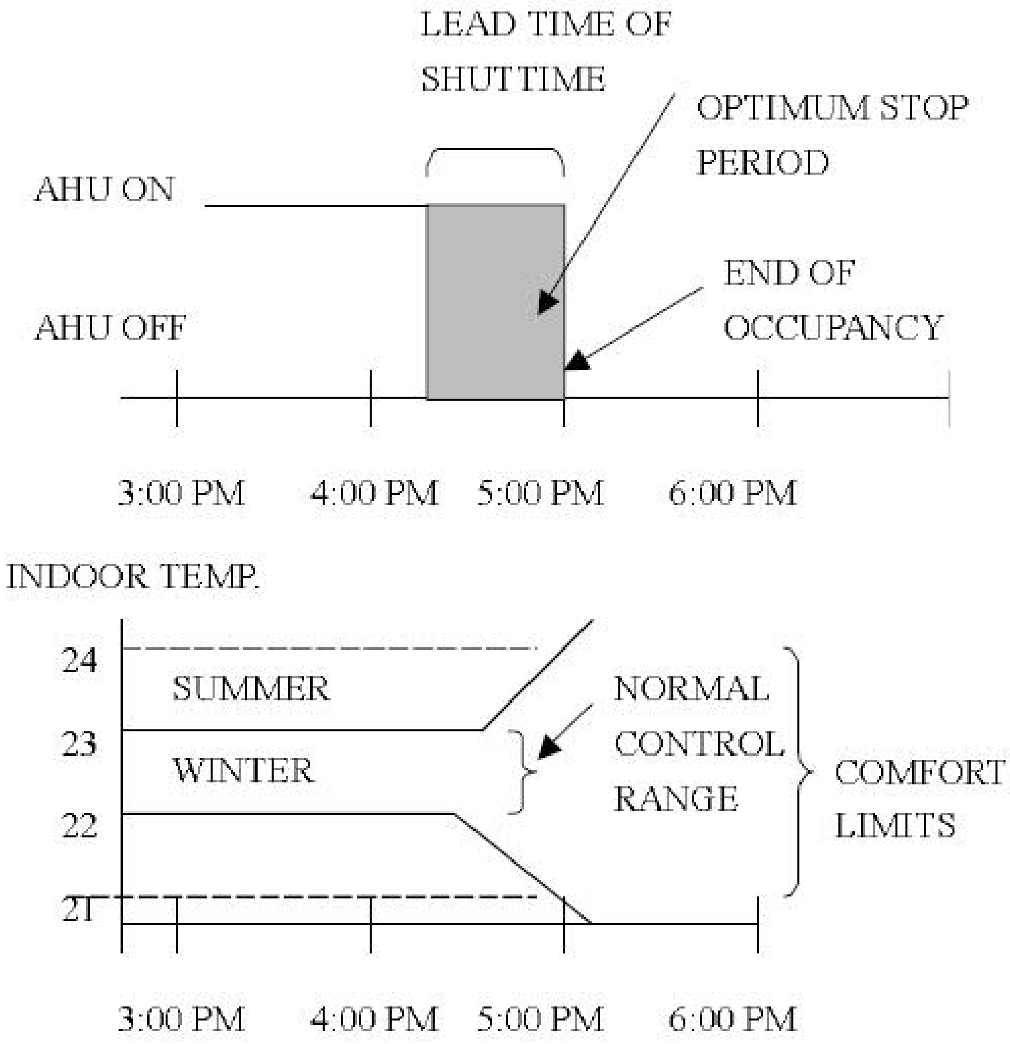


(Source: EMSD)

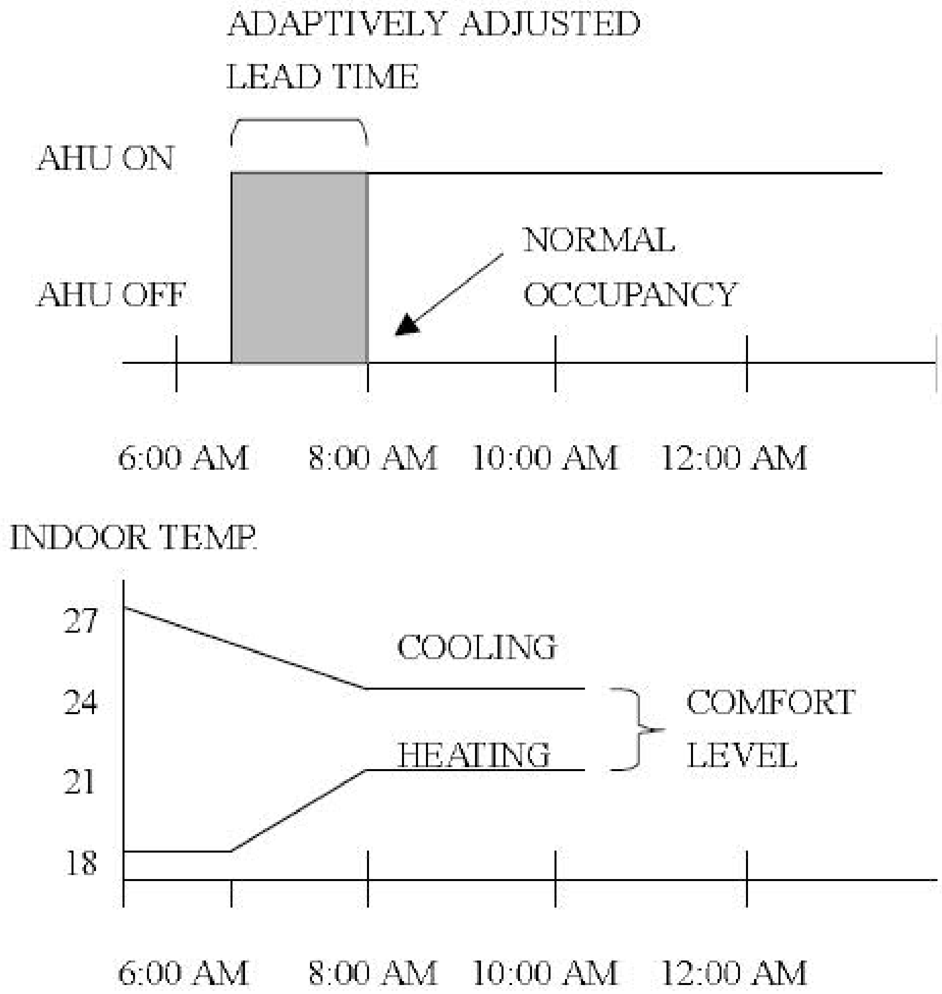
Building Management System



- Typical energy management strategies:
  - Time of day scheduling
  - Optimum start/optimum stop
  - Duty cycling
  - Demand limiting
  - Temperature reset
  - Airside economizer



Optimum Stop

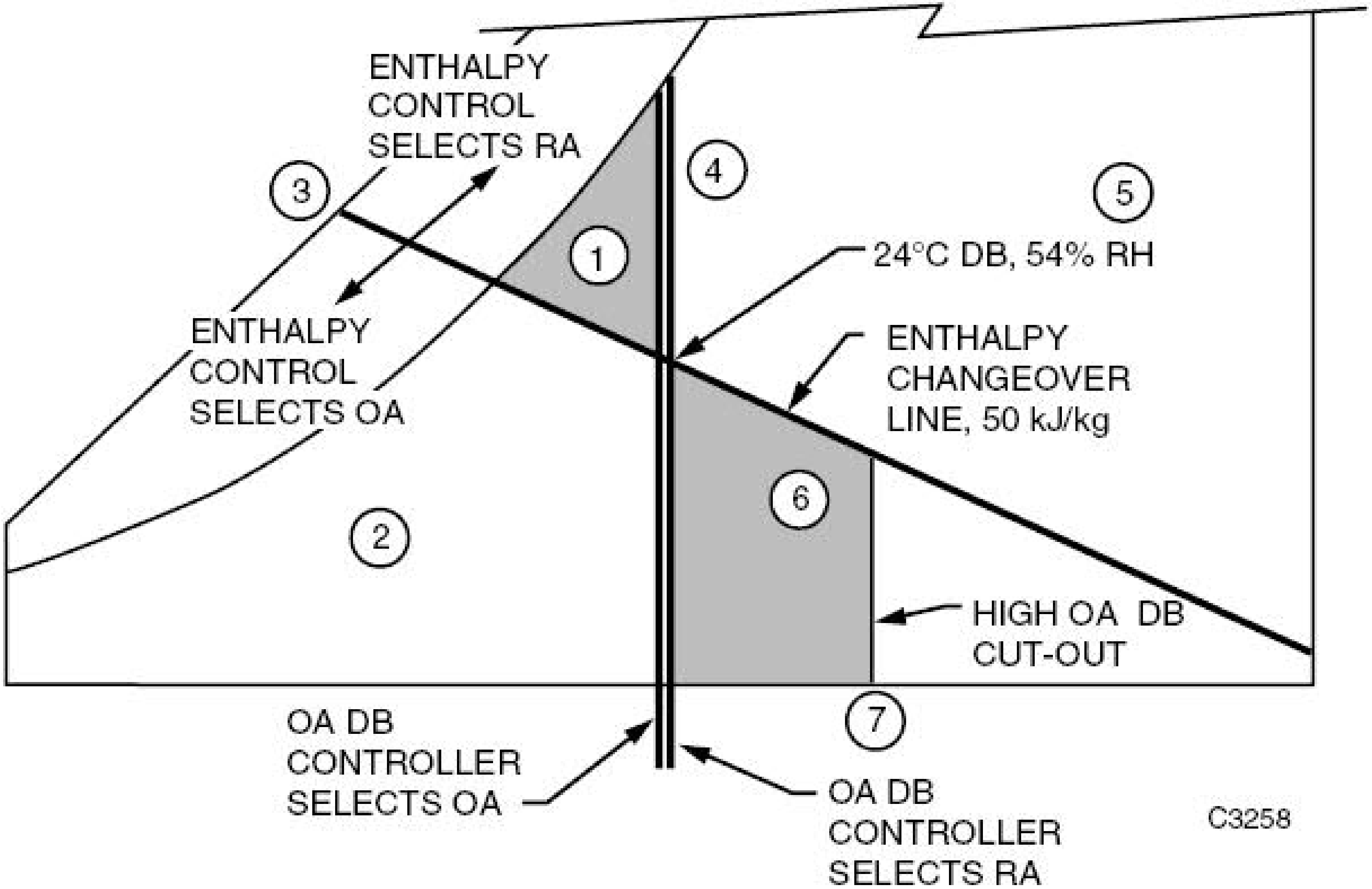


Optimum Start

Optimum start/optimum stop

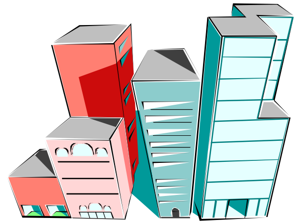
(Source: *EMSD, 2002. Guidelines on Application of Central Control and Monitoring Systems*)

Economizer cycle control (outdoor air enthalpy)

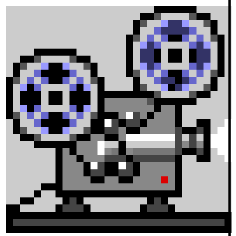


[Source: Honeywell, 1997. *Engineering Manual of Automatic Control: for Commercial Buildings*]

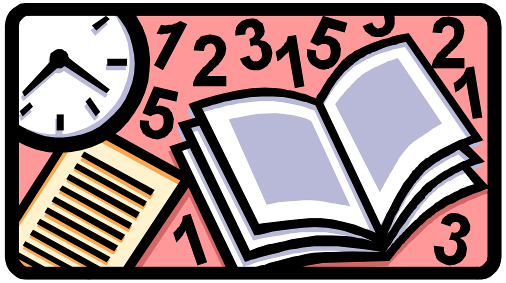
Building Management System



- Video: Achieving Net-Zero-Energy Buildings - ASHRAE (2:05)
  - http://youtu.be/pQFJr5E7_R0
  - By American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE)
  - 1. Building envelope measures
  - 2. HVAC, service water heating and lighting measures
  - 3. Renewable energy measures



Useful Websites



- Advanced Energy Saving Technologies (EMSD)
  - http://www.emsd.gov.hk/emsd/eng/pee/aest.shtml
  - Publications
    - http://www.emsd.gov.hk/emsd/eng/pee/aest_pub.shtml
- EMSD Energy Efficient Technologies Net
  - http://ee.emsd.gov.hk
- Energy Design Resources (EDR)
  - http://energydesignresources.com/

Further Reading

- Innovative Energy-efficiency Pilot Projects carried out by EEO, EMSD (by Ir Martin Wu)
  - http://www.emsd.gov.hk/emsd/e_download/pee/hkie100.pdf

- ** In memory of Ir Martin WU Kwok-tin (EEO EMSD) for his contribution to energy efficiency in Hong Kong