MEBS6004 Built Environment

http://ibse.hk/MEBS6004/

Building envelope design

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Contents

- Basic principles
- Design factors
- Response to local climate
- Ventilation strategy
- Building codes in HK

Basic principles

- The building is not just a shelter, or a barrier against unwanted influences (rain, wind, cold)
- The building envelope should be considered a selective filter to exclude the unwanted influences, but admit the desirable & useful ones, such as daylight, solar radiation in winter or natural ventilation
  - Building envelope affects the interior/indoor environment & determines the building aesthetics

Examples of building envelopes

(Source: https://www.architecturalrecord.com/articles/14896-best-building-envelopes-of-2020)

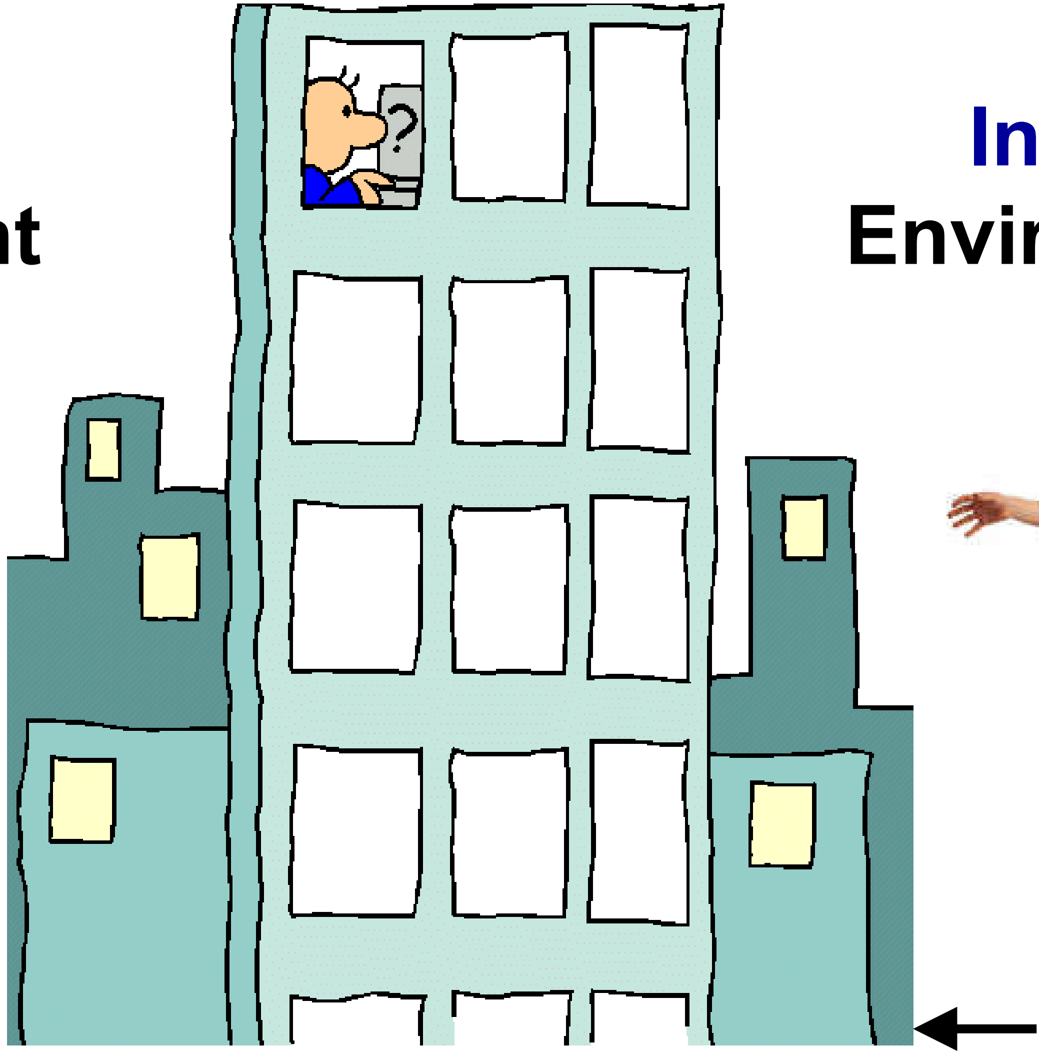
Basic principles

- A **building envelope** (or building enclosure) is the physical separator between the conditioned & unconditioned environment of a building
  - Respond to natural forces & human concerns
  - Provide protection by enclosure and by balancing internal and external environmental forces (including the resistance to air, water, heat, light, and noise transfer)
- Related terms: building façade, building skin

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

Shelter

Outdoor Environment

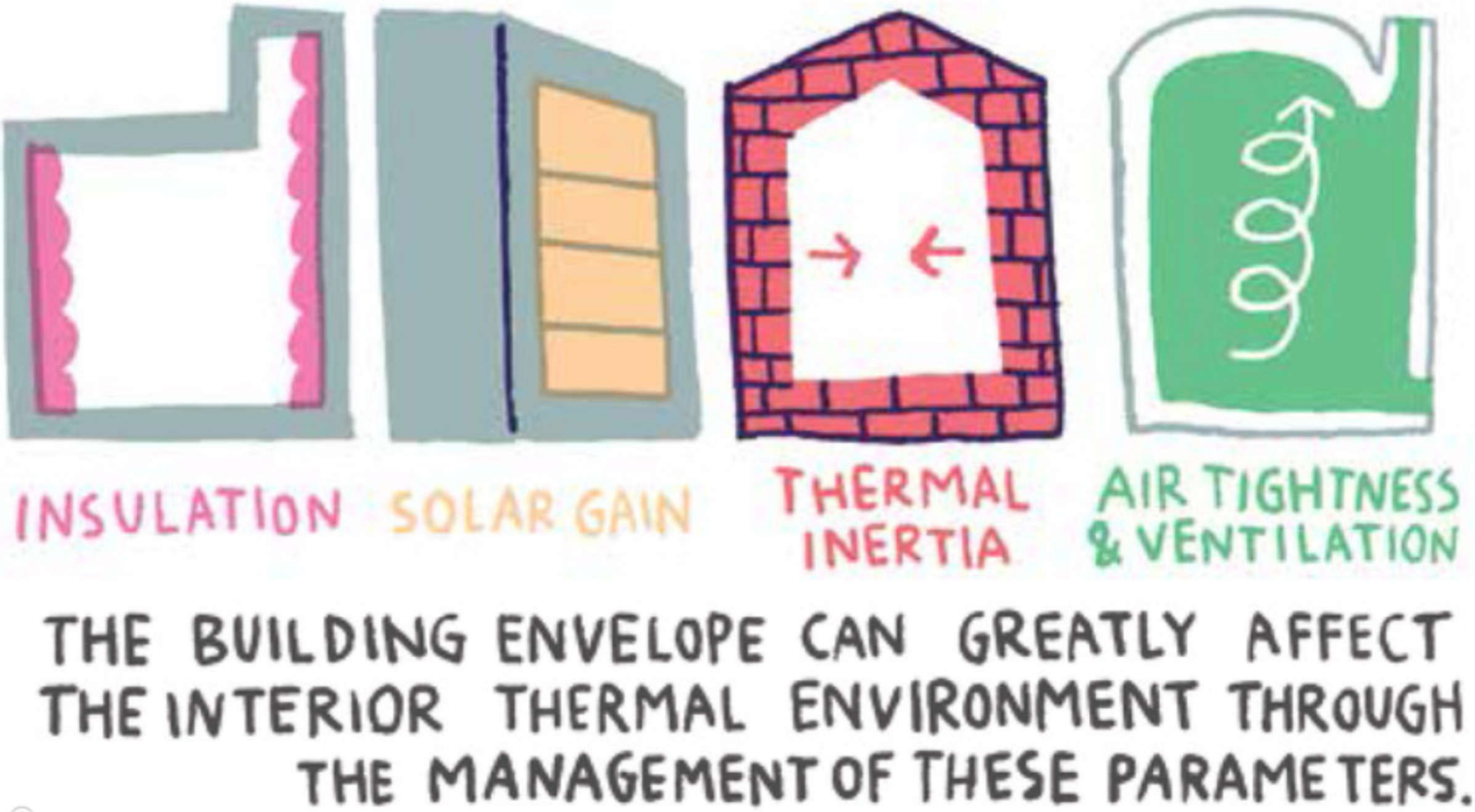


Indoor Environment

Energy supply to the building

Energy demand and energy use by the building and its building systems

Building envelope and the interior thermal environment

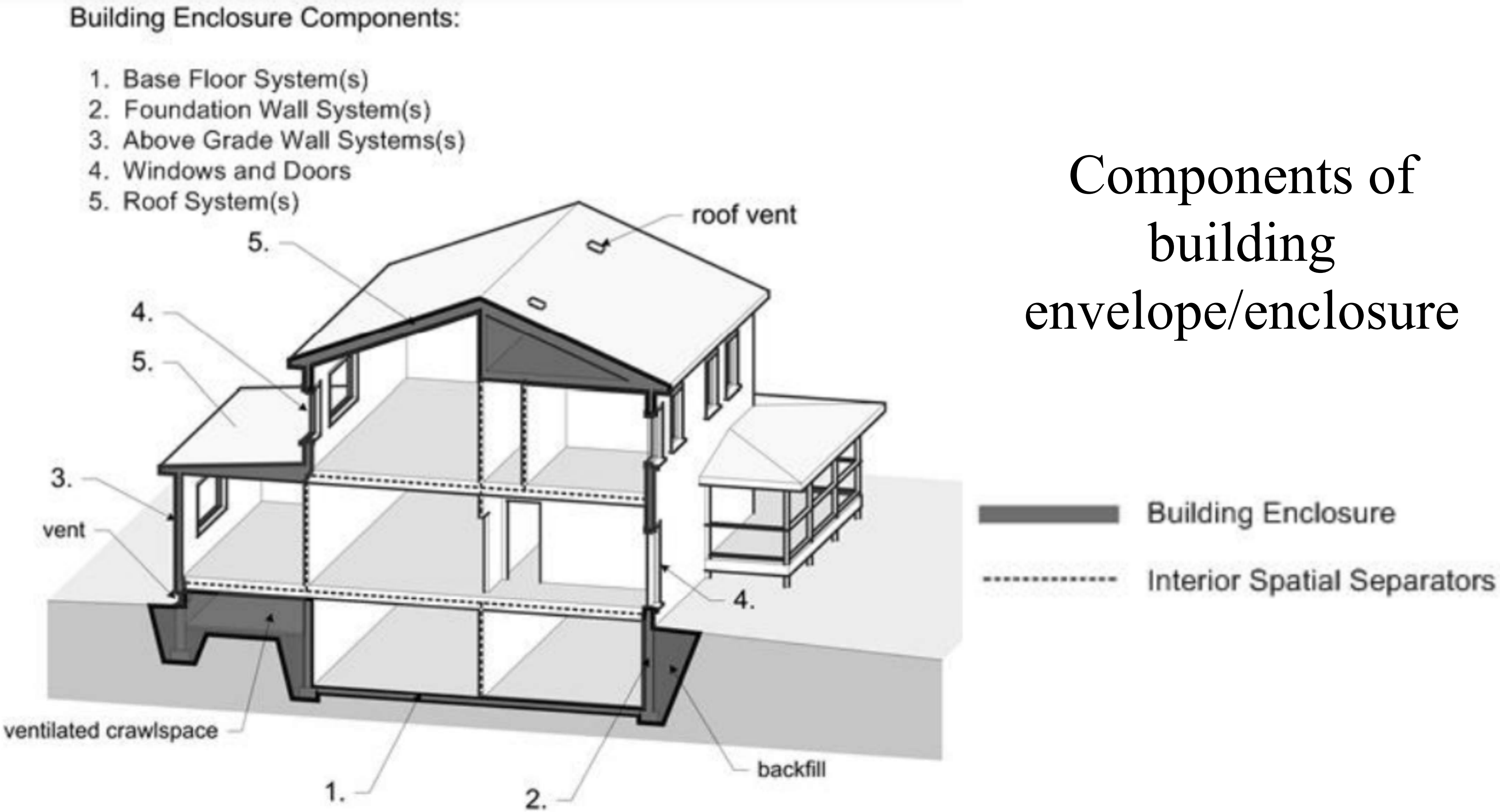


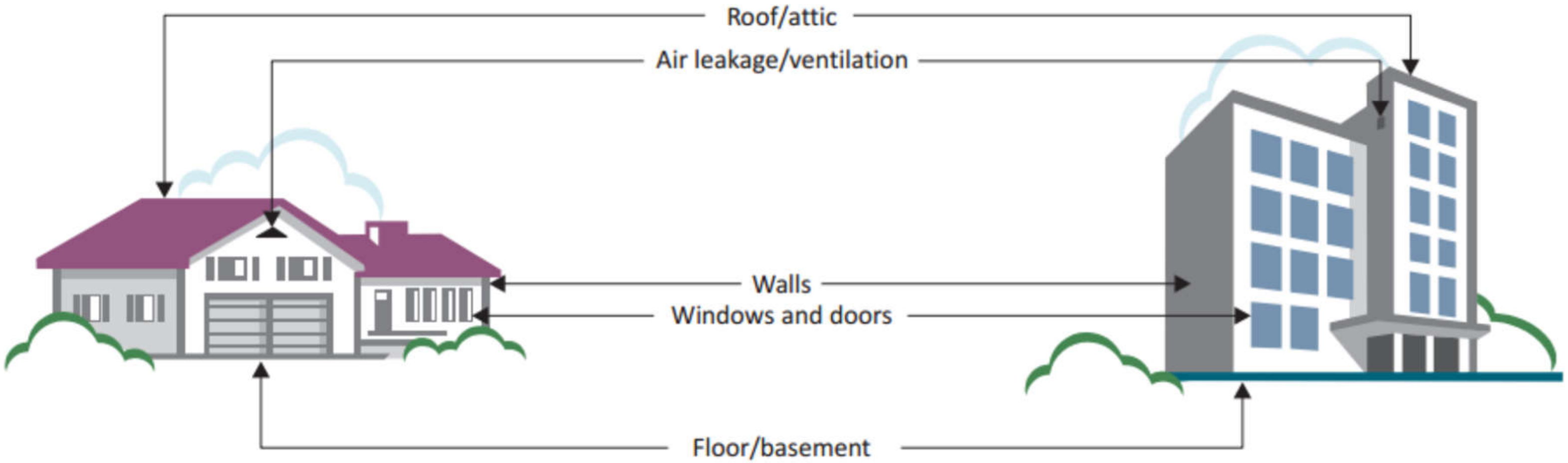
(Source: https://www.archdaily.com/908320/how-to-design-for-optimal-thermal-comfort-and-why-it-matters)

Basic principles

- Building envelope components
  - Roof, walls, windows, skylights, doors, floor, basement (below grade), foundation
  - Related issues: thermal insulation, air leakage, ventilation, material durability
  - Safety requirements: fire, floods, wind, seismic

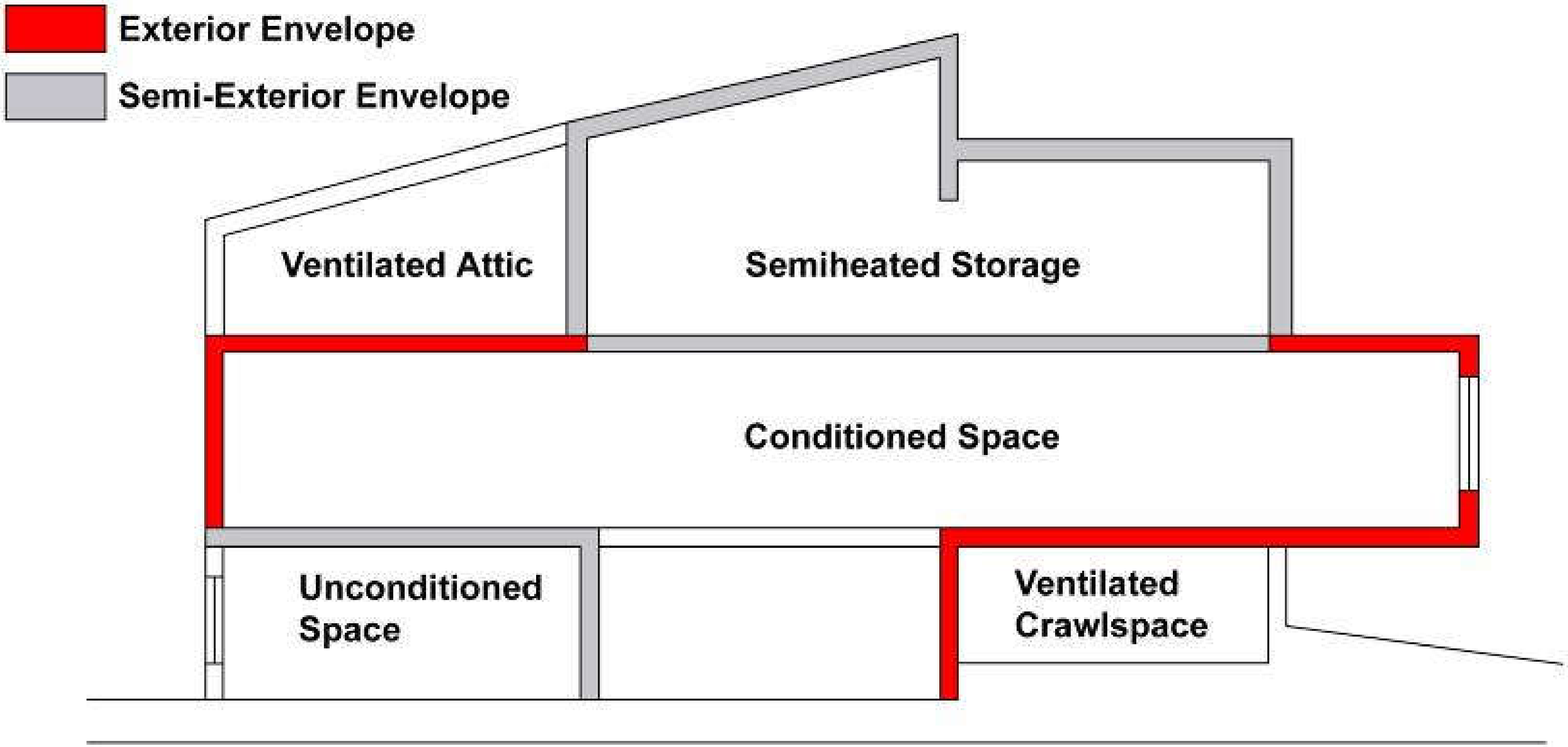
Components of building envelope/enclosure





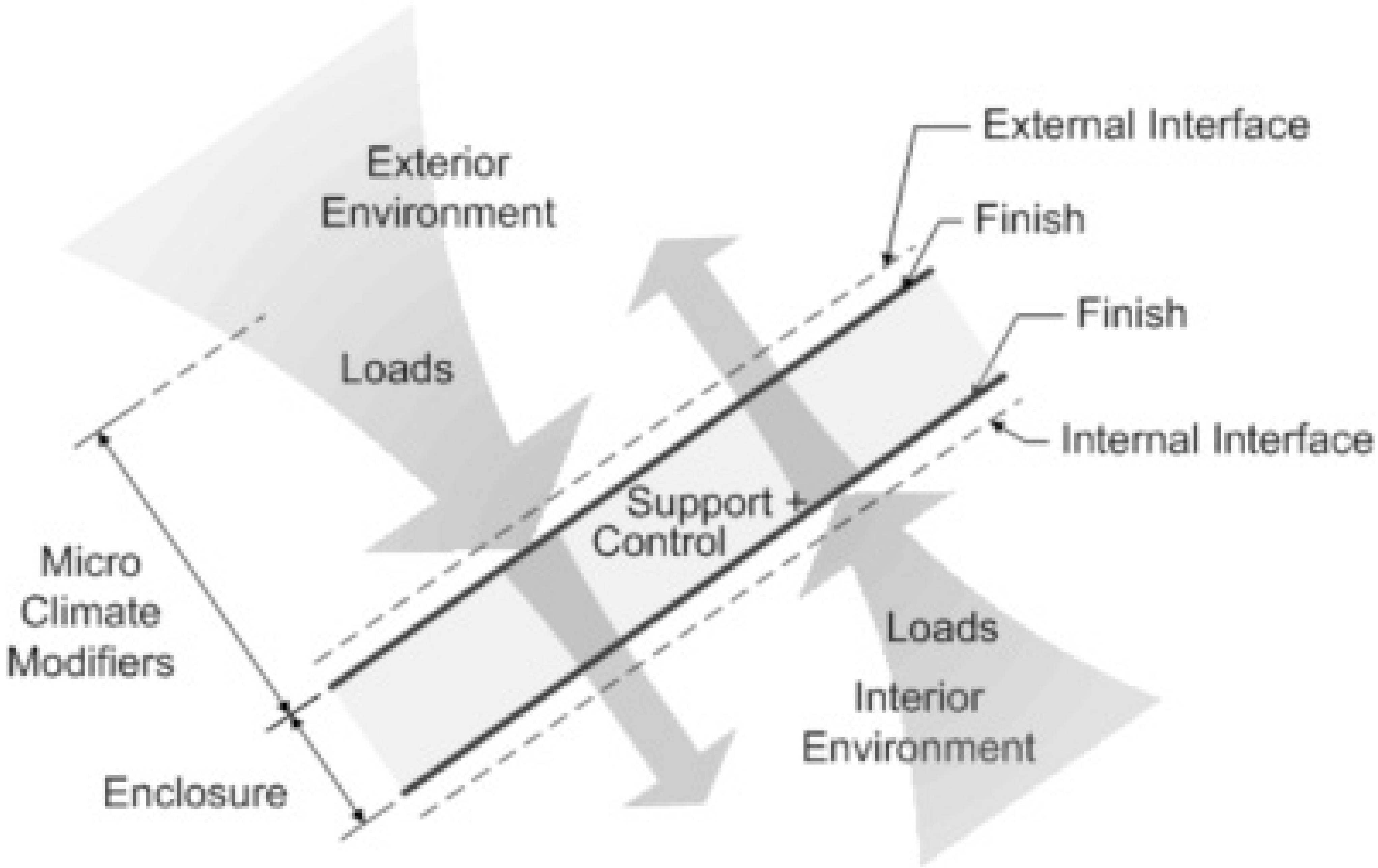
(Source: https://www.buildingscience.com/documents/digests/bsd-018-the-building-enclosure_revised & 2013 IEA Technology Roadmap -- Energy efficient building envelopes)

Exterior envelope and semi-exterior envelope



(Source: US Department of Energy)

Building envelope/enclosure and its functions



(Source: https://www.buildingscience.com/documents/digests/bsd-018-the-building-enclosure_revised)

Basic principles

- Major functions of a building envelope
  - Structural Support: to ensure strength & rigidity; providing structural support against internal & external loads and forces
  - Climate Control: to control the exchange of water, air, condensation and heat between the interior & exterior of the building
  - Finish: for aesthetic purposes. To make the building look attractive while still performing support & control functions

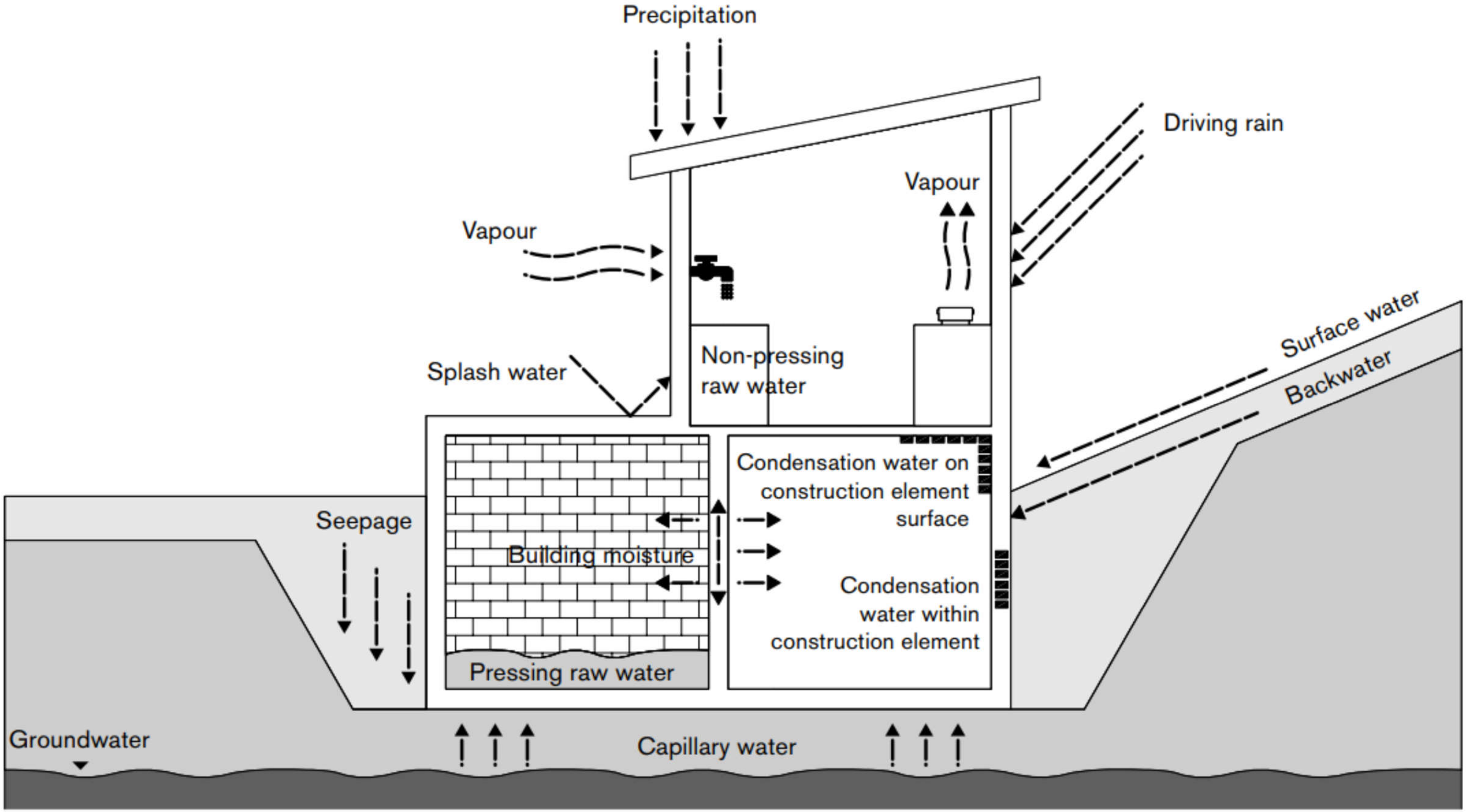
Basic performance requirements of the building envelope

	Walls	Glazing	Roof	Below grade
Thermal	X	X	X	
Moisture protection	X	X	X	X
Acoustics	X	(X)		
Light transmission		X	(X)	
Indoor air quality	(X)	(X)		
Mold protection	(X)	(X)		
HVAC integration	X	X	(X)	
Natural ventilation		X		
Durability	X	X	X	X
Sustainability	X	X	X	(X)

Key: X = Major determinant or influence
(X) = Minor determinant or influence

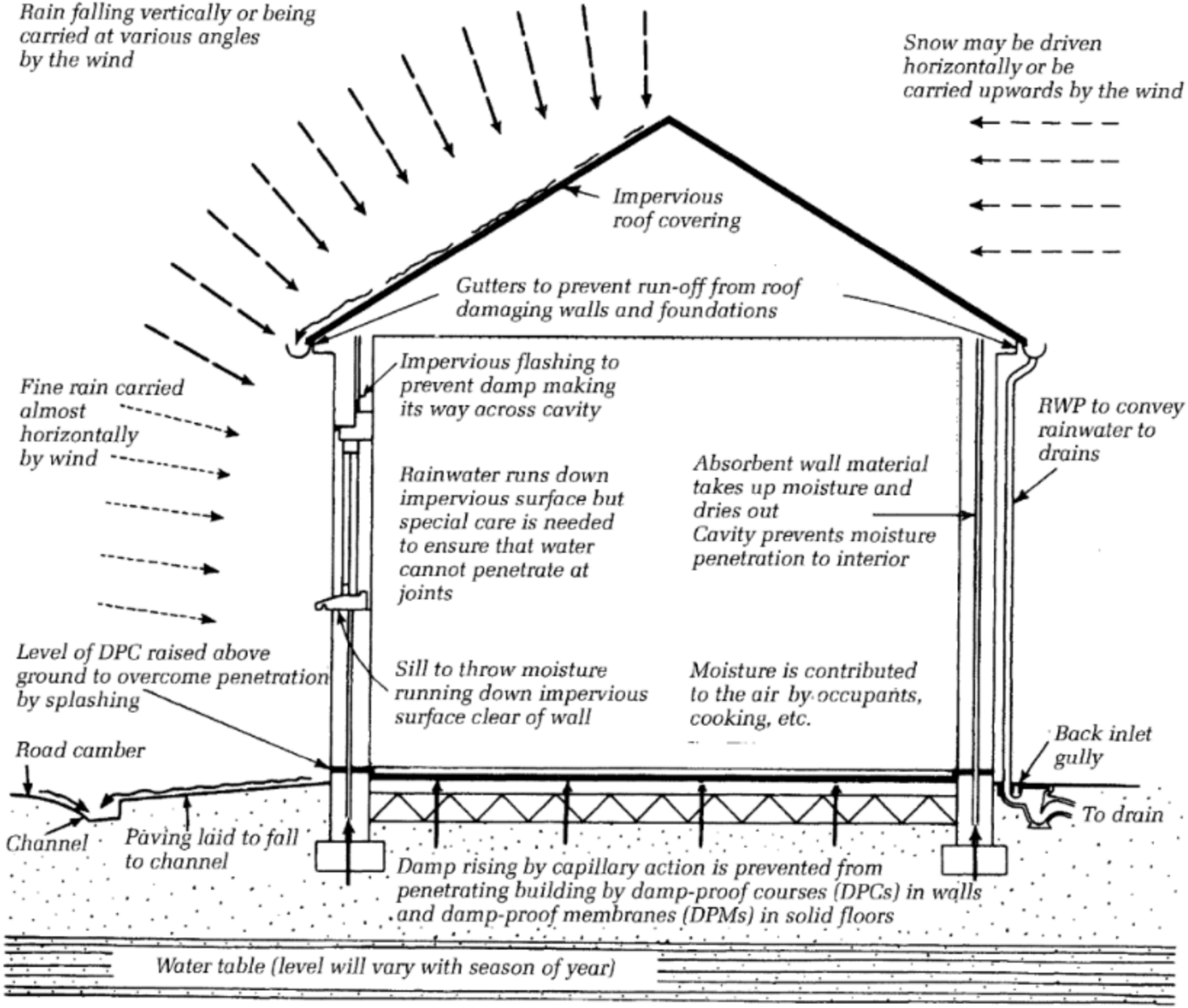
(Source: https://www.wbdg.org/guides-specifications/building-envelope-design-guide/)

Building-relevant types of water
(throughout the years, a building is exposed to various types of water loads that need to be considered during planning)



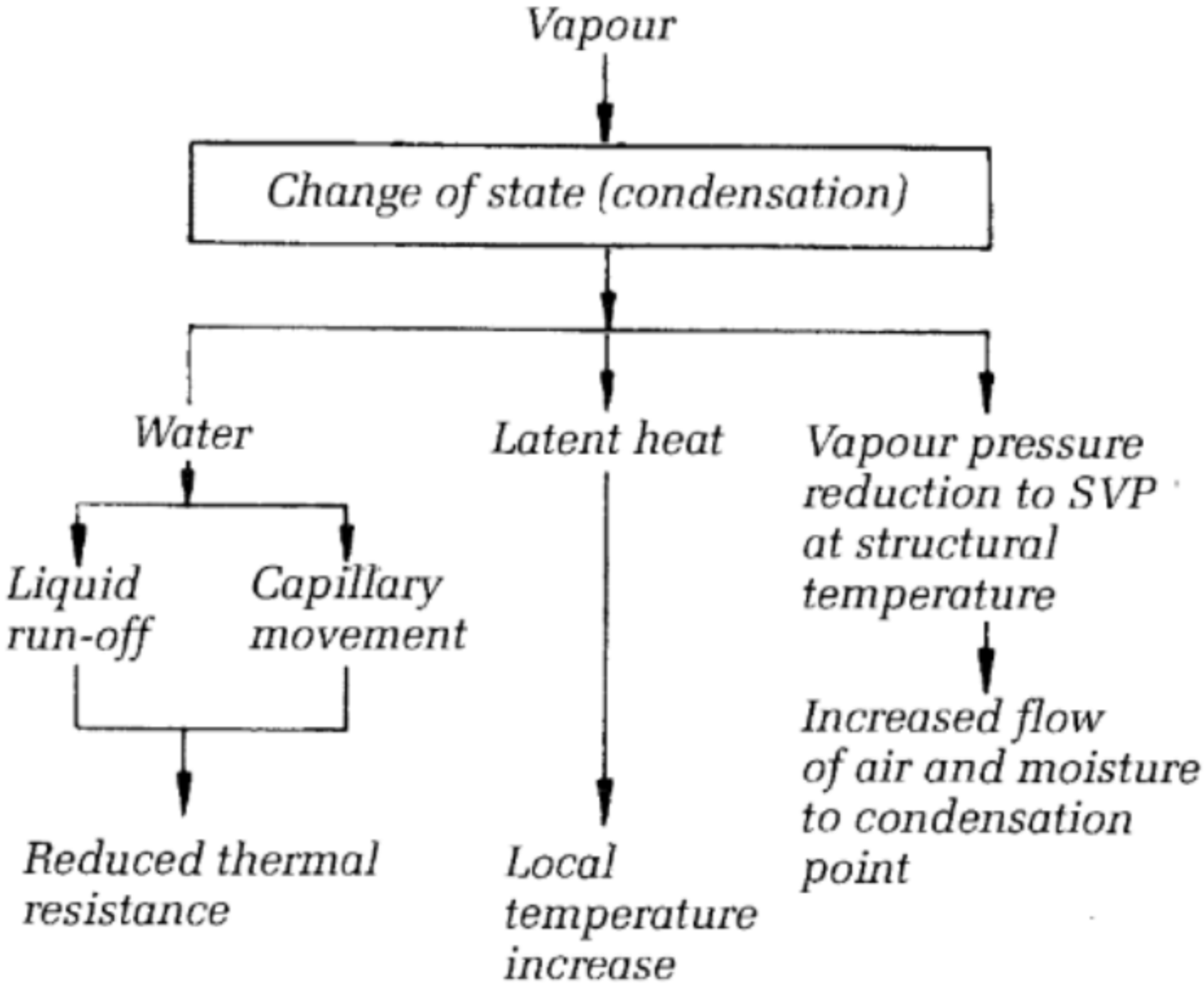
(Source: Knaack U. & Koenders E. A. B., 2018. *Building Physics of the Envelope: Principles of Construction*, Ebook Central.)

How to control moisture penetration in buildings



(Source: Burberry P., 1997. *Environment and Services*, 8th ed., Longman.)

Condensation phenomena



(Source: Burberry P., 1997. *Environment and Services*, 8th ed., Longman.)

Environmental conditions that affect thermal, visual & acoustic comfort

Environmental conditions	Thermal comfort	Visual comfort	Acoustic comfort
Outdoor design criteria	· Sun & wind obstructions · Building dimensions · Air temperature range · Relative humidity range · Wind velocity · Solar radiation	· View & daylight obstructions · Building dimensions · Latitude & location · Time of day · External horizontal illuminance · Ground reflectivity	· Noise obstructions · Building dimensions · Exterior noise level · Exterior noise source
Indoor design criteria	· Space dimensions · User's activity level · User's clothing insulation	· Space dimensions · Colours of surfaces · Working plane location	· Space dimensions · Absorption coefficients of interior surfaces
Indoor comfort criteria	· Air temperature · Relative humidity · Air velocity · Mean radiant temperature	· Illuminance level & distribution · Glare index	· Acceptable interior noise levels

(Source: Aksamija A., 2013. *Sustainable Facades: Design Methods for High-performance Building Envelopes*, John Wiley & Sons, Inc.)

Facade elements properties that affect thermal, visual & acoustic comfort

Environmental conditions	Thermal comfort	Visual comfort	Acoustic comfort
Opaque facades	· Material properties of cladding · Amount of insulation · Effective heat resistance properties (R-value)	· Window-to-wall ratio	· Material selection & properties
Glazing	· Orientation · Number of glass layers · Layer thicknesses · Heat transfer coefficient (U-value) · Visual transmittance · Solar heat gain coefficient (SHGC)	· Orientation · Window properties, size, location, & shape · Glass thickness & colour · Visual transmittance · Reflectance	· Number of layers · Layer thicknesses · Layer density
Frames & supporting structure for glazed facades	· Thermal properties of the frames		· Material types

(Source: Aksamija A., 2013. *Sustainable Facades: Design Methods for High-performance Building Envelopes*, John Wiley & Sons, Inc.)

Design factors

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

* Face House, Kyoto, Japan

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

Main criteria:

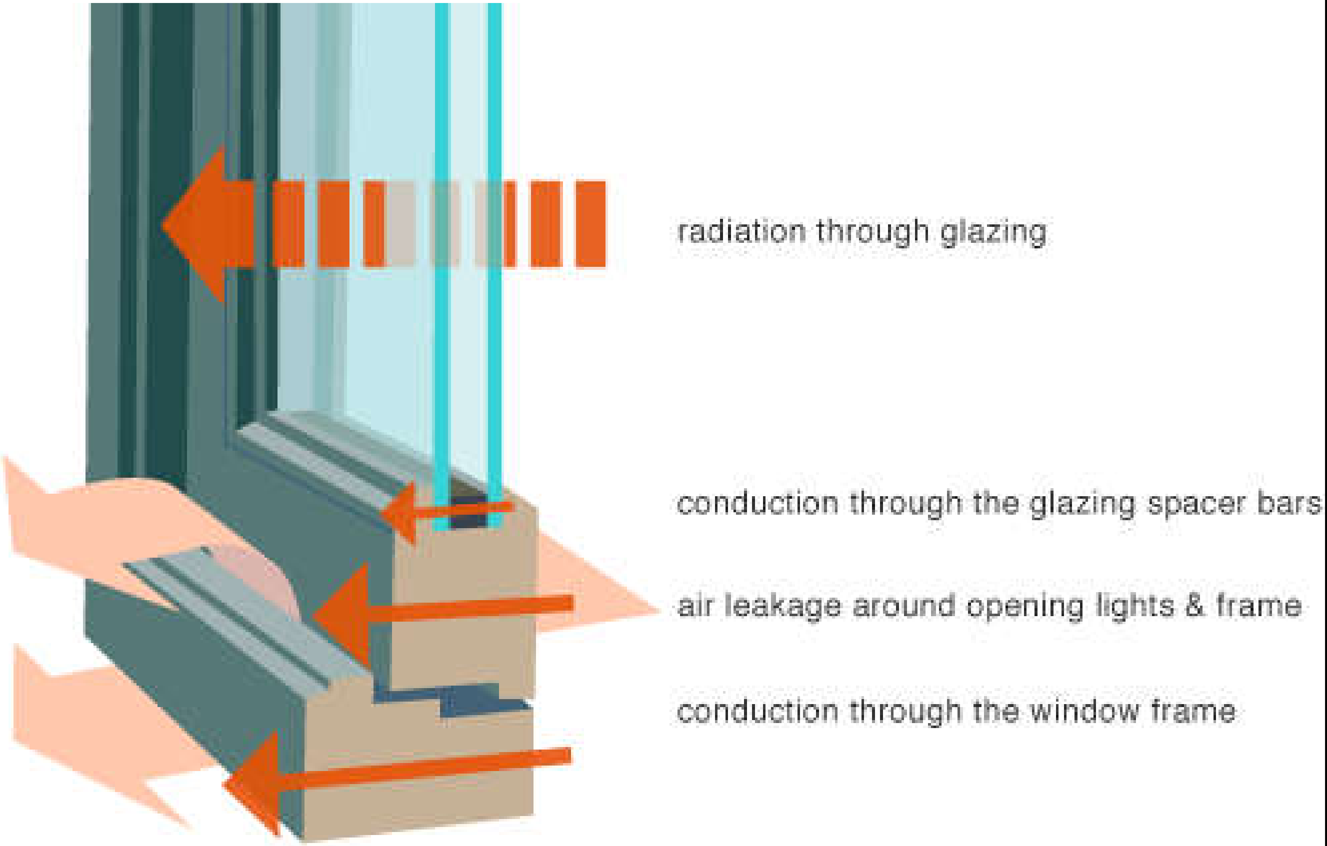
- wall area
- window area
- thermal properties
- orientations
- thermal mass
- shading device

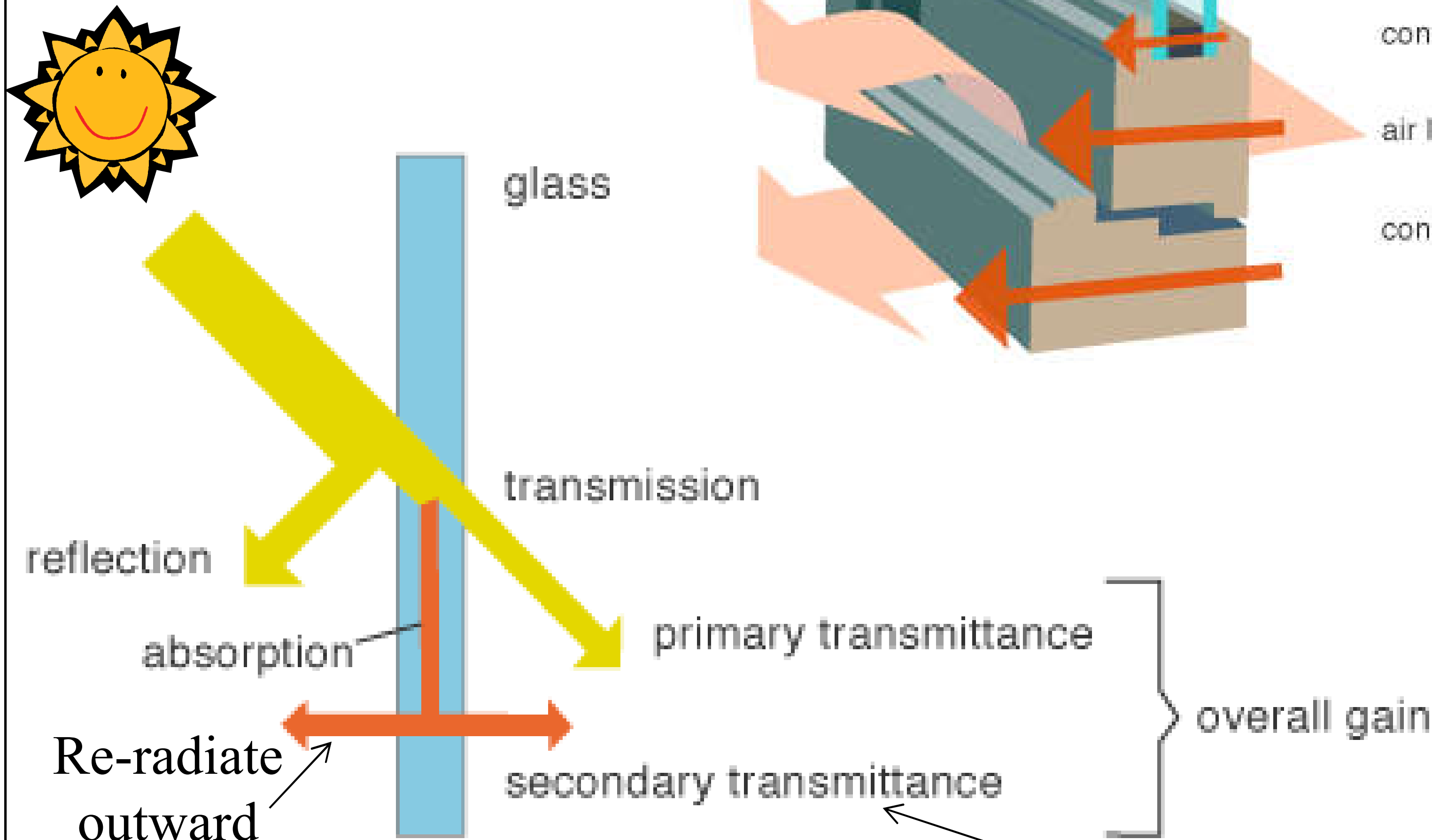
Design factors

- Major factors determining envelope heat flow:
  - Temperature differential, ΔT
  - Area of exposed building surfaces, A
  - Heat transmission properties, like U-value
  - Thermal storage capacity
  - Window-to-wall ratio (WWR)
- Effect of thermal mass
  - Delay heat transfer or act as a cooling source
  - Important for intermittently cooled spaces

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

Solar heat gain and heat loss through window glass

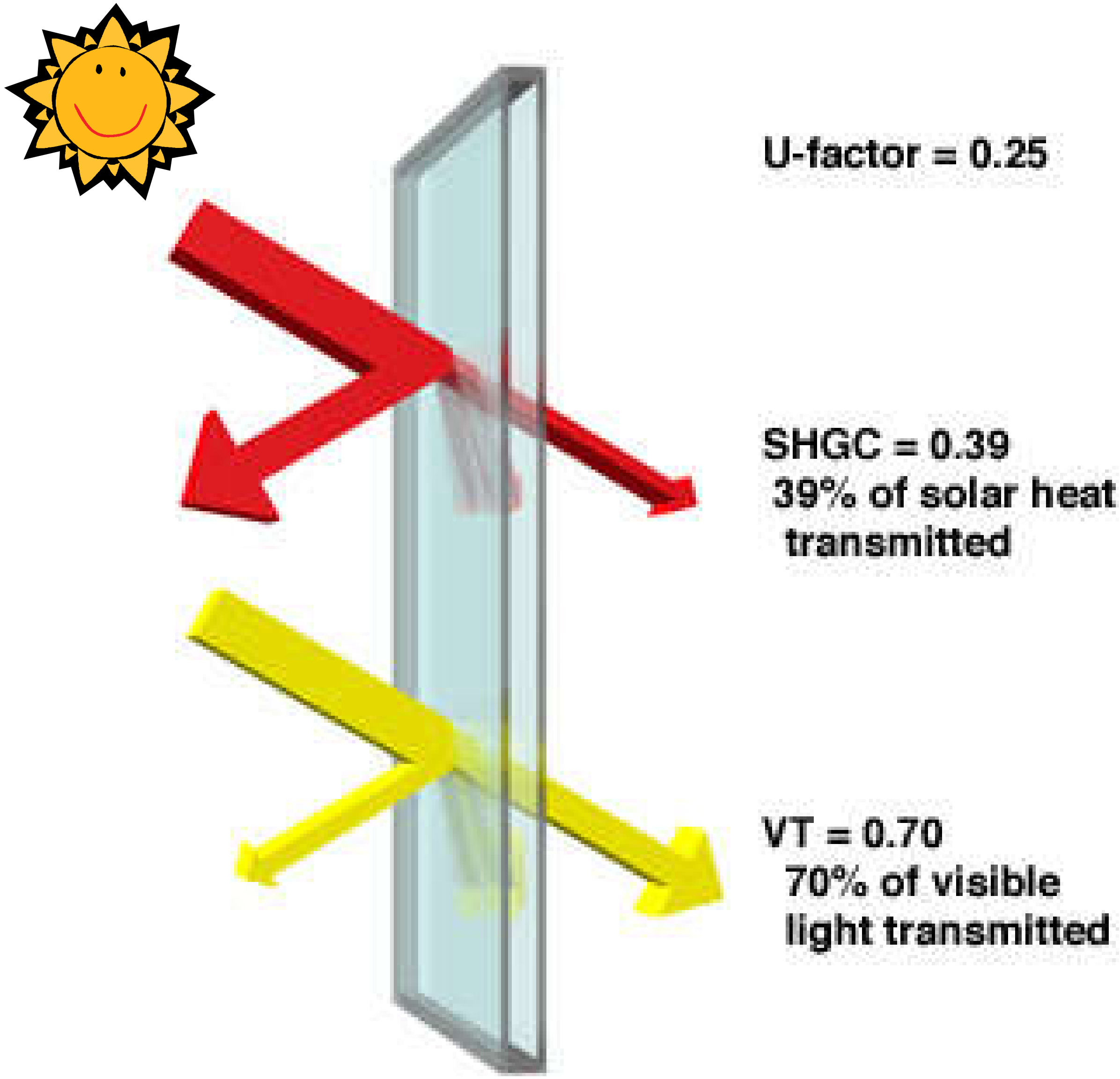




(Source: www.greenspec.co.uk/windows.php)

Absorbed & re-radiate inward

Understanding window performance



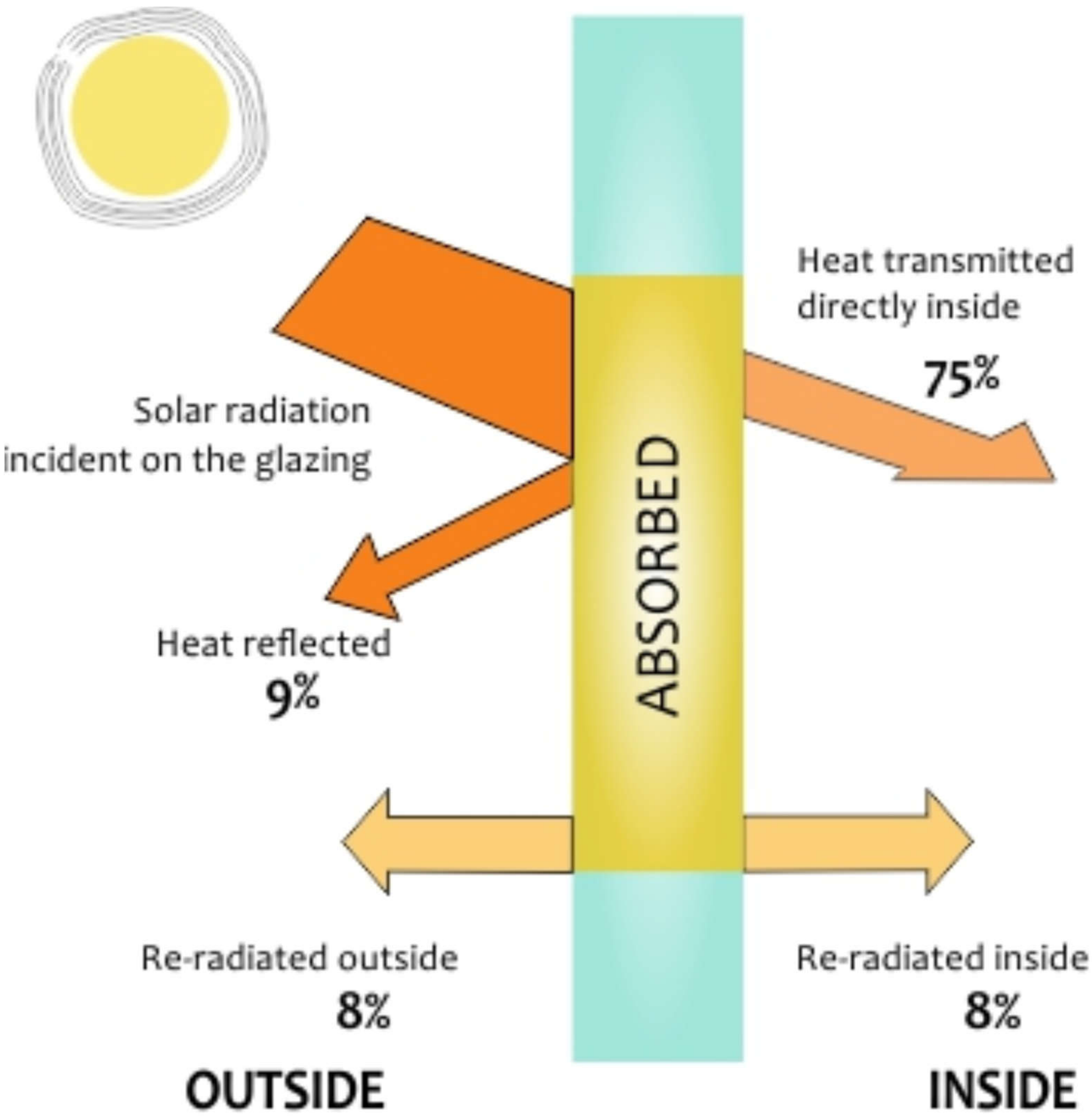
U-factor (or U-value) = overall thermal transmittance ($W.m^{-2}.K^{-1}$)

SHGC = solar heat gain coefficient

VT = visible transmittance

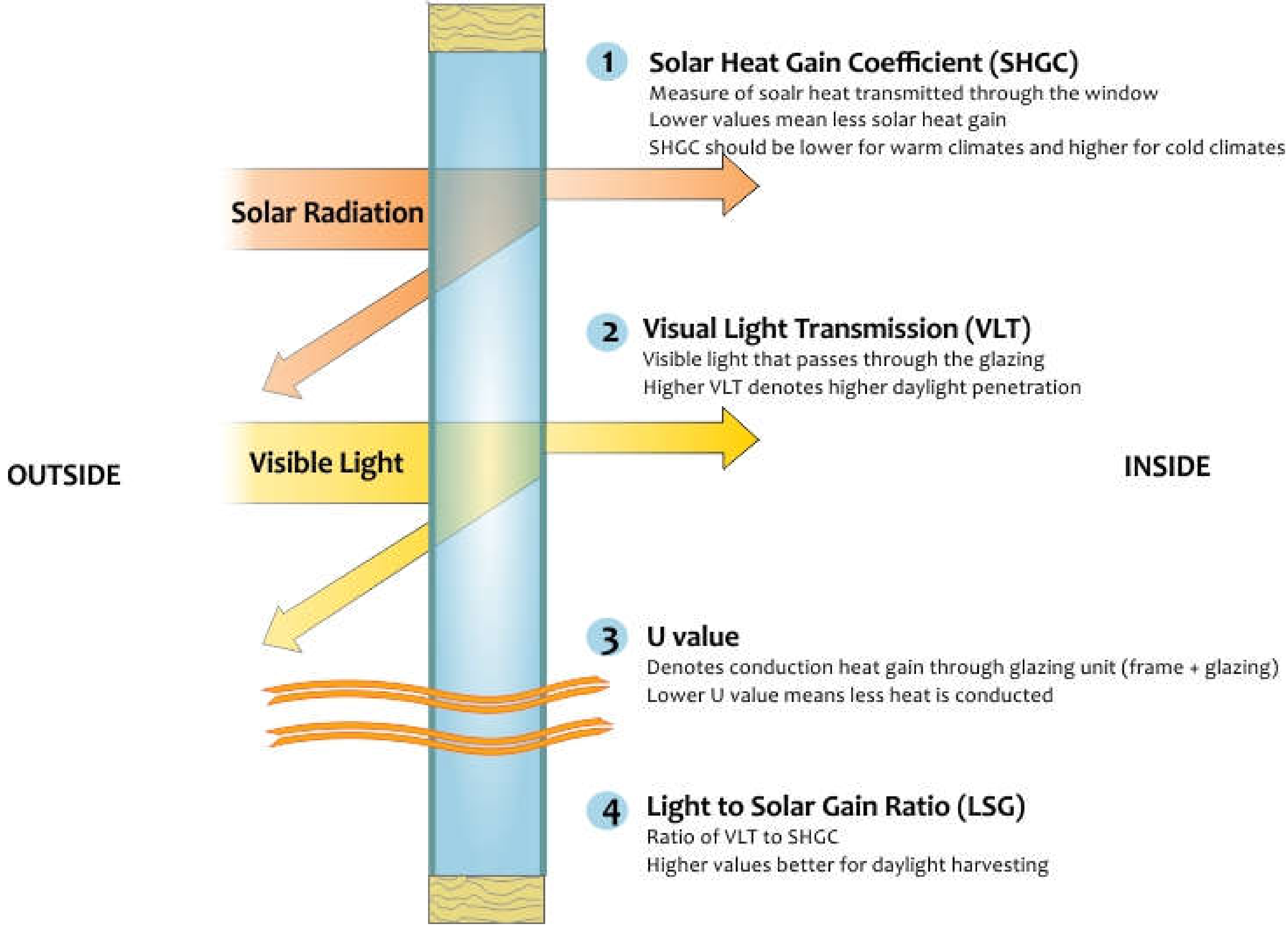
$$Shading\ Coefficient\ (SC) = \frac{Solar\ heat\ gain\ of\ the\ window\ glazing}{Solar\ heat\ gain\ of\ unshaded\ 3\ mm\ clear\ float\ glass}$$

Heat transmission in a single glazing clear glass



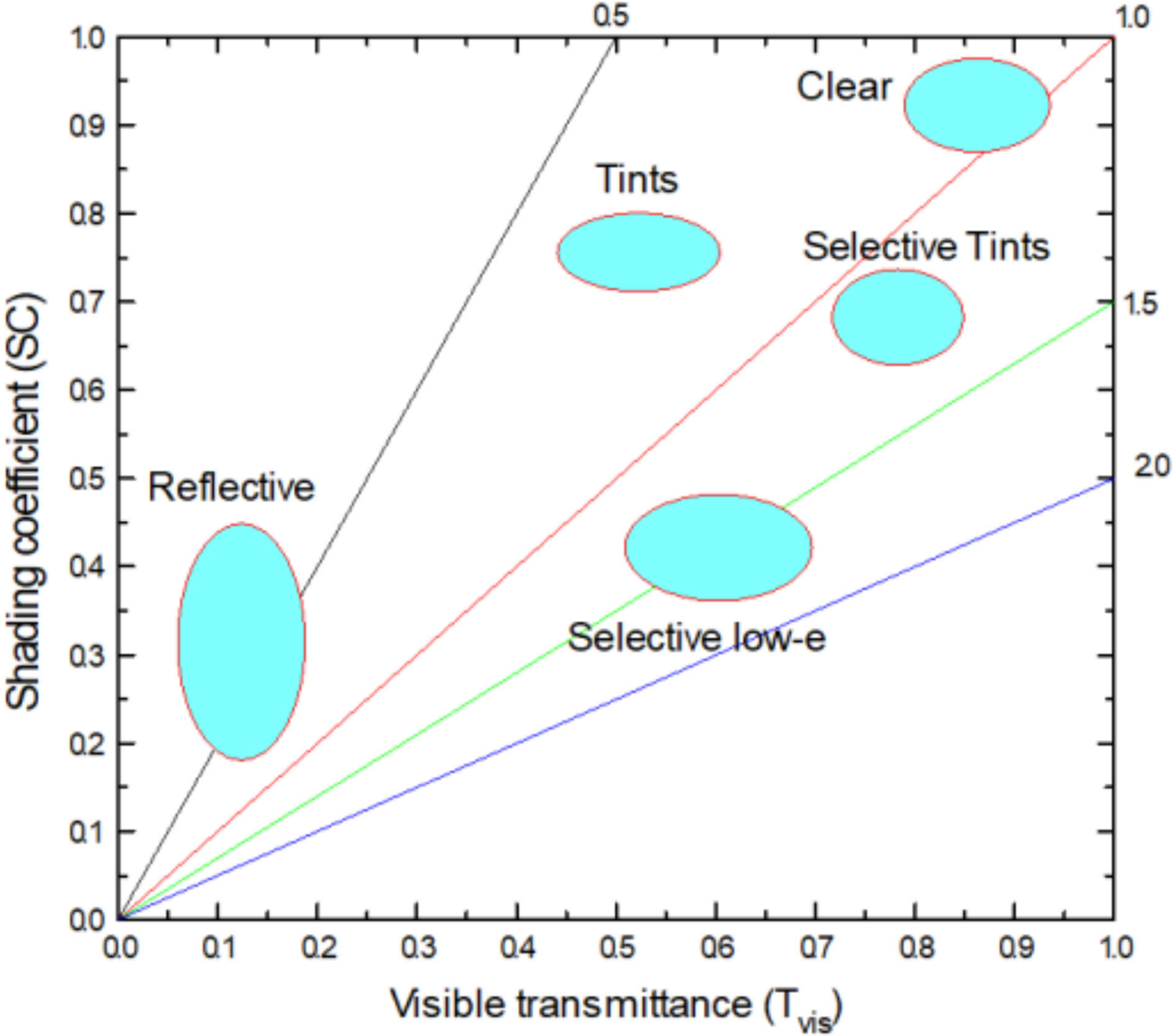
(Source: https://nzeb.in/knowledge-centre/passive-design/fenestration/)

Major properties of fenestration



(Source: https://nzeb.in/knowledge-centre/passive-design/fenestration/)

Properties and selection of window glasses



Design factors

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

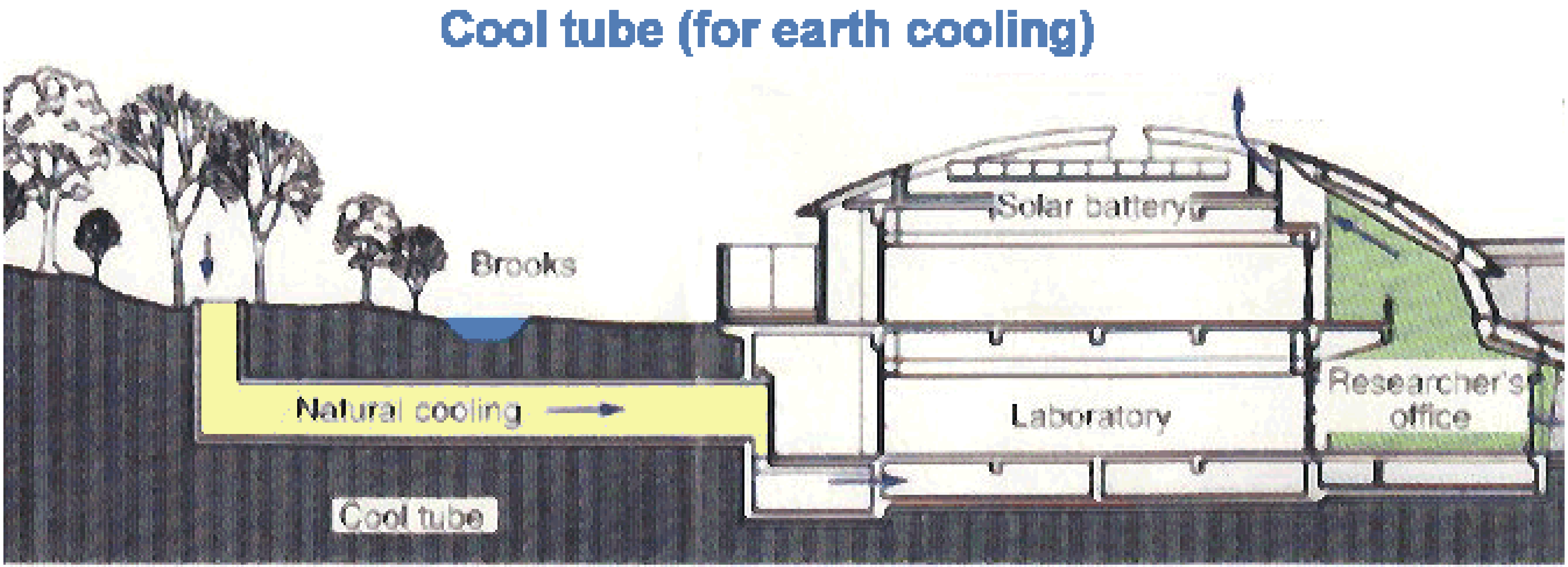
New buildings: advanced design & codes

Existing buildings: How to upgrade the building envelopes?

- Promote energy-efficient building materials & innovative designs

Examples of passive cooling designs – earth tube cooling

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



Earth tube cooling (Japan)

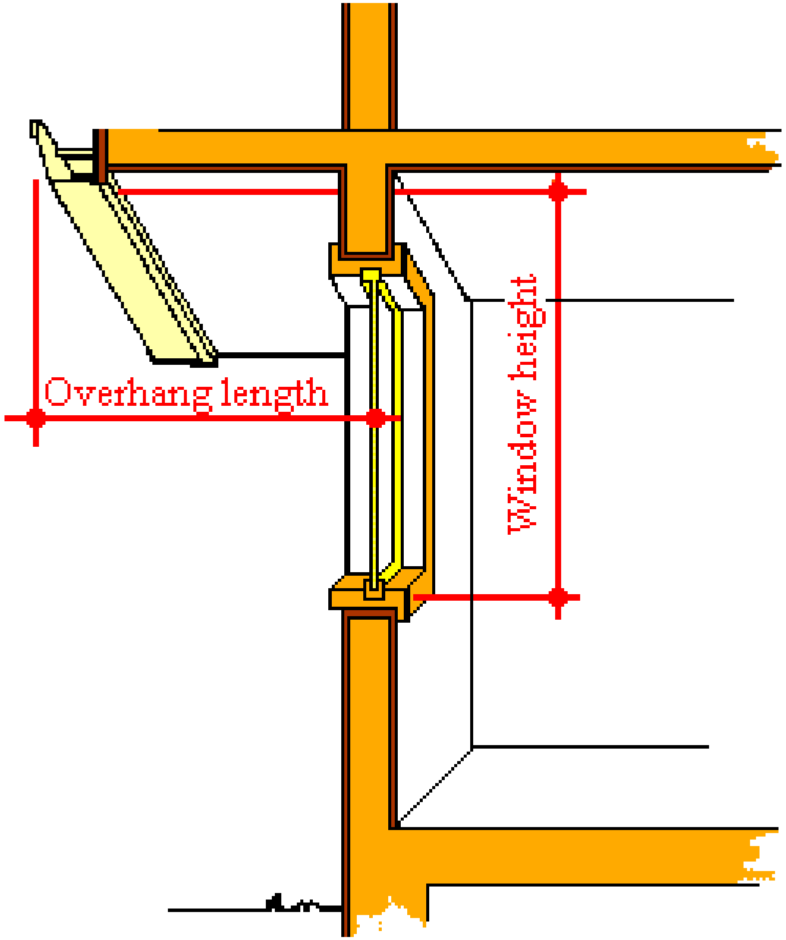
(Source: http://www.mech.hku.hk/sbe/case_study/case/jap/RITE_Building/energy.html)

Design factors

- 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 & exterior insulation
  - Advanced insulation (e.g. aerogel)
  - Air sealing
  - Cool roofs, advanced roofs, green roofs

Shading devices (external and internal) for sun control

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



Overhang

Louvers

Awnings

Shutters

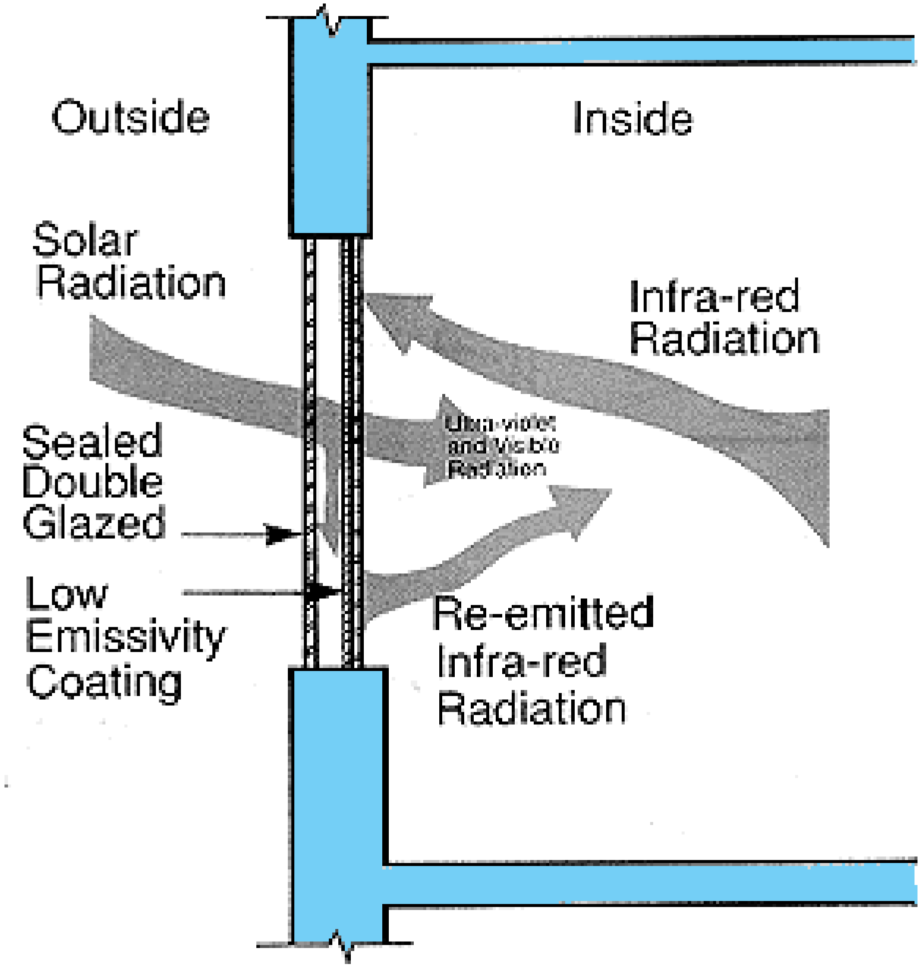
Drapes and curtains

Venetian blinds

Roller shades

Advanced window and insulation technology

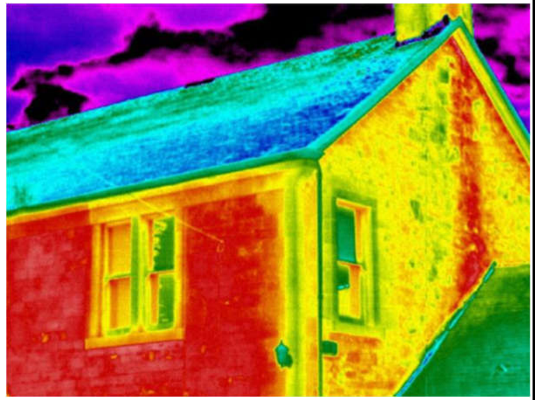
(reduce solar heat gain => reduce cooling energy)



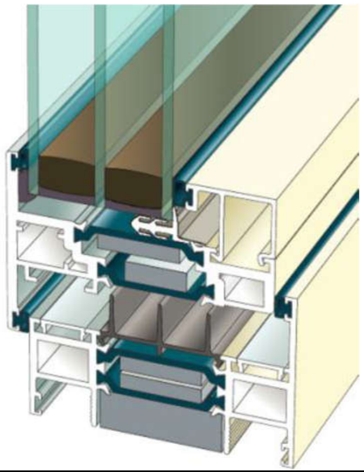
Low-e (emissivity) glazing

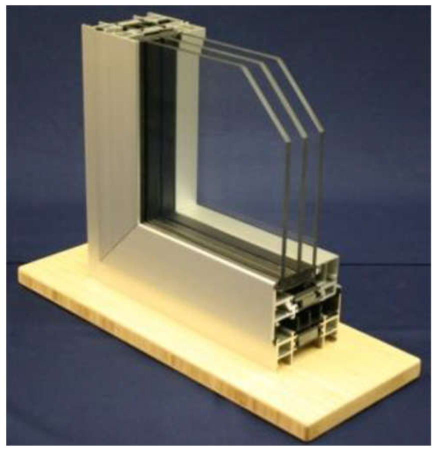
Gas filled panel (high performance insulation)

Design factors



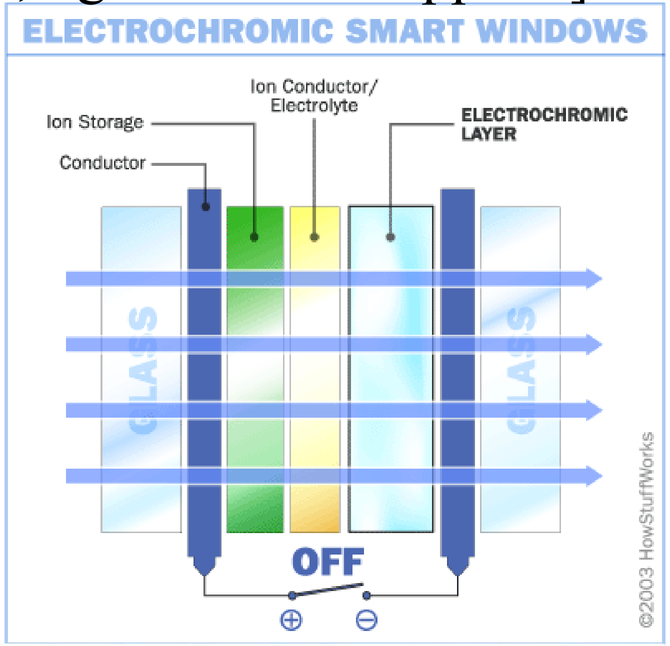
- Advanced/emerging technologies
  - Highly insulating windows
  - Building envelope material
  - Air-sealing technologies (systems-level approach)
  - Dynamic windows and window films
  - Visible light redirection
  - Highly insulating roofs
  - Double-skin/active façades
- More R&D are needed





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/)

Facade design strategies for different climate zones

Climate type	Design strategies for sustainable facades
Heating-dominated climates Zones 5, 6, 7, 8	· *Solar collection & passive heating*: collect solar heat through envelope · *Heat storage*: storage of heat in the mass of the walls · *Heat conservation*: preserve heat through improved insulation · *Daylight*: use of natural light sources & increased glazed areas of the facade, use of high-performance glass, and use of light shelves to redirect light into interior spaces
Cooling-dominated climates Zones 1, 2, 3	· *Solar control*: protect the facade from direct solar radiation through self-shading methods (building form) or shading devices · *Reduction of external heat gains*: protect from solar heat gain by infiltration (by using well-insulated opaque facade elements) or conduction (by using shading devices) · *Cooling*: use of natural ventilation where environmental characteristics & building function permit · *Daylight*: use of natural light sources while minimizing solar heat gain through use of shading devices and light shelves
Mixed climates Zone 4	· *Solar control*: protect facade from direct solar radiation (shading) during warm seasons · *Solar collection and passive heating*: solar collection during cold seasons · *Daylight*: use of natural light sources & increased glazed areas of the facade with shading devices

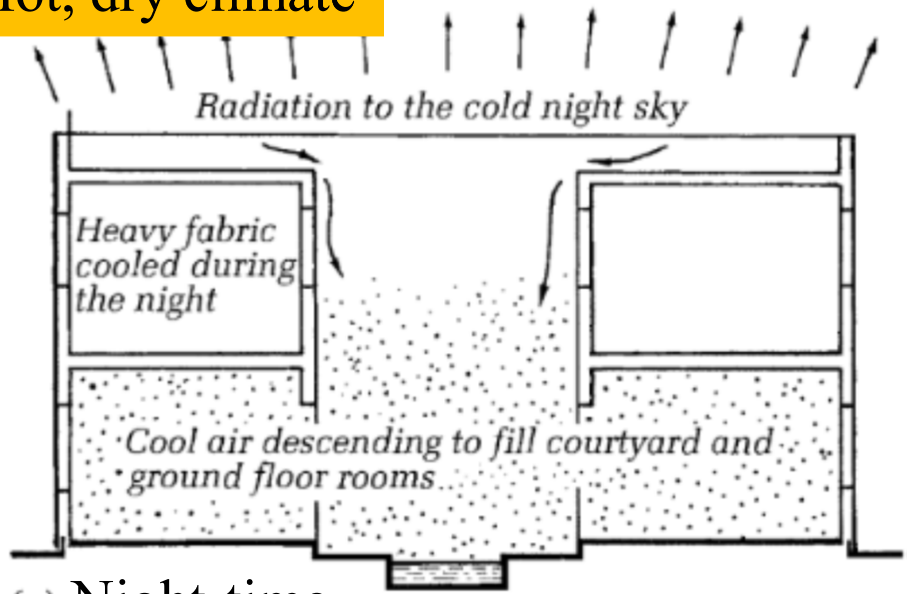
(Source: Aksamija A., 2013. *Sustainable Facades: Design Methods for High-performance Building Envelopes*, John Wiley & Sons, Inc.)

Response to local climate

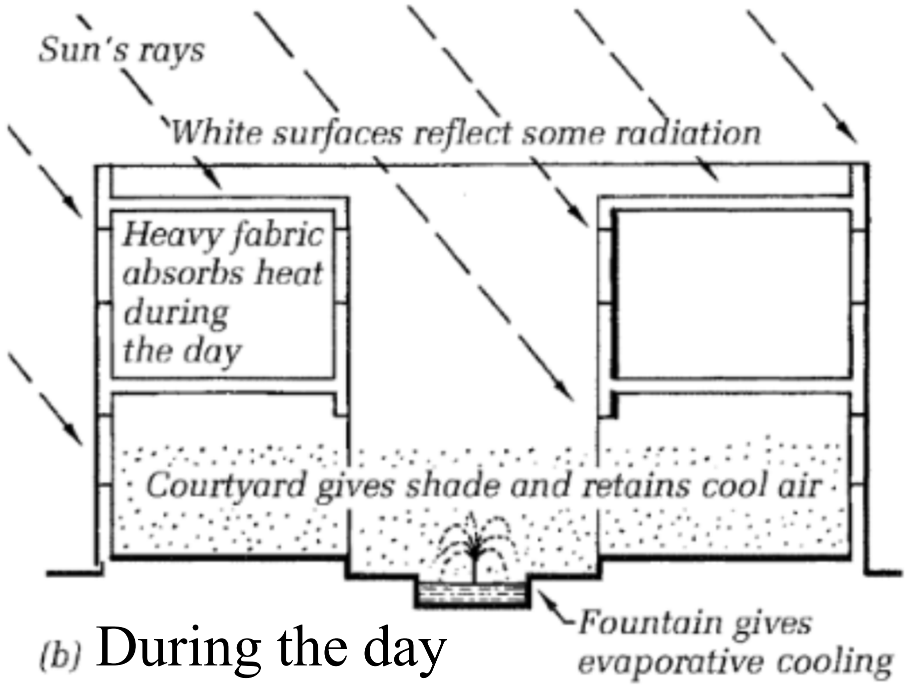
- Building envelope design: response to climate
  - Hot, dry climate with clear skies
    - At night, the building radiates to the clear sky & cool air accumulates in the courtyard & the ground floor
      - The fabric is cooled by both convection & radiation
    - During the day, the sun shines on the building, where the white surfaces reflect some of the radiation
      - The courtyard & the ground floor remain shaded from the sun
      - A fountain can be used to give evaporative cooling

Control of environment through construction

Hot, dry climate



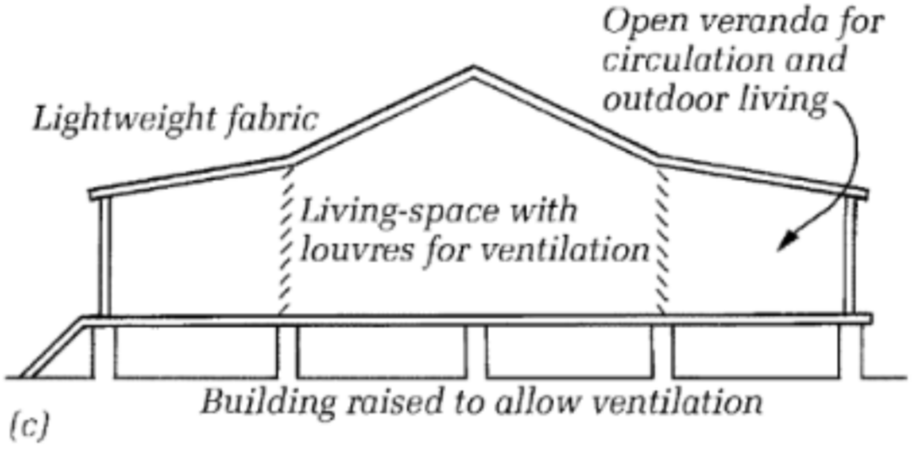
(a) Night-time



(b) During the day

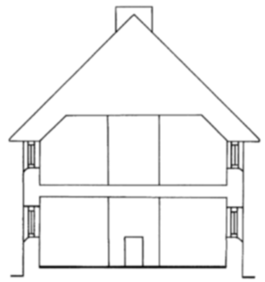
(Source: Burberry P., 1997. *Environment and Services*, 8th ed., Longman.)

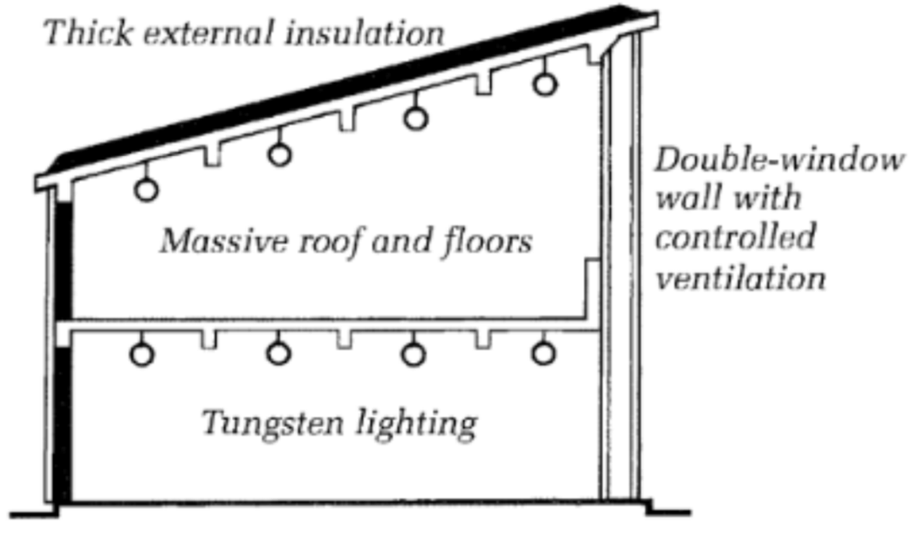
Hot and humid climate



(c)

Cold/mild climate





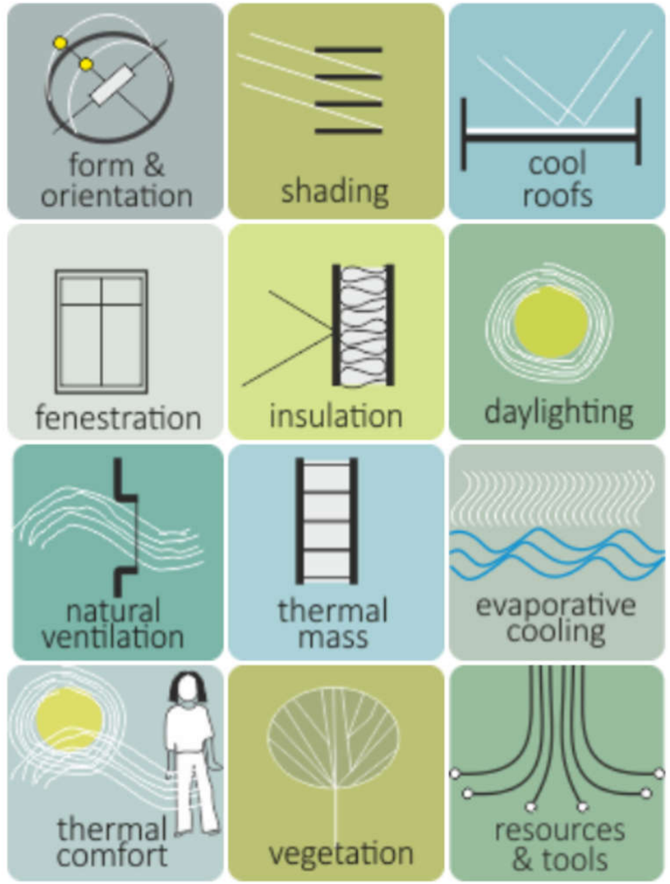
(e)

Response to local climate

- Building envelope design: response to climate
  - Hot and humid climate
    - Opportunities to improve comfort are very limited due to high air temperature & relative humidity
    - Encourage air movement (ventilation) as much as possible to help the evaporative cooling of perspiration
    - Use open verandas as living spaces & provide privacy with louvred walls which restrict air flow less
  - Cold/mild climate
    - Thick walls & the roof with massive insulation
    - The windows are small, with controlled ventilation

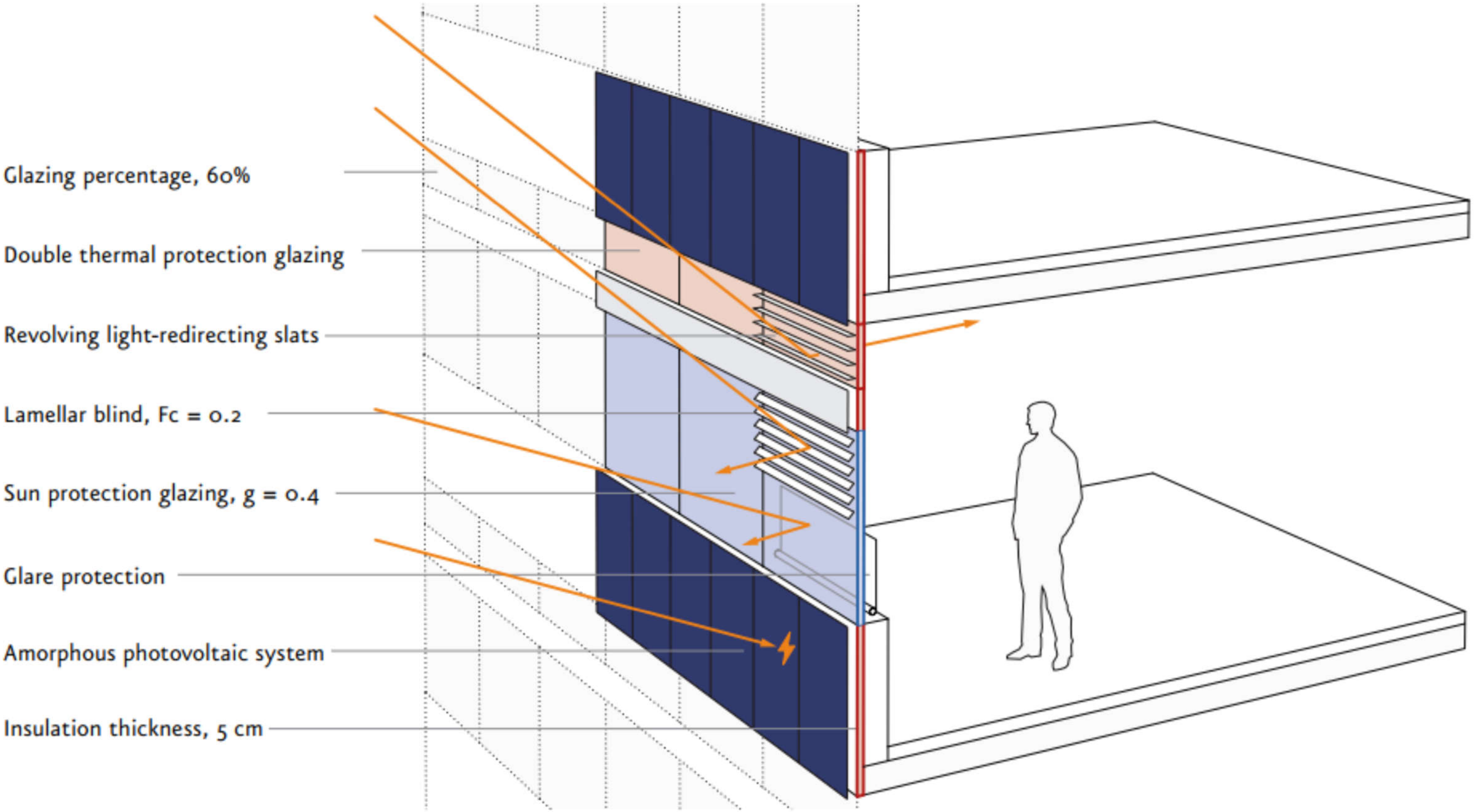
Response to local climate

- Passive building design strategies
  - Form & orientation
  - Sun shading & cool roofs
  - Fenestration & thermal insulation
  - Daylighting
  - Natural ventilation
  - Thermal mass
  - Evaporative cooling
  - Vegetation



(Source: https://nzeb.in/knowledge-centre/passive-design/)

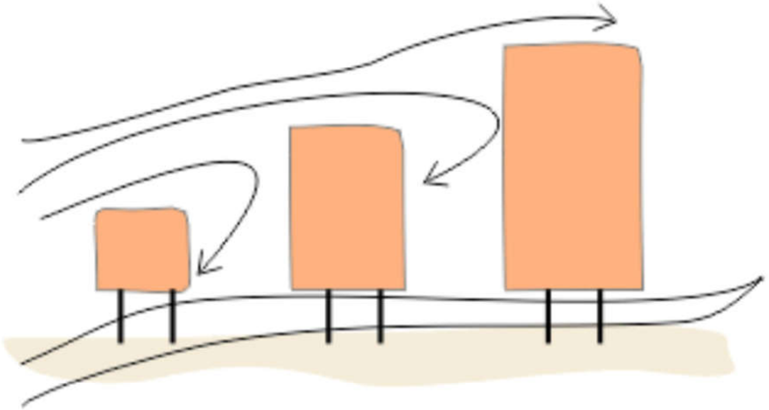
Facade concept for the subtropics (strategies for a south facade optimised in terms of energy, room climate & daylight)



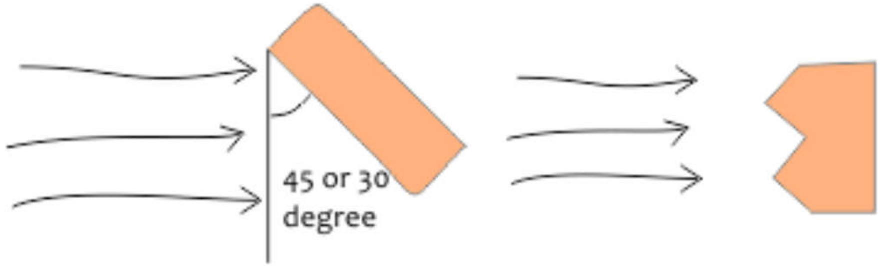
(Source: Liedl P., Hausladen G. & Saldanha M., 2012. *Building to Suit the Climate: A Handbook*)

Building form and orientation

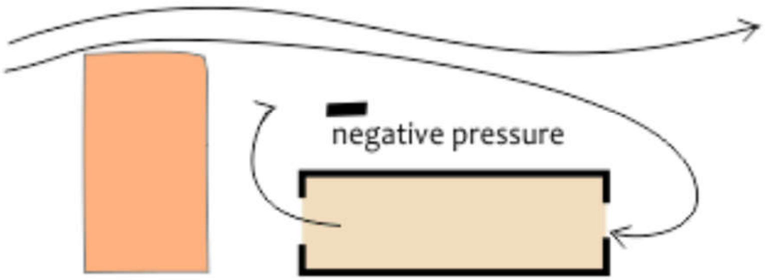
Orient longer facades along the north. This will provide glare free light in summer from north without shading and winter sun penetration from the south.



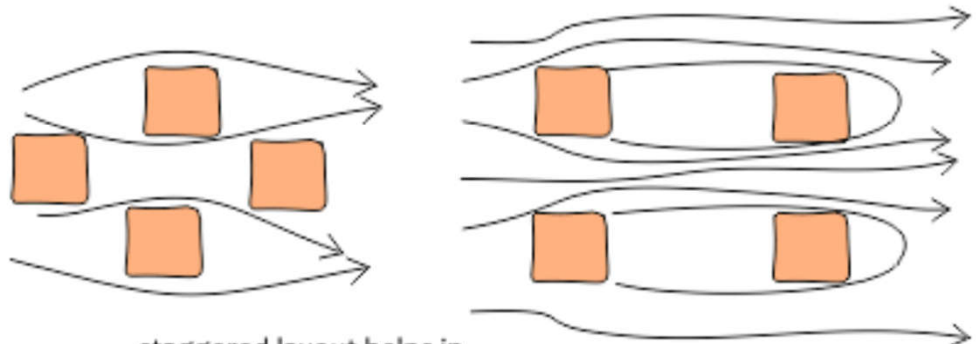
if a site has multiple buildings, they should be arranged in ascending order of their heights and be built on stilts to allow ventilation



Place buildings at a 30 or 45 degree angle to the direction of wind for enhanced ventilation. Form can be staggered in the wind facing direction also to achieve the same result.



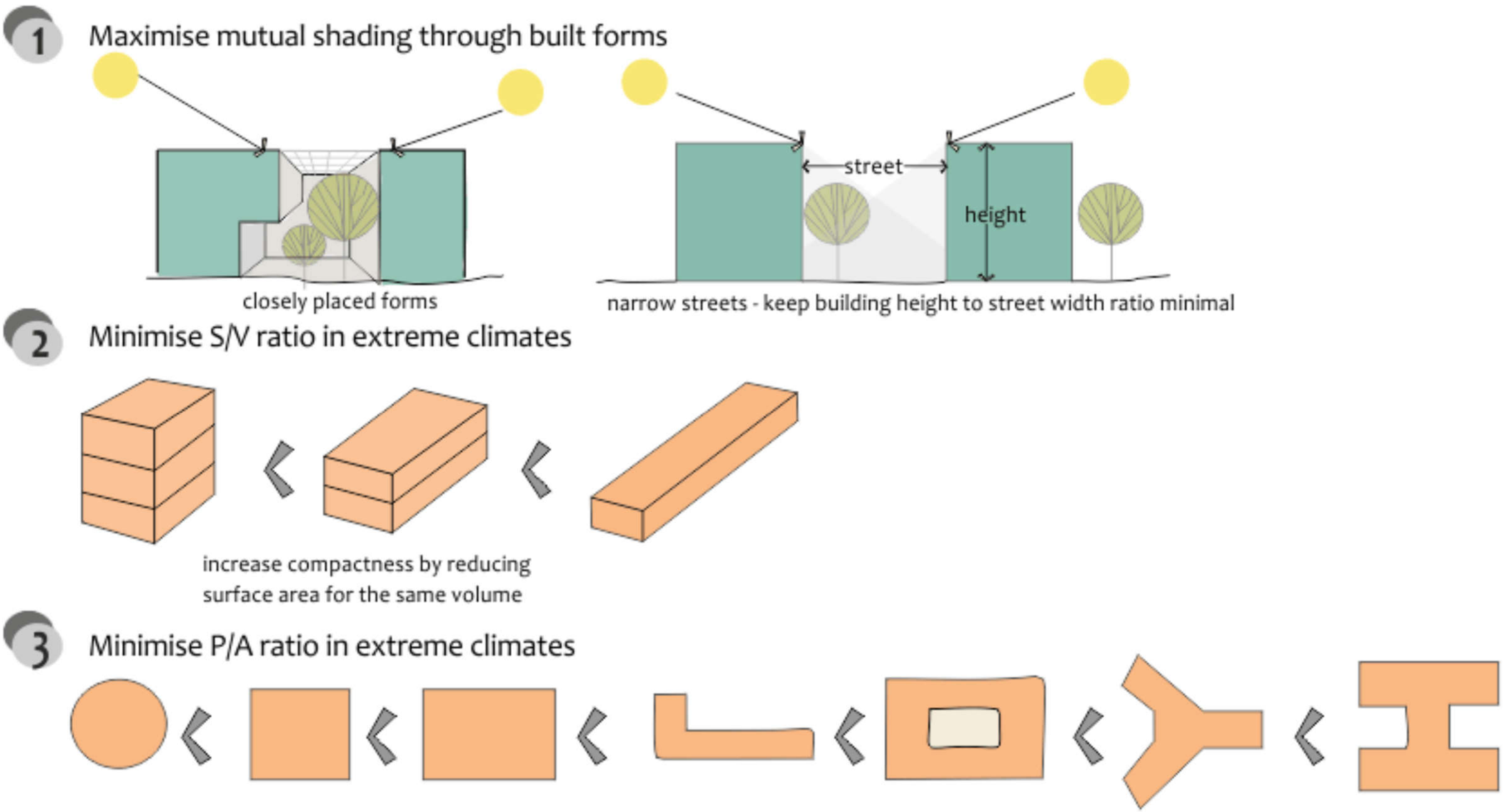
Taller forms in the wind direction of prevailing wind can alter the wind movement pattern for low lying buildings behind them



staggered layout helps in accentuating wind movement

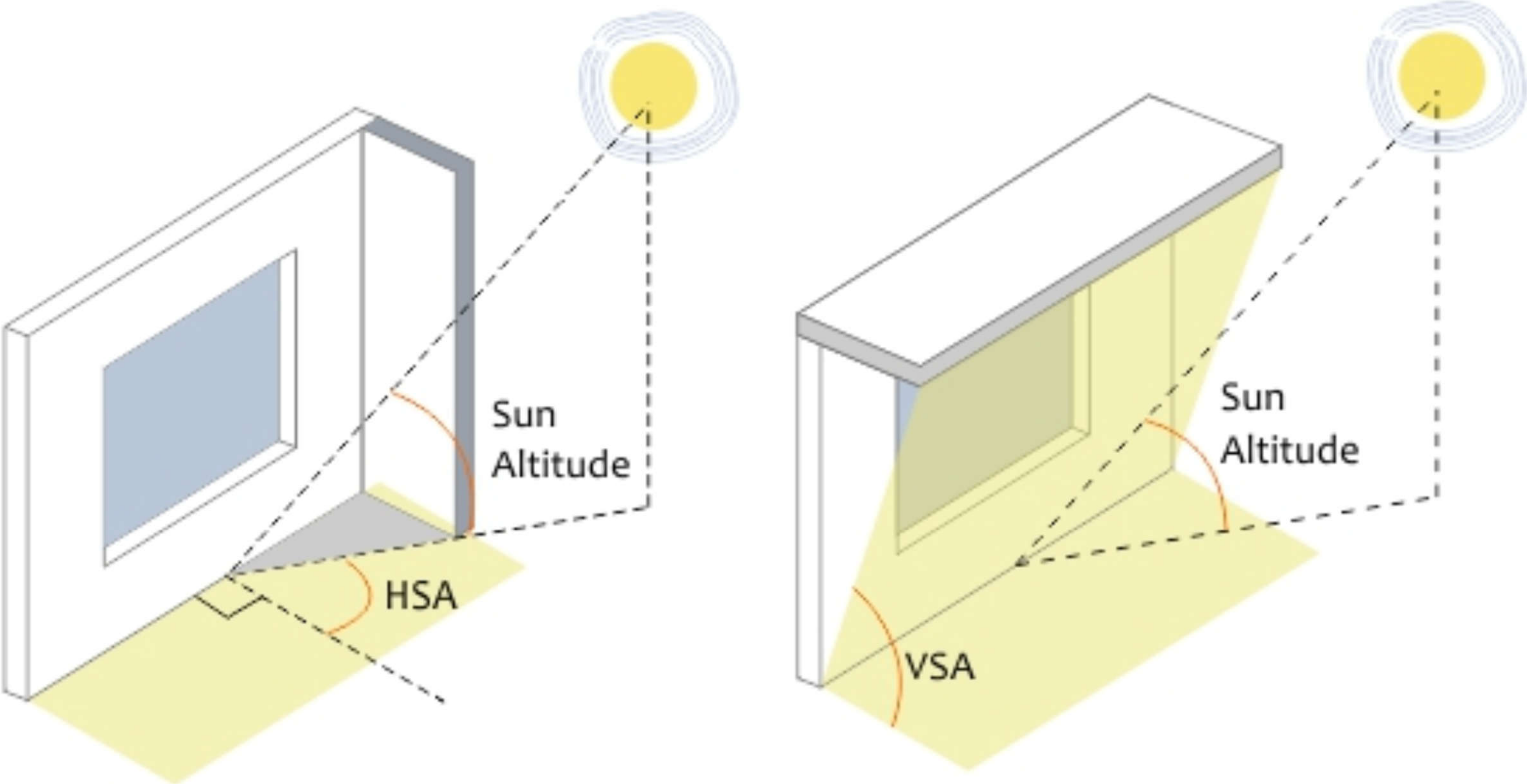
(Source: https://nzeb.in/knowledge-centre/passive-design/form-orientation/)

Building envelope design for hot region and extreme climates



(Source: https://nzeb.in/knowledge-centre/passive-design/form-orientation/)

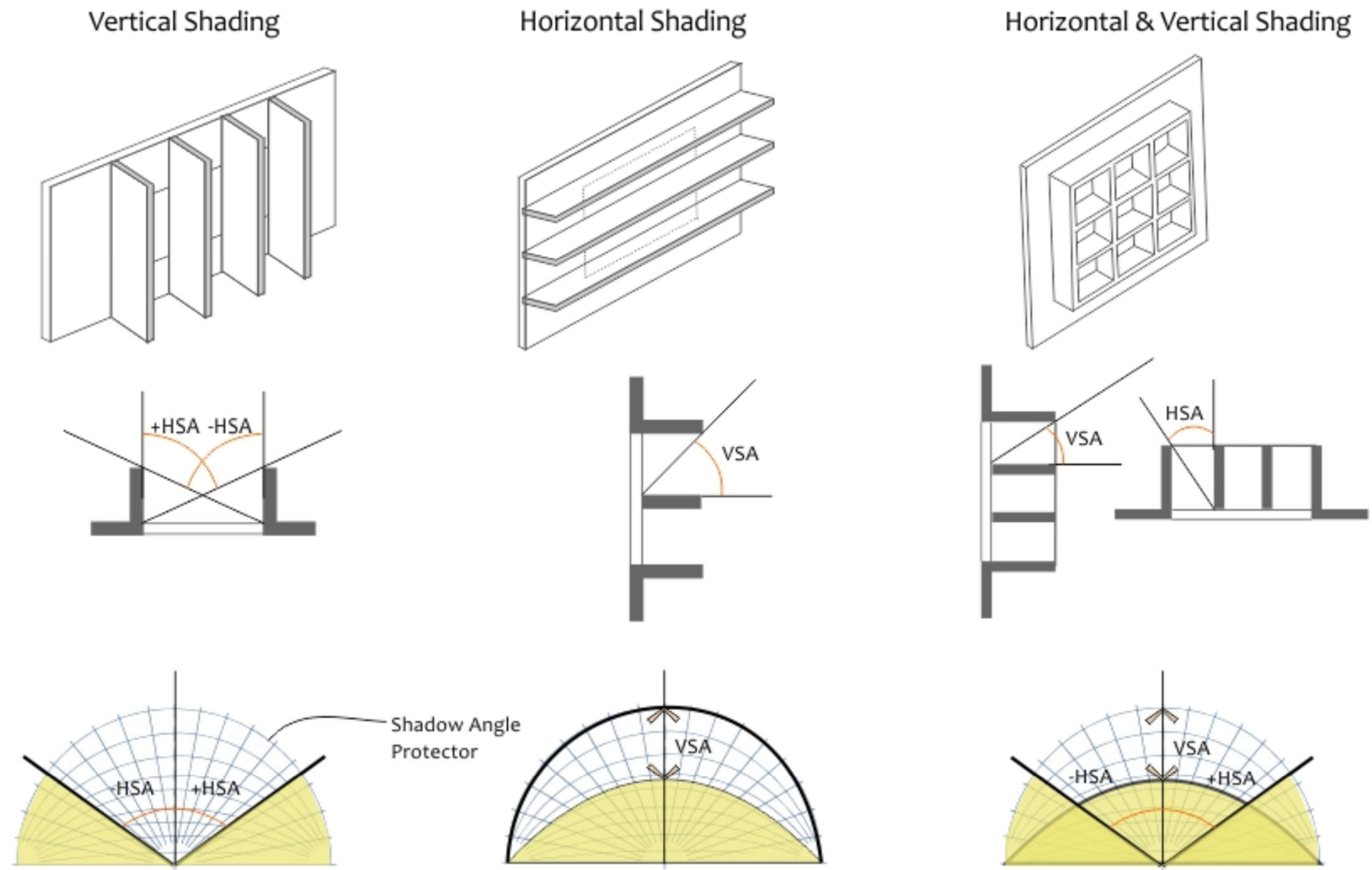
Design of side fin and overhang for solar shading



Video: Process for Designing Climate Specific Solar Shading Devices (16:59)
https://youtu.be/9girn6Y1BOE

(Source: https://nzeb.in/knowledge-centre/passive-design/shading/)

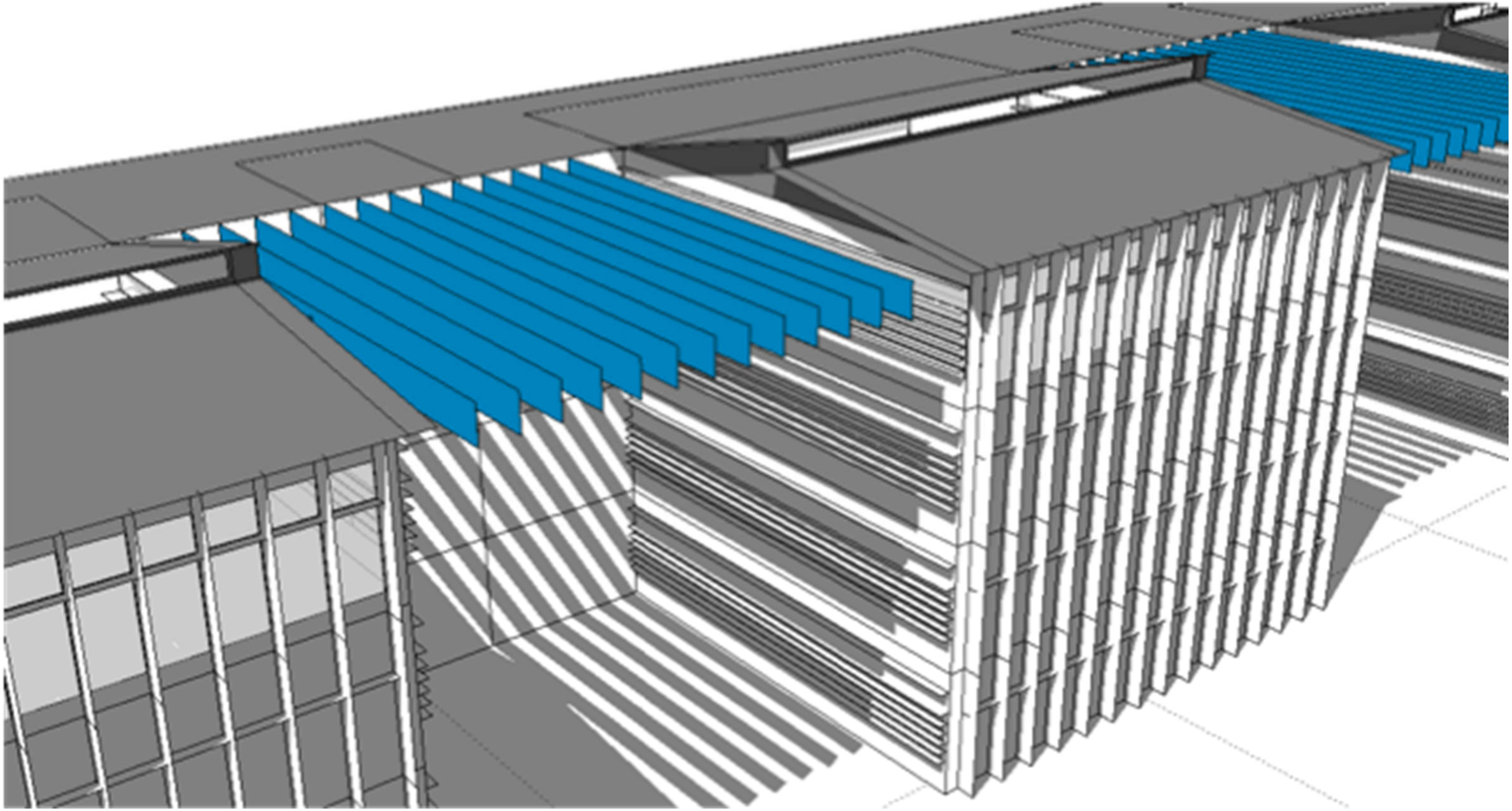
Design and analysis of shading devices



Shading mask of vertical shading device	Shading mask of horizontal shading device	Shading mask of egg crate shading device
vertical shading devices protect from sun at sides of the elevation such as east and west side	horizontal shading devices protect from sun at high angles and opposite to the wall to be shaded such as north and south sides	comination of horizontal and vertical shading devices protect from sun in all orientations

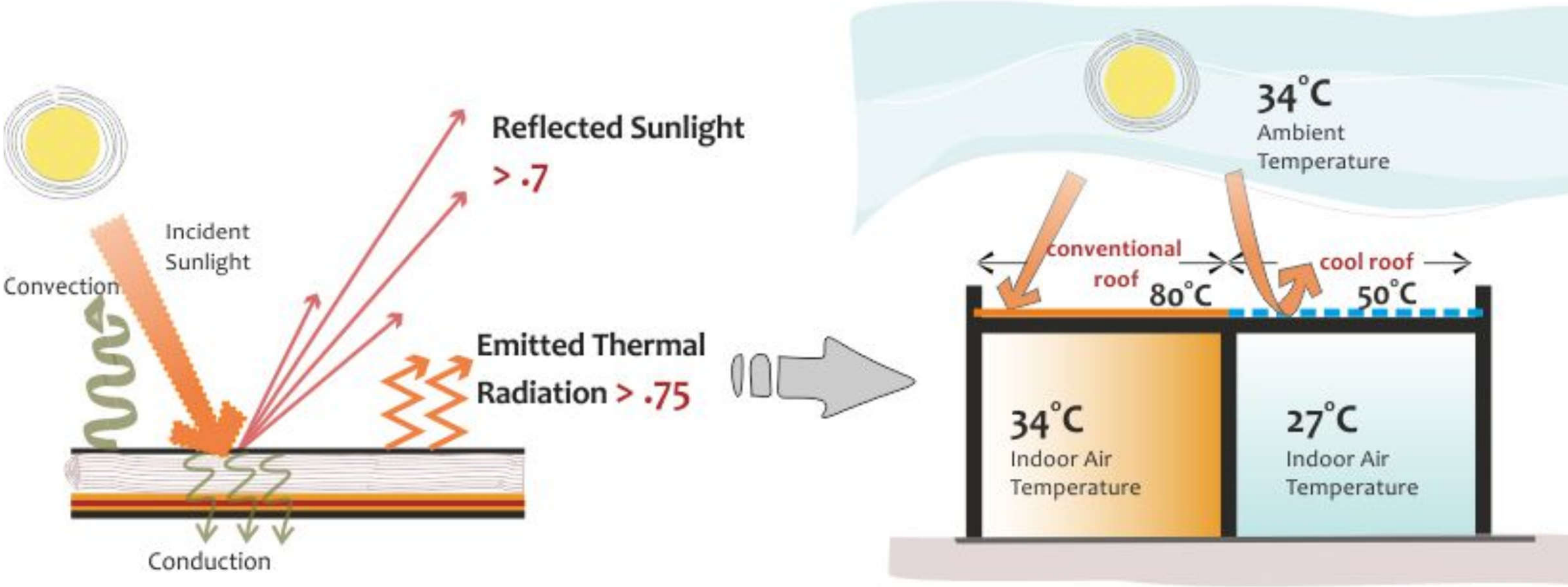
(Source: https://nzeb.in/knowledge-centre/passive-design/shading/)

Example of external shading devices



(Source: https://nzeb.in/knowledge-centre/passive-design/shading/)

Cool roof properties and performance

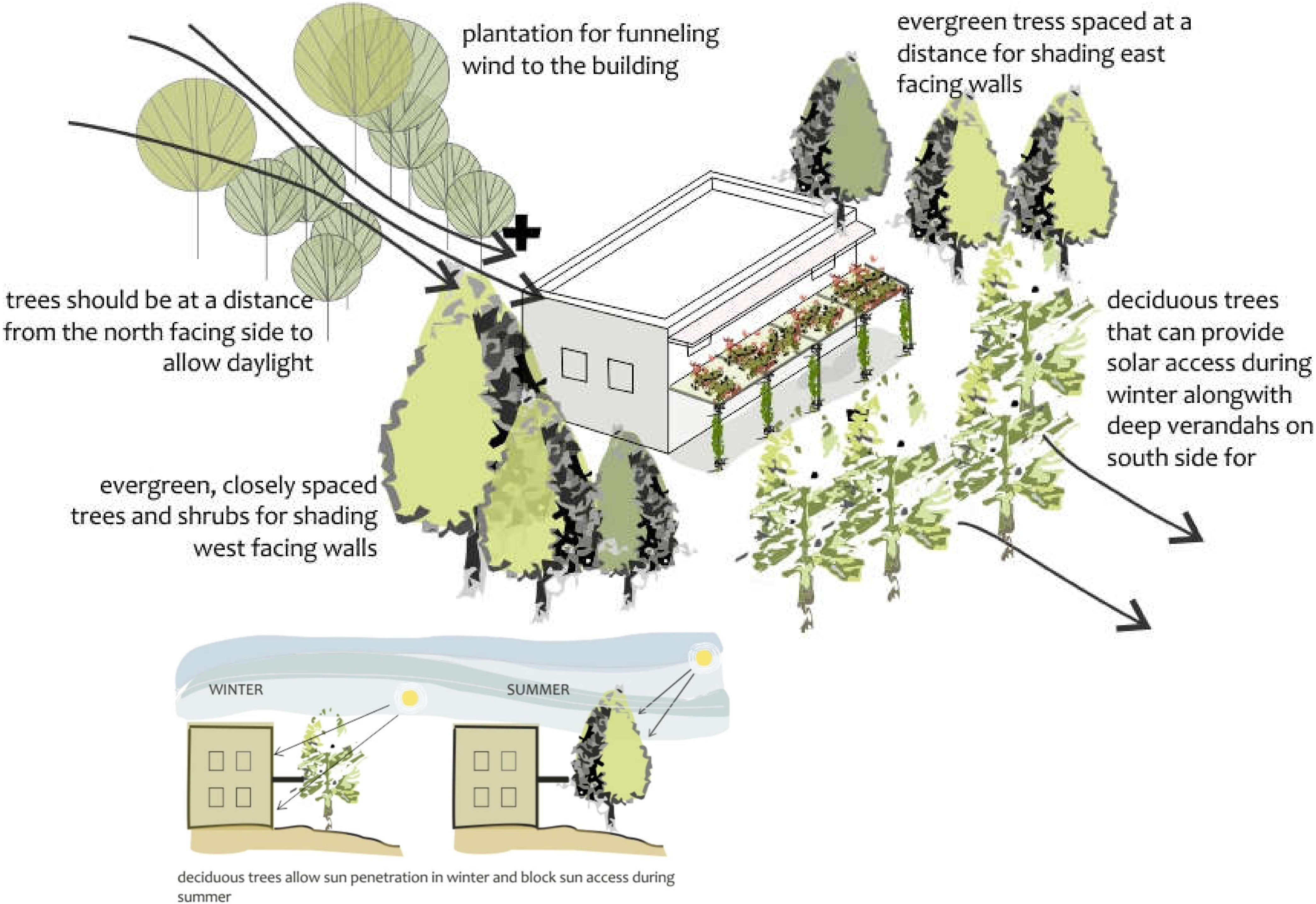


Performance of cool roofs can be assessed in terms of thermal emittance, solar reflectance or Solar Reflectance Index (SRI), which is a measure of both emittance and reflectance.

Cool roofs are able to maintain a temperature differential of 6-8 deg celcius between ambient and indoor air temperature due to high thermal emittance and solar reflectance.

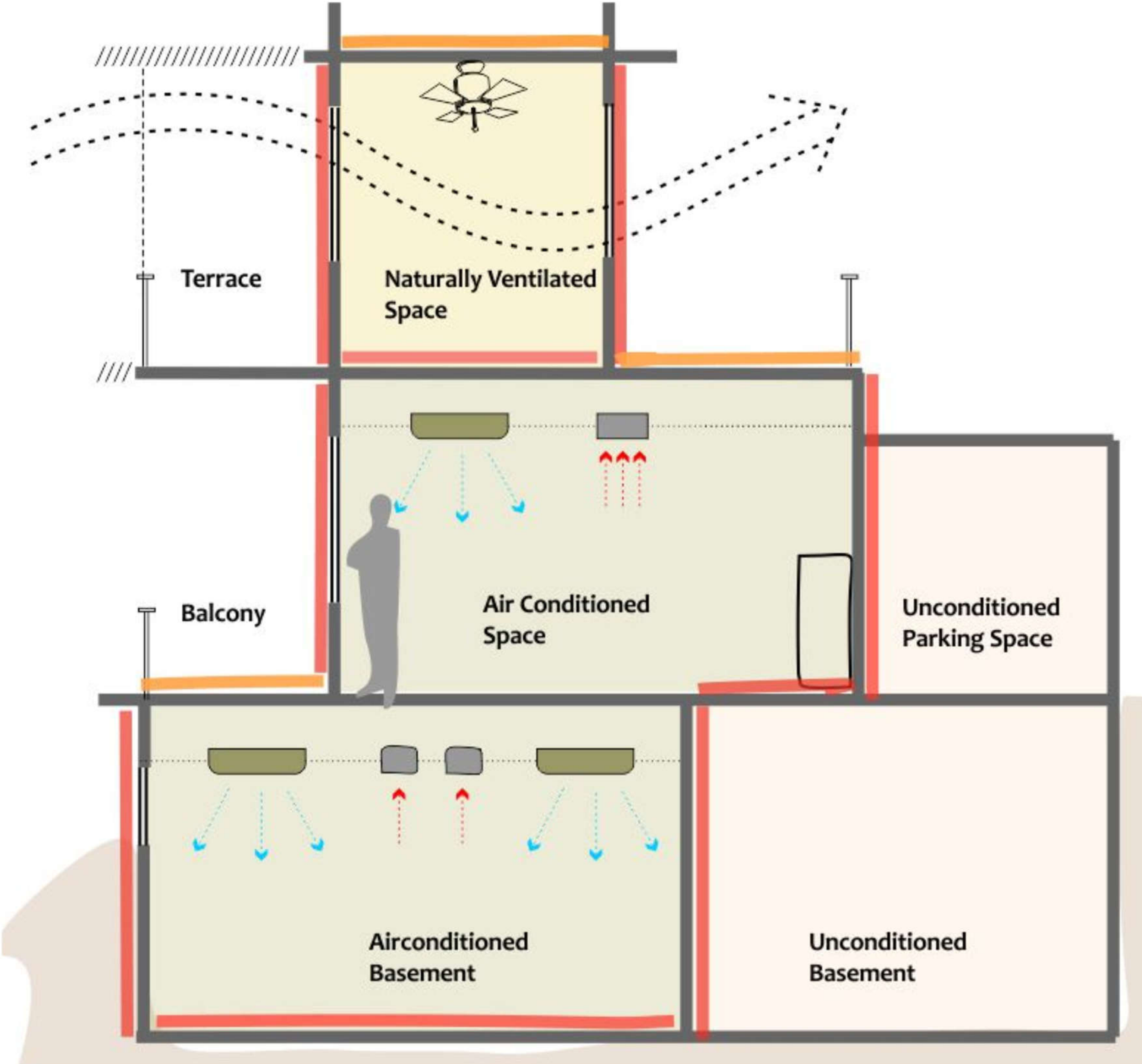
(Source: https://nzeb.in/knowledge-centre/passive-design/cool-roofs/)

Vegetation for shading and modifying microclimate and wind



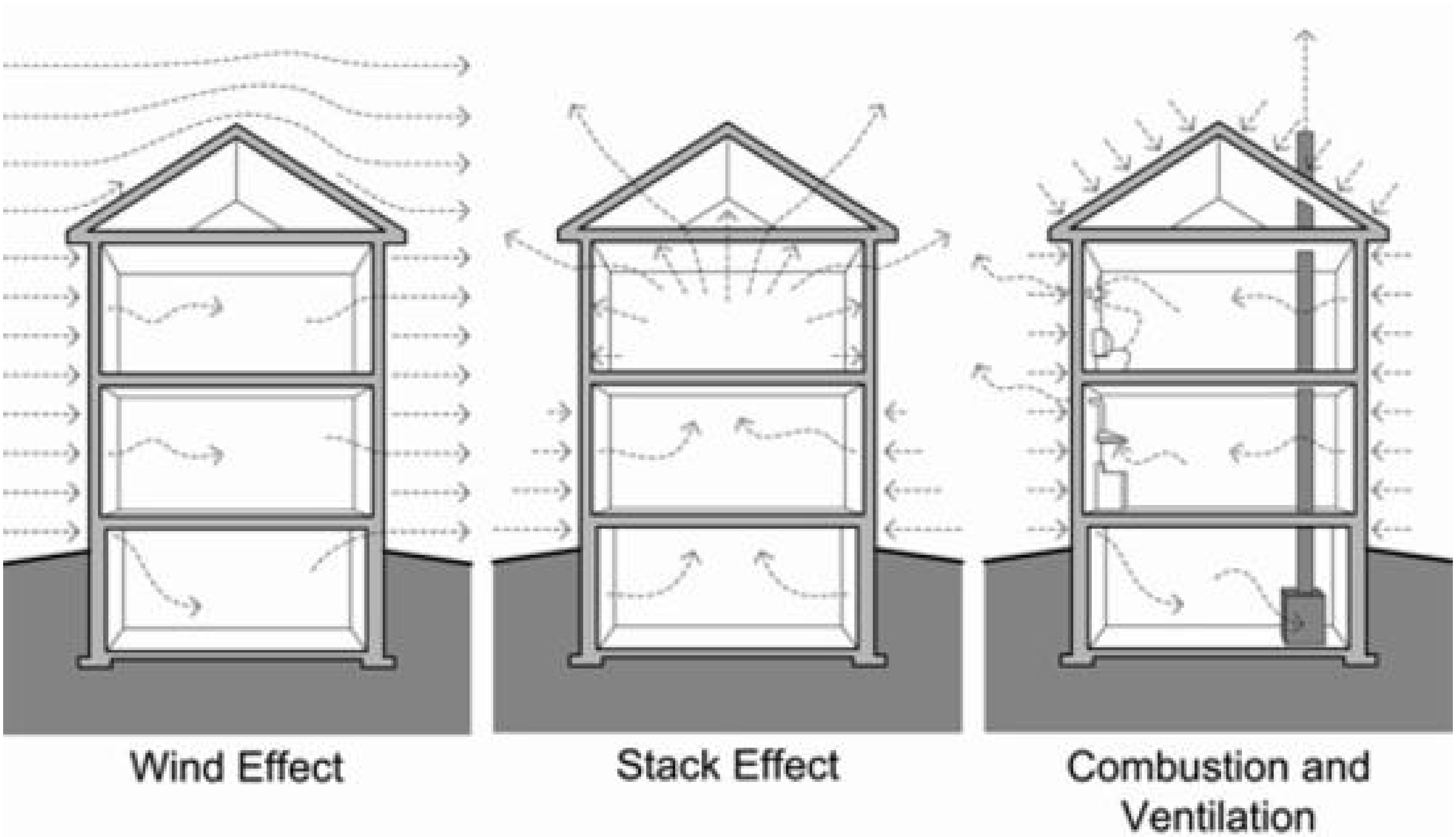
(Source: https://nzeb.in/knowledge-centre/passive-design/vegetation/)

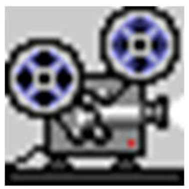
Thermal insulation in walls and roofs to reduce heat transfer



(Source: https://nzeb.in/knowledge-centre/passive-design/insulation/)

Forces driving air flow through building envelopes/enclosures





Video: Natural Ventilation - Passive Cross Wind System Explained (1:40)
https://youtu.be/PsQNvTlBiLk

(Source: https://www.buildingscience.com/documents/digests/bsd-014-air-flow-control-in-buildings)

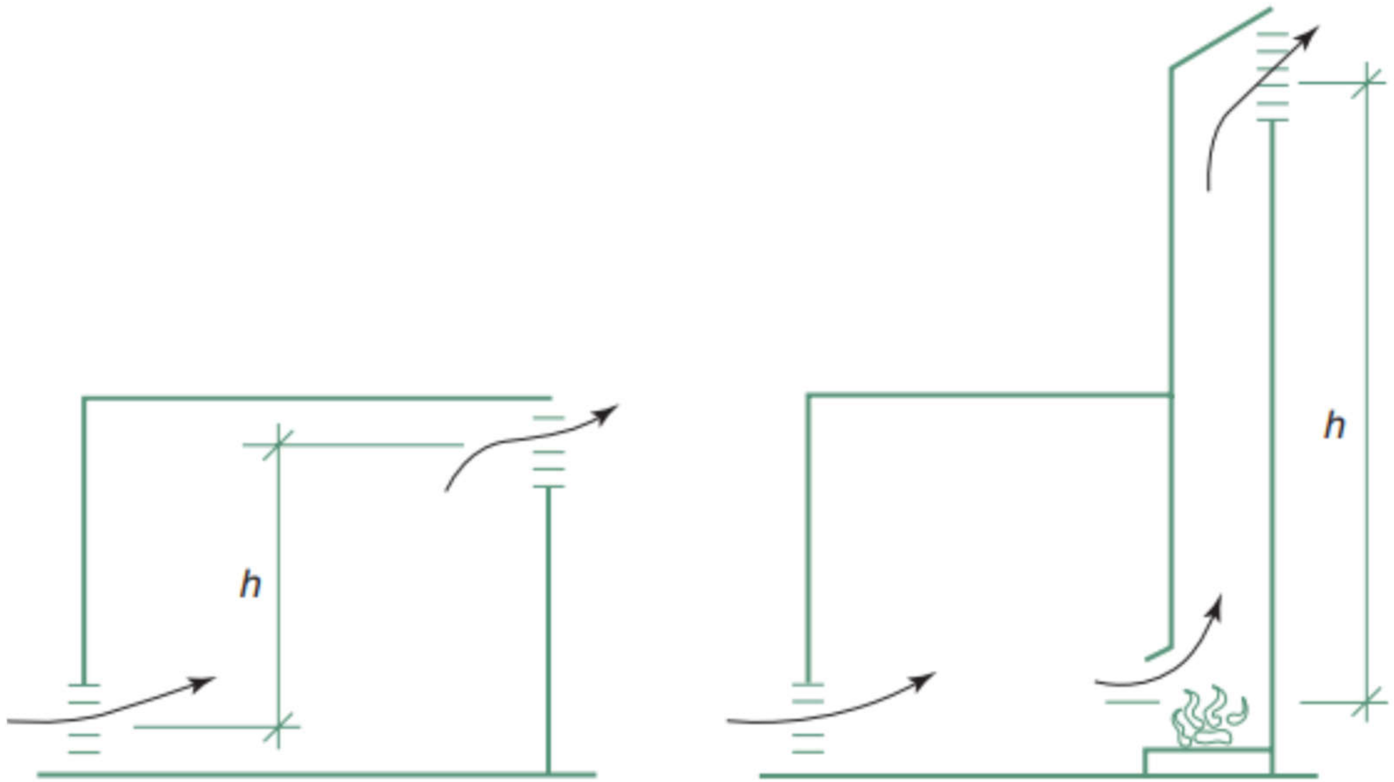
Ventilation strategy

- Maximise natural & wind-induced ventilation
- Allow for adequate internal airflow
- Consider the use of fan-assisted cooling strategies & mechanical cooling
- Air flow & ventilation
  - Stack effect: occurs when the air inside a vertical stack is warmer than the outside air
  - Wind effects: windward side > positive pressure, leeward side > negative pressure

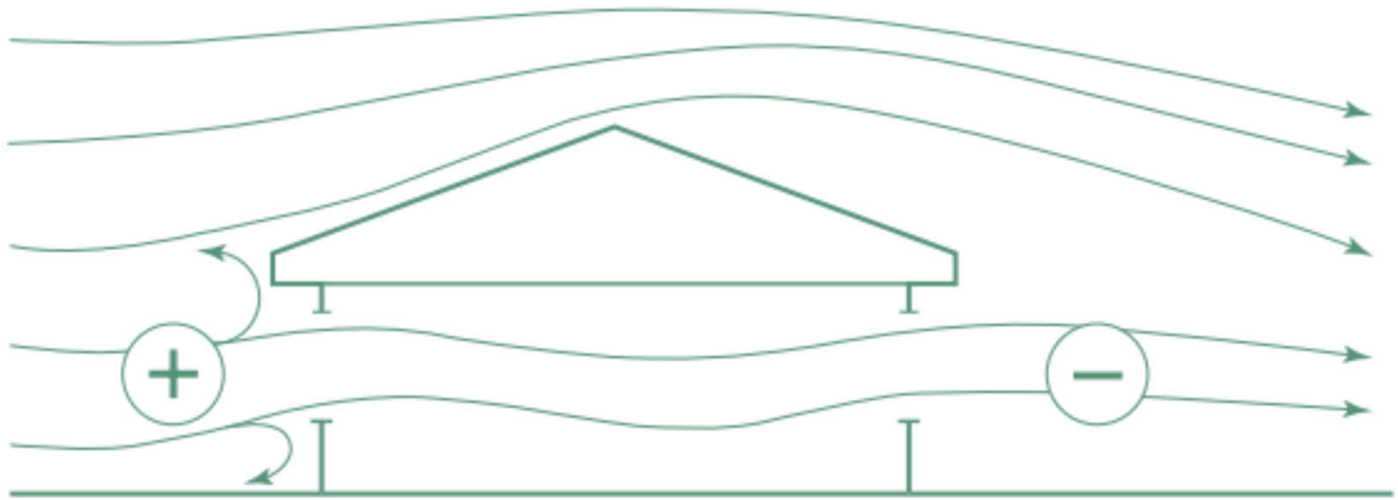
(See also: Natural Ventilation (WBDG) https://www.wbdg.org/resources/natural-ventilation)

Stack effect and wind effect

Stack effect in a room and in a chimney

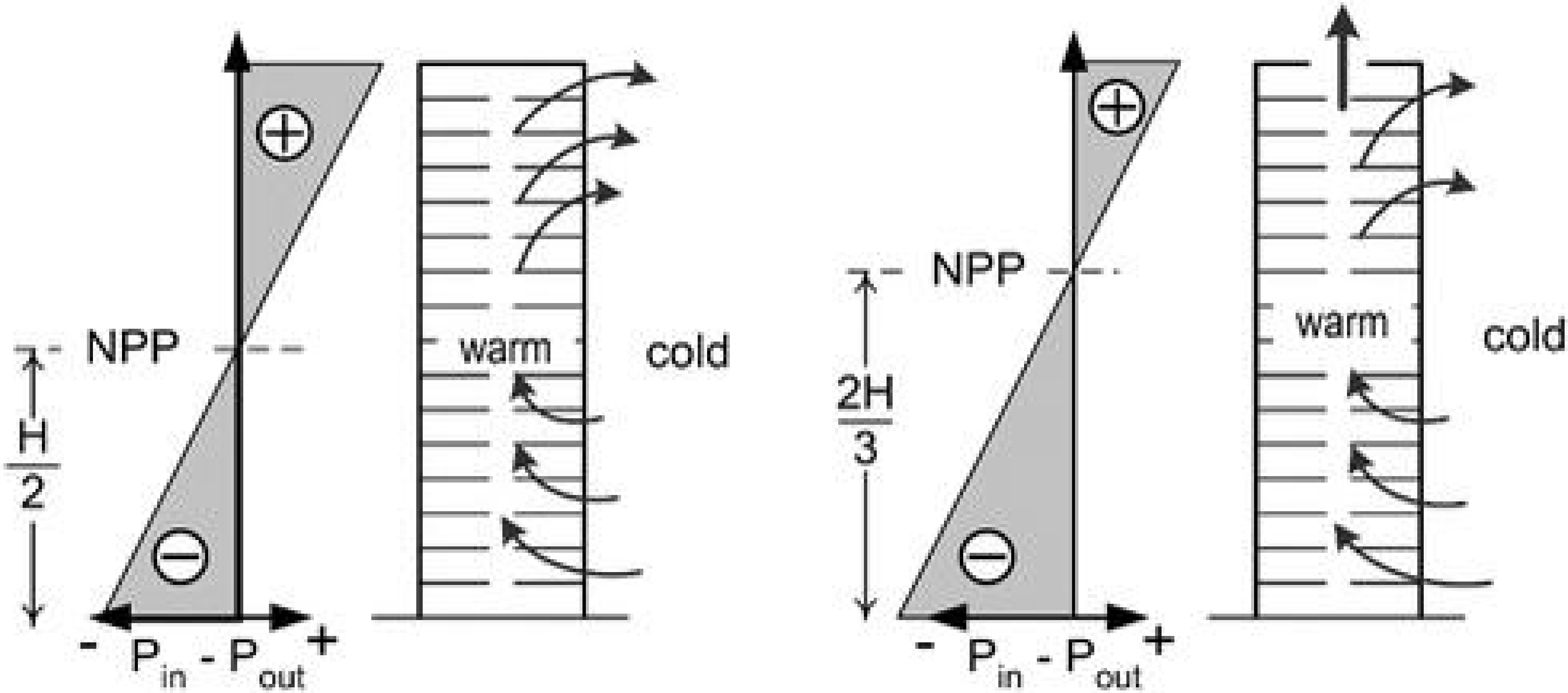


Wind effect: cross-ventilation



(Source: Szokolay S. V., 2008. *Introduction to Architectural Science: the Basis of Sustainable Design*, Second edition.)

Stack effect in real buildings



NPP = Neutral Pressure Plane

(*Left*) Floors leakier than walls: building acts like a perforated tub
(*Right*) Top leakier than bottom: NPP rise

(Source: https://www.buildingscience.com/documents/digests/bsd-014-air-flow-control-in-buildings)

Stack Ventilation Analysis

Stack ventilation rate q_B through two openings is:

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

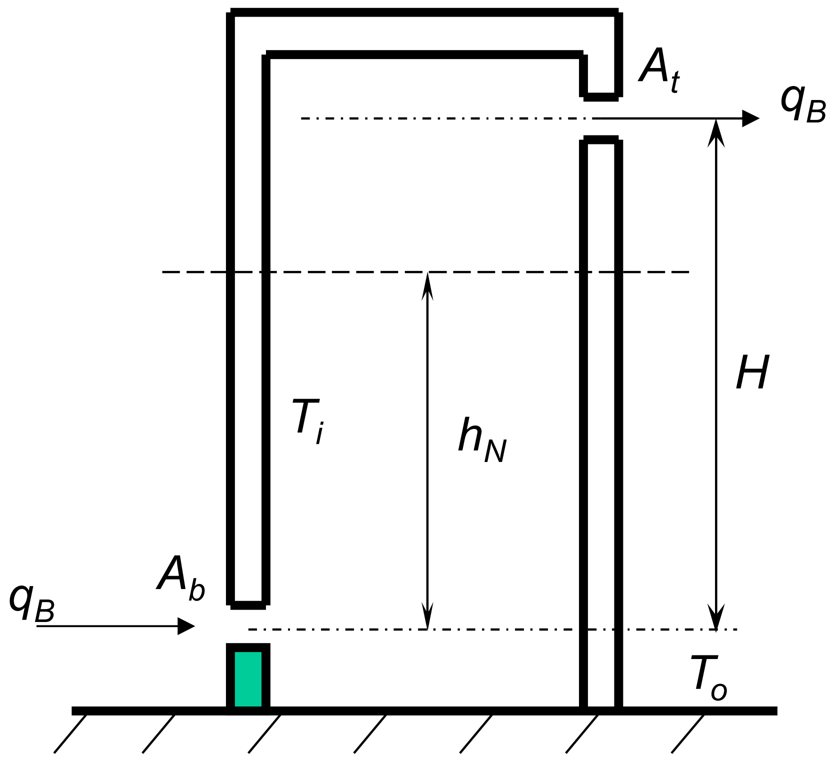
where

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

the Neutral Plane Level h_N is:

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

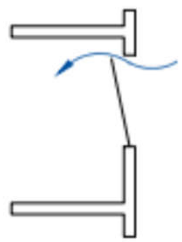
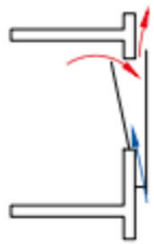
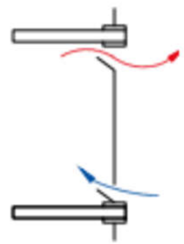
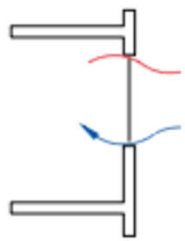
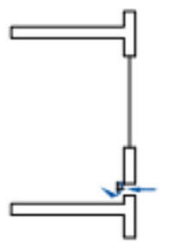
and C_d = discharge coefficient for opening, $C_d = 0.61$ for sharp-edge orifice.



Ventilation strategy

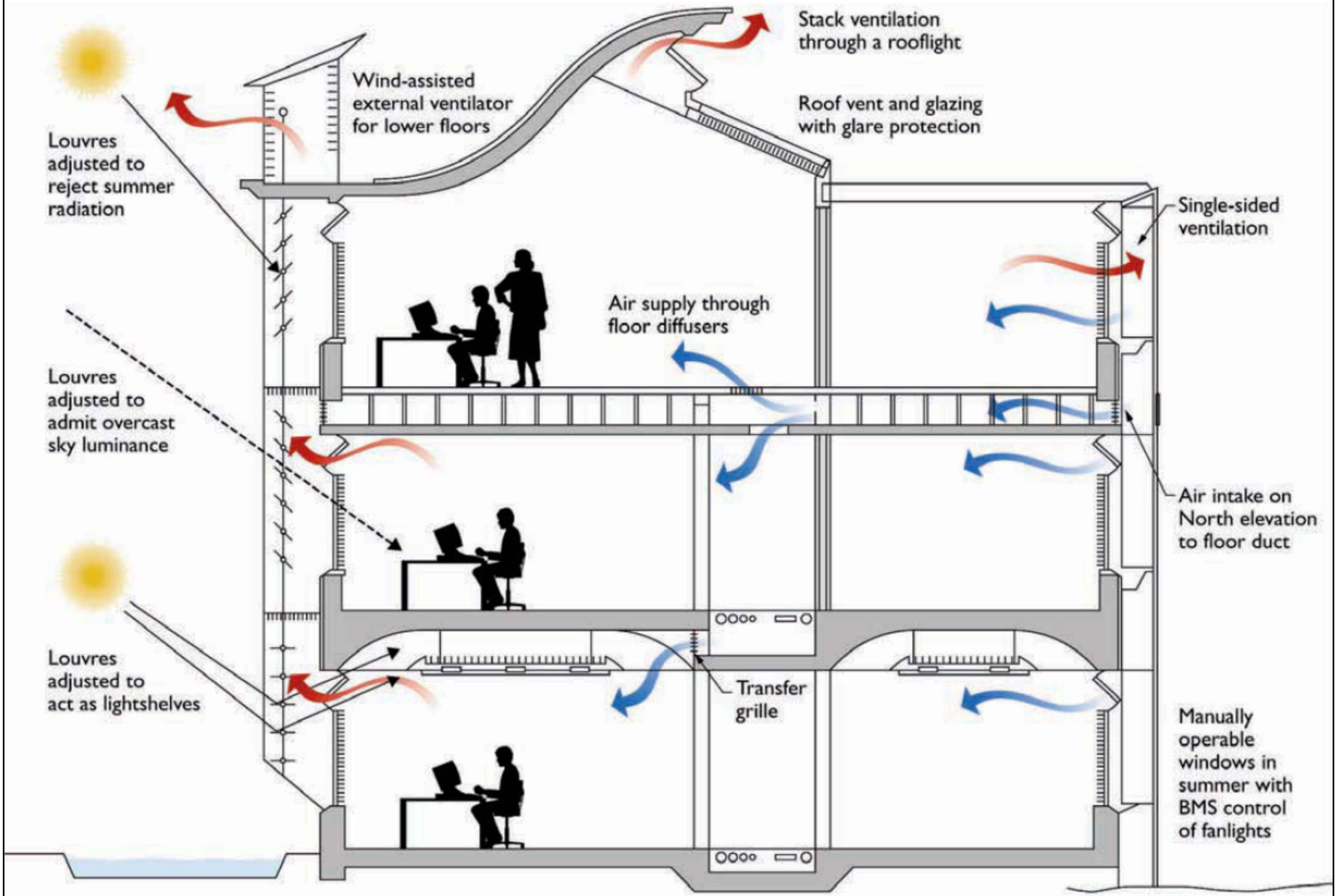
- Key factors affecting natural ventilation:
  - Depth of space related to ventilation openings
  - Ceiling height
  - Thermal mass exposed to the air
  - Location of building & possible air pollutants
  - Climate, e.g. outdoor temperature or wind velocity
- Can achieve passive cooling effect
  - Technologies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

Ventilation openings in the façade

	Air exchange rate [1/h]	Adjustability	Acoustic protection	
Ventilation through window	0.5–20	medium	low	
Ventilation through window with exterior impact pane	0.5–5	low	high	
Ventilation flaps	1–3	low	low	
Gap ventilation	0.5–2	high	high	
Ventilation opening (sensor- or pressure-controlled)	0.5–2	low–medium	very high	

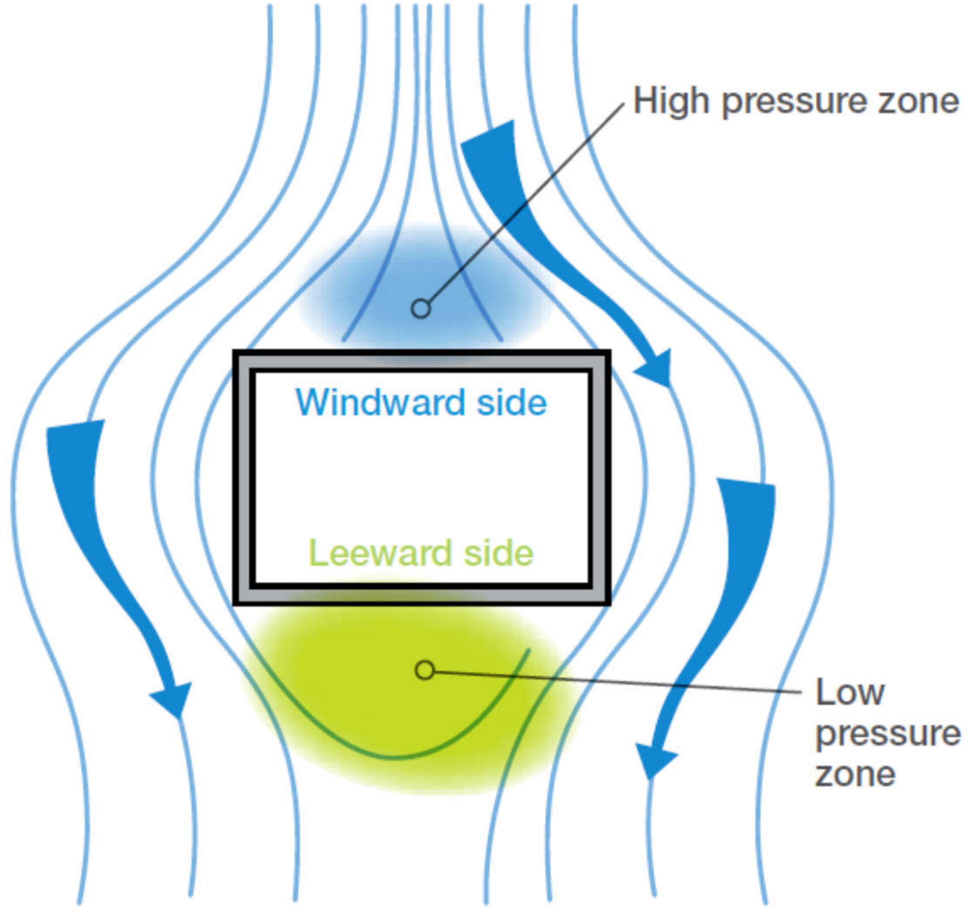
(Source: Knaack U. & Koenders E. A. B., 2018. *Building Physics of the Envelope: Principles of Construction*, Ebook Central.)

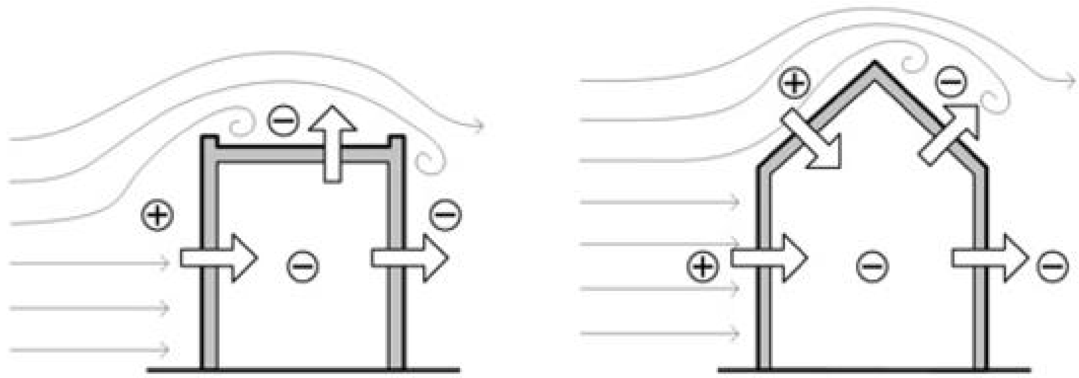
Design strategies of natural ventilation



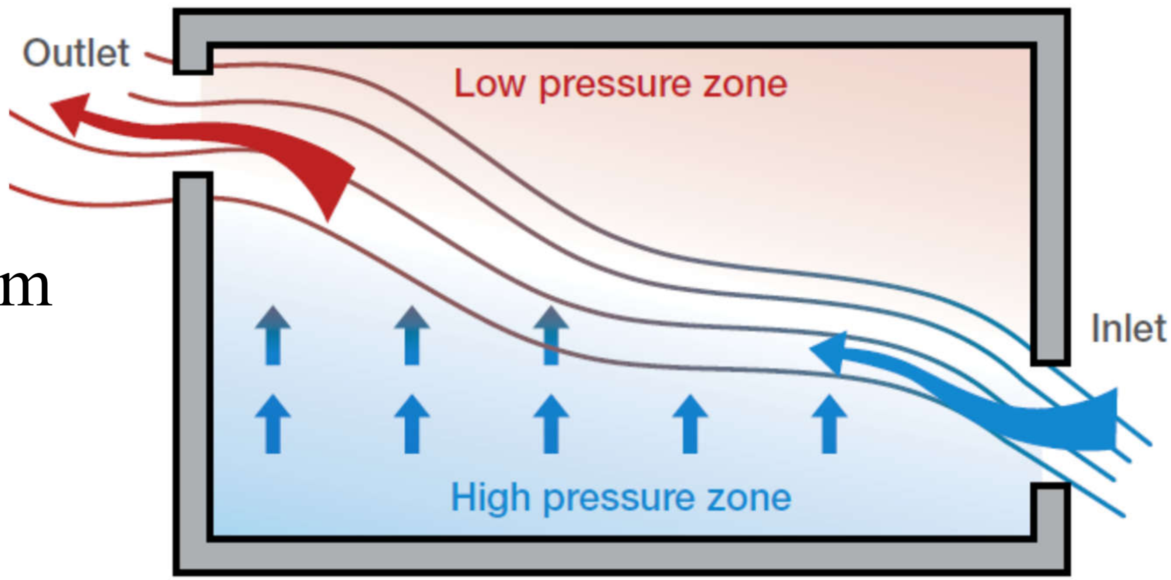
(Source: Pennycook, K., 2009. *The Illustrated Guide to Ventilation*)

Pressure effect from wind

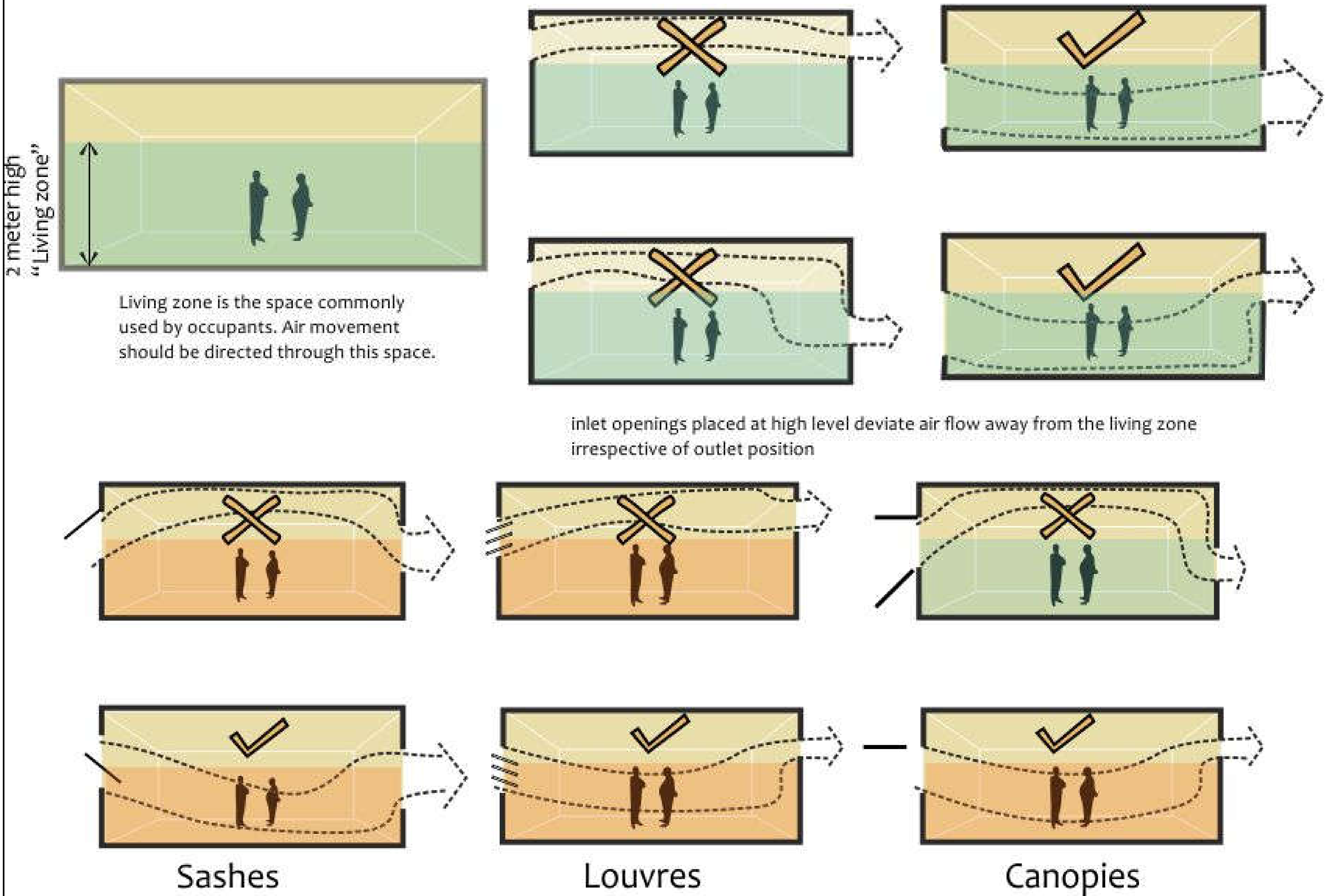




Pressure effect from stack ventilation

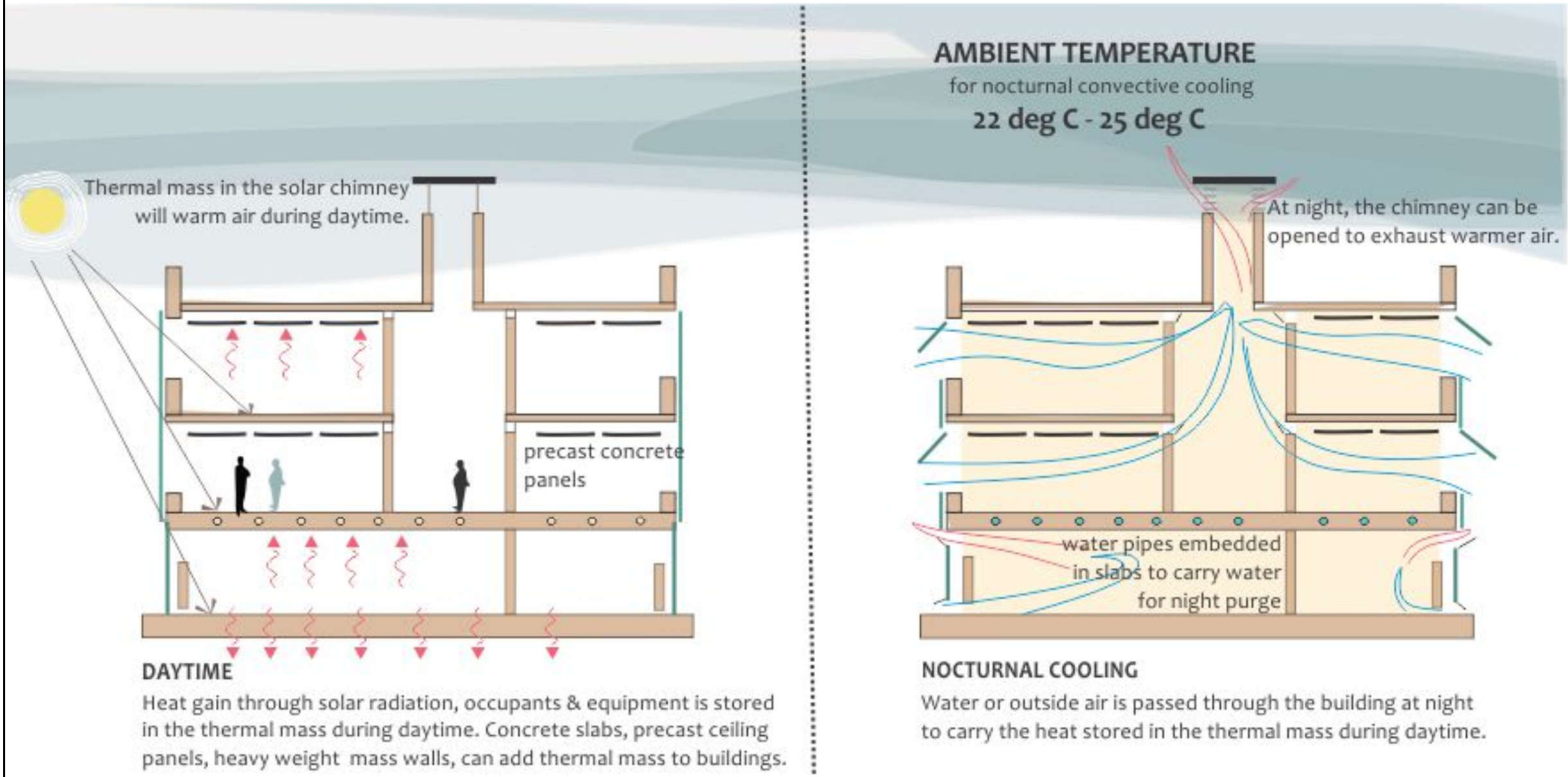


Design of building openings for good natural ventilation



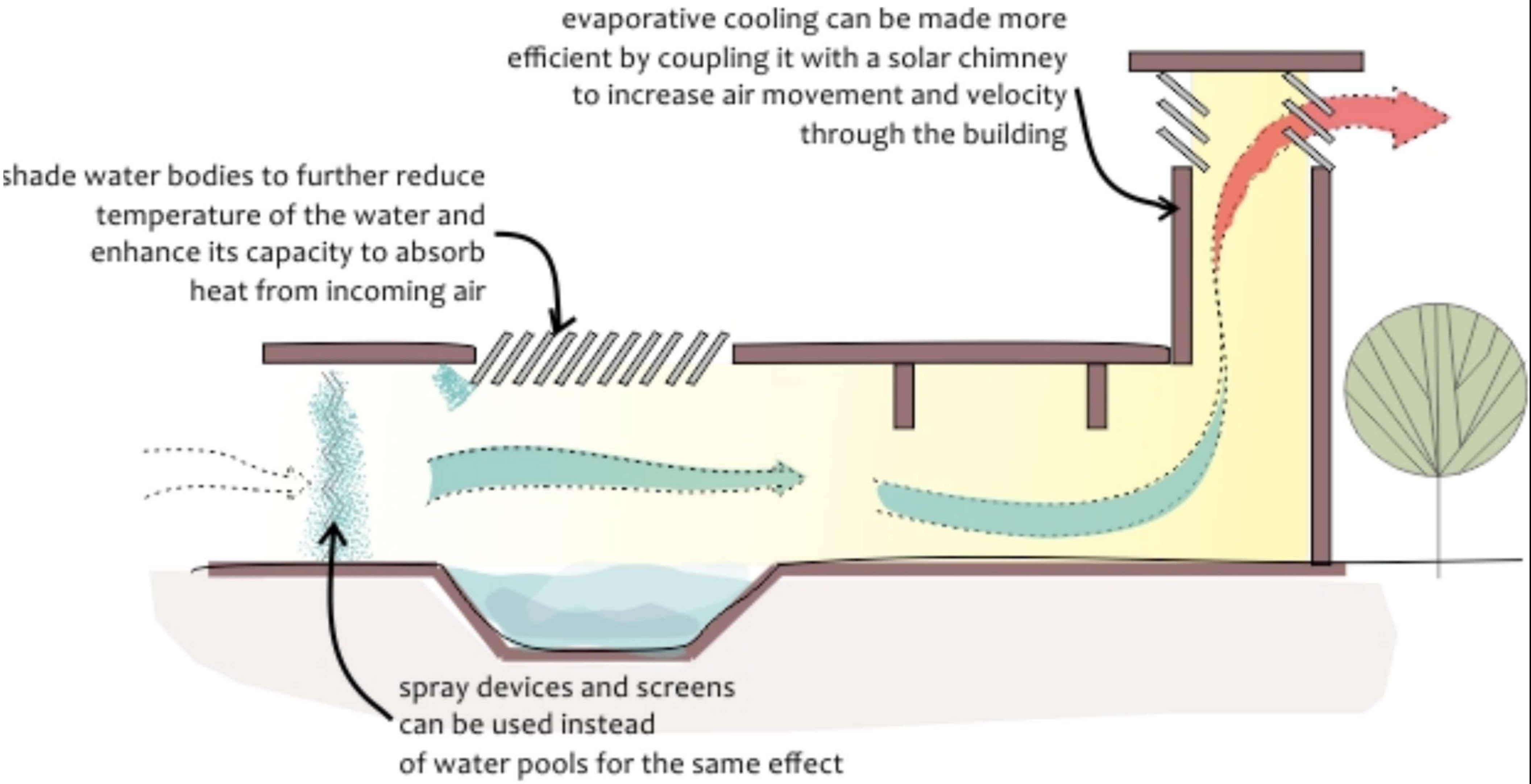
(Source: https://nzeb.in/knowledge-centre/passive-design/natural-ventilation/)

Thermal mass and nocturnal (night-time) cooling



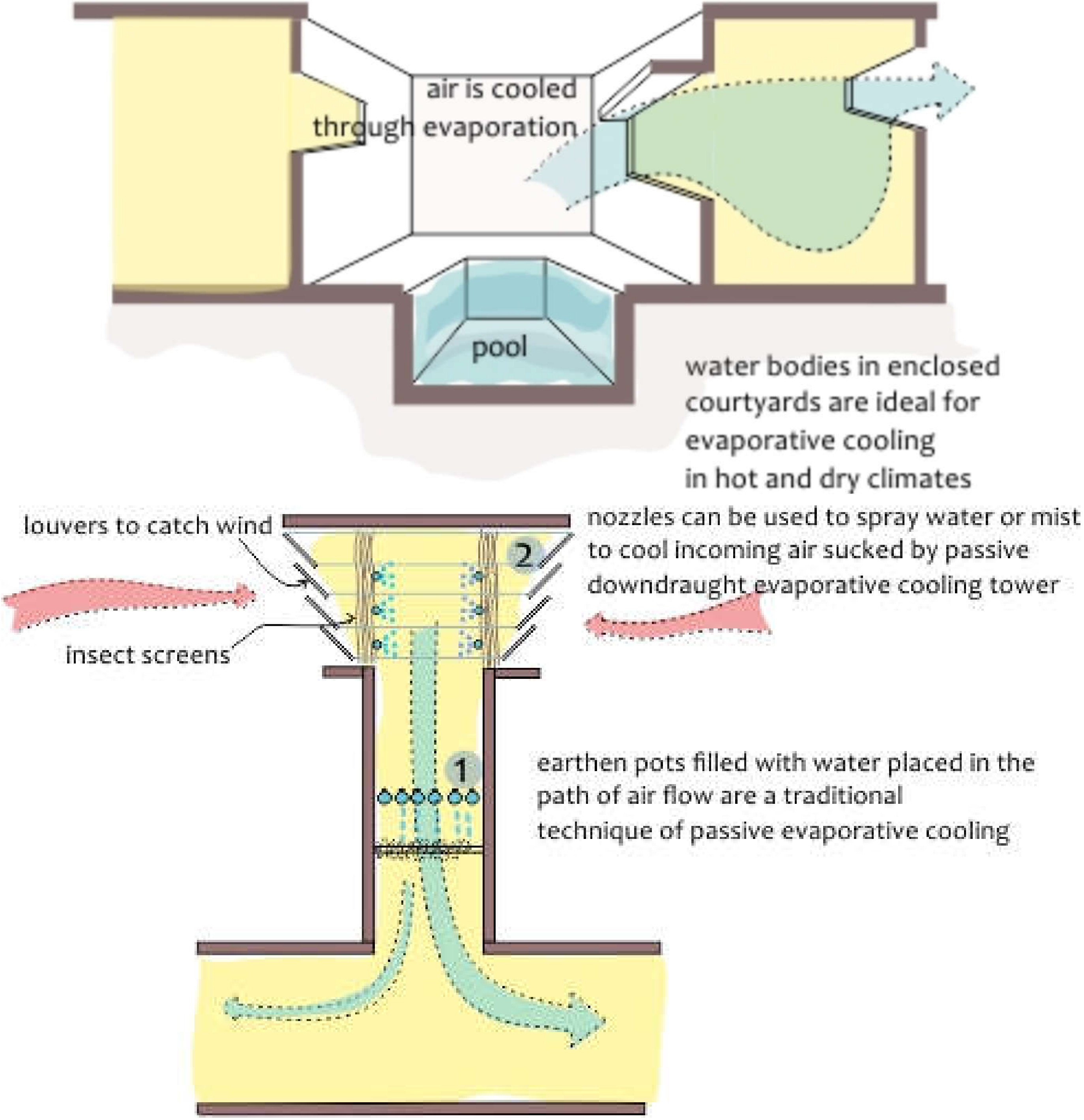
(Source: https://nzeb.in/knowledge-centre/passive-design/thermal-mass/)

Example of evaporative cooling using a water pond and solar chimney



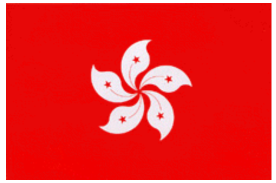
(Source: https://nzeb.in/knowledge-centre/passive-design/evaporative-cooling/)

Techniques of passive evaporative cooling



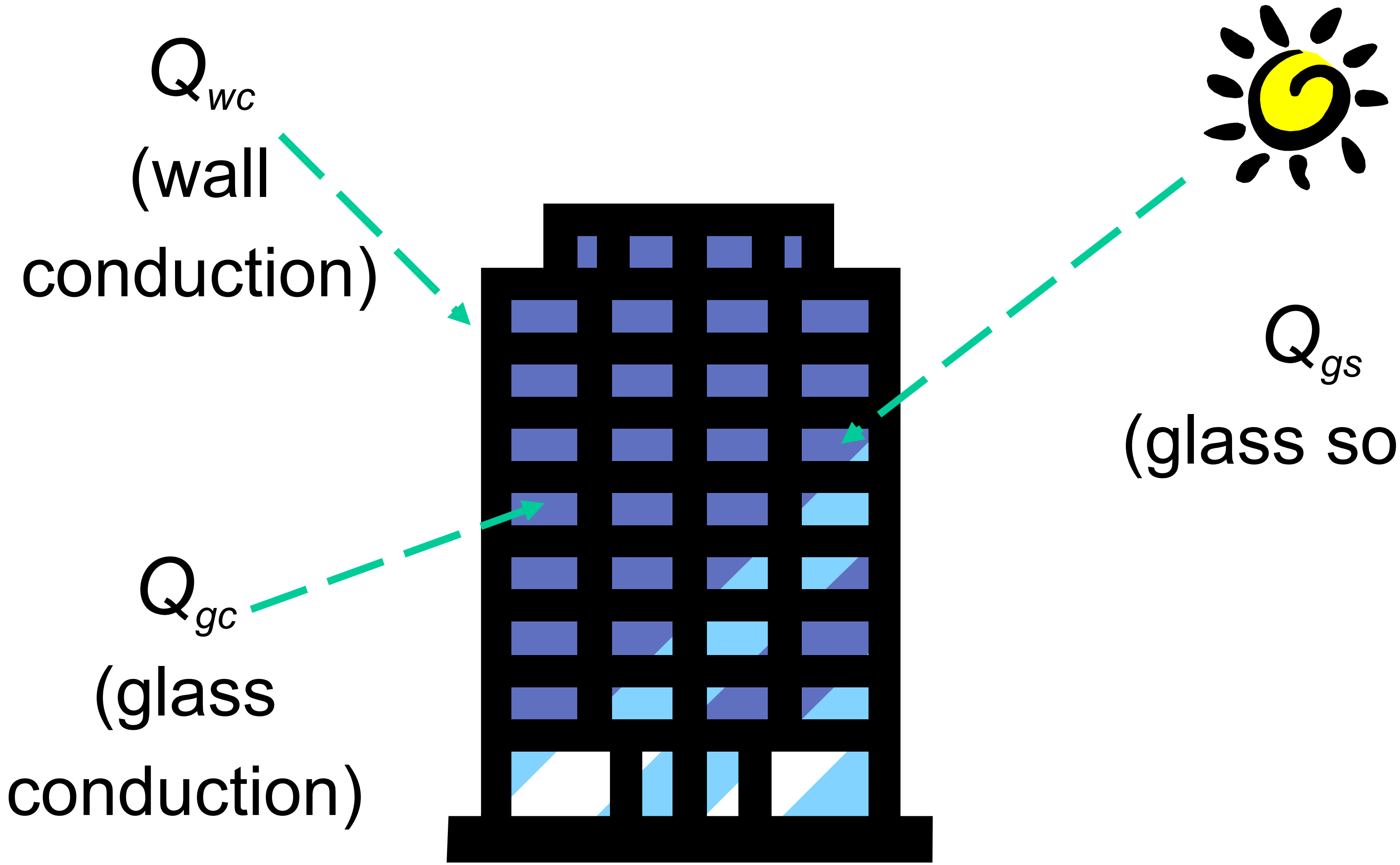
(Source: https://nzeb.in/knowledge-centre/passive-design/evaporative-cooling/)

Building codes in HK



- First energy efficiency regulation in HK
  - Building (Energy Efficiency) Regulation, Cap. 123 sub. Leg. M [implemented in July 1995]
  - Using Overall Thermal Transfer Value (OTTV) method for building envelope design control
  - Applied mainly to commercial buildings and hotels; requirements revised in 2000, 2011, 2016
    - OTTV for Tower must not exceed 21 W/m^2, and OTTV for Podium must not exceed 50 W/m^2

(Ref: Hui S. C. M., 1997. Overall thermal transfer value (OTTV): how to improve its control in Hong Kong, In *Proceedings of the One-day Symposium on Building, Energy and Environment*, 16 October 1997, Shangri-la Hotel, Kowloon, Hong Kong, HKIE BS Division/CIBSE/ASHRAE/PolyU, p. 12-1 to 12-11. http://ibse.hk/cmhui/bse97a.pdf)



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

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

Building codes in HK

- OTTV equation for Hong Kong:

$$OTTV_i = \frac{(A_w \cdot U_w \cdot \alpha \cdot TD_{eq}) + (A_f \cdot SC \cdot ESM \cdot SF)}{A_i}$$

- Two major differences from the general form:
  - Glass conduction term was omitted
  - Solar absorptivity and external shading multipler were introduced

Overall Thermal Transfer Value (OTTV)

OTTV requirement in Hong Kong

•The OTTV code was subsequently amended (for all buildings except residential buildings) in 1995 as follows: (revised 2010)

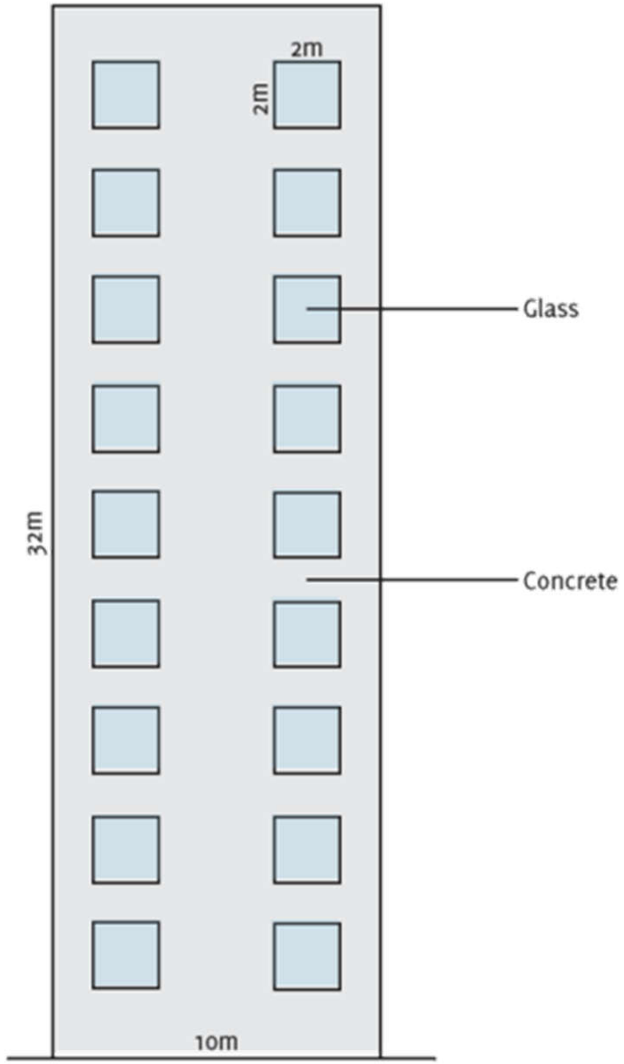
- In the case of a building tower, the OTTV should not exceed 24 W/m^2
- In the case of a podium, the OTTV should not exceed 58 W/m^2
- open-front shops or the like on ground level may be exempted from the OTTV calculations upon applications

(Source: Calculation and Application of OTTV and U-value (Science Teaching Kit for Senior Secondary Curriculum))

Overall Thermal Transfer Value (OTTV)

Exercise 1

Study the drawing and figures below and calculate the OTTV of this building. Assume that the four elevations of the building are identical. Calculate the OTTV of the building. Determine if this building follows the OTTV code in Hong Kong ($24 W/m^2$).



U-value of a wall Uw = $1.9 W/m^2K$
Outdoor temperature = 28.4ºC
Indoor temperature = 27ºC
Solar absorptivity of wall α = 0.58
External shading multiplier ESM= 1
Shading coefficient of window glass SC= 0.4
Solar factor SF = $191 W/m^2$

(Source: Calculation and Application of OTTV and U-value (Science Teaching Kit for Senior Secondary Curriculum))

Overall Thermal Transfer Value (OTTV)

Reference answer

Considering the tower part of the building:

Total area of all windows on one façade A_f = 2m x 2m x 18 = 72m^2

Area of the wall Aw = (32m x 10m)-72m^2= 248m^2

Equivalent temperature difference TDeq = 28.4°C-27°C = 1.4°C

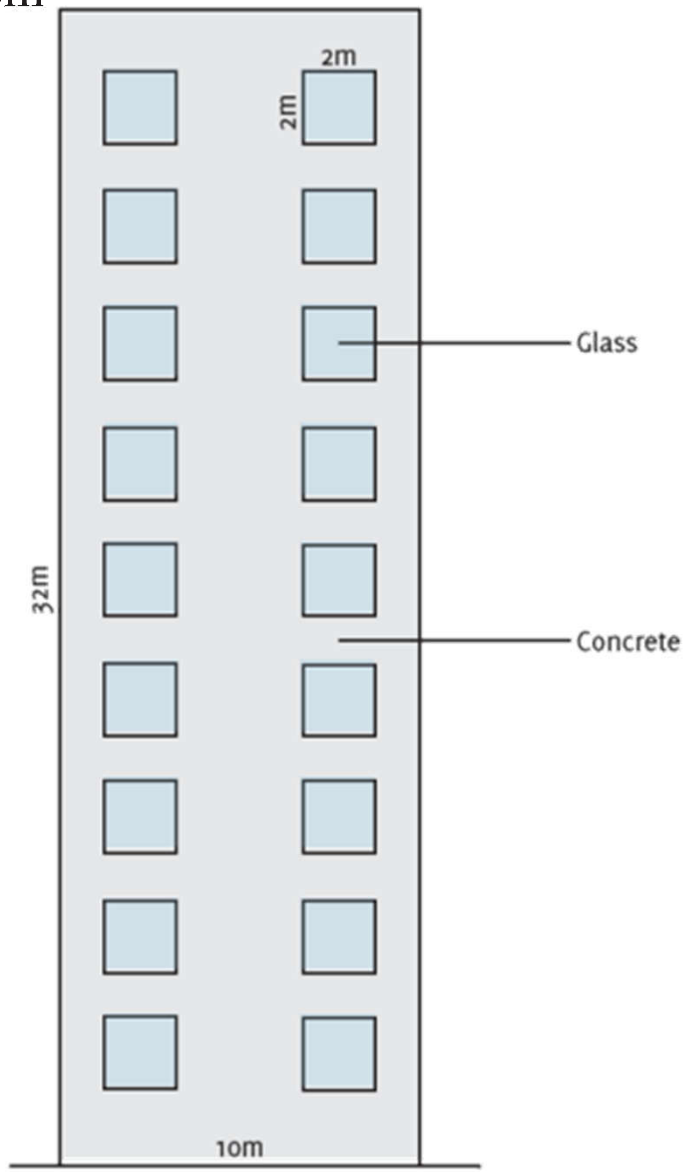
$$OTTV = \frac{Q_{wc} + Q_{gs}}{\Sigma A}$$

$$= \frac{(A_w \times U_w \times \alpha \times TD_{eq}) + (A_f \times SC \times ESM \times SF)}{A_w + A_f}$$

$$= \frac{(248 \times 1.9 \times 0.58 \times 1.4) + (72 \times 0.4 \times 1 \times 191)}{248 + 72}$$

$$= \frac{382.6 + 5500}{320}$$

$$= 18.39 \text{ W/m}^2 \ (< 24 \text{ W/m}^2)$$



(Source: Calculation and Application of OTTV and U-value (Science Teaching Kit for Senior Secondary Curriculum))

Building codes in HK

- Residential Thermal Transfer Value (RTTV)
  - To promote energy efficiency of residential buildings in Hong Kong
  - The overall RTTV of external walls and roof should not exceed 12.5 W/m^2 and 3.5 W/m^2 respectively (revised in 2022)
  - Also, promote natural ventilation in window design for maintaining thermal comfort

(Ref: BD, 2014. *Guidelines on Design and Construction Requirements for Energy Efficiency of Residential Buildings*, Buildings Department (BD), Hong Kong. https://www.bd.gov.hk/doc/en/resources/codes-and-references/code-and-design-manuals/Guidelines_DCREERB2014e.pdf; https://www.bd.gov.hk/doc/en/resources/codes-and-references/practice-notes-and-circular-letters/pnap/APP/APP156.pdf)

$RTTV_{wall}$ Calculation Formula

$$= [41.75\ WWR \times SC \times ESC \times G_w] + [3.57(1-WWR) \times U_w \times \alpha \times G_w] + [0.64\ WWR \times U_f \times G_w]$$

Radiation Through Glazing	Conduction Through Opaque Wall	Conduction Through Glazing

WWR: Window to Wall Ratio

G_w : Wall Orientation Factor

SC : Shading Coefficient **ESC:** Shading Coeff. of External Shades	**U_w:** U-value of the opaque wall α : Absorptivity of the wall	**U_f :** U-value of the glazing

$RTTV_{roof}$ Calculation Formula

$$= [41.10(SRR)(SC_r)(G_s)] + [3.47(1-SRR)\ U_r\ \alpha_r\ G_s] + [0.40(SRR)U_{sl}G_s]$$

Radiation Through Skylight	Conduction Through Roof	Conduction Through Skylight

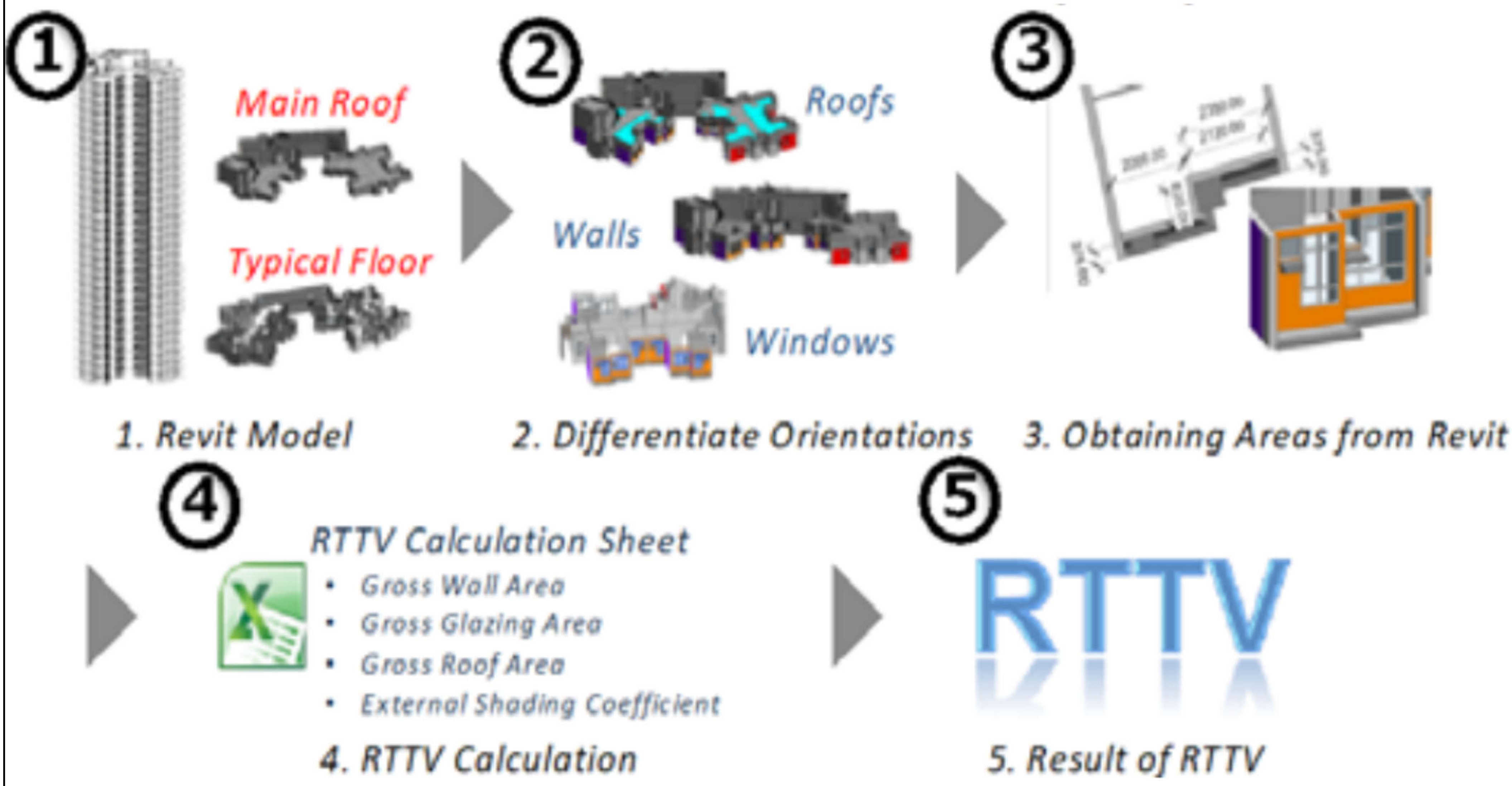
SRR : Skylight to Roof Ratio

G_s : Roof Orientation Factor

SC_r: Shading Coeff. of Skylight Glazing	U_r: U-value of the roof α_r: Absorptivity of the roof	**U_{sl} :** U-value of the skylight glazing

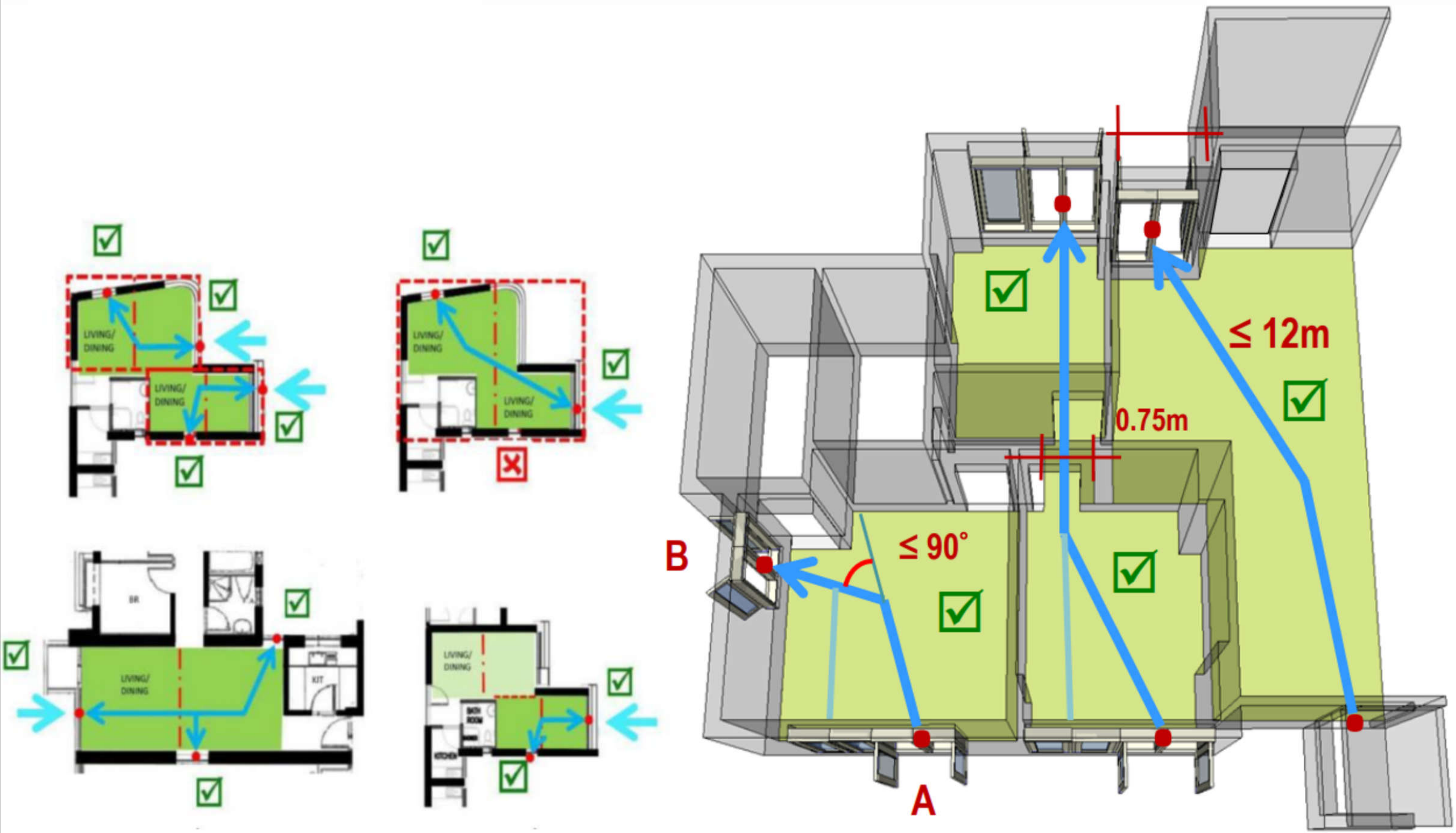
(Source: https://www.beamsociety.org.hk/files/BEC/20161123_BEAM%20Plus%20EU_Session3_MKL.pdf)

Calculation of Residential Thermal Transfer Value (RTTV) for submission of General Building Plans in Hong Kong



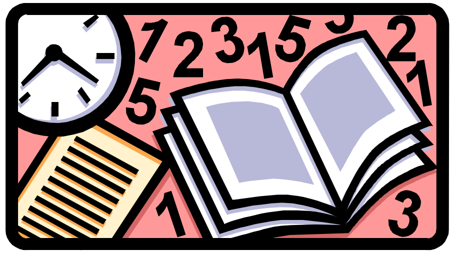
(Source: HKIP Journal Volume 34 (2020) https://www.hkip.org.hk/en-hkipjournals-search/2020/10/20/volume-34-2020)

Promote cross ventilation in window design for residential buildings



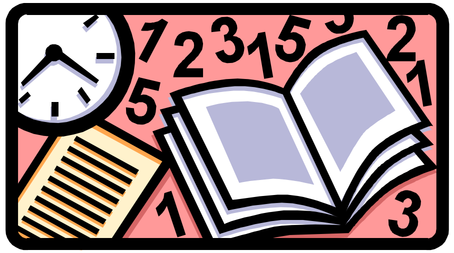
(Source: https://www.beamsociety.org.hk/files/BEC/20161123_BEAM%20Plus%20EU_Session3_MKL.pdf)

Further Reading



- Building Envelope Design Guide
  https://www.wbdg.org/guides-specifications/building-envelope-design-guide
- BSD-018: The Building Enclosure
  https://www.buildingscience.com/documents/digests/bsd-018-the-building-enclosure_revised
- BSD-014: Air Flow Control in Buildings
  https://www.buildingscience.com/documents/digests/bsd-014-air-flow-control-in-buildings

Further Reading



- Back to Basics: Natural Ventilation and its Use in Different Contexts
  - https://www.archdaily.com/963706/back-to-basics-natural-ventilation-and-its-use-in-different-contexts
- Hui S. C. M., 1997. Overall thermal transfer value (OTTV): how to improve its control in Hong Kong, In *Proceedings of the One-day Symposium on Building, Energy and Environment*, 16 October 1997, Shangri-la Hotel, Kowloon, Hong Kong, HKIE BS Division/CIBSE/ASHRAE/PolyU, p. 12-1 to 12-11. http://ibse.hk/cmhui/bse97a.pdf