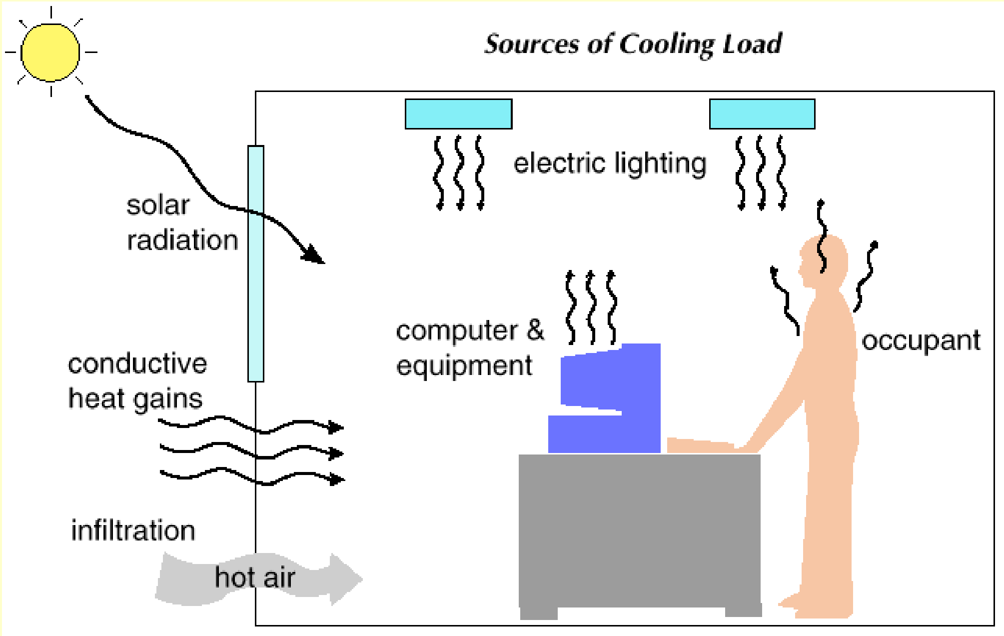

Load Estimation (I)

Ir Dr. Sam C. M. Hui
Department of Mechanical Engineering
The University of Hong Kong
E-mail: cmhui@hku.hk

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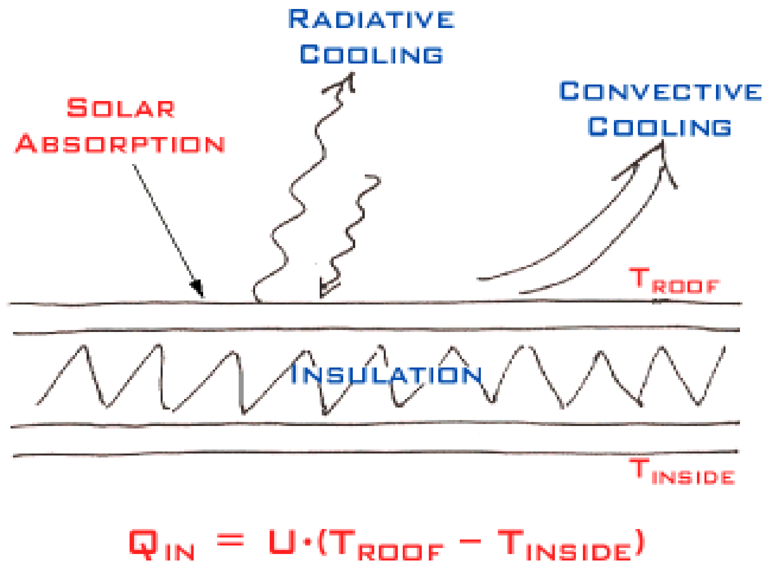
Contents

- Basic Concepts
- Load Calculations
- Outdoor Design Conditions
- Indoor Design Conditions
- Cooling Load Components
- HVAC Design Issues

Basic Concepts

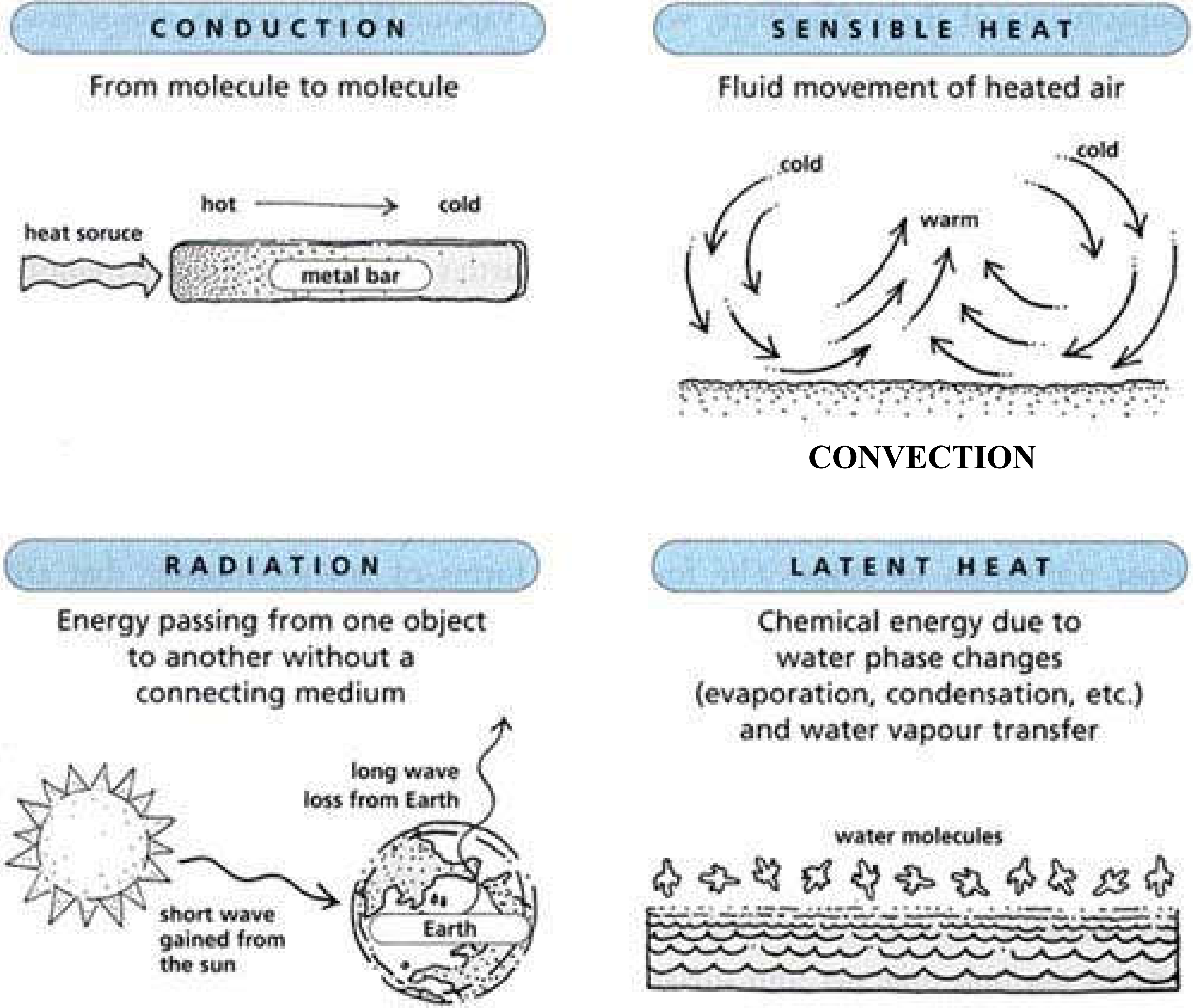
- Heat transfer mechanism
  - Conduction
  - Convection
  - Radiation



- Thermal properties of building materials & construction components
  - Overall thermal transmittance (U-value)
  - Thermal conductivity
  - Thermal capacity/mass (specific heat)

$$Q = U\,A\,(\Delta t)$$

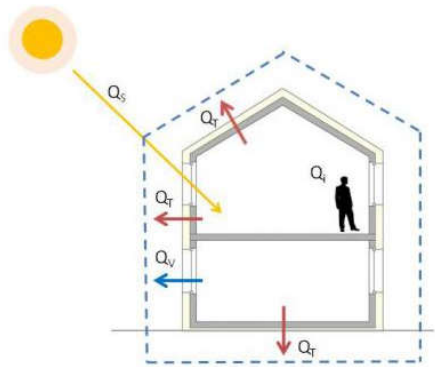
Four forms of heat transfer



(Source: Food and Agriculture Organization of the United Nations, www.fao.org)

Basic Concepts

- Heat transfer in buildings
  - http://www.designingbuildings.co.uk/wiki/Heat_transfer_in_buildings
  - Conduction, convection, radiation, phase change (e.g. water evaporates)
- Thermal performance of buildings
  - http://www.designingbuildings.co.uk/wiki/Thermal_performance_of_buildings
  - Conductivity, U-values, air tightness, others
- U-values
  - https://www.designingbuildings.co.uk/wiki/U-values
  - Typical values & calculation



U-value calculation & typical values for building components

The U-value of a component is calculated by

$$U = \frac{1}{R_T} = \frac{1}{R_{se} + \frac{d_1}{\lambda_1} + \frac{d_2}{\lambda_2} + \cdots + R_{si}}$$

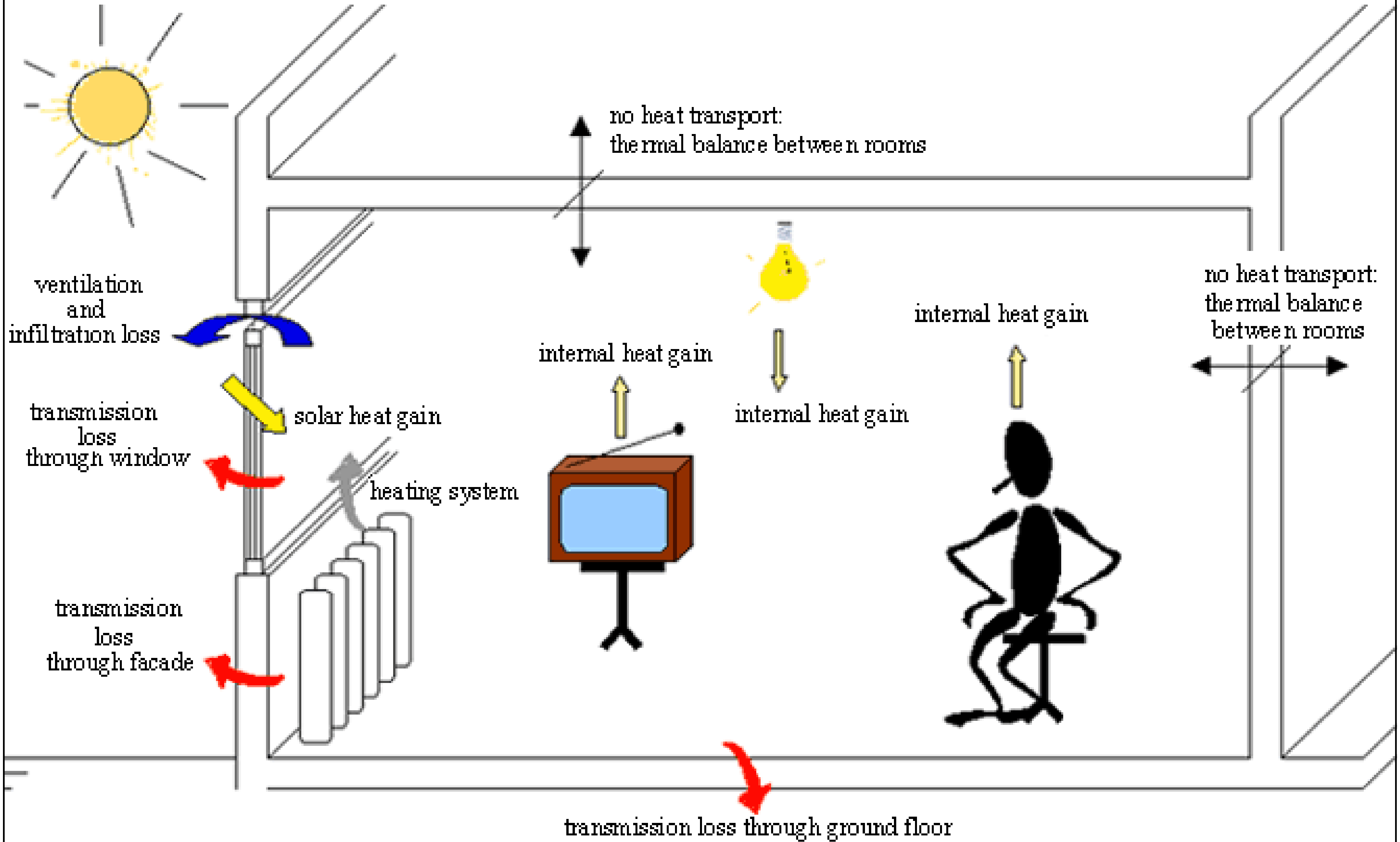
U: heat transfer coefficient in W / (K · m²)
R_T: thermal resistance in (K · m²) / W
R_{se}: external heat transfer resistance in (K · m²) / W
d_i: thickness of the layer number i in m
λ_i: specific thermal conductivity of this layer in W / (K · m)
$^1/ R_\lambda$ = .lambda..sub.i, i: the specific heat resistance of the i-th layer in (K · m) / W
$^d{}_i$ / .lambda..sub.i = $_R$ i: the thermal resistance of this layer in (K · m²) / W
R_{si}: internal heat transfer resistance in (K · m²) / W

Typical U-values for building components:

- Solid brick wall: 2 W/(m²K)
- Cavity wall with no insulation: 1.5 W/(m²K)
- Insulated wall: 0.18 W/(m²K)
- Single glazing: 4.8 to 5.8 W/(m²K.
- Double glazing: 1.2 to 3.7 W/(m²K) depending on typ.
- Triple glazing below: 1 W/(m²K)
- Solid timber door: 3 W/(m²K)

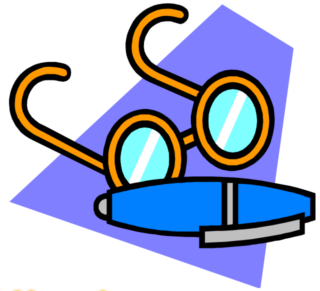
(See also: Thermal transmittance -- Wikipedia http://en.wikipedia.org/wiki/Thermal_transmittance)

Heat transmission & heat transport in buildings



(Source: https://www.new-learn.info/packages/clear/thermal/buildings/building_fabric/index.html)

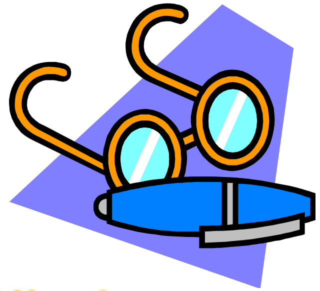
Basic Concepts



- Thermal load
  - The amount of heat that must be added or removed from the space to maintain the proper temperature in the space
- When thermal loads push conditions outside of the comfort range, HVAC systems are used to bring the thermal conditions back to comfort conditions

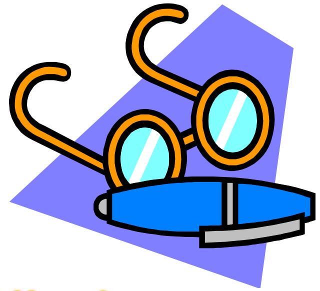
What will happen if the thermal load cannot be tackled by the HVAC system?

Basic Concepts



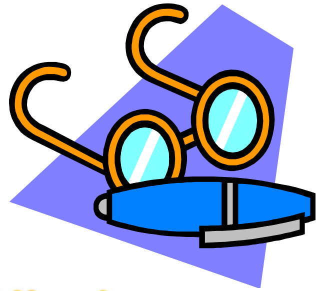
- Main questions of HVAC designer:
  - 1. What is the required equipment size?
  - 2. How do the cooling/heating requirements vary spatially within the building?
  - 3. What are the relative sizes of the various contributors to the cooling/heating load?
- Load estimation also provides a basis for specifying the required air flow to individual spaces within the building

Basic Concepts



- Purpose of HVAC load estimation
  - Calculate peak design loads (cooling/heating)
  - Estimate likely plant/equipment capacity or size
  - Specify the required airflow to individual spaces
  - Provide info for HVAC design e.g. load profiles
  - Form the basis for building energy analysis
- Cooling load is our main target
  - Important for warm climates & summer design
  - Affect building performance & its first cost

Basic Concepts



- Sizing air conditioning systems
  - To determine the cooling capacity required
  - Rules-of-thumb method (e.g. based on floor area)
  - Load estimation using engineering calculations
- Effects of oversizing air-conditioners
  - Draught due to excessive air flow
  - Inefficient part-load operation & performance
  - Over cooling & dehumidification (waste energy)

(See also: Sizing residential air-conditioners - mistakes and remedies (HK Engineers, Vol 42, Nov 2014) http://www.hkengineer.org.hk/issue/vol42-nov2014/notices_others/)

Cooling load estimation guidelines from a manufacturer

冷氣機製冷量與房間面積參考
Reference for Cooling Capacity of Air Conditioner and Room Size

房間面積Room Size （以石屎間隔為準 Calculated according to concrete partition）	製冷量 Cooling Capacity	
70平方呎內 Within 70 Square Feet	7,000	Btu/小時 Btu/hour
90平方呎內 Within 90 Square Feet	9,000	Btu/小時 Btu/hour
120平方呎內 Within 120 Square Feet	12,000	Btu/小時 Btu/hour
170平方呎內 Within 170 Square Feet	17,000	Btu/小時 Btu/hour
230平方呎內 Within 230 Square Feet	23,000	Btu/小時 Btu/hour

1. BTU是一個以英制的能量單位。
   BTU refers to British Thermal Unit.

1 kW = 3412 Btu/hour

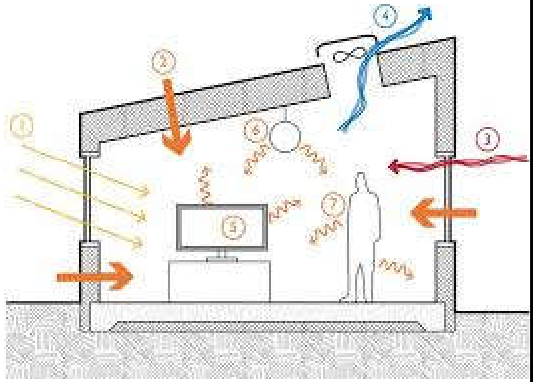
(Source: https://www.panasonic.hk/)

Load Calculations

- Heating load calculations
  - Estimate heat loss from the building in winter to determine required heating capacities
  - Assume steady state conditions (no solar radiation & steady outdoor conditions) & neglect internal heat sources
- Cooling load calculations
  - Estimate heat gains & peak cooling load in summer to determine required cooling capacities
  - Unsteady state processes (more complicated)

Load Calculations

- Calculating heat gains
  - Heat gain through external walls
  - Heat gain through roof
  - Solar heat gain through window glass
  - Conduction heat through window glass
  - Internal heat gains
  - Ventilation and/or infiltration heat gains
  - Latent heat gains (moisture transfer/generation)

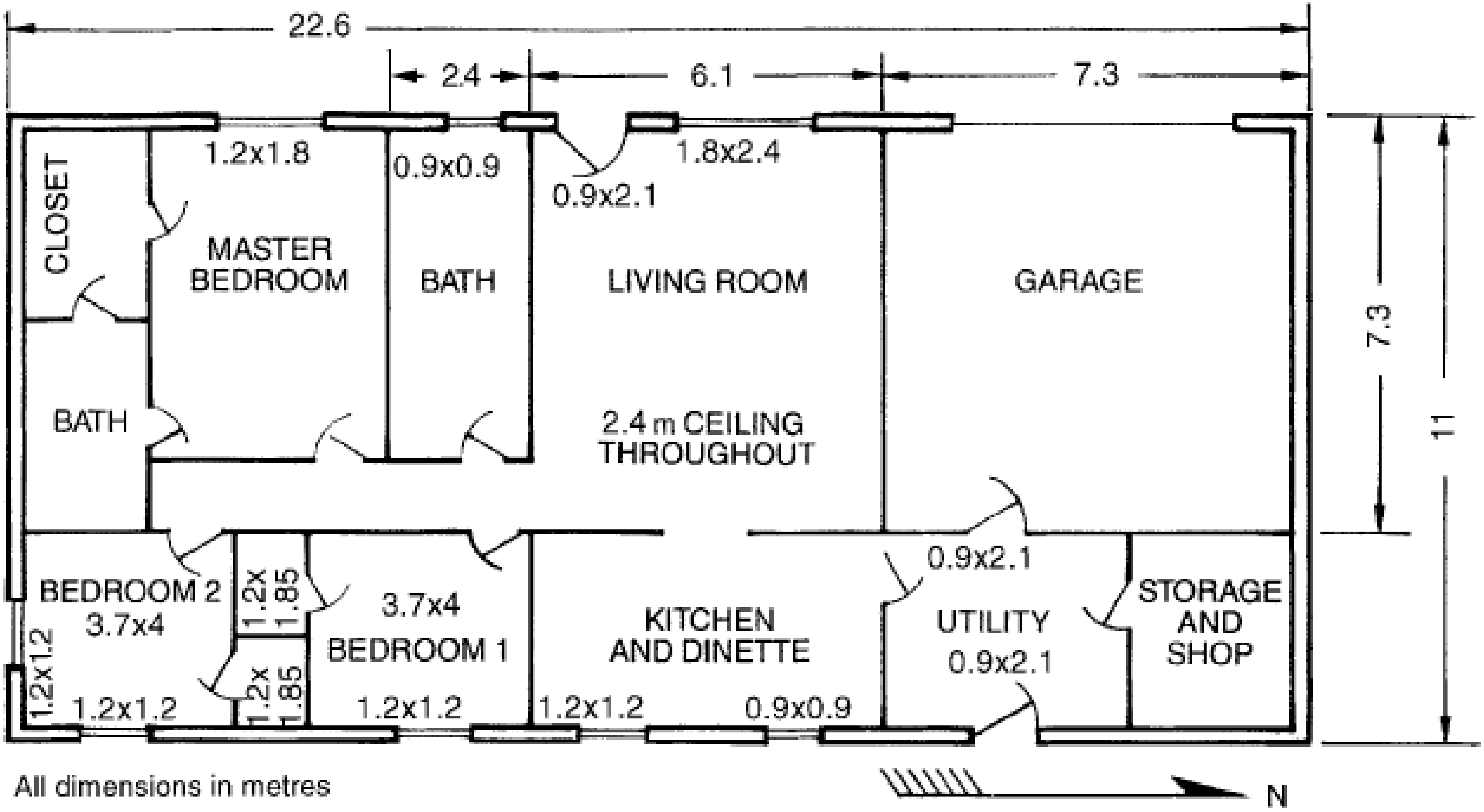


Load Calculations

- Heat transfer basic relationships (for air at sea level) (SI units)
  - Sensible heat transfer rate (kW):
    - $q_{sensible} = 1.23$ (Flow rate, L/s) (Δt)
  - Latent heat transfer rate (kW):
    - $q_{latent} = 3010$ (Flow rate, L/s) (Δw)
  - Total heat transfer rate (kW):
    - $q_{total} = 1.2$ (Flow rate, L/s) (Δh)
  - $q_{total} = q_{sensible} + q_{latent}$

Load Calculations

- General procedure for cooling load calculations
  - 1. Obtain the characteristics of the building, building materials, components, etc. from building plans and specifications
  - 2. Determine the building location, orientation, external shading (like adjacent buildings)
  - 3. Obtain appropriate weather data and select outdoor design conditions
  - 4. Select indoor design conditions (include permissible variations and control limits)

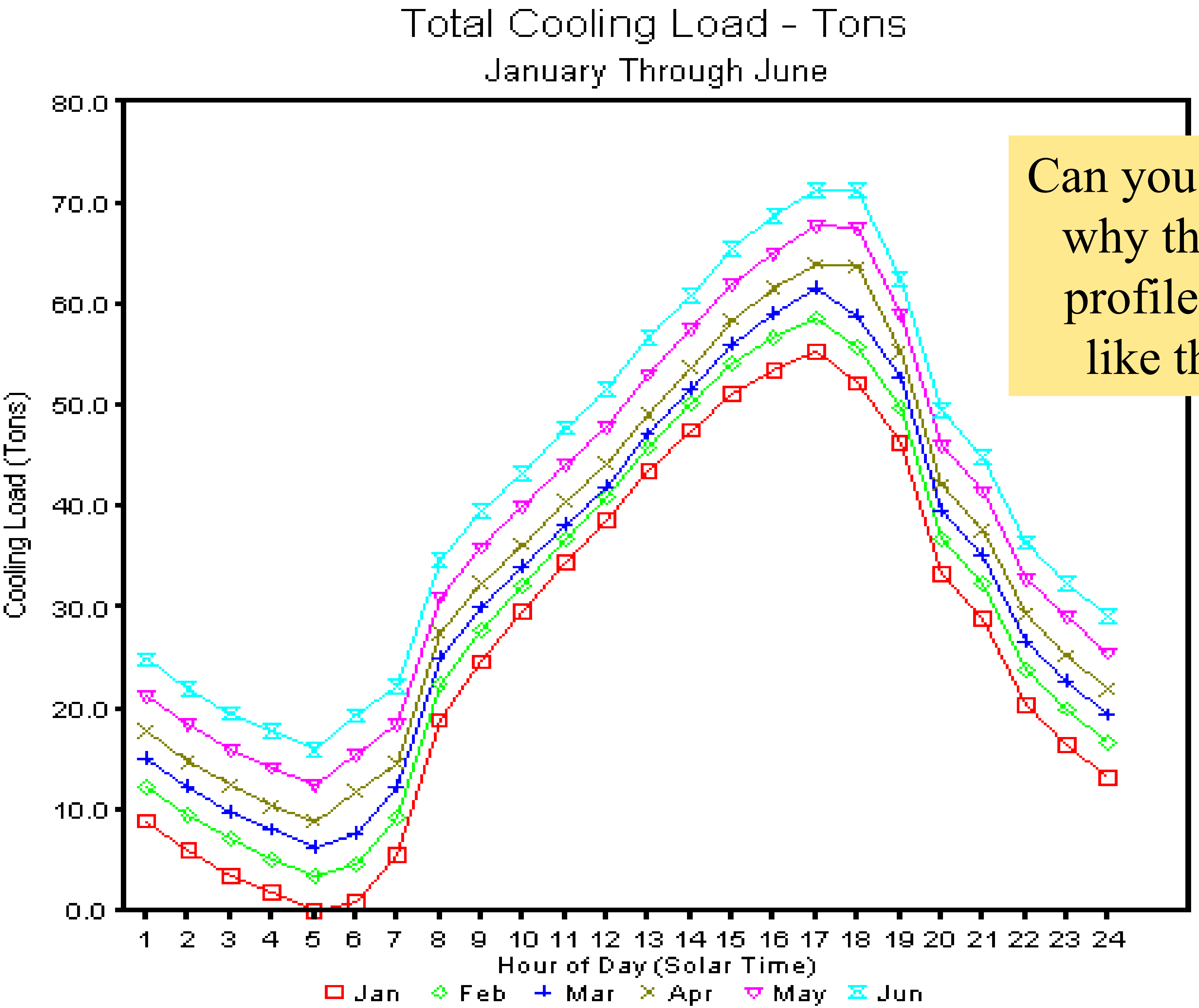


(Source: ASHRAE Handbook Fundamentals 2005)

Load Calculations

- General procedure for cooling load calculations (cont'd)
  - 5. Obtain a proposed schedule of lighting, occupants, internal equipment appliances and processes that would contribute to internal thermal load
  - 6. Select the time of day and month for the cooling load calculation
  - 7. Calculate the space cooling load at design conditions
  - 8. Assess the cooling loads at several different time or a design day to find out the peak design load

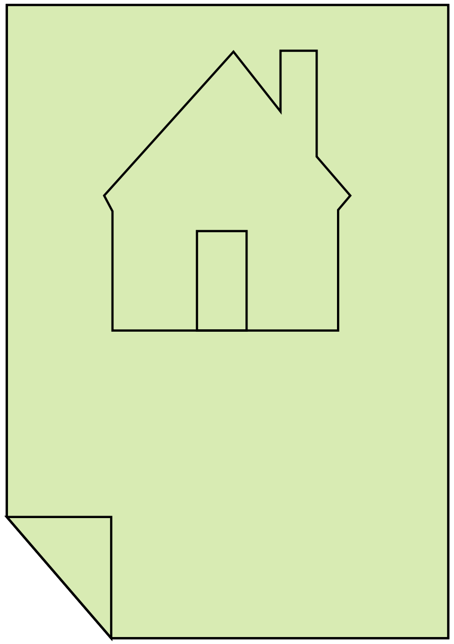
Examples of cooling load profiles



Can you explain why the load profiles look like these?

Load Calculations

- A building survey will help us achieve a realistic estimate of thermal loads
  - Orientation of the building
  - Use of spaces
  - Physical dimensions of spaces
  - Ceiling height
  - Columns and beams
  - Construction materials
  - Surrounding conditions
  - Windows, doors, stairways



Load Calculations

- Key info for load estimation
  - People (number or density, duration of occupancy, nature of activity)
  - Lighting (W/m^2, type)
  - Appliances (wattage, location, usage)
  - Ventilation (criteria, requirements)
  - Thermal storage (if any)
  - Continuous or intermittent operation

Evaluate these factors to improve the accuracy of load estimation

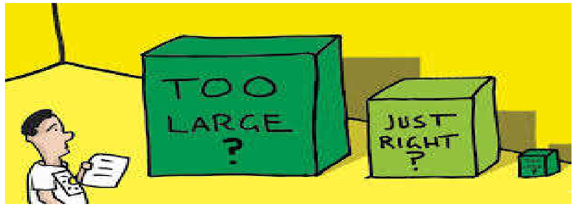
Load Calculations

- Typical HVAC load design process
  - 1. Rough estimates of design loads & energy use
    - Such as by rules of thumb & floor areas
    - See "Cooling Load Check Figures" *
    - See references for some examples of databooks
  - 2. Develop & assess more info (design criteria, building info, system info)
    - Building layouts & plans are developed
  - 3. Perform detailed load & energy calculations

(* Cooling Load Check Figures http://www.iklimnet.com/expert_hvac/cooling_load_check_figures.html; http://ibse.hk/cpd/HVACdesign-L1/CoolingLoadCheckFigures_CLTDequations.pdf)

Load Calculations

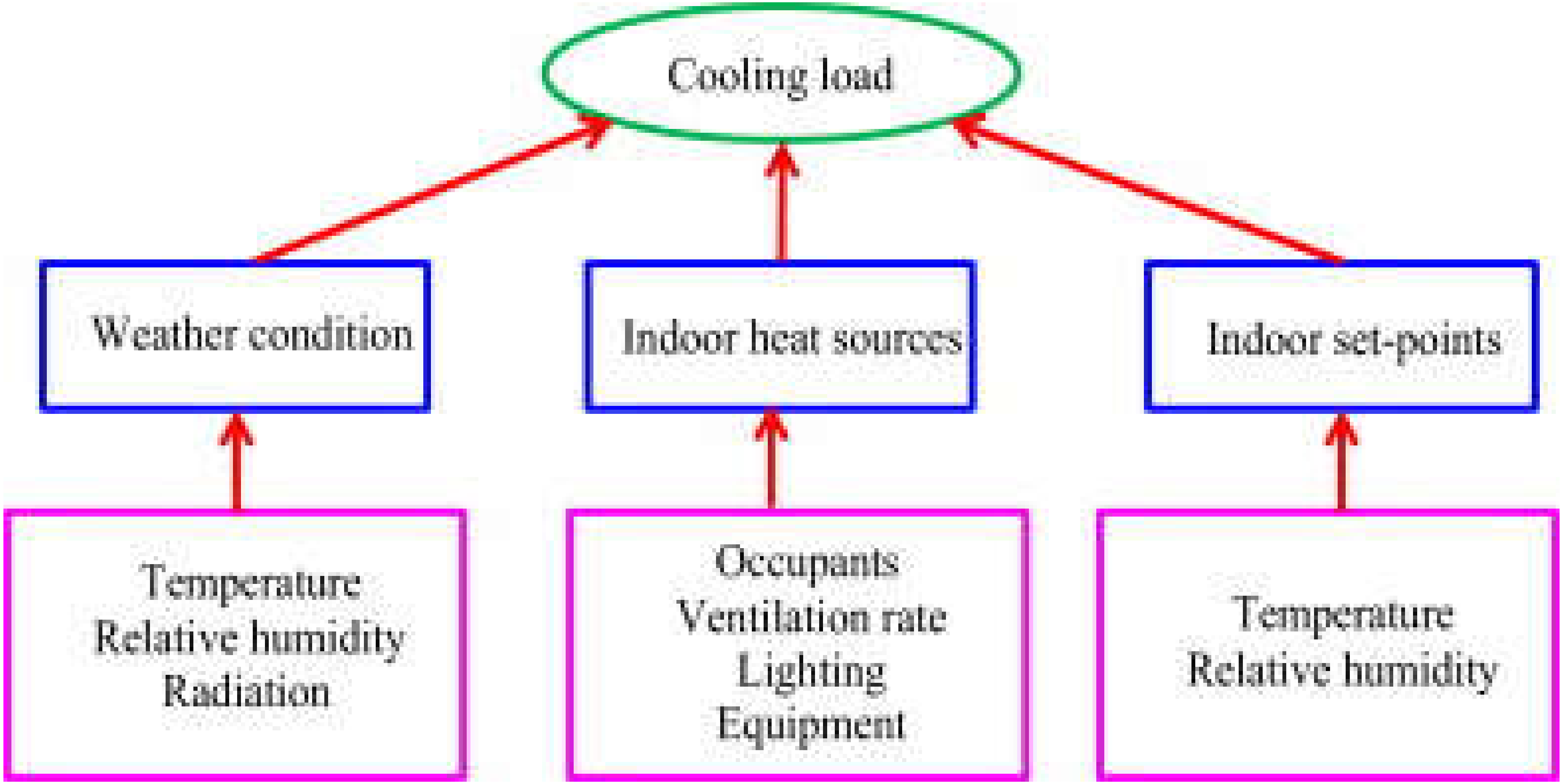
- Issues with oversizing



有大無壞?? Big Or Not ??

  - Since getting an accurate cooling load estimate can be difficult (or even impossible at an early design stage) some engineers design conservatively and deliberately oversize systems
  - Oversizing a system is problematic because:
    - They are less efficient, harder to control, and noisier than properly sized systems
    - They tend to duty cycle (turn on and off) which reduces reliability and increases maintenance costs
    - They take up more space and cost more $$$

Uncertainty factors in cooling load calculation



Should understand the uncertainty & assess the impacts

(Source: Gang W., Wang S., Shan K. & Gao D., 2015. Impacts of cooling load calculation uncertainties on the design optimization of building cooling systems, *Energy and Buildings*, 94: 1-9.)

Outdoor Design Conditions

- They are used to calculate design space loads
- Climatic design information
  - General info: e.g. latitude, longitude, altitude, atmospheric pressure
  - Outdoor design conditions include
    - Derived from statistical analysis of weather data
    - Typical data can be found in handbooks/databooks, such as ASHRAE Fundamentals Handbook

Outdoor Design Conditions

- Climatic design info from ASHRAE
  - Previous data & method (before 1997)
    - For Summer (Jun to Sep) & Winter (Dec, Jan, Feb)
    - Based on 1%, 2.5% & 5% nos. hours of occurrence
  - New method (ASHRAE Fundamentals 2001+):
    - Based on <u>annual</u> percentiles and cumulative frequency of occurrence, e.g. 0.4%, 1%, 2% (of whole year)
    - More info on coincident conditions
    - Findings obtained from ASHRAE research projects
      - Data can be found on a relevant CD-ROM

Outdoor Design Conditions

- Climatic design conditions (ASHRAE, 2009):
  - Annual heating & humidif. design conditions
    - Coldest month
    - Heating dry-bulb (DB) temp.
    - Humidification dew point (DP)/ mean coincident dry-bulb temp. (MCDB) and humidity ratio (HR)
    - Coldest month wind speed (WS)/mean coincident dry-bulb temp. (MCDB)
    - Mean coincident wind speed (MCWS) & prevailing coincident wind direction (PCWD) to 99.6% DB

(Latest information from ASHRAE Handbook Fundamentals 2009)

Outdoor Design Conditions

- Climatic design conditions (ASHRAE, 2009):
  - Cooling and dehumidification design conditions
    - Hottest month and DB range
    - Cooling DB/MCWB: Dry-bulb temp. (DB) + Mean coincident wet-bulb temp. (MCWB)
    - Evaporation WB/MCDB: Web-bulb temp. (WB) + Mean coincident dry-bulb temp. (MCDB)
    - MCWS/PCWD to 0.4% DB
    - Dehumidification DP/MCDB and HR: Dew-point temp. (DP) + MDB + Humidity ratio (HR)
    - Enthalpy/MCDB

Do you know when to use each of them?

Outdoor Design Conditions

- Climatic design conditions (ASHRAE, 2009):
  - Extreme annual design conditions
  - Monthly climatic design conditions
    - Temperature, degree-days and degree-hours
    - Monthly design DB and mean coincident WB
    - Monthly design WB and mean coincident DB
    - Mean daily temperature range
    - Clear sky solar irradiance

Outdoor Design Conditions

- Other sources of climatic info:
  - Joint frequency tables of psychrometric conditions
    - Annual, monthly and hourly data
  - Degree-days (cooling/heating) & climatic normals
    - To classify climate characteristics
  - Typical year data sets
    - For energy calculations & analysis
    - Such as 1 year = 365 days x 24 hour = 8,760 hours

Outdoor Design Conditions

- Design cooling load calculations are typically performed first for annual design conditions
  - A **design day** with a statistically high peak temperature. This peak day is assumed to occur in the month with the highest mean dry-bulb temperature. The month information is used to determine the incident solar radiation, assuming clear-sky conditions
    - The mean coincident wind speed and direction corresponding to the design condition may be used to help estimate infiltration

Recommended Outdoor Design Conditions for Hong Kong

Location	Hong Kong (latitude 22° 18′ N, longitude 114° 10′ E, elevation 33 m)			
Weather station	Royal Observatory Hong Kong			
Summer months	June to September (four hottest months), total 2928 hours			
Winter months	December, January & February (three coldest months), total 2160 hours			
Design temperatures:	For comfort HVAC (based on summer 2.5% or annualised 1% and winter 97.5% or annualised 99.3%)		For critical processes (based on summer 1% or annualised 0.4% and winter 99% or annualised 99.6%)	
	Summer	Winter	Summer	Winter
DDB / CWB	32.0 ^oC / 26.9 ^oC	9.5 ^oC / 6.7 ^oC	32.6 ^oC / 27.0 ^oC	8.2 ^oC / 6.0 ^oC
CDB / DWB	31.0 ^oC / 27.5 ^oC	10.4 ^oC / 6.2 ^oC	31.3 ^oC / 27.8 ^oC	9.1 ^oC / 5.0 ^oC

Note:
1. DDB is the design dry-bulb and CWB is the coincident wet-bulb temperature with it; DWB is the design wet-bulb and CDB is the coincident dry-bulb with it.
2. The design temperatures and daily ranges were determined based on hourly data for the 35-year period from 1960 to 1994; extreme temperatures were determined based on extreme values between 1884-1939 and 1947-1994.

(Source: Research findings from Dr. Sam C M Hui)

Recommended Outdoor Design Conditions for Hong Kong (cont'd)

Extreme temperatures:	Hottest month: July mean DBT = 28.6 ^{o}C absolute max. DBT = 36.1 ^{o}C mean daily max. DBT = 25.7 ^{o}C		Coldest month: January mean DBT = 15.7 ^{o}C absolute min. DBT = 0.0 ^{o}C mean daily min. DBT = 20.9 ^{o}C	
Diurnal range:	Summer	Winter	Whole year	
- Mean DBT	28.2	16.4	22.8	
- Daily range	4.95	5.01	5.0	
Wind data:	Summer	Winter	Whole year	
- Wind direction	090 (East)	070 (N 70° E)	080 (N 80° E)	
- Wind speed	5.7 m/s	6.8 m/s	6.3 m/s	

Note: 3. Wind data are the prevailing wind data based on the weather summary for the 30-year period 1960-1990. Wind direction is the prevailing wind direction in degrees clockwise from north and the wind speed is the mean prevailing wind speed.

(Source: Research findings from Dr. Sam C M Hui)

ASHRAE outdoor design conditions for Hong Kong and Macau

Station	Lat	Long	Elev	Heating DB		Cooling DB/MCWB 0.4%		Cooling DB/MCWB 1%		Cooling DB/MCWB 2%		Evaporation WB/MCDB 0.4%		Evaporation WB/MCDB 1%	
Hong Kong															
HONG KONG INTL	22.309N	113.915E	9	8.8	10.1	34.0	26.5	33.2	26.3	32.8	26.2	27.7	31.1	27.3	30.8
HONG KONG OBSERVATORY	22.300N	114.167E	62	9.6	10.9	32.2	26.5	31.7	26.4	31.2	26.3	27.4	30.5	27.1	30.1

Station	Lat	Long	Elev	Dehumidification DP/HR/MCDB 0.4% DP / HR / MCDB			Dehumidification DP/HR/MCDB 1% DP / HR / MCDB			Extreme Annual WS 1%	2.5%	5%	Heat./Cool. Degree-Days HDD / CDD 18.3	
Hong Kong										*2 sites, 4 more on CD-ROM*				
HONG KONG INTL	22.309N	113.915E	9	26.9	22.5	30.2	26.2	21.6	29.8	10.5	9.3	8.3	180	2346
HONG KONG OBSERVATORY	22.300N	114.167E	62	26.6	22.3	29.3	26.2	21.8	29.1	8.6	7.4	6.5	237	1976

Station	Lat	Long	Elev	Heating DB 99.6%	Heating DB 99%	Cooling DB/MCWB 0.4% DB / MCWB		Cooling DB/MCWB 1% DB / MCWB		Cooling DB/MCWB 2% DB / MCWB		Evaporation WB/MCDB 0.4% WB / MCDB		Evaporation WB/MCDB 1% WB / MCDB	
Macao															
MACAU INTL	22.150N	113.592E	6	7.4	9.0	32.9	27.0	32.1	26.9	31.2	26.8	28.2	30.7	27.8	30.2

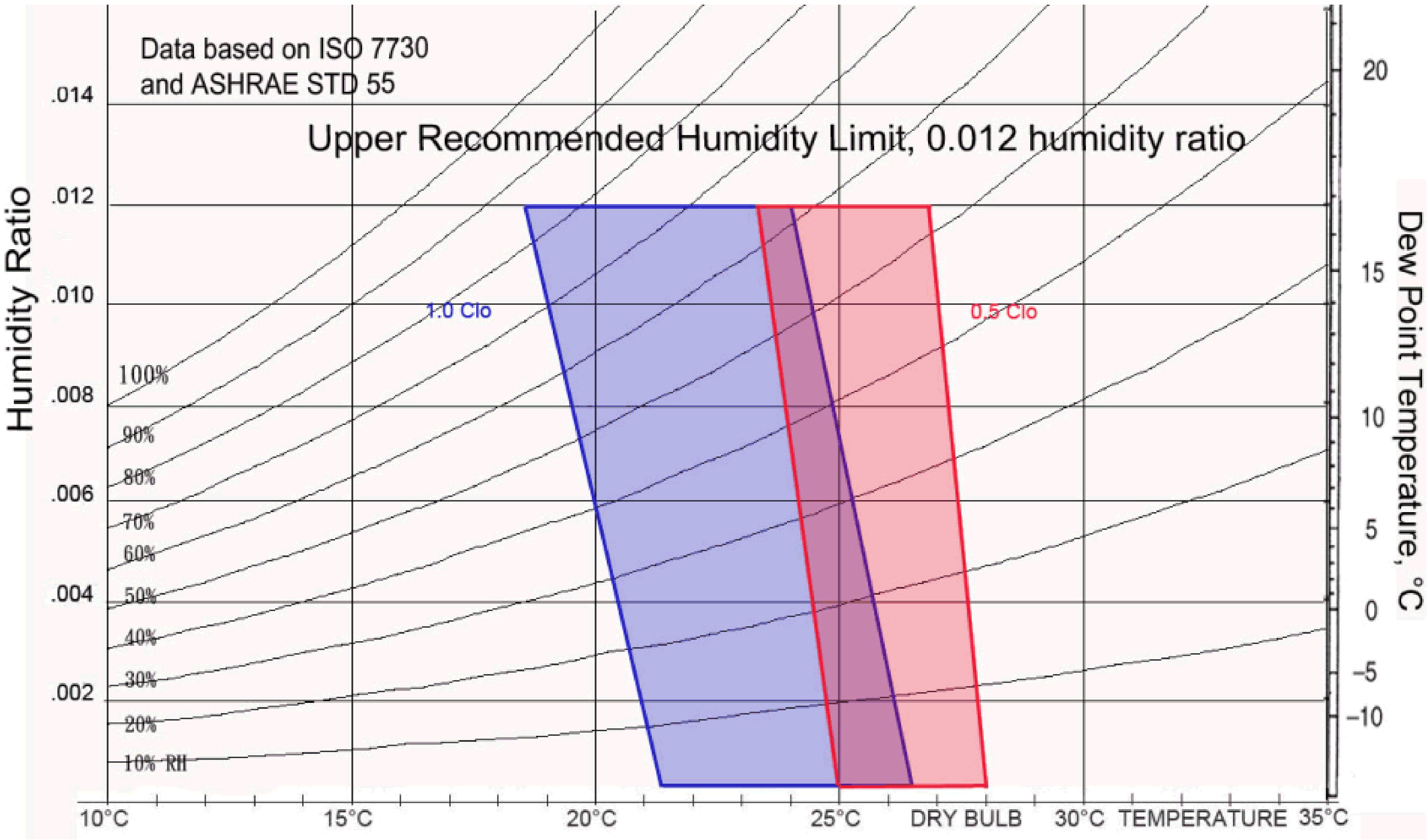
Station	Lat	Long	Elev	Dehumidification DP/HR/MCDB 0.4% DP / HR / MCDB			Dehumidification DP/HR/MCDB 1% DP / HR / MCDB			Extreme Annual WS 1%	2.5%	5%	Heat./Cool. Degree-Days HDD / CDD 18.3	
Macao										*1 site, 0 more on CD-ROM*				
MACAU INTL	22.150N	113.592E	6	27.2	23.1	29.6	27.1	22.9	29.5	11.2	9.9	8.9	282	2014

(Source: ASHRAE Handbook Fundamentals 2017)

Indoor Design Conditions

- Basic design parameters: (for thermal comfort)
  - Air temp. & air movement
    - Typical: summer 24-26 ^oC; winter 21-23 ^oC
    - Air velocity: summer < 0.25 m/s; winter < 0.15 m/s
  - Relative humidity
    - Summer: 40-50% (preferred), 30-65 (tolerable)
    - Winter: 25-30% (with humidifier); not specified (w/o humidifier)
  - See also ASHRAE Standard 55
    - ASHRAE comfort zone

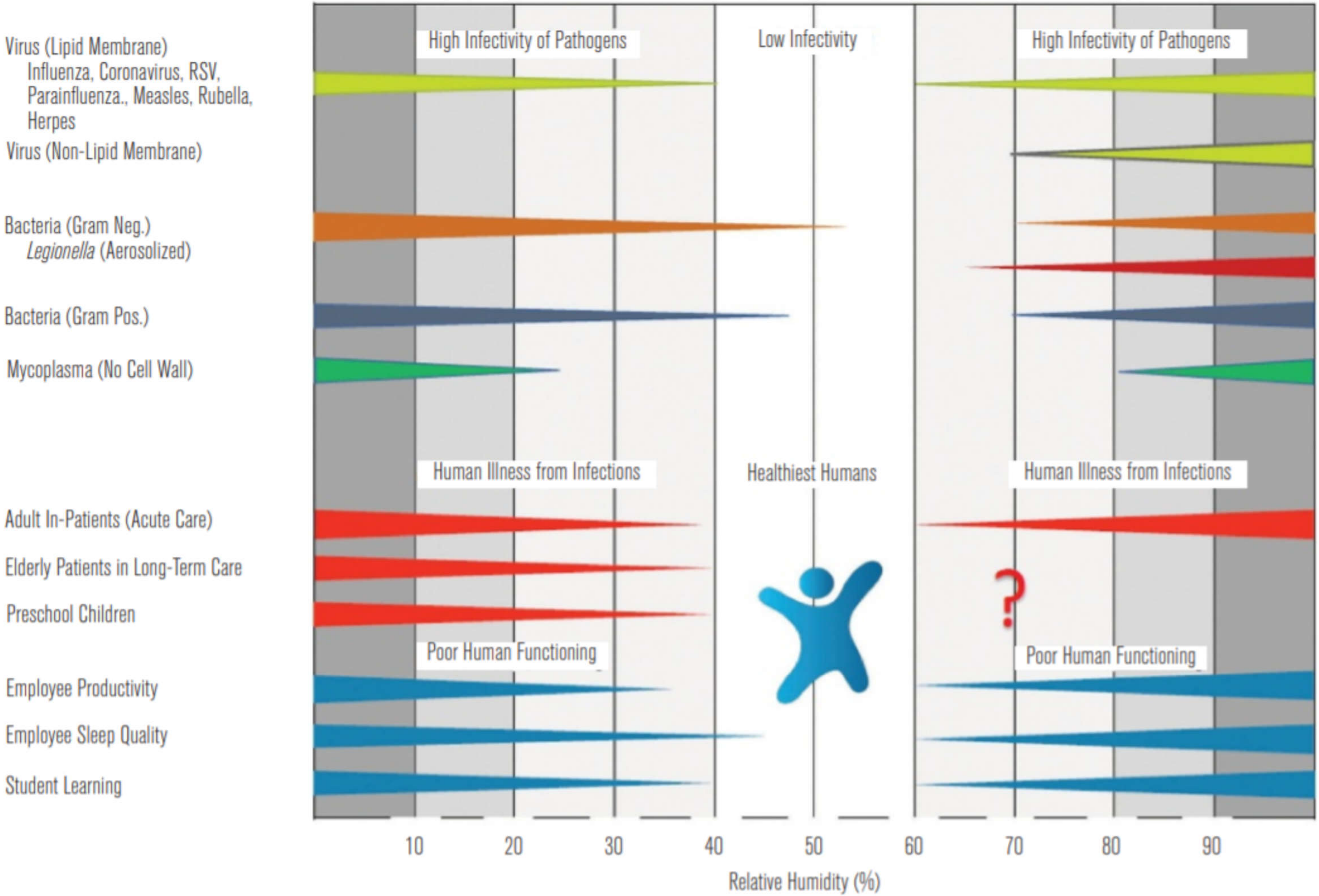
ASHRAE Comfort Zones
(based on 2004 version of ASHRAE Standard 55)



Indoor Design Conditions

- Indoor air quality: (for health & well-being)
  - Air contaminants
    - e.g. particulates, VOC, radon, bioeffluents
  - Outdoor ventilation rate provided
    - ASHRAE Standard 62.1
  - Air cleanliness (e.g. for processing), air movement
- Other design parameters:
  - Sound level (noise criteria)
  - Pressure differential between the space & surroundings (e.g. +ve to prevent infiltration)

Relative humidity of 40% to 60% is optimal for human health



(Source: Taylor, S., Scofield, C. M. & Graef, P. T., 2020. Improving IEQ to reduce transmission of airborne pathogens in cold climates, *ASHRAE Journal*, 62 (9) 30-47.)

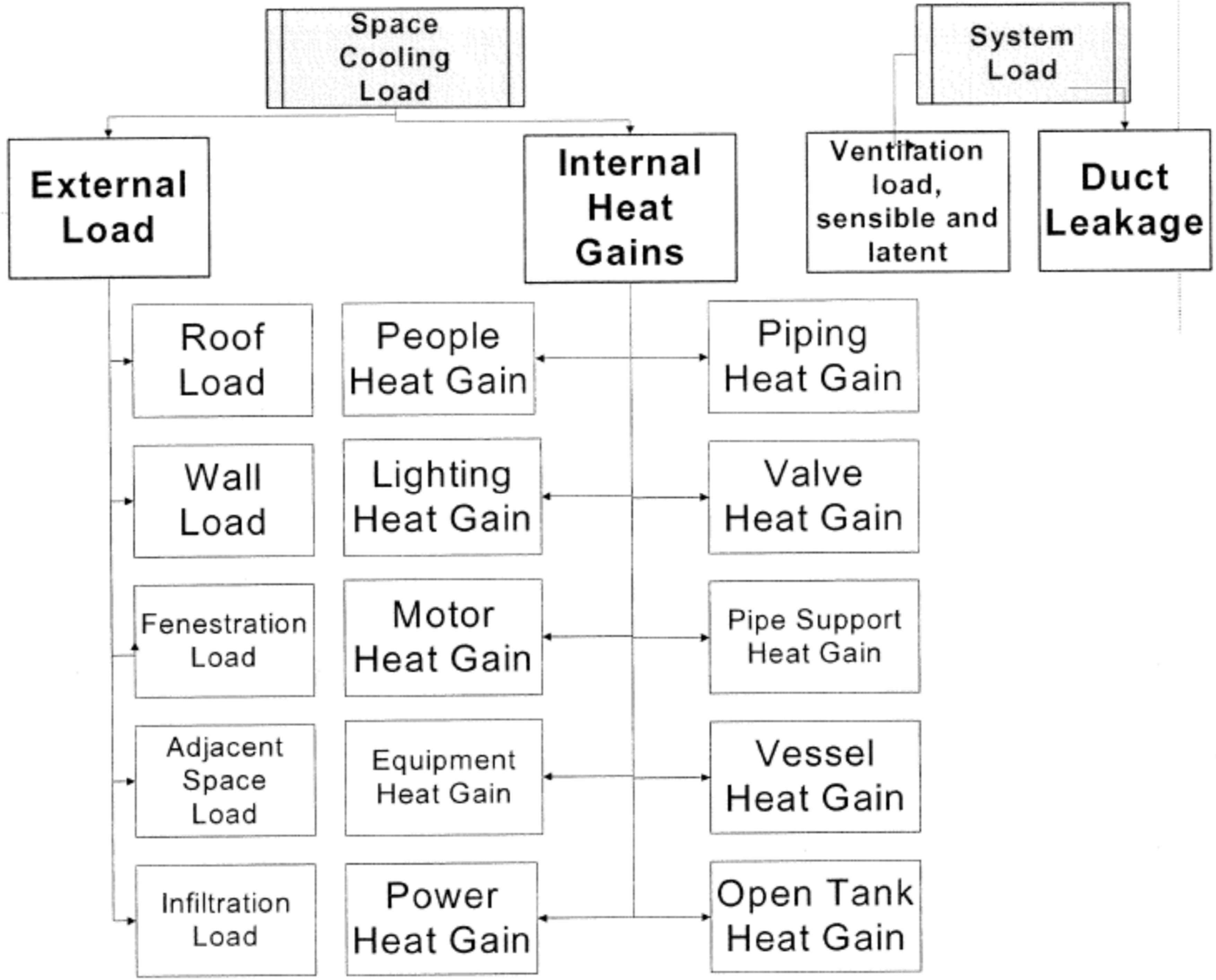
Type of area	Recommended NC or RC range (dB)
Hotel guest rooms	30–35
Office	
Private	30–35
Conference	25–30
Open	30–35
Computer equipment	40–45
Hospital, private	25–30
Churches	25–30
Movie theaters	30–35

(NC = noise critera; RC = room criteria)

* Remark: buildings in HK often have higher NC, say add 5-10 dB (more noisy).

(Source: ASHRAE Handbook Fundamentals 2005)

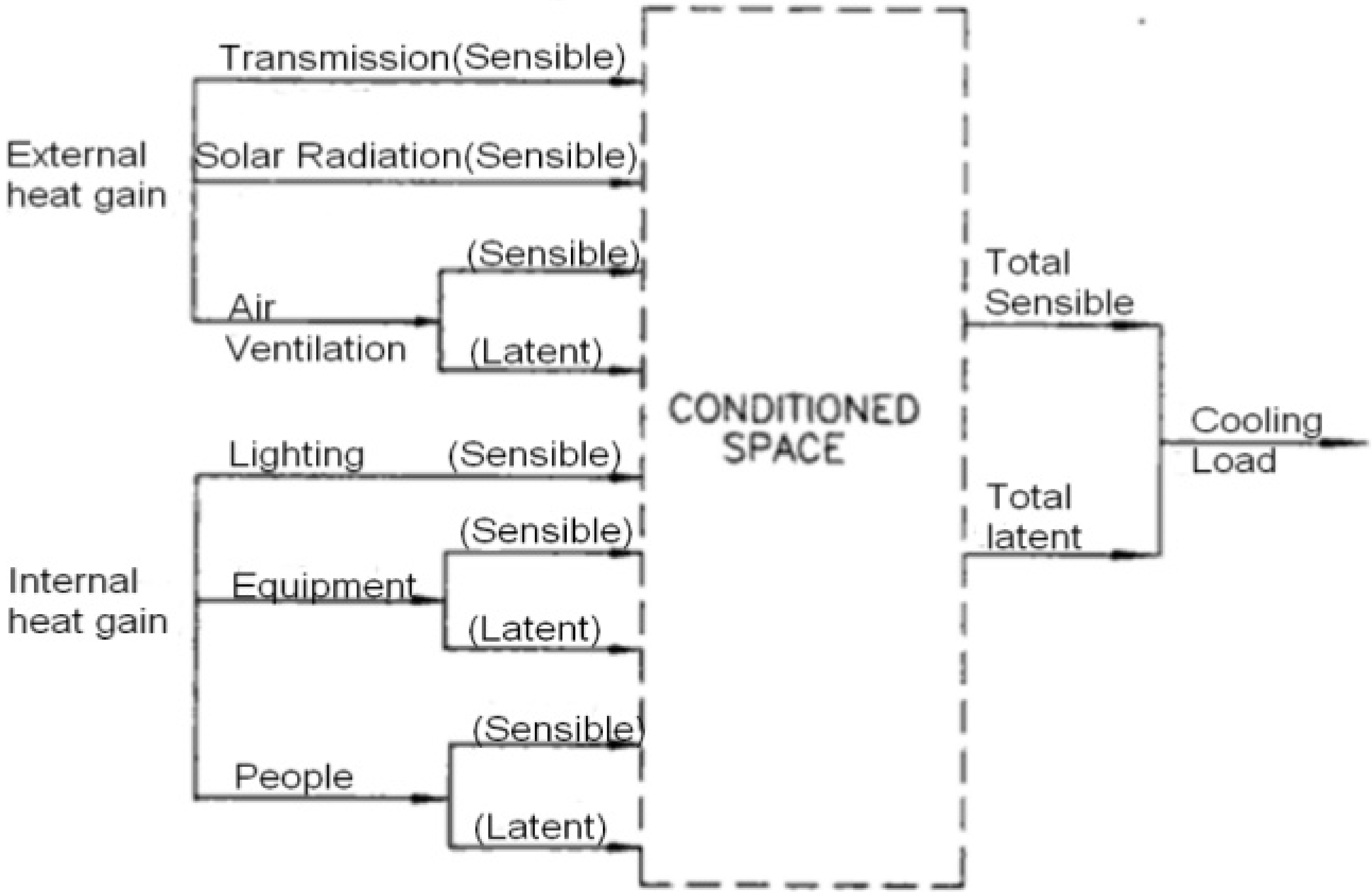
Inputs for cooling load calculations



Cooling Load Components

- <u>External</u>
  - 1. Heat gain through exterior walls and roofs
  - 2. Solar heat gain through fenestrations (windows)
  - 3. Conductive heat gain through fenestrations
  - 4. Heat gain through partitions & interior doors
- <u>Internal</u>
  - 1. People
  - 2. Electric lights
  - 3. Equipment and appliances

Components of heat gains and cooling load

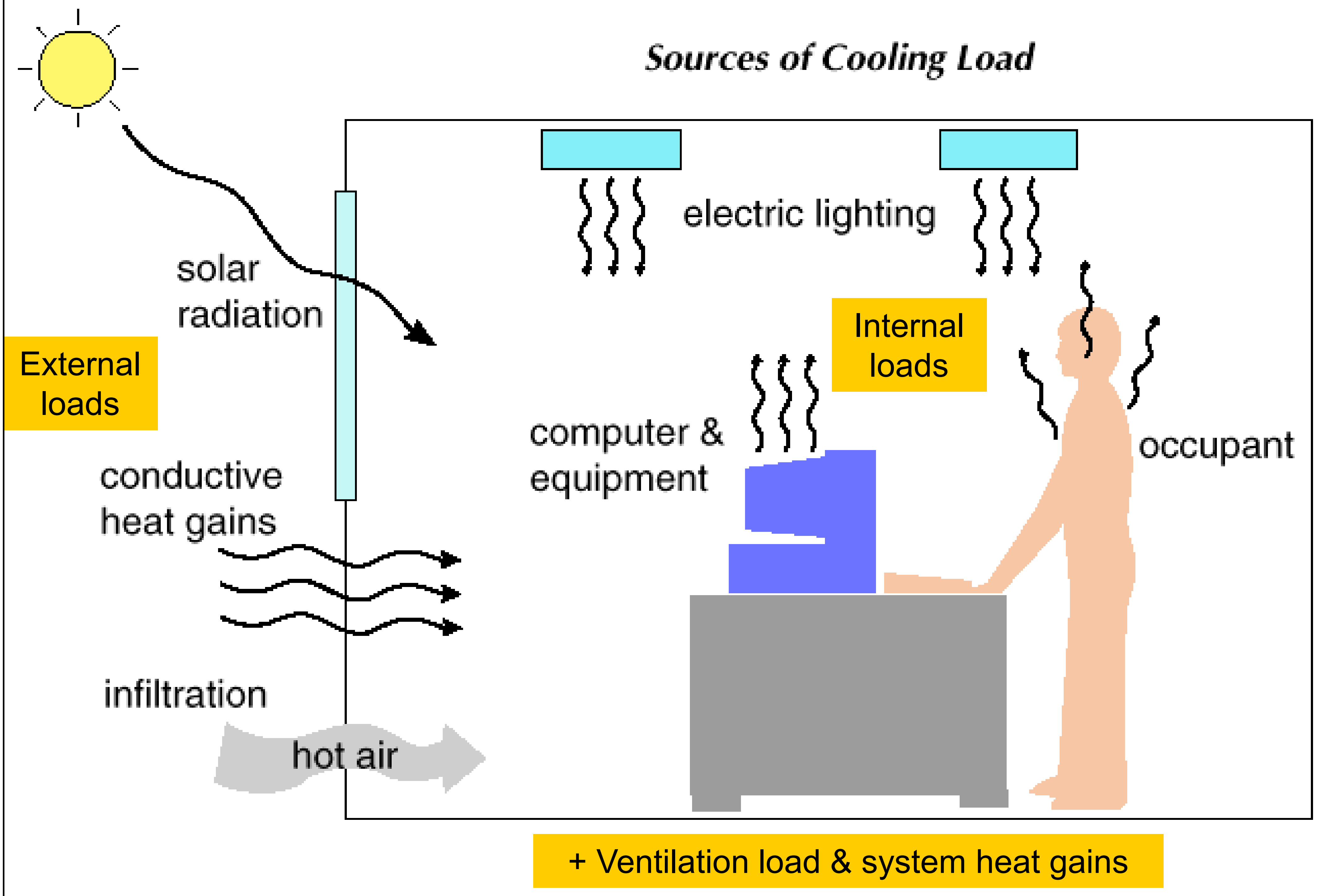


(Source: http://coolingchiwayake.blogspot.com/2017/03/cooling-load.html)

Cooling Load Components

- Infiltration
  - Air leakage and moisture migration, e.g. flow of outdoor air into a building through cracks, unintentional openings, normal use of exterior doors for entrance
- System (HVAC)
  - Outdoor ventilation air
  - System heat gain: duct leakage & heat gain, reheat, fan & pump energy, energy recovery

Components of building cooling load



Cooling Load Components

- Total cooling load
  - Sensible cooling load + Latent cooling load
  - = Σ(sensible items) + Σ(latent items)
- Which components have latent loads? Which only have sensible load? Why?
- Three major parts for load calculation
  - External cooling load
  - Internal cooling load
  - Ventilation and infiltration air

Table 1 Representative Rates at Which Heat and Moisture Are Given Off by Human Beings in Different States of Activity

		Total Heat, W				% Sensible Heat that is Radiant[b]	
Degree of Activity		**Adult Male**	**Adjusted, M/F[a]**	**Sensible Heat, W**	**Latent Heat, W**	**Low *V***	**High *V***
Seated at theater	Theater, matinee	115	95	65	30		
Seated at theater, night	Theater, night	115	105	70	35	60	27
Seated, very light work	Offices, hotels, apartments	130	115	70	45		
Moderately active office work	Offices, hotels, apartments	140	130	75	55		
Standing, light work; walking	Department store; retail store	160	130	75	55	58	38
Walking, standing	Drug store, bank	160	145	75	70		
Sedentary work	Restaurant[c]	145	160	80	80		
Light bench work	Factory	235	220	80	140		
Moderate dancing	Dance hall	265	250	90	160	49	35
Walking 4.8 km/h; light machine work	Factory	295	295	110	185		
Bowling[d]	Bowling alley	440	425	170	255		
Heavy work	Factory	440	425	170	255	54	19
Heavy machine work; lifting	Factory	470	470	185	285		
Athletics	Gymnasium	585	525	210	315		

Notes:

1. Tabulated values are based on 24°C room dry-bulb temperature. For 27°C room dry bulb, the total heat remains the same, but the sensible heat values should be decreased by approximately 20%, and the latent heat values increased accordingly.
2. Also refer to Table 4, Chapter 8, for additional rates of metabolic heat generation.
3. All values are rounded to nearest 5 W.

[a] Adjusted heat gain is based on normal percentage of men, women, and children for the application listed, with the postulate that the gain from an adult female is 85% of that for an adult male, and that the gain from a child is 75% of that for an adult male.

[b] Values approximated from data in Table 6, Chapter 8, where is air velocity with limits shown in that table.

[c] Adjusted heat gain includes 18 W for food per individual (9 W sensible and 9 W latent).

[d] Figure one person per alley actually bowling, and all others as sitting (117 W) or standing or walking slowly (231 W).

(Source: ASHRAE Handbook Fundamentals 2005)

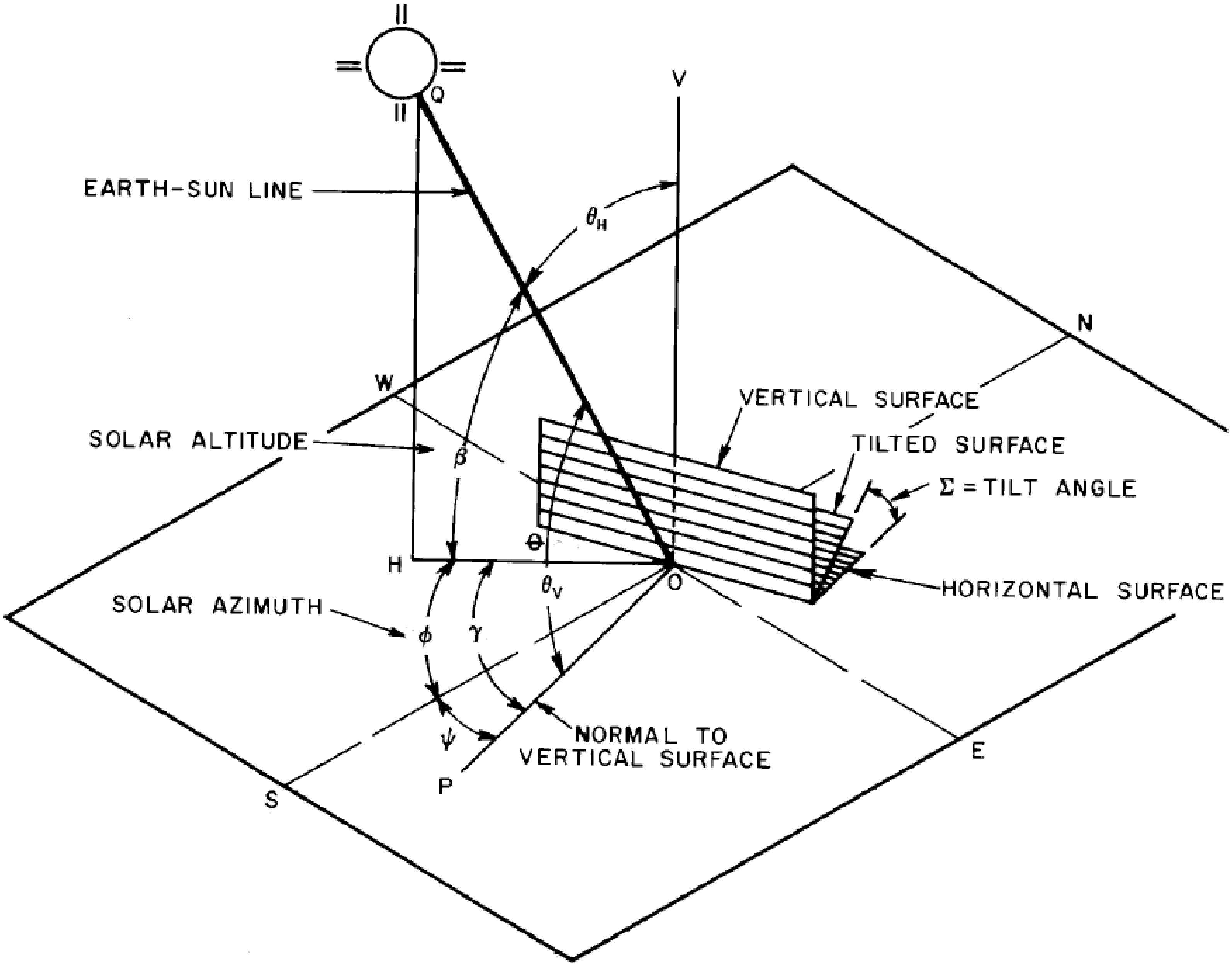


Fig. 10 Solar Angles for Vertical and Horizontal Surfaces

(Source: ASHRAE Handbook Fundamentals 2005)

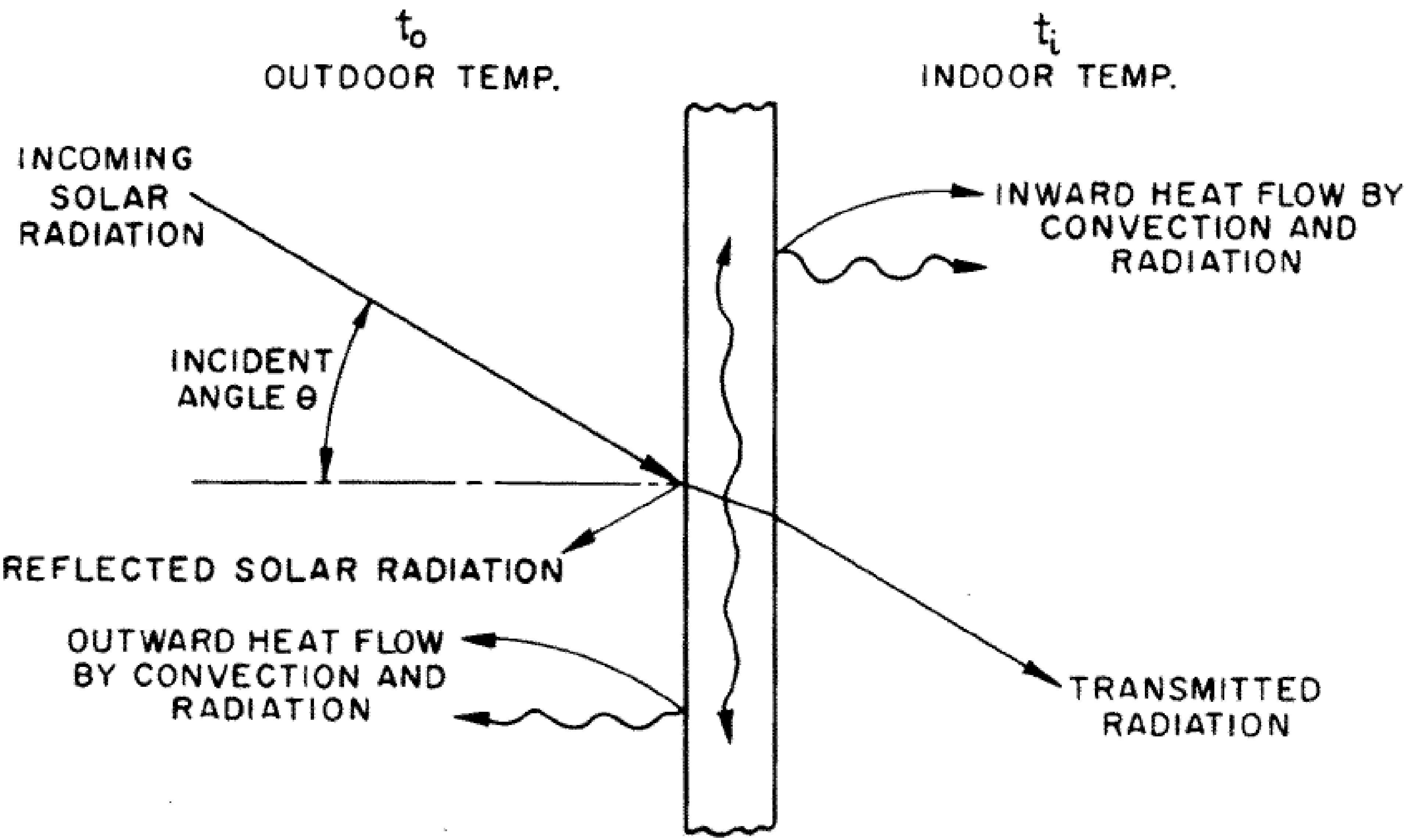
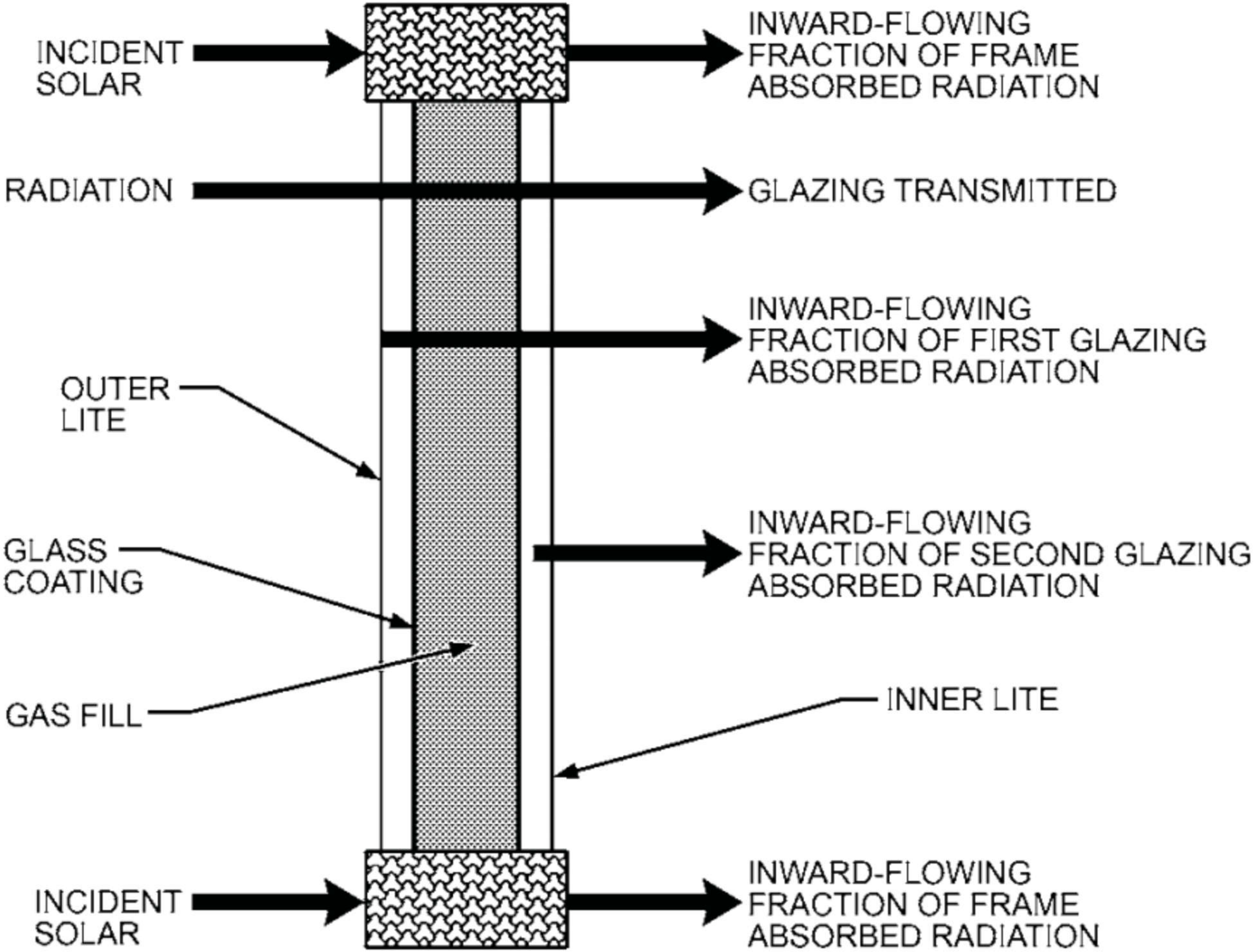


Fig. 26 Instantaneous Heat Balance for Sunlit Glazing Material

(Source: ASHRAE Handbook Fundamentals 2005)

Components of solar radiant heat gain with double-pane fenestration, including both frame and glazing contributions



(Source: ASHRAE Handbook Fundamentals 20017)

Cooling Load Components

- Cooling load calculation method
  - Example: CLTD/SCL/CLF method
    - It is a one-step, simple calculation procedure developed by ASHRAE
    - CLTD = cooling load temperature difference
    - SCL = solar cooling load
    - CLF = cooling load factor
  - See ASHRAE Handbook Fundamentals for details
    - Tables for CLTD, SCL and CLF

(See also: Cooling load temperature difference calculation method - Wikipedia http://en.wikipedia.org/wiki/Cooling_load_temperature_difference_calculation_method; Heating, Cooling Loads and Energy Use http://www.iklimnet.com/expert_hvac/cooling_load.html)

Cooling Load Components

- External
  - Roofs, walls, and glass conduction
    - $q = U\,A$ (CLTD) U = U-value; A = area
  - Solar load through glass
    - $q = A$ (SC) (SCL) SC = shading coefficient
      - For unshaded area and shaded area
  - Partitions, ceilings, floors
    - $q = U\,A\,(t_{adjacent} - t_{inside})$

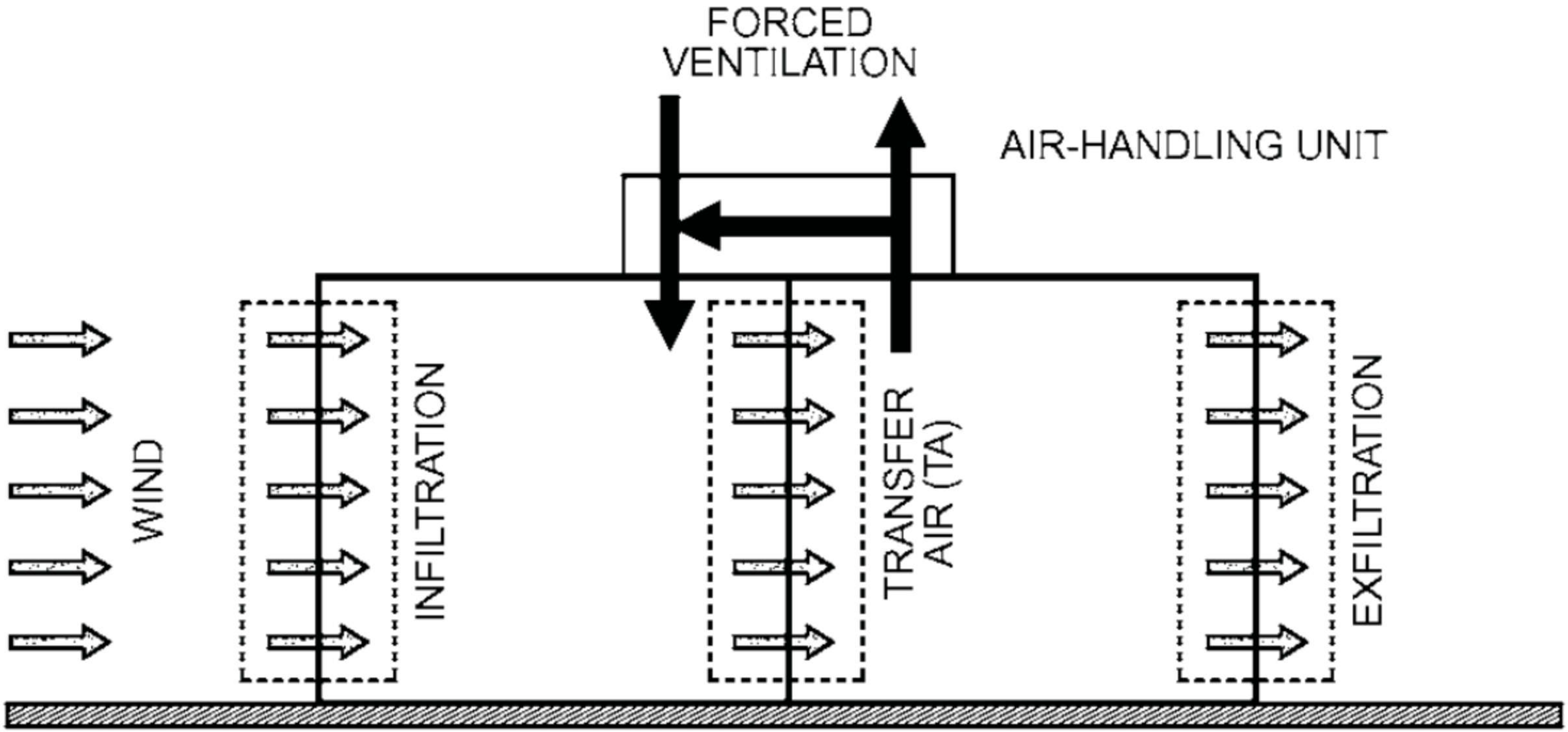
Cooling Load Components

- Internal
  - People
    - $q_{sensible} = N$ (Sensible heat gain) (CLF)
    - $q_{latent} = N$ (Latent heat gain)
  - Lights
    - q = Watt x F_{ul} x F_{sa} (CLF)
      - F_{ul} = lighting use factor; F_{sa} = special allowance factor
  - Appliances
    - $q_{sensible} = q_{input}$ x usage factors (CLF)
    - $q_{latent} = q_{input}$ x load factor (CLF)

Cooling Load Components

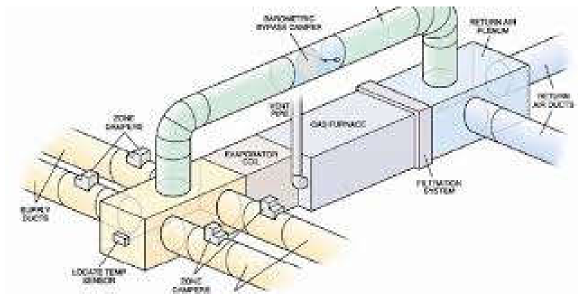
- Ventilation and infiltration air
  - $q_{sensible} = 1.23\ Q\ (t_{outside} - t_{inside})$
  - $q_{latent} = 3010\ Q\ (w_{outside} - w_{inside})$
  - $q_{total} = 1.2\ Q\ (h_{outside} - h_{inside})$
- System heat gain
  - Fan heat gain
  - Duct heat gain and leakage
  - Ceiling return air plenum

Two-space building with mechanical ventilation, infiltration, and exfiltration



(Source: ASHRAE Handbook Fundamentals 2017)

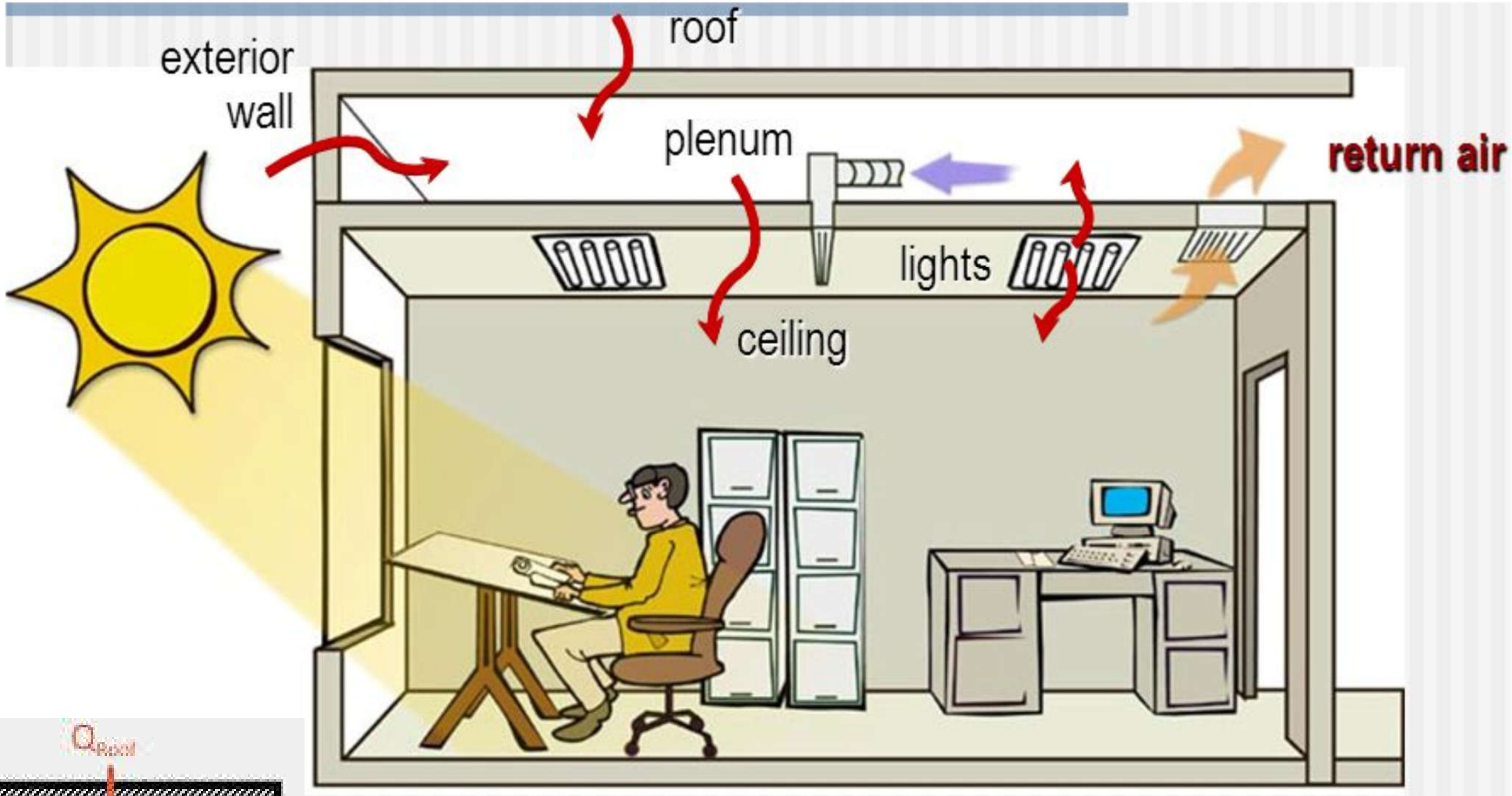
HVAC Design Issues

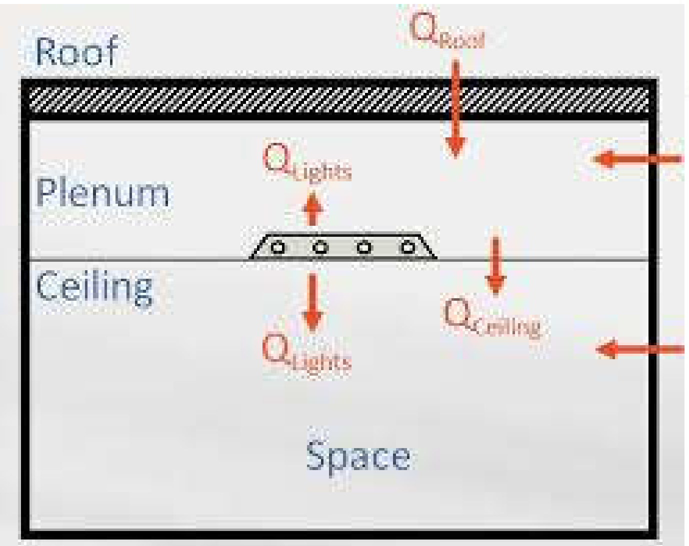


- Ceiling load and plenum space
  - Space between the structural ceiling and the dropped false ceiling or under a raised floor is typically considered plenum
  - The plenum/cavity space may provide a pathway for return air flow
  - Ceiling or plenum load = arises from heat enters the occupied space through the ceiling tiles
    - A result of the temperature difference between the plenum and occupied space

(See also: Plenum space - Wikipedia https://en.wikipedia.org/wiki/Plenum_space)

Heat transfer in an air-conditioned space with a ceiling plenum





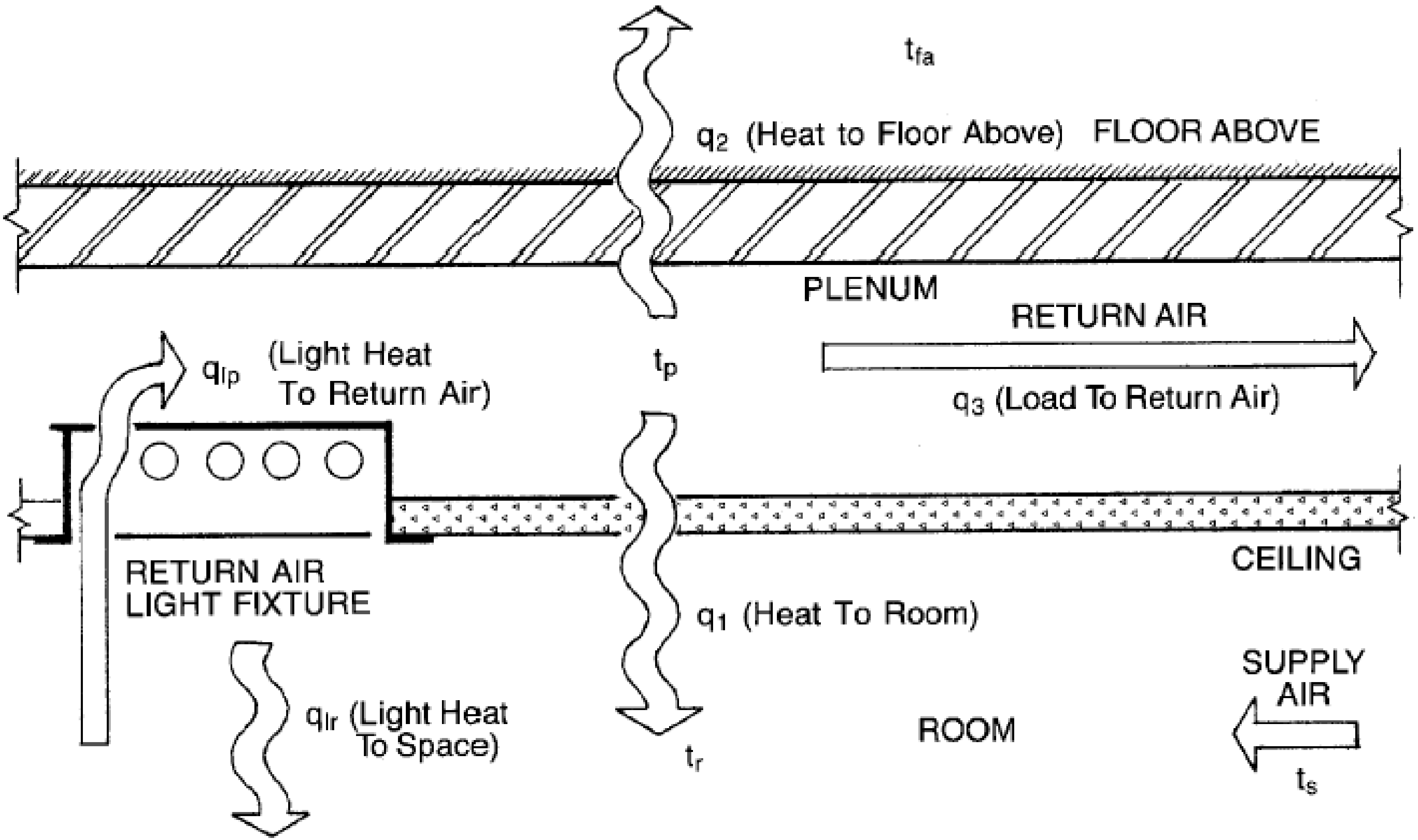
Heat gains affecting the plenum:

- Through the roof
- Through a portion of exterior wall
- Lighting systems

Return air may pick up heat from the plenum

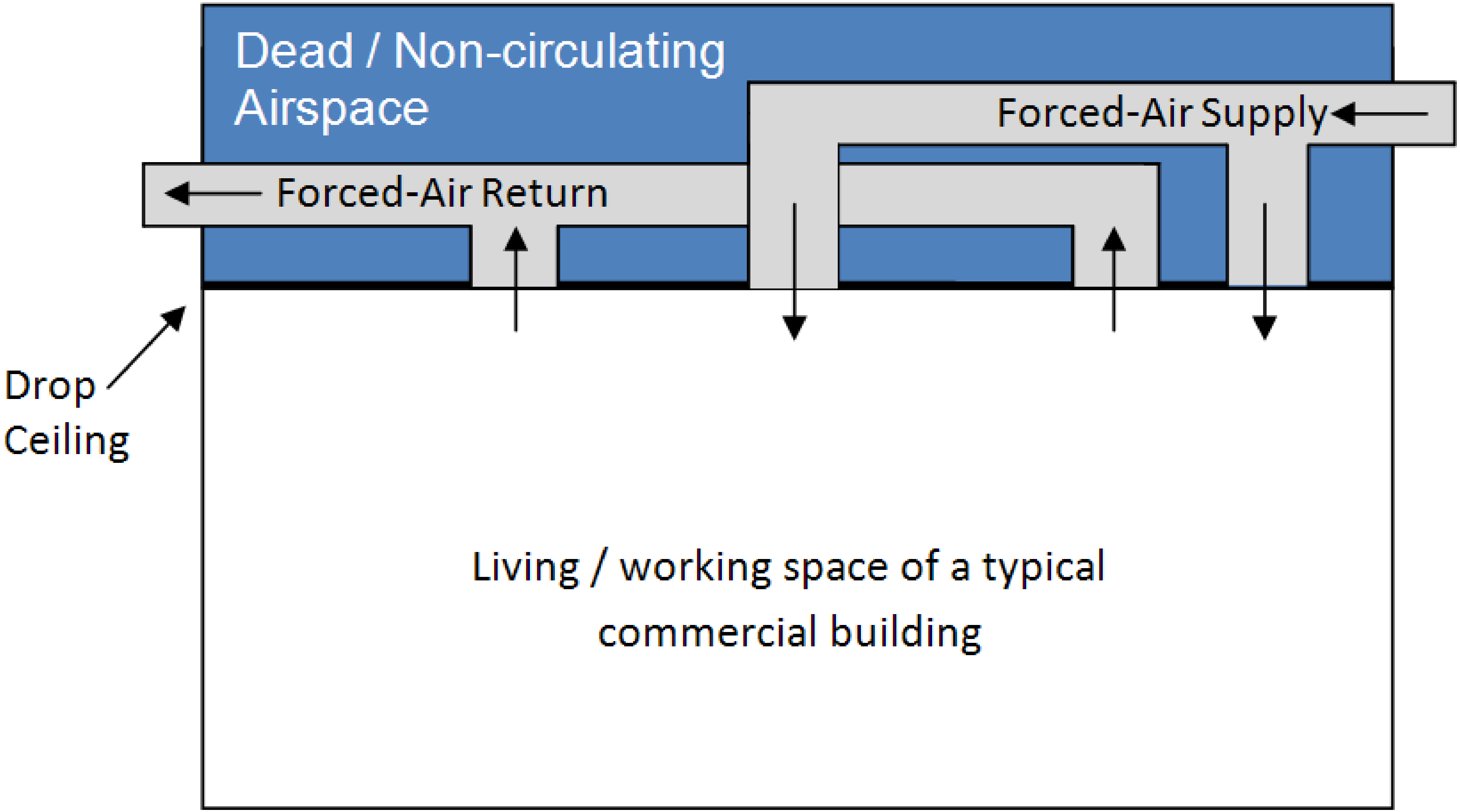
(Source: Trane)

Schematic diagram of typical return air plenum



(Source: ASHRAE Handbook Fundamentals 2005)

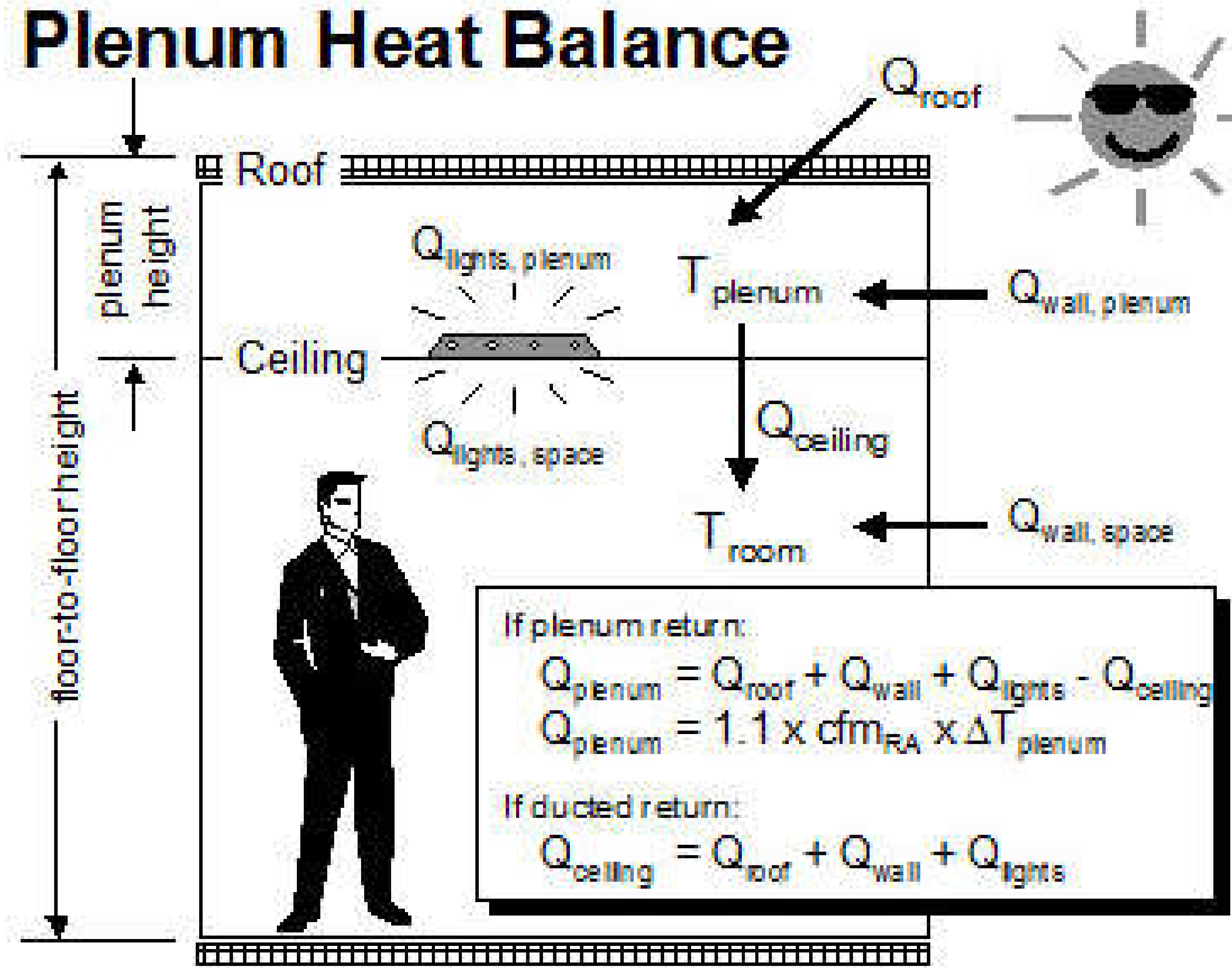
Ceiling load and plenum space



Vertical section through a commercial building without a plenum airspace. When both the supply and return ducts are constructed in this manner, it is possible to insulate the ducts and the dropped ceiling so that the upper airspace is not heated or cooled, increasing energy efficiency.

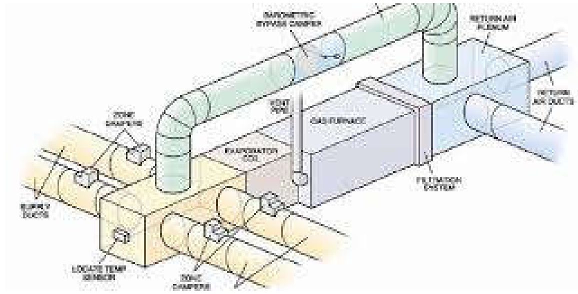
(Source: Plenum space - Wikipedia https://en.wikipedia.org/wiki/Plenum_space)

Ceiling load and plenum heat balance



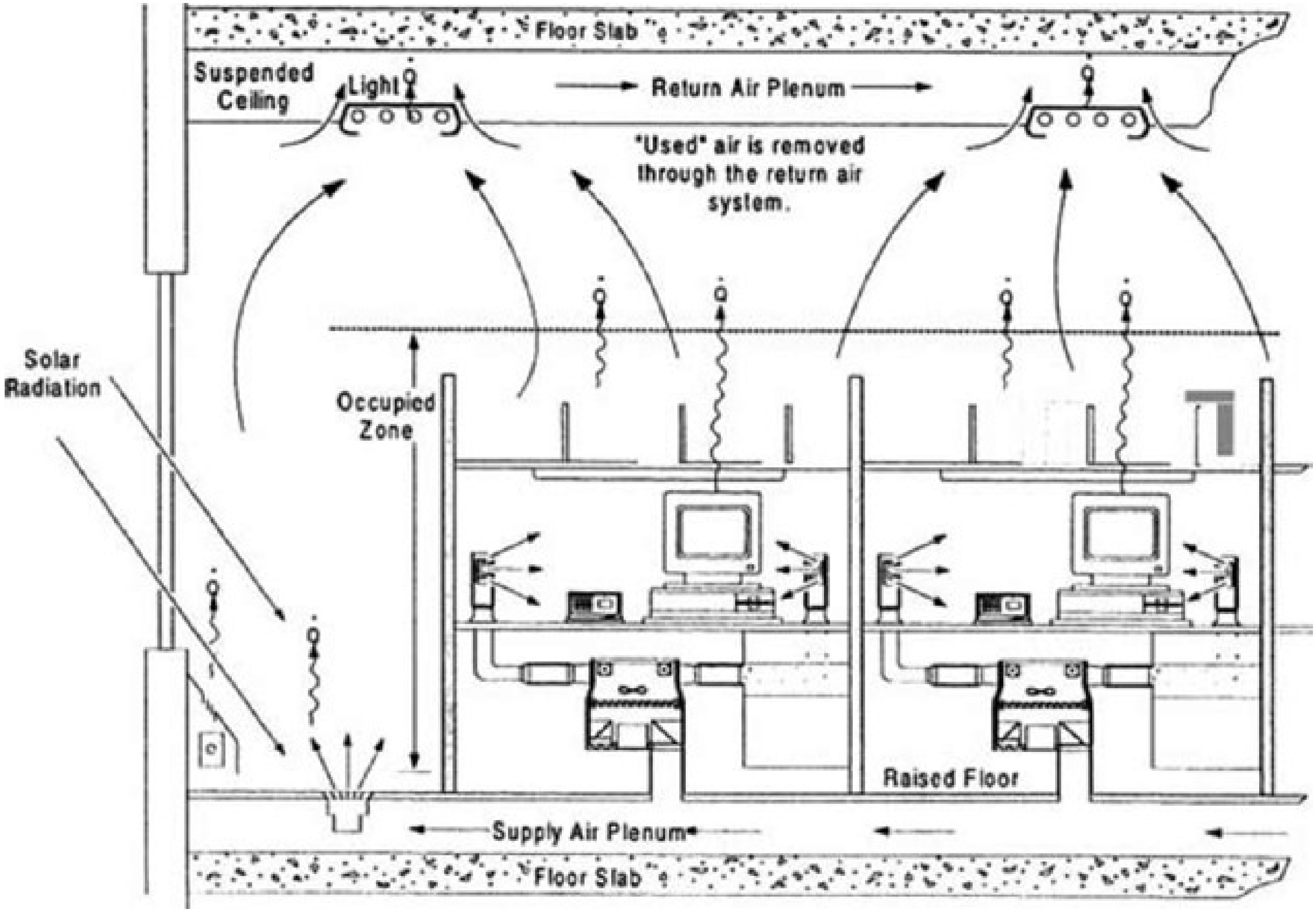
(Source: https://tranecds.custhelp.com/app/answers/detail/a_id/339/~/trace-700-ceiling-load-and-plenum-heat-balance/)

HVAC Design Issues



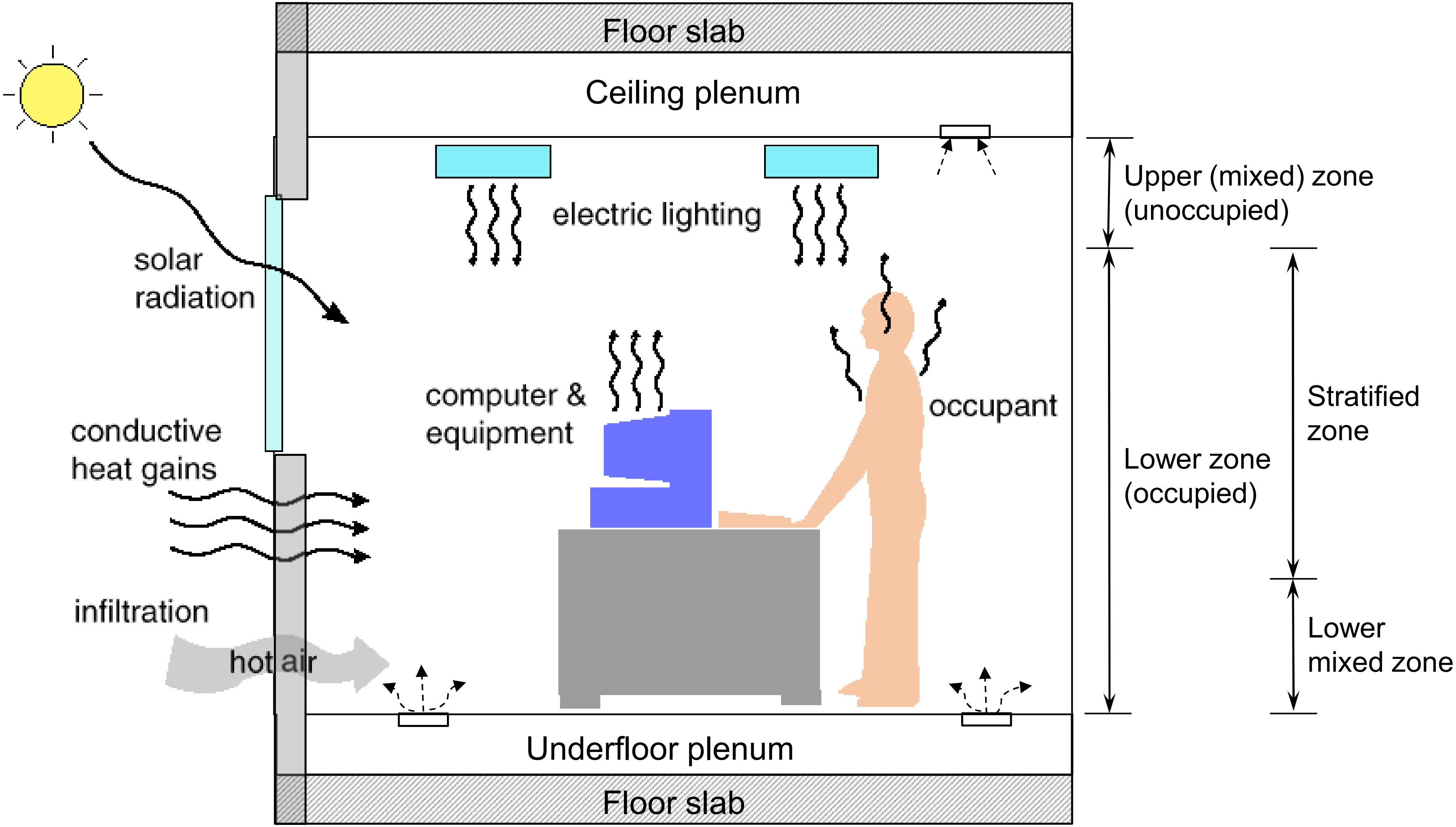
- Load calculations and energy analysis for new HVAC systems, such as
  - Underfloor air distribution (UFAD) systems
    - UFAD Cooling Load Design Tool (online)
      - http://www.cbe.berkeley.edu/ufad-designtool/online.htm
  - Radiant cooling systems (e.g. chilled ceiling)
    - Bauman, F., *et al.*, 2013. Cooling load calculations for radiant systems: Are they the same as traditional methods?, *ASHRAE Journal*, 55 (12): 20-27.
  - Variable refrigerant flow (VRF) systems

Heat gains and load calculation for underfloor air distribution system



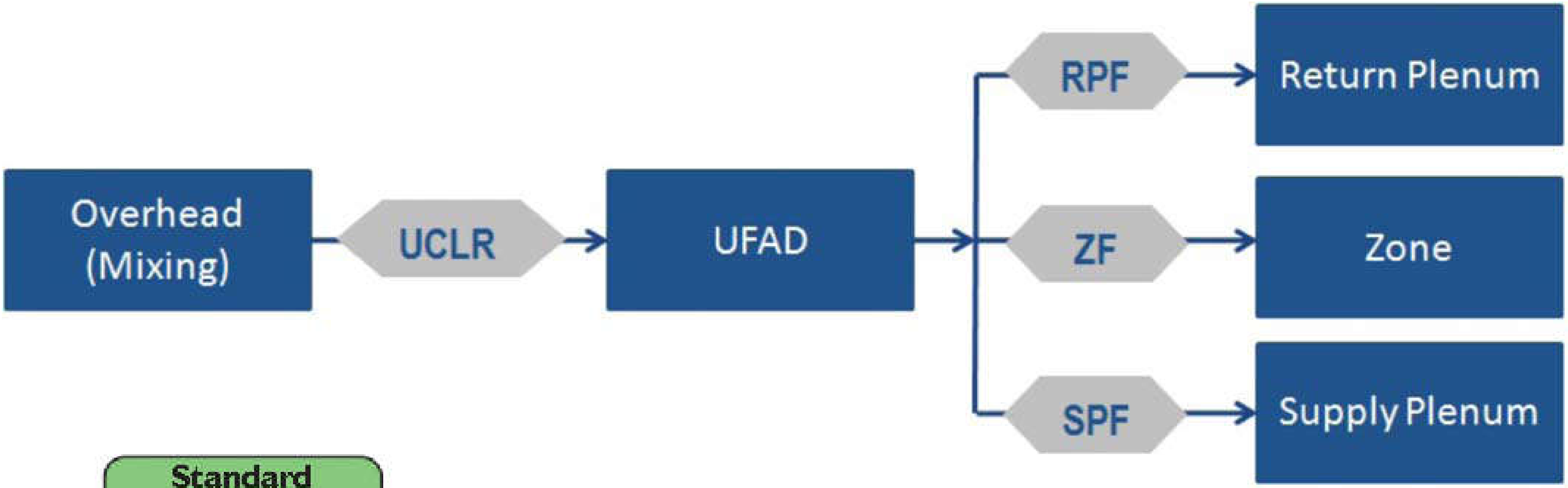
(Source: https://what-when-how.com/energy-engineering/underfloor-air-distribution-ufad-energy-engineering/)

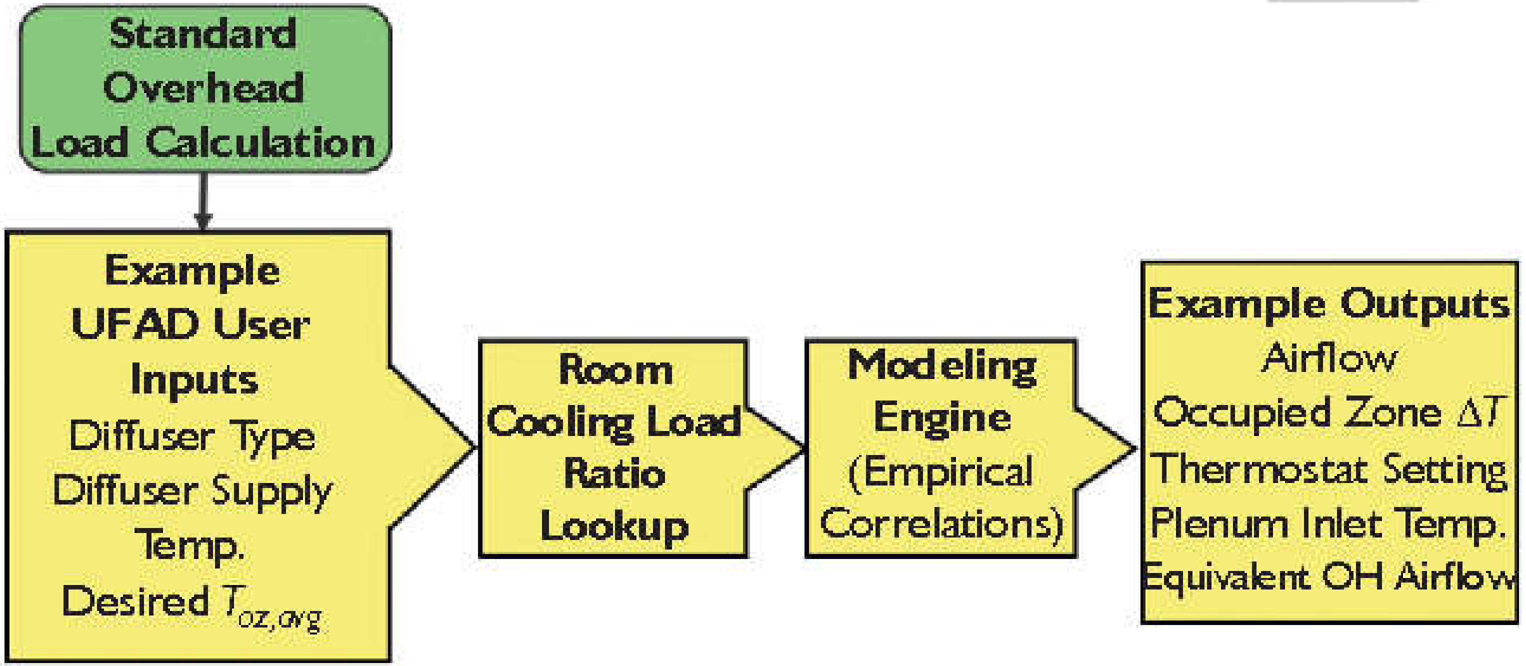
Cooling load calculation for underfloor air distribution (UFAD) system



(Source: Hui, S. C. M. and Zhou, Y. C., 2015. Analysis of cooling load calculations for underfloor air distribution systems, In Proc. of *the 13th Asia Pacific Conference on the Built Environment: Next Gen Technology to Make Green Building Sustainable*, 19-20 Nov 2015 (Thu-Fri), Hong Kong, 15 pp. [PDF])

Cooling load calculation for underfloor air distribution (UFAD) system



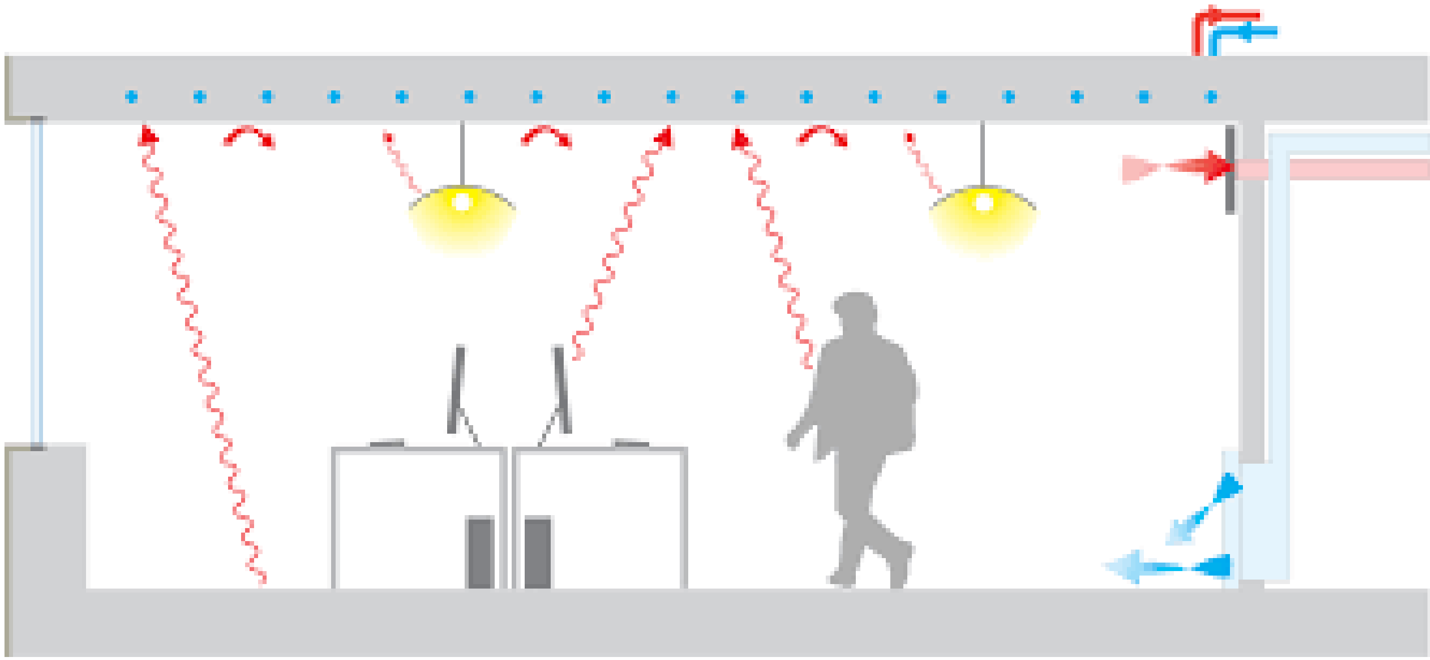


*See also UFAD Cooling Load Design Tool (online) http://www.cbe.berkeley.edu/ufad-designtool/online.htm

(Source: https://cbe.berkeley.edu/research/underfloor-air-distribution-ufad-cooling-load-design-tool/)

Overhead air distribution system and radiant ceiling cooling system

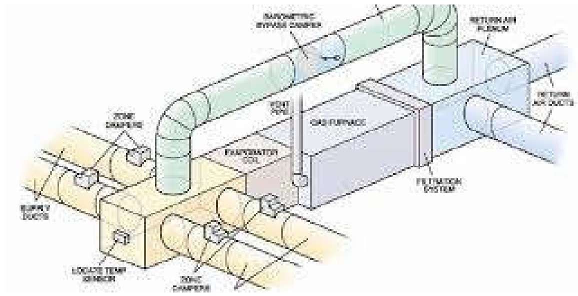
Overhead air distribution system



Radiant ceiling cooling system

(Source: Bauman F., Feng J. & Schiavon S., 2013. . Cooling load calculations for radiant systems: are they the same as traditional methods?, *ASHRAE Journal*, 55 (12) 20-27.)

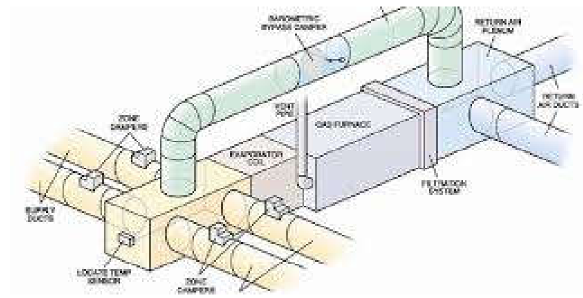
HVAC Design Issues



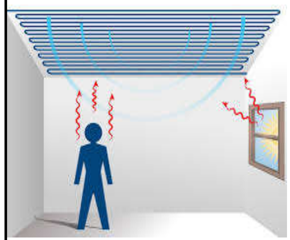
- <u>Cooling loads in air systems</u>

  - Convective heat gains are assumed to become a cooling load instantly
  - Radiative heat gains are absorbed by walls, floors, ceilings, and furnishings causing an increase in their temperature which will then transfer heat to the space air by convection
  - Conductive heat gains are converted to convective and radiative heat gains
    - If the space air temperature and humidity are kept constant then heat extraction rate and space cooling load are equal
  - The resulting cooling load through different air system types in the same built environment can be different

HVAC Design Issues

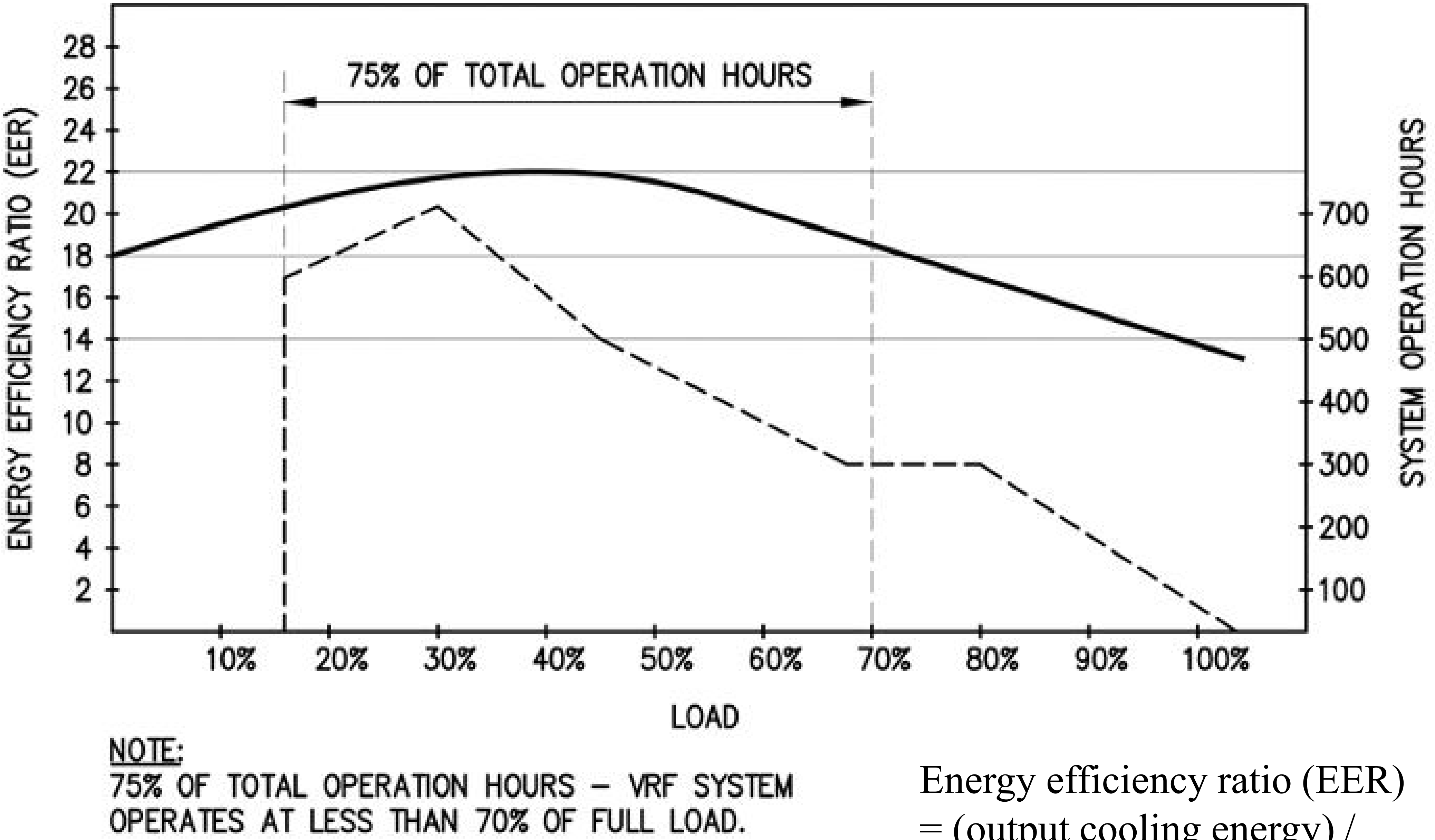


- <u>Cooling loads in radiant systems</u>



  - Not all convective heat gains become a cooling load instantly because radiant systems are not able to remove heat through convection causing air temperature to rise and increase the surface temperatures of non-active surfaces
    - Non-active surfaces then release heat through convection or radiate heat to an active cooling surface
  - Radiative heat gains are absorbed by active and non-active cooling surfaces. If absorbed by active surfaces then heat gains become an instant cooling load otherwise a temperature increase will occur in the non-active surface that will eventually cause heat transfer to the space by convection and radiation

Typical energy efficiency ratio (EER) of VRF systems



Energy efficiency ratio (EER)
= (output cooling energy) /
(input electrical energy)

(Source: http://www.csemag.com/single-article/back-to-basics-vrf-systems/)

Further Reading

- Cooling and Heating Load Estimation (TRG-TRC002-EN, April 2011), Trane Air Conditioning Clinic https://www.tranebelgium.com/files/book-doc/13/fr/13.5cbzdt11.pdf
- Bruning, S. F., 2012. Load calculation spreadsheets: Quick answers without relying on rules of thumb, *ASHRAE Journal*, 54 (1): 40-46. [PDF]
- HVAC Made Easy: A Guide to Heating & Cooling Load Estimation http://www.pdhonline.org/courses/m196/m196.htm
  - Course Content http://www.pdhonline.org/courses/m196/m196content.pdf

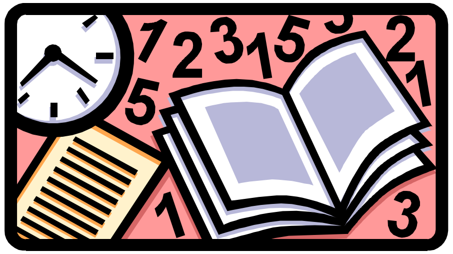
Further Reading

- Cooling Load Check Figures:
  - Cooling Load Check Figures http://www.iklimnet.com/expert_hvac/cooling_load_check_figures.html
  - Cooling Load Check Figures and CLTD Equations [PDF]
  - Cooling Load Check Figures (based on the AIRAH Handbook 3rd edition) [PDF]

Further Reading

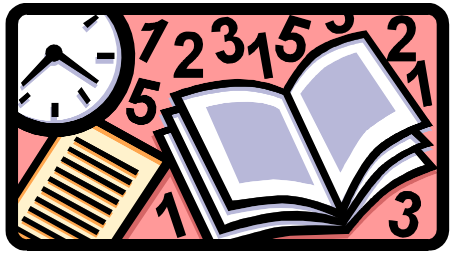
- Cooling load calculation methods -- examples:
  - Heating & Cooling Load Calculation Form - CLTD/CLF/SCL Method (IP units) [http://geokiss.com/wp-content/uploads/2018/07/TideLoadFeb17_1.xlsm]
  - Cooling load calculation of a single family house using CLTD/CLF method [PDF]
  - RTS cooling load calculations - input and results [JPG]
  - Cooling load components [JPG]

References



- ASHRAE, 2017. *ASHRAE Handbook Fundamentals 2017*, Chps. 14-18, American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc., Atlanta, GA. [ASHRAE Catalog: 697 A82 T4]
  - Chapter 14. Climatic Design Information
  - Chapter 15. Fenestration
  - Chapter 16. Ventilation and Infiltration
  - Chapter 17. Residential Cooling and Heating Load Calculations
  - Chapter 18. Nonresidential Cooling and Heating Load Calculations

References



- Pedersen, C. O., et al., 1998. *Cooling and Heating Load Calculation Principles*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA. [697 C77]
- Spitler, J. D., 2014. *Load Calculation Applications Manual*, 2nd ed., SI ed., American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA. [HKU ebook]