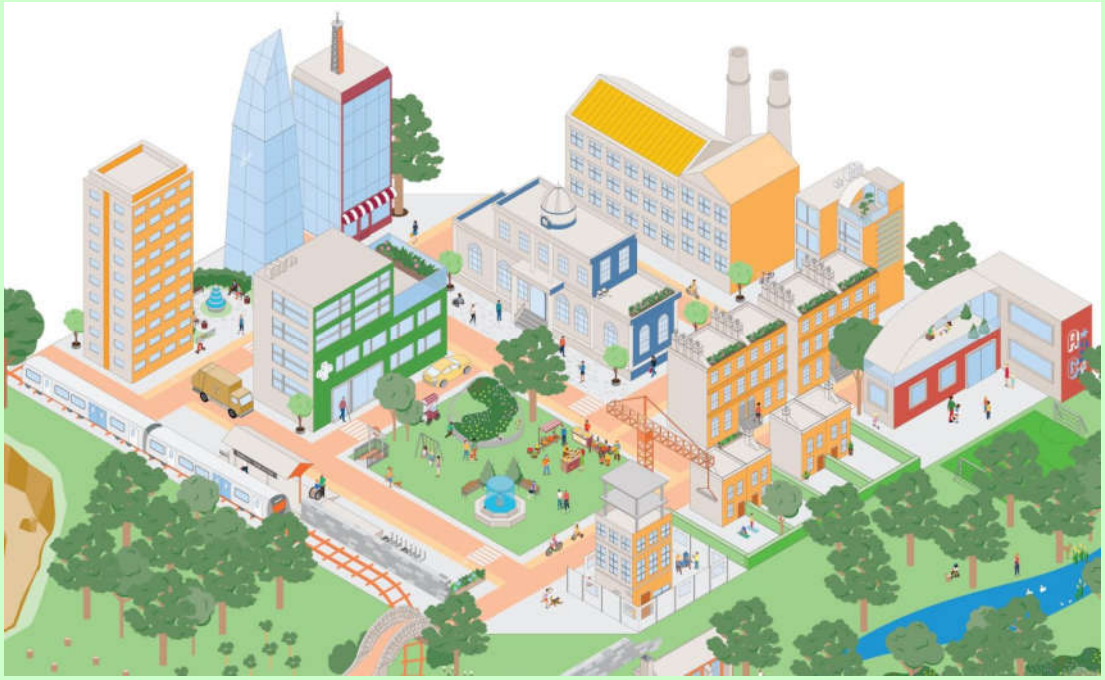
MEBS6004 Built Environment

http://ibse.hk/MEBS6004/



Introduction

Ir Dr. Sam C. M. Hui
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Aug 2024

About the Lecturer

- ***Ir Dr. Sam C. M. Hui*** *許俊民 博士 工程師* http://ibse.hk/cmhui
  - Adjunct Assistant Professor 客席助理教授, HKU Dept of Mech Engg
  - PhD, BEng(Hons), CEng, CEM, BEMP, HBDP, MASHRAE, MCIBSE, MHKIE, MIESNA, LifeMAEE, AssocAIA
    - CEng = Chartered Engineer
    - CEM = Certified Energy Manager
    - BEMP = Building Energy Modeling Professional
    - HBDP = High-performance Building Design Professional
    - LifeMAEE = Life Member, Association of Energy Engineers
    - AssocAIA = Associate Member, American Institute of Architects
  - ASHRAE Distinguished Lecturer (2009-2011)
  - President, ASHRAE Hong Kong Chapter (2006-2007)

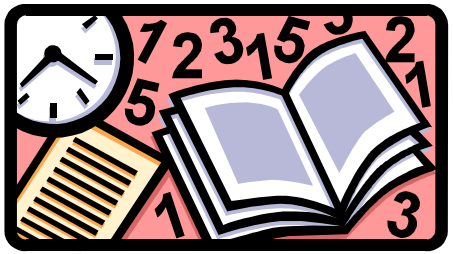
Lighting/Illuminating Engineers

Architectural/Building Science

Contents

- Course background
- Built environment
- Human factors
- Science principles
- Engineering fundamentals

Course background



- Educational Objectives:
  - To introduce students to the basic functions of buildings as a controlled environment for human activities in modern societies
  - To enable students to understand and apply the design principles for desired thermal, visual and aural environments

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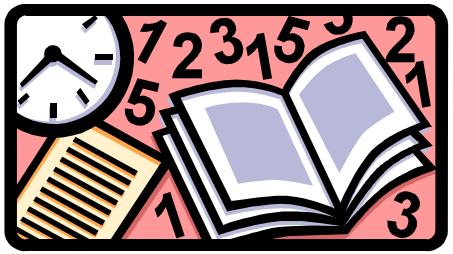
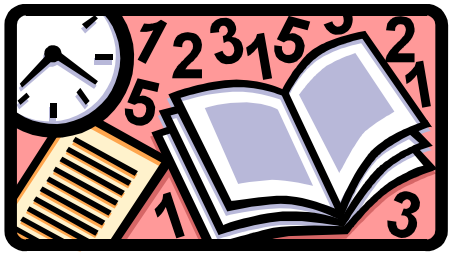
Course background

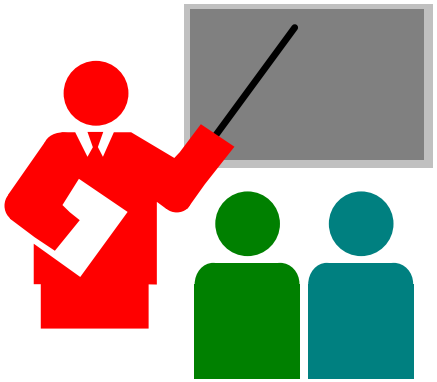


- Learning Outcomes:
  - Understand the basic functions of buildings as a controlled environment for human activities in modern societies
  - Develop practical skills to apply the design principles for desired thermal, visual and aural environments

Course background



- Prerequisite:
  - Nil
- Assessment Methods:
  - 60% by written examination (2 hours)
  - 40% by continuous assessment (3 nos. assignments)
- Course Website:
  - http://ibse.hk/MEBS6004/



Study topics of MEBS6004 Built Environment (2024-2025)

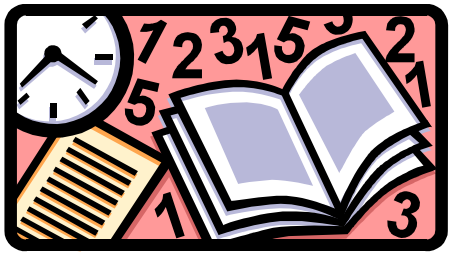
1. Introduction (3 Sep 2024)(3 hrs)
2. Climatology and climatic factors (10 Sep 2024)(3 hrs)
3. Thermal environment and heat transmission (17 Sep 2024)(3 hrs)
4. Thermal comfort and human factors (24 Sep 2024)(3 hrs)
(1 Oct 2024) National Day holiday (no lecture)
5. Building envelope design (8 Oct 2024)(3 hrs)
(15 Oct 2024) Reading week (no lecture)
6. Visual environment: basic concepts and principles (22 Oct 2024)
7. Lighting systems and components (29 Oct 2024)
8. Lighting and daylighting design (5 Nov 2024)
9. Aural environment and noise criteria (12 Nov 2024)
10. Acoustic design for buildings (19 Nov 2024)
11. Noise and vibration control (26 Nov 2024)

Ir Dr. Sam C. M. Hui

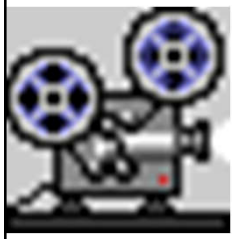
Dr. Benjamin P. L. Ho

Note: Study topics no. 6 to 11 are 2.5 hrs each

Course background



- Study methods
  - Lectures (core knowledge & discussions)
  - Further Readings (essential study information)
  - Videos (illustration & demonstration)
  - References (useful supporting information)
  - Web Links (related links & resources)
- Assignments
  - Practical skills & applications



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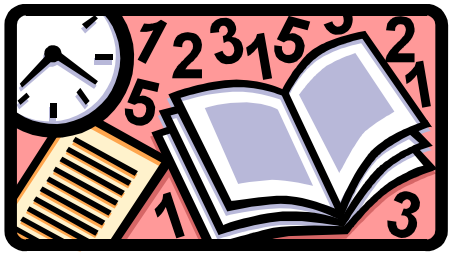
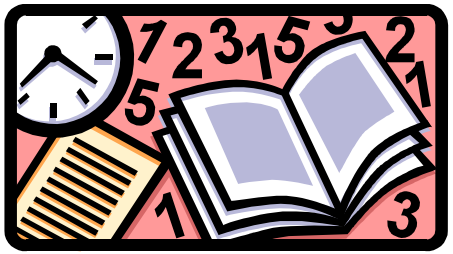
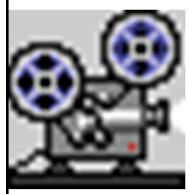


- Useful references:
  - Bradshaw V., 2006. *The Building Environment: Active and Passive Control Systems*, 3rd Edition, Wiley.
  - Heerwagen D., 2004. *Passive and Active Environmental Controls: Informing the schematic designing of buildings*, McGraw-Hill Higher Education.
  - McMullan R., 2017. *Environmental Science in Building*, 8th ed., Palgrave Macmillan.
  - Pinterić M., 2021. *Building Physics: From physical principles to international standards*, Second Edition, Springer International Publishing AG, Cham, Switzerland.
  - Szokolay S. V., 2014. *Introduction to Architectural Science: the Basis of Sustainable Design*, Third edition, Routledge, Abingdon, Oxon and New York, NY.

Course background

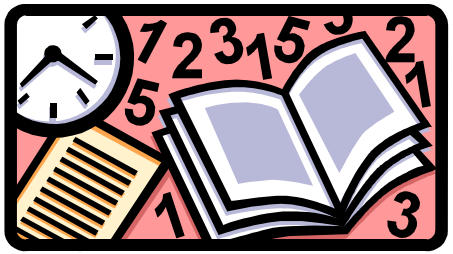


- Related professional institutions:
  - Chartered Institution of Building Services Engineers (CIBSE) http://www.cibse.org
    - CIBSE Hong Kong Region http://www.cibse.org.hk/
    - Society of Light and Lighting (SLL) http://www.sll.org.uk/
  - Hong Kong Institution of Engineers (HKIE) 香港工程師學會 http://www.hkie.org.hk/
    - Building Services Division 屋宇裝備分部 https://www.hkie-bsd.org/



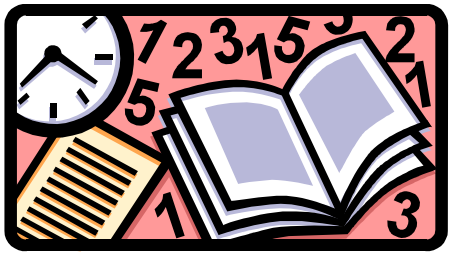
Video: 等阿Sirs話過你知，HKU學生如何取得HKIE的Building Services專業資格。(4:11) https://youtu.be/LusdQ48pfSs

Course background



- Admission requirements for HKIE Building Services Discipline
  - https://hkie.org.hk/en/membership/download_mem2/
  - Top up requirements - Six core subject areas:
    - Heating, Ventilation and Air-Conditioning (HVAC)
    - Electrical Services
    - Fire Services
    - Utility Services
    - Lighting Engineering
    - Project and Engineering Management

Course background



- List A discipline courses:
  - MEBS6000 Utility Services
  - MEBS6001 Electrical Installations
  - MEBS6002 Lighting Engineering
  - MEBS6003 Project Management
  - MEBS7012 Air Conditioning and Refrigeration
  - MEBS7013 Fire Service Installations
- List B discipline courses, such as:
  - MEBS6004 Built Environment ← Closely related to the other courses

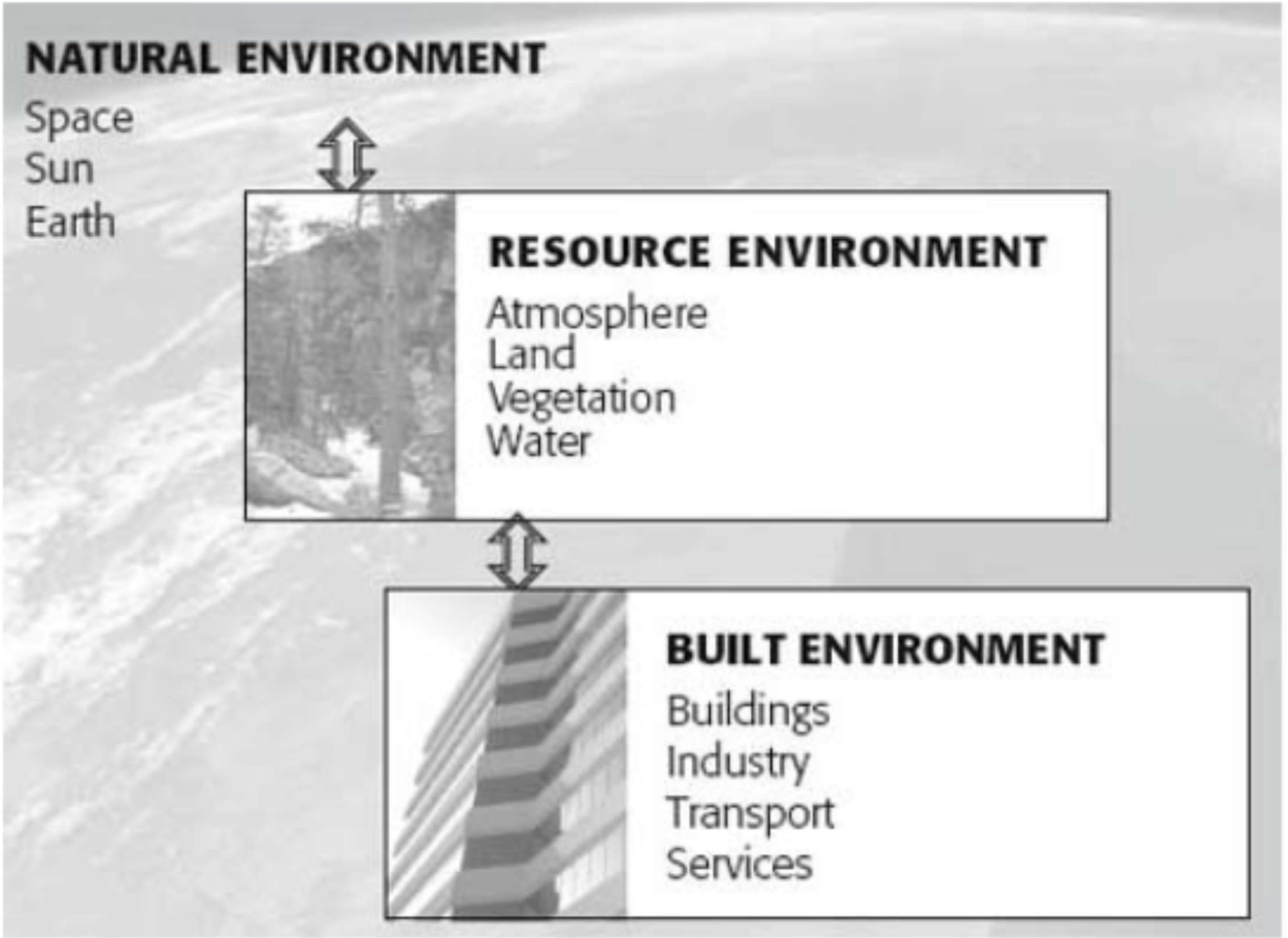
Built environment

- What is environment?
  - The global surroundings that affect our lives
  - Maintaining & improving the quality of our environment is important to the quality of life
- Science, technology & services relating to the comfort of humans in buildings and the environmental performance of the buildings
- Interactions & connections with the wider environment

Built environment

- Natural environment is the entire environment, without human presence or interference
  - Include climate, mountains and hills, rivers and lakes, rocks and soil, trees and plants
- Built environment is formed by the buildings and other structures that humans construct in the natural environment
  - Include buildings, water & drainage systems, transport systems, power systems, and communication systems

Parts of the environment



(Source: McMullan R., 2017. *Environmental Science in Building*, 8th ed., Palgrave Macmillan.)

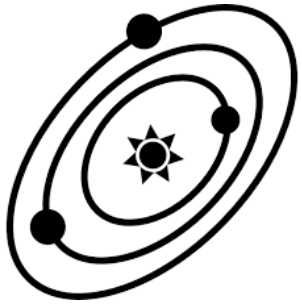
Examples of environmental connections

Natural environment features	Built environment features
Hot, dry climates	Light-coloured surfaces; Roof overhang to provide shade; Openings for breezes; Courtyards to trap cooler air
Warm, humid climates	Lightweight materials; Buildings on stilts for ventilation
Cold climates	Naturally sheltered sites; High insulation; Tightly-sealed construction
Snowfalls	Strong roofs for load; Sloping roofs to discard snow
High winds	Naturally sheltered sites; Low sunken buildings
Forests	Timber as construction material
Loose stone or quarries	Stone as construction material
Clay soil	Mud brick or adobe construction; Fired brick as construction material
Earthquake zones	Low-rise flexible construction; Reinforced concrete structures; Avoidance of unsecured masonry

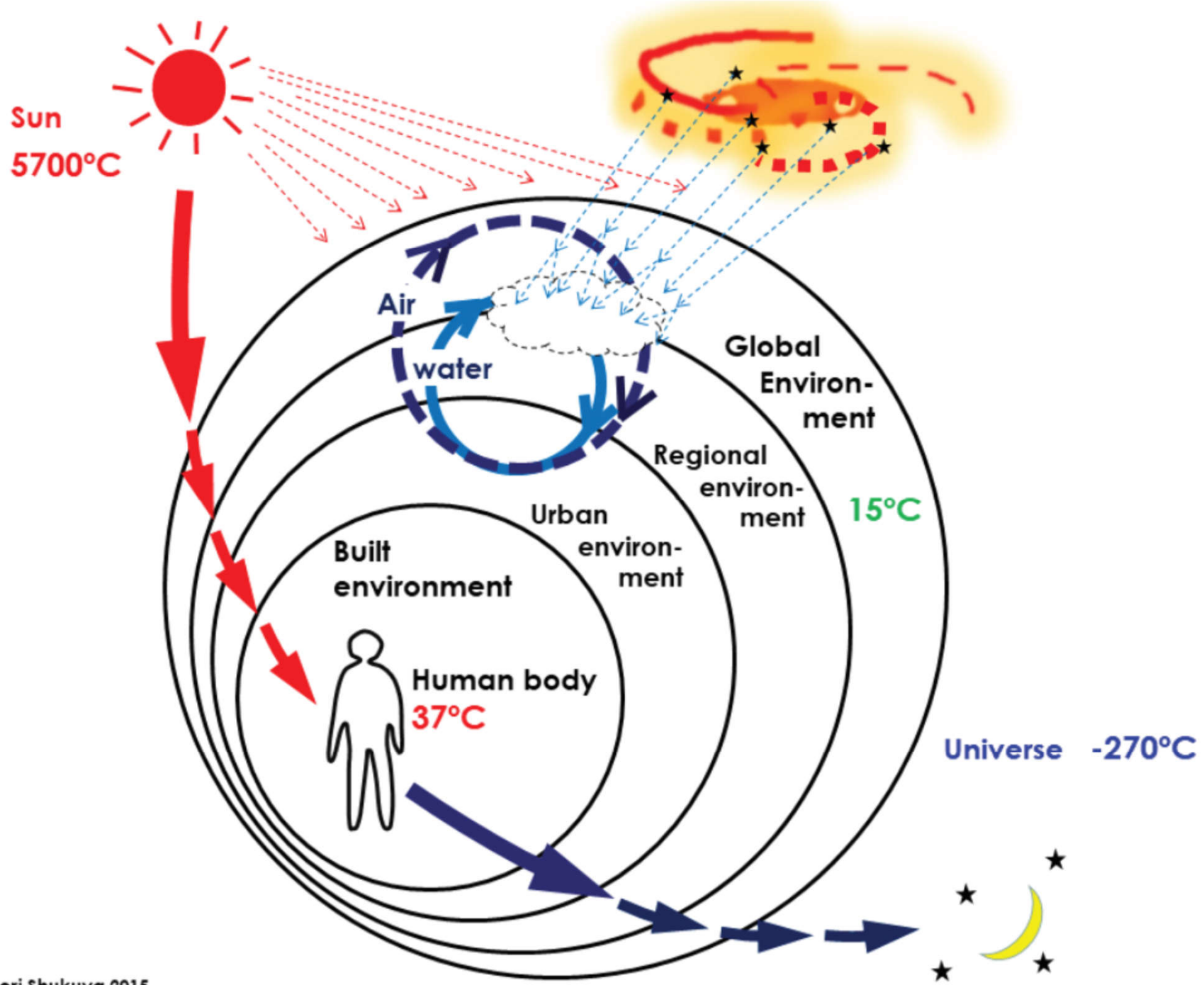
(Source: McMullan R., 2017. *Environmental Science in Building*, 8th ed., Palgrave Macmillan.)

Built environment

- Structure of environmental spaces
  - The universe & milky-way galaxy
  - Solar system & the earth
  - Global environment (land & sea)
  - Regional environment (city, town, village)
  - Urban environment (buildings)
  - Built environment
  - Human body (organs, tissues, cells)

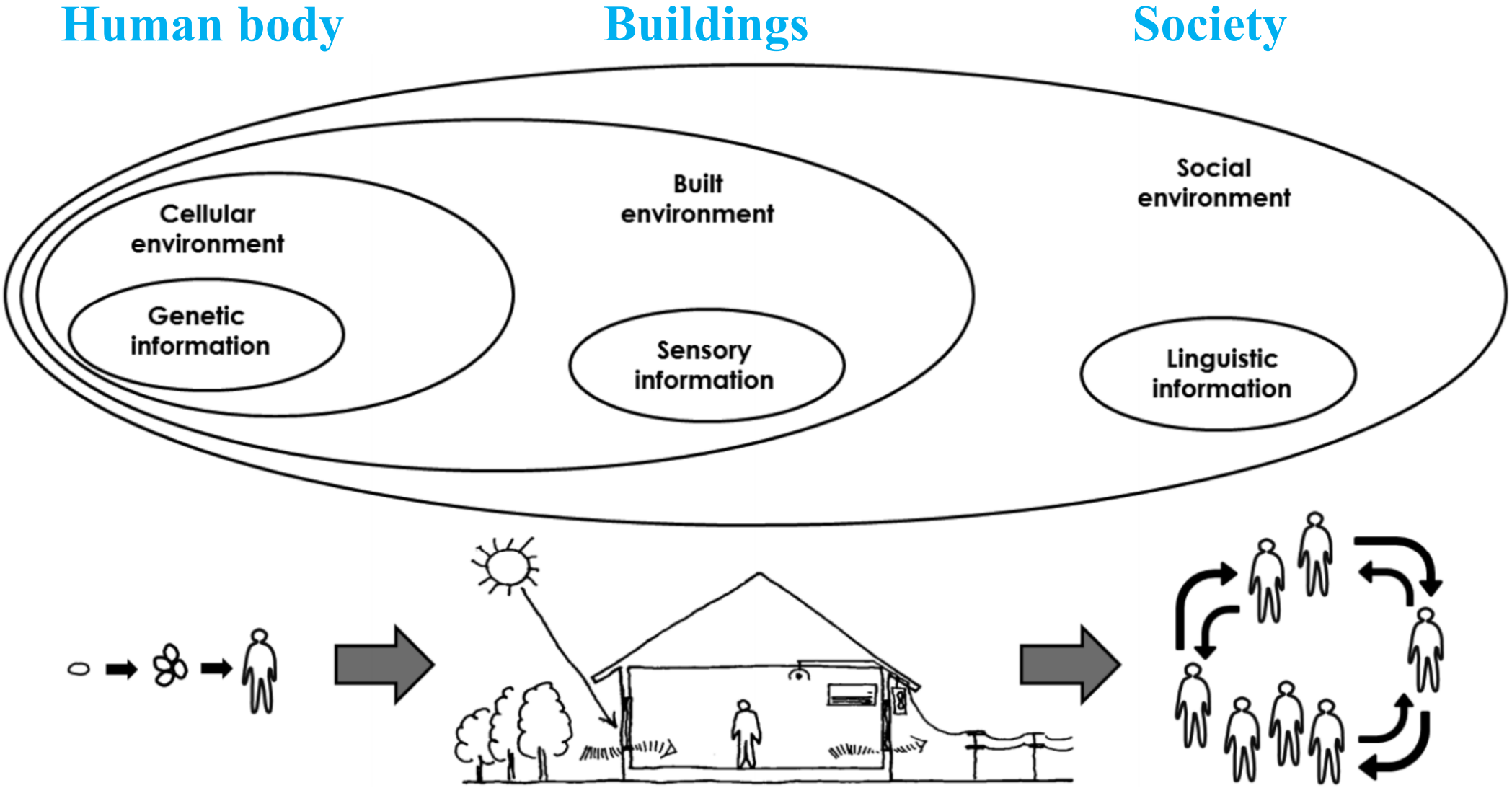


Nested structure of systems and environments



(Source: Shukuya M., 2019. *Bio-Climatology for the Built Environment*, Chapman and Hall/CRC, Milton.)

Three classified environments together with the respective corresponding information

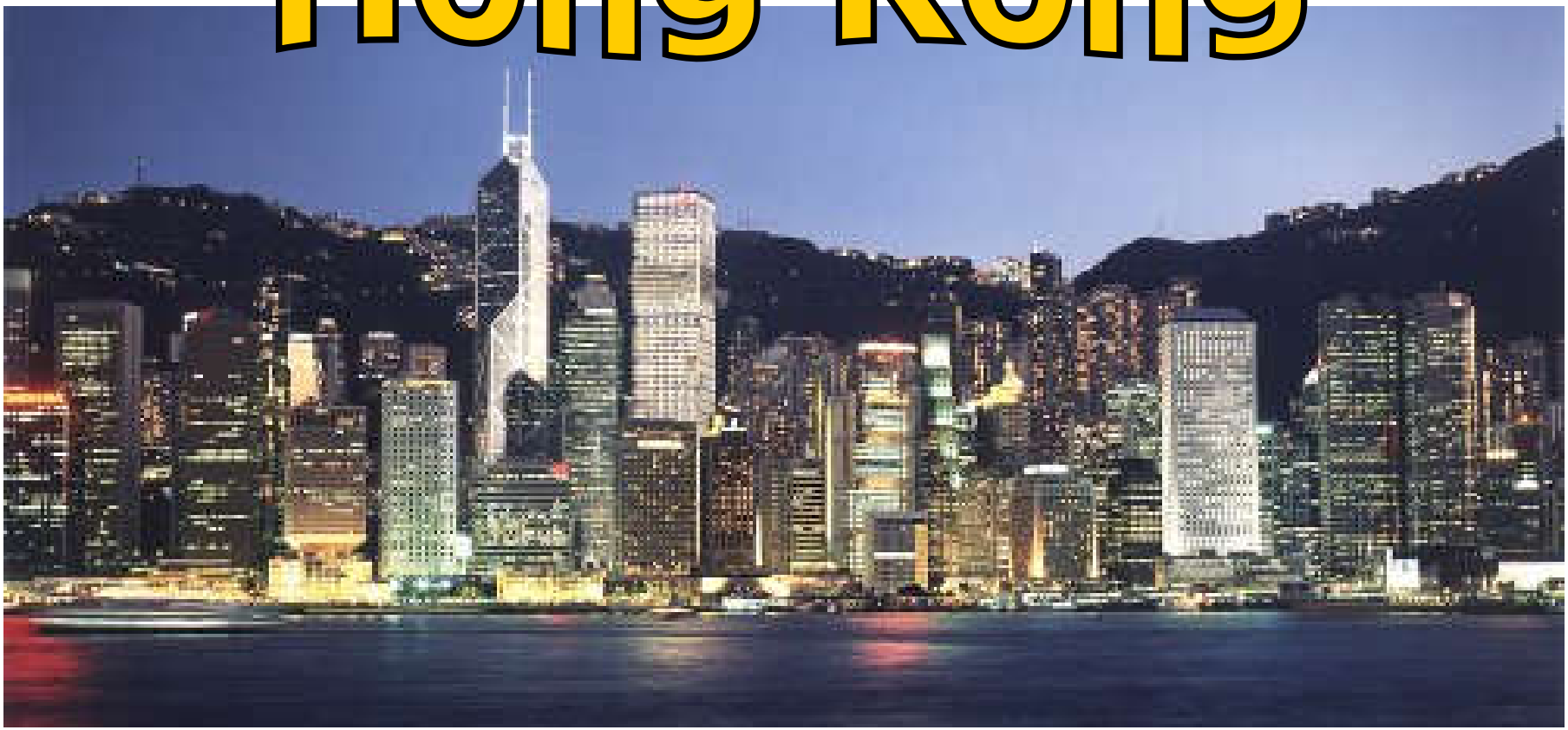


(Source: Shukuya M., 2019. *Bio-Climatology for the Built Environment*, Chapman and Hall/CRC, Milton.)

Built environment

- ***Built environment*** refers to aspects of our surroundings that are built by humans, that is, distinguished from the ***natural environment***
  - Includes not only buildings (residential, industrial, commercial, hospitals, schools), but the human-made spaces between buildings (urban space and landscape), e.g. parks, and the infrastructure that supports human activity (above and below ground) e.g. transportation networks, utilities networks, flood defences, telecommunications, and so on

Hong Kong



High-density, high-rise built environment in Hong Kong

(Source: https://www.gameover.com.hk/news/271103)

Built environment

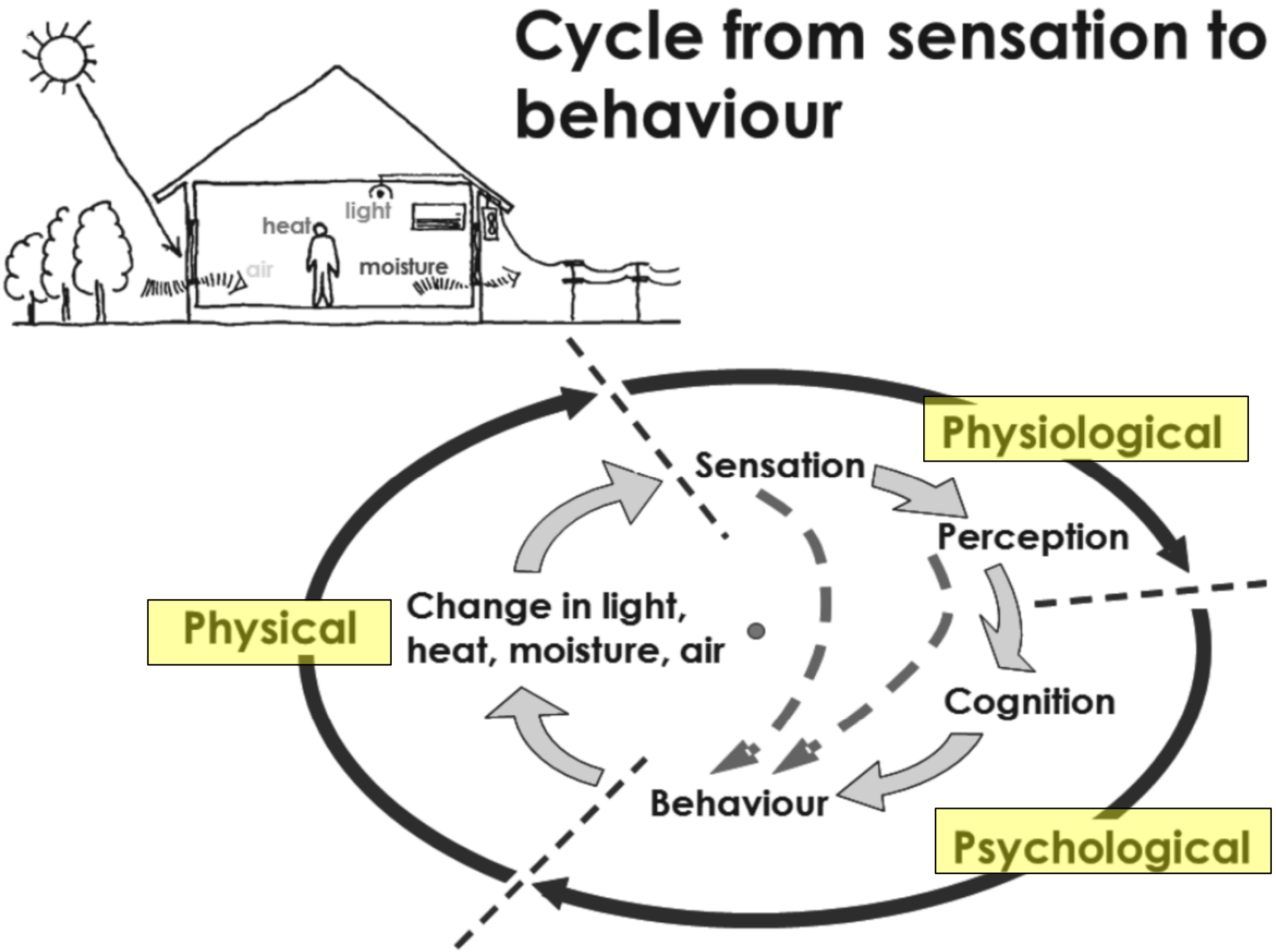
- Five built-environmental elements:
  - Light (artificial light & daylight) 光
  - Heat (temperature, radiation, warmth/coolness) 熱
  - Air (atmosphere, air quality, wind/ventilation) 氣
  - Moisture (water vapour) 濕
  - Sound (acoustic) 聲
- Influence the health & well-being of people
  - Affected by passive & active system components

Comparison of passive and active system components

Objective	Passive Technology		Active Technology	
	Components	**Physical characteristics**	**Components**	**Physical characteristics**
Lighting	• Windows • Shadings • Glass panes • Ceiling • Internal wall surfaces	• Solar optical properties of window materials • Reflectivity of ceiling and internal wall surfaces	• Lamps • Luminaires • Ceiling • Internal wall surfaces	• Luminous efficacy • Optical properties of Luminaires • Reflectivity of ceiling and internal wall surfaces
Heating	• Windows • Walls • Floor • Ceiling	• Solar optical properties of window materials • Conductivity • Radiative and convective transfer • Thermal mass • Air tightness • Permeability	• Heat exchangers • Fans and pumps • Heat pumps • Boilers	• Convective and radiative transfer • Conductivity • Radiation • Pressure • Friction • Efficiency
Cooling	• Windows • Shadings • Walls • Floor • Ceiling	• Solar optical properties of window materials • Conductivity • Radiative and convective transfer • Thermal mass • Permeability	• Heat exchangers • Fans and pumps • Heat pumps	• Convection • Radiation • Pressure • Friction • Efficiency
Ventilation	• Windows • Doors • Vents	• Wind • Buoyancy • Pressure • Water vapour • Friction	• Fans • Ducts • Shutters	• Pressure • Water vapour • Friction • Efficiency

(Source: Shukuya M., 2019. *Bio-Climatology for the Built Environment*, Chapman and Hall/CRC, Milton.)

Cyclic process from sensations via perception & cognition to behaviour



(Source: Shukuya M., 2019. *Bio-Climatology for the Built Environment*, Chapman and Hall/CRC, Milton.)

Built environment

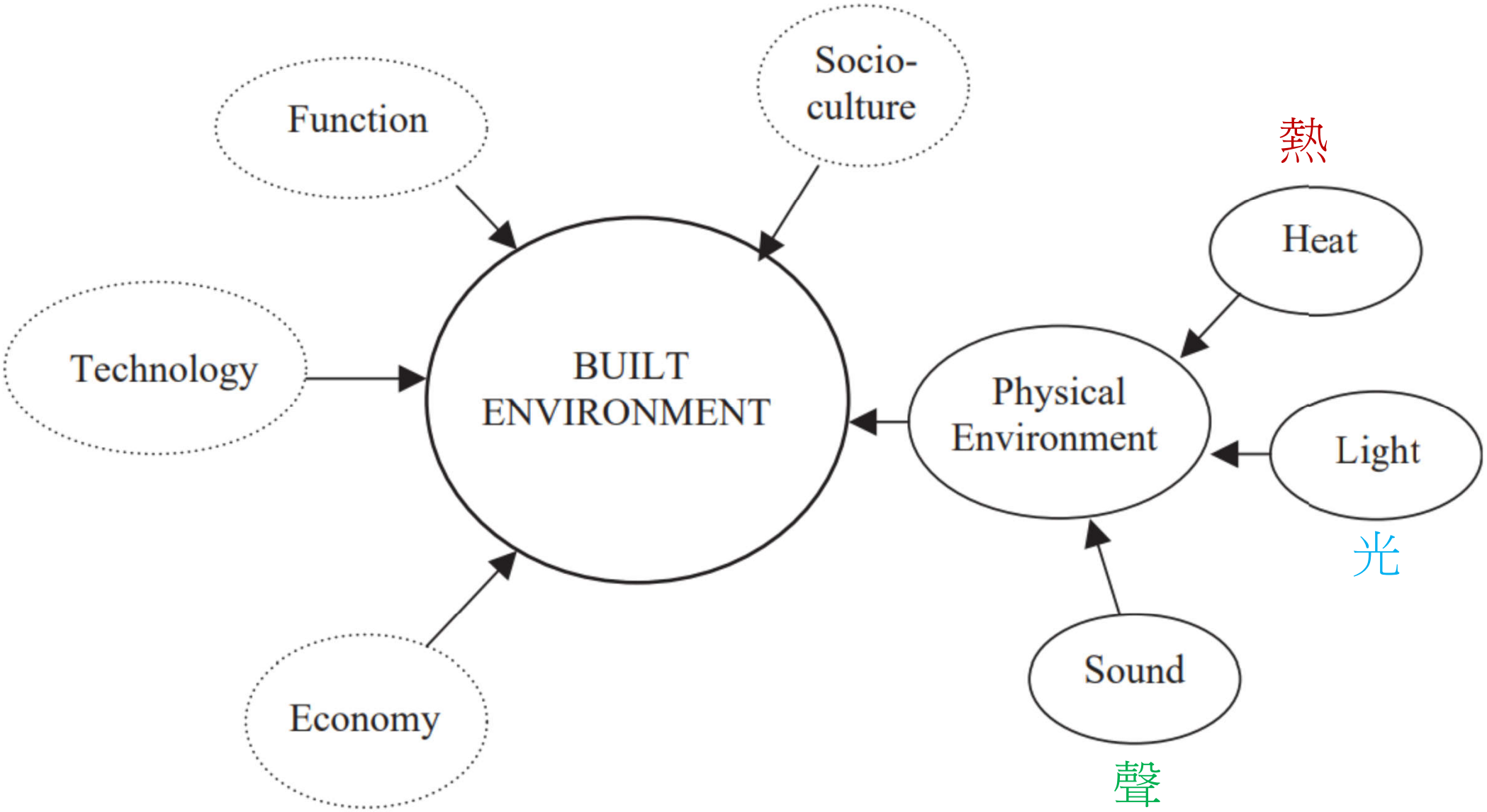
- Personal environmental conditions
  - Thermal environment (air temperature, radiant temperature, air velocity and humidity)
  - Visual environment (colour, views, lighting levels, glare, visual information and so on)
  - Acoustic environment (sound & noise)
  - Air quality (pollution, smells and so on)
  - Textures

Human factors

- Heat: the thermal environment 熱
  - Thermal sensors, located in the human skin
  - Conditions appropriate for human well-being
- Light: the luminous environment 光
  - The eye (i.e. vision) & visual comfort

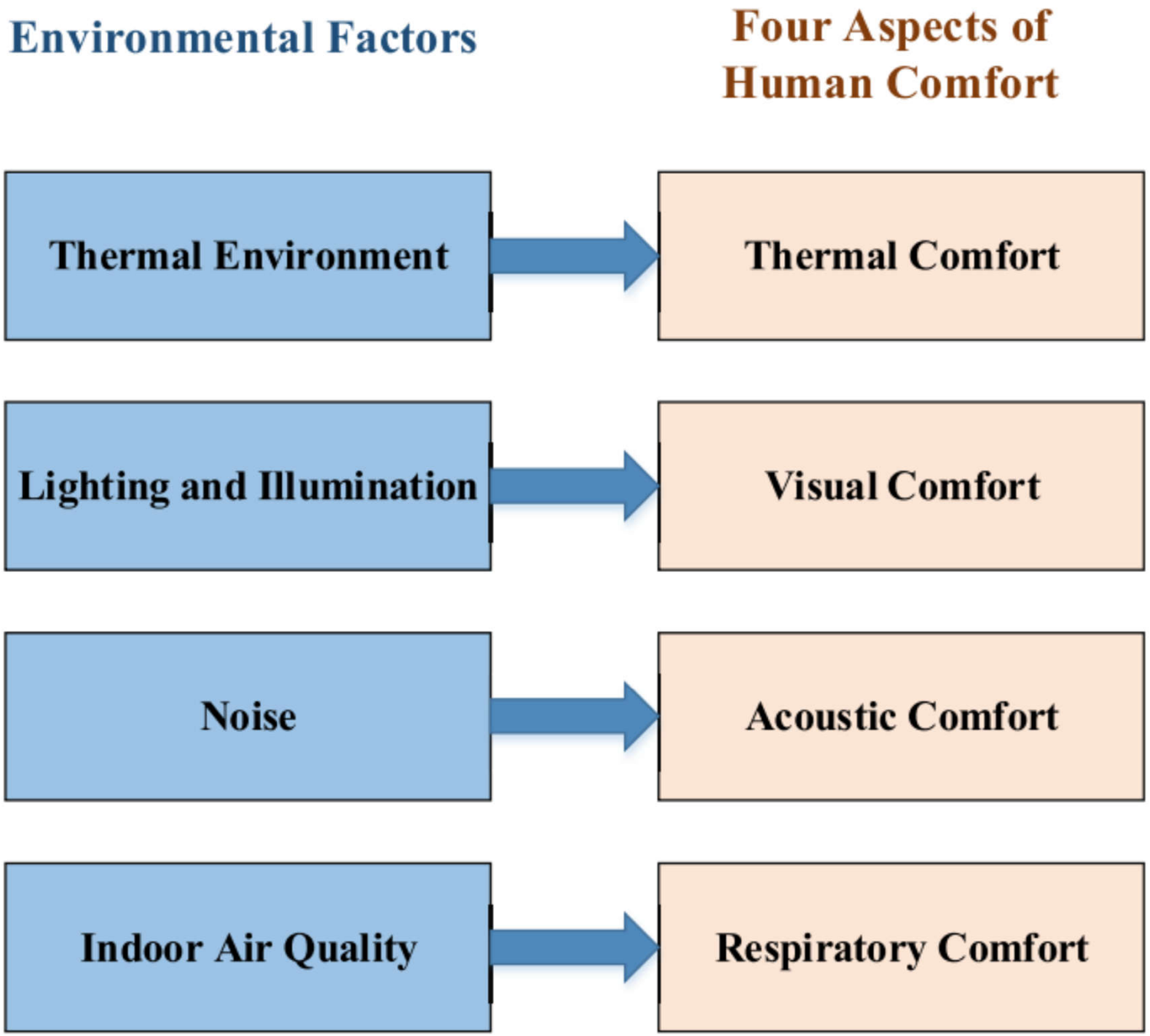
- Sound: the sonic environment 聲
  - The ear (i.e. hearing); appropriate conditions for listening to wanted sound, but also the elimination (or control) of unwanted sound/noise

Parameters with an influence on the design of the building envelope



(Source: https://doi.org/10.1016/S0360-1323(03)00141-0)

Relationship between environmental factors and human comfort



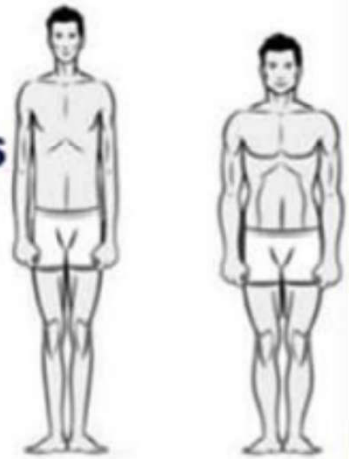
(Source: http://dx.doi.org/10.1109/ACCESS.2019.2937320)

Human factors and environmental factors affecting comfort

HUMAN FACTORS

Physiological Factors

(e.g., Heart Rate, Gender, Skin Temperature)



Behavioral Factors

(e.g., Activity Level, Clothing Level)

ENVIRONMENTAL FACTORS

Indoor Environmental Quality (IEQ)

(e.g., Temperature, Humidity, CO_2 Level, Window State, Lighting Conditions, Noise)

Outdoor Environment

(e.g., Temperature, Humidity, Weather)

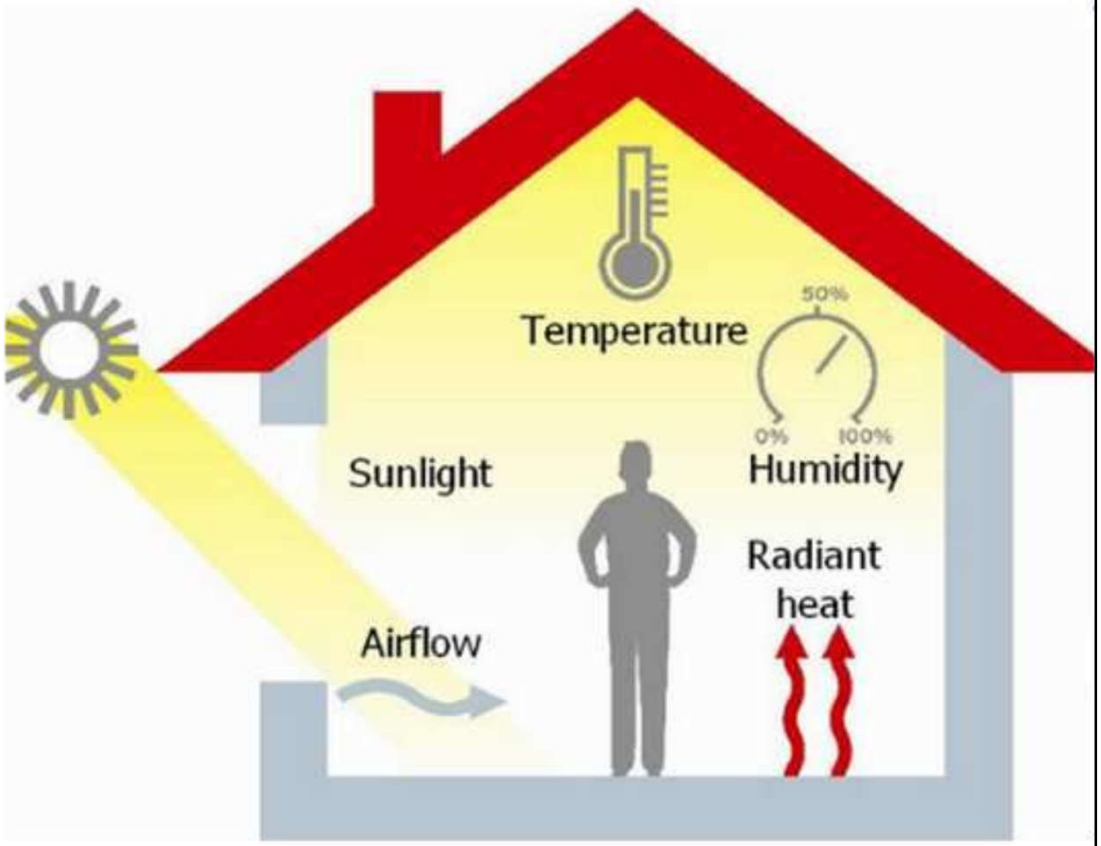
Type of Occupancy

(e.g., Single Occupancy, Multi-Occupancy)

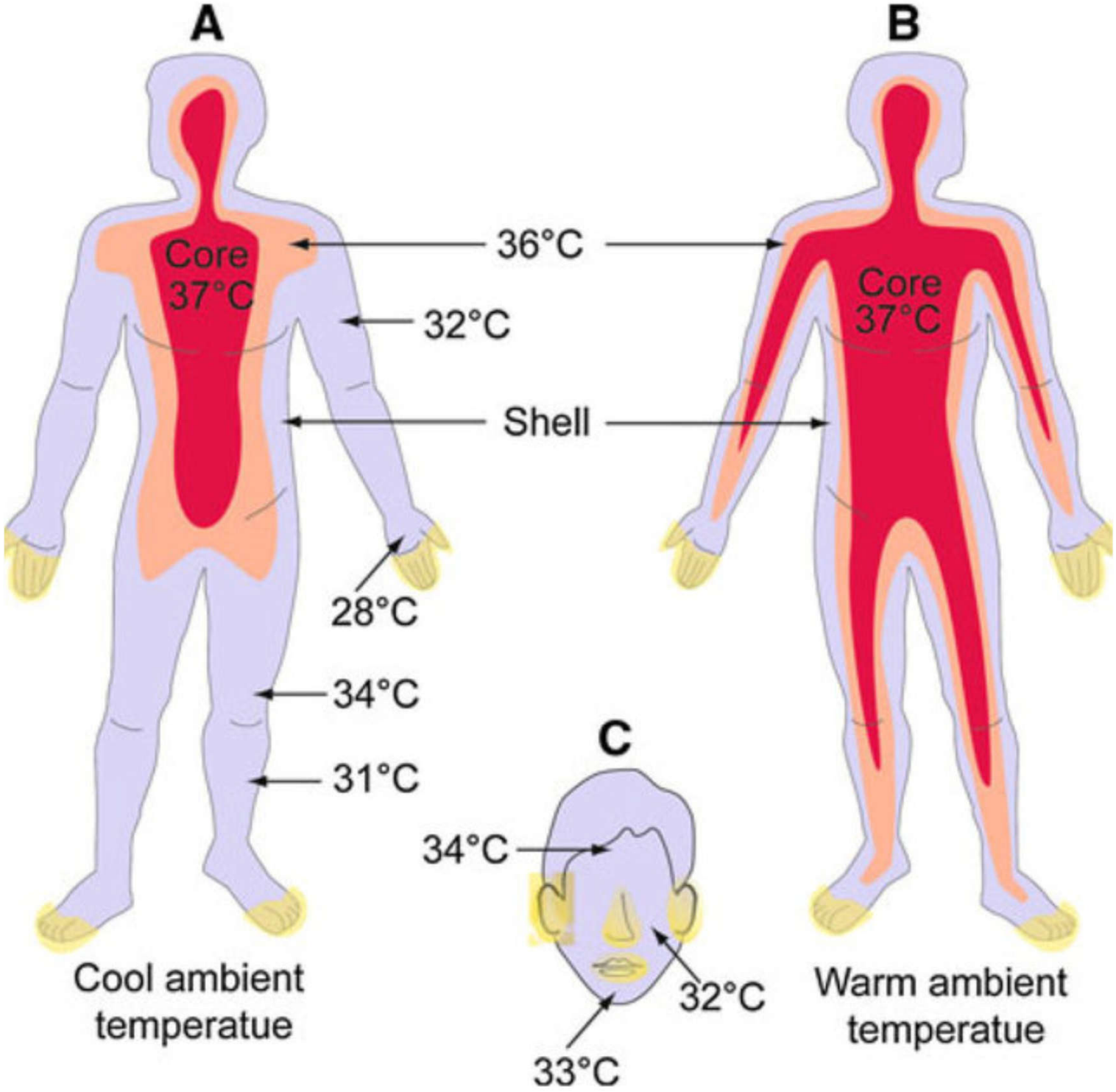
(Source: https://doi.org/10.1016/j.buildenv.2017.10.004)

Human factors

- Human comfort in buildings
  - Personal factors
  - Health and wellbeing
  - Thermal comfort
  - Indoor air quality
  - Visual comfort
  - Noise nuisance
  - Ergonomics



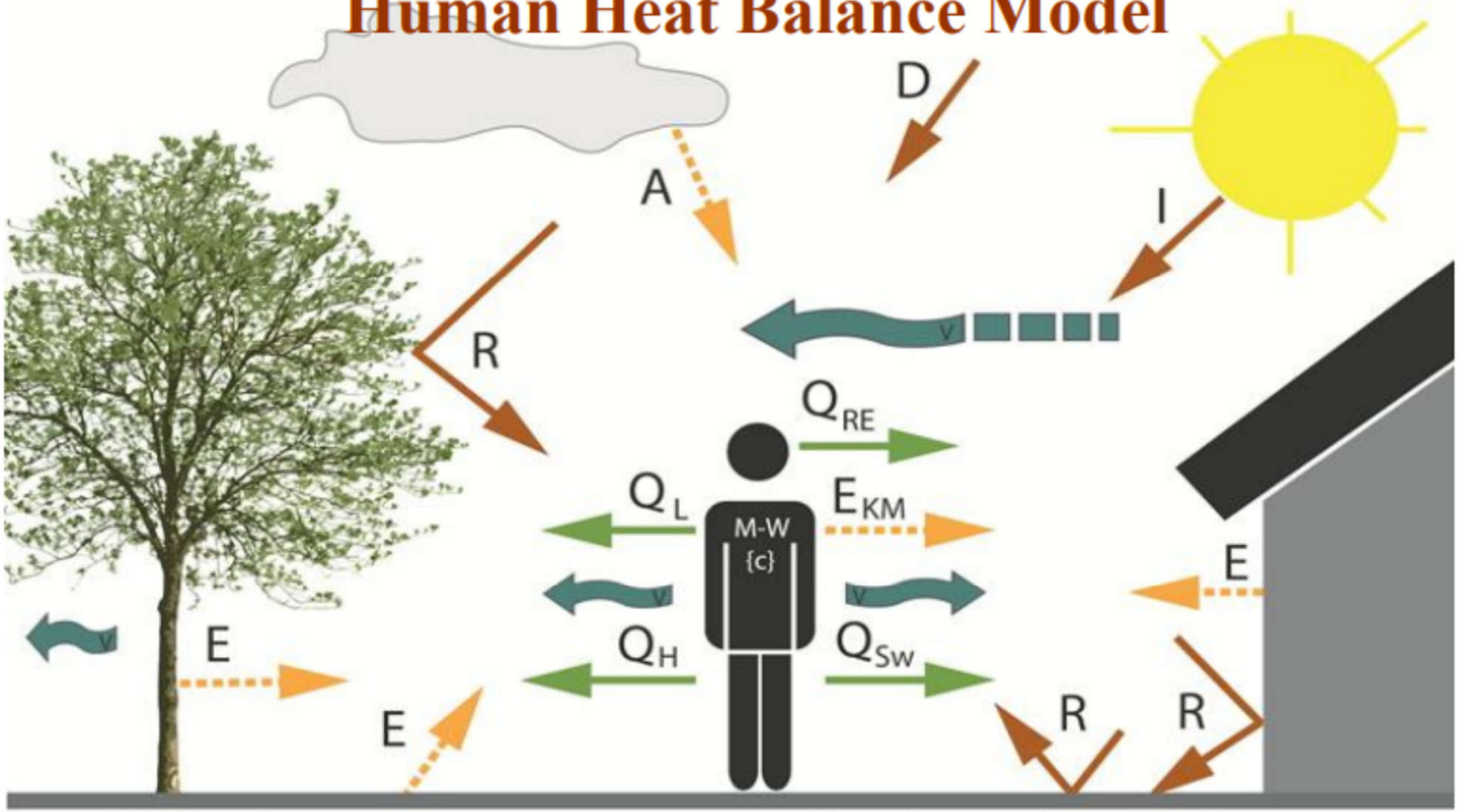
(Source: https://www.designingbuildings.co.uk/wiki/Human_comfort_in_buildings)



Human body temperature

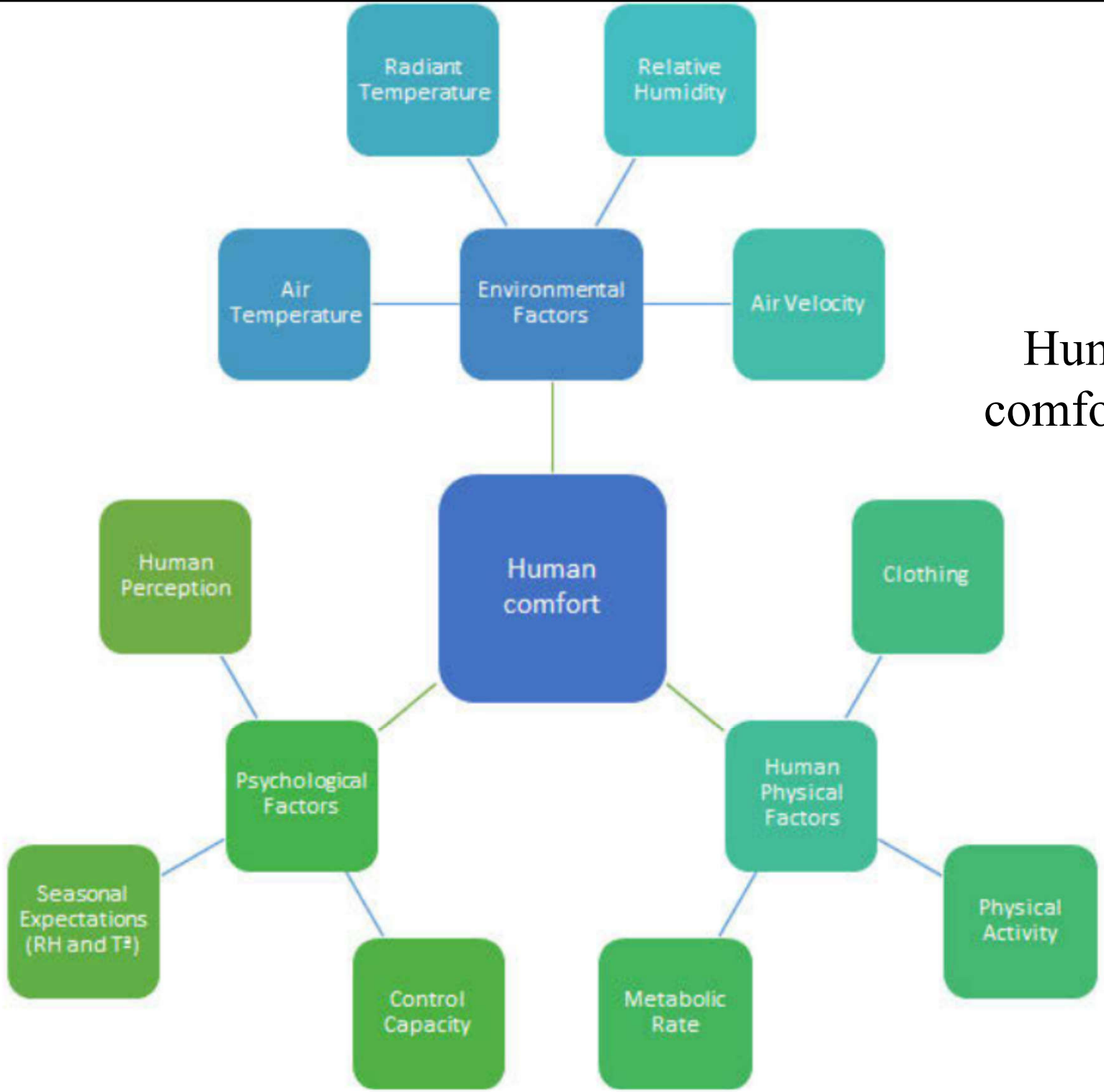
(Source: https://www.researchgate.net/publication/51178470_Human_body_temperature_and_new_approaches_to_constructing_temperature-sensitive_bacterial_vaccines)

Human Heat Balance Model



M	metabolic rate	I	direct solar radiation
Q_H	turbulent sensible heat fluxes	D	diffuse solar radiation
Q_{Sw}	turbulant latent heat fluxes	R	reflecting solar radiation
Q_L	latent heat fluxes by water vapour diffusion	A	atmospheric radiation
Q_{RE}	heat fluxes by respiration (sensible and latent	E	long-wave emission of the surrounding surface
V	wind speed	E_{KM}	infrared radiation of human surface
M-W	heat production by energy metabolism	{c}	thermal isolation of clothing

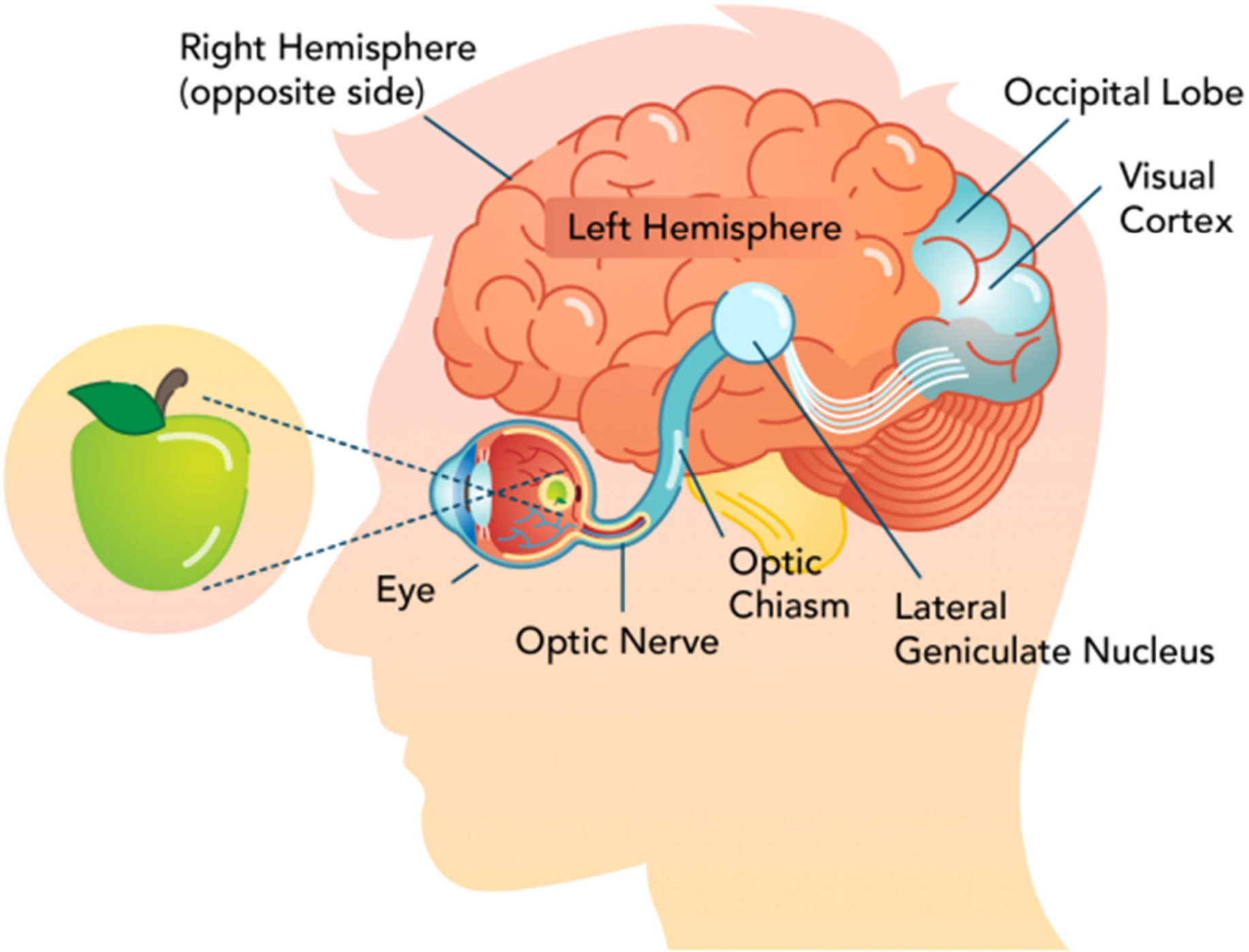
(Source: https://www.pland.gov.hk/pland_en/p_study/prog_s/ucmapweb/)



Human thermal comfort parameters

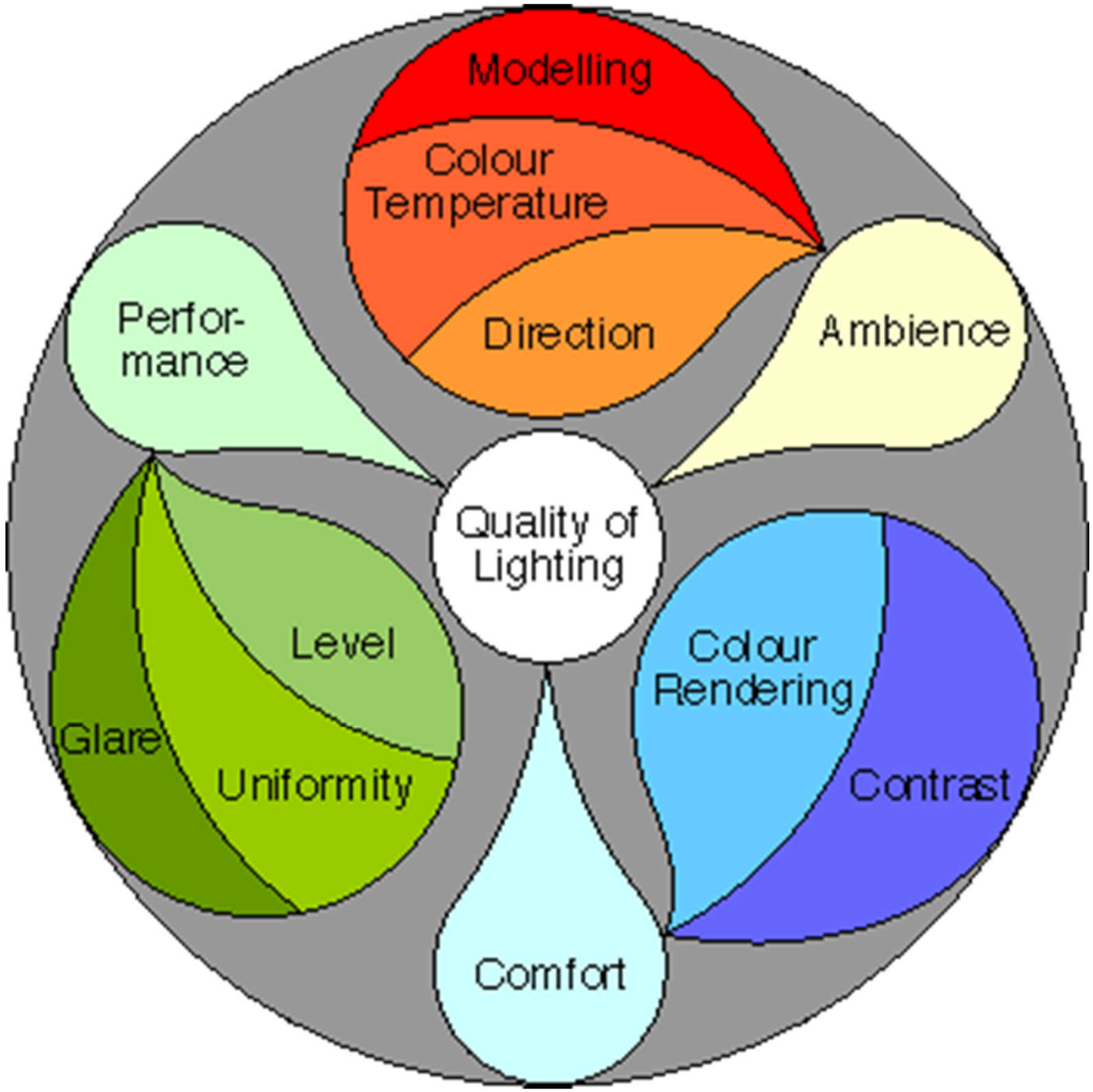
(Source: https://energypedia.info/images/c/c7/Building_Energy_Efficiency_Guideline_for_Nigeria_2016.pdf)

Sight and brain pathway in human body



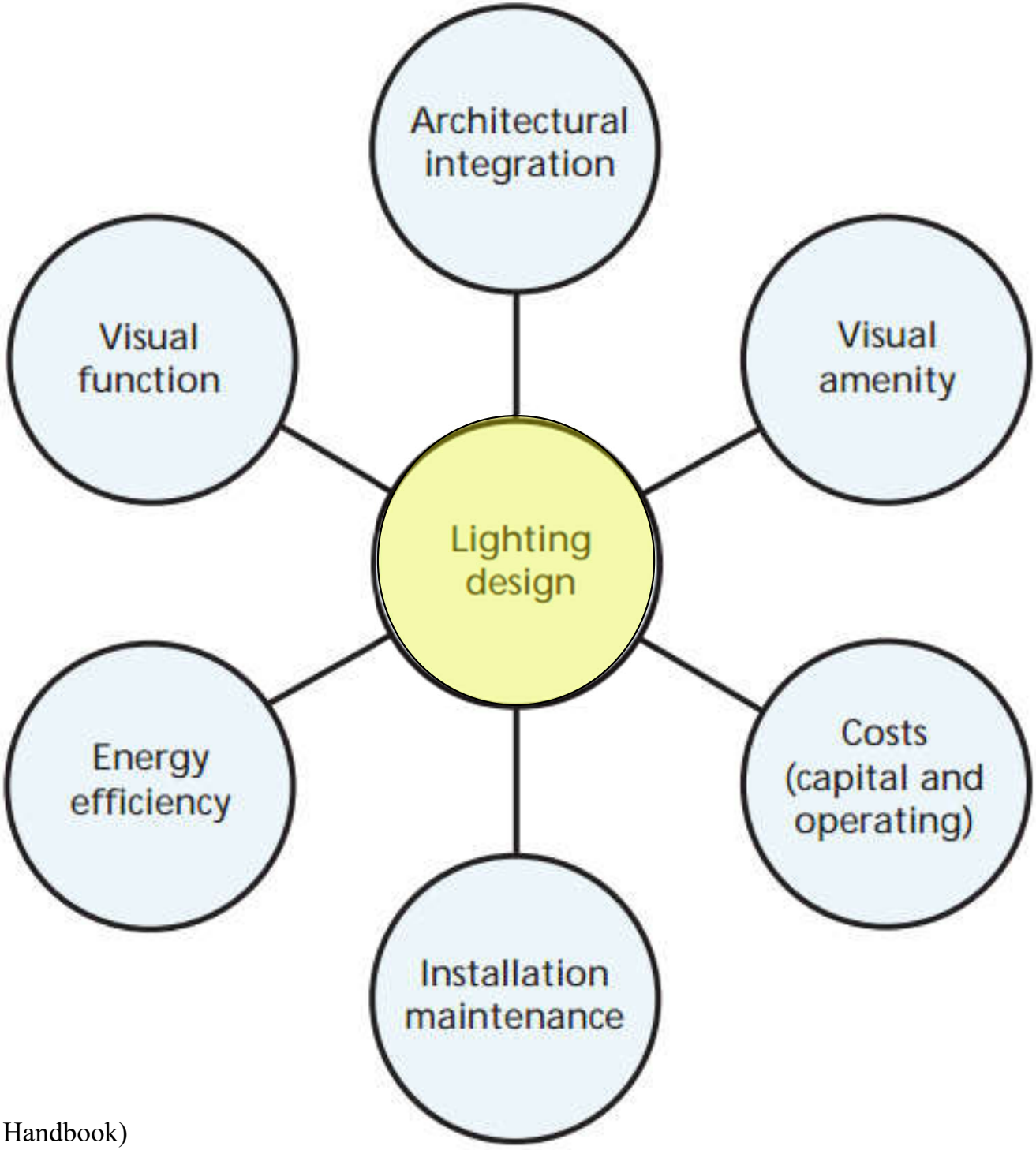
(Source: https://letstalkscience.ca/educational-resources/backgrounders/how-we-see)

Visual: the quality of the lighting depends on a number of factors



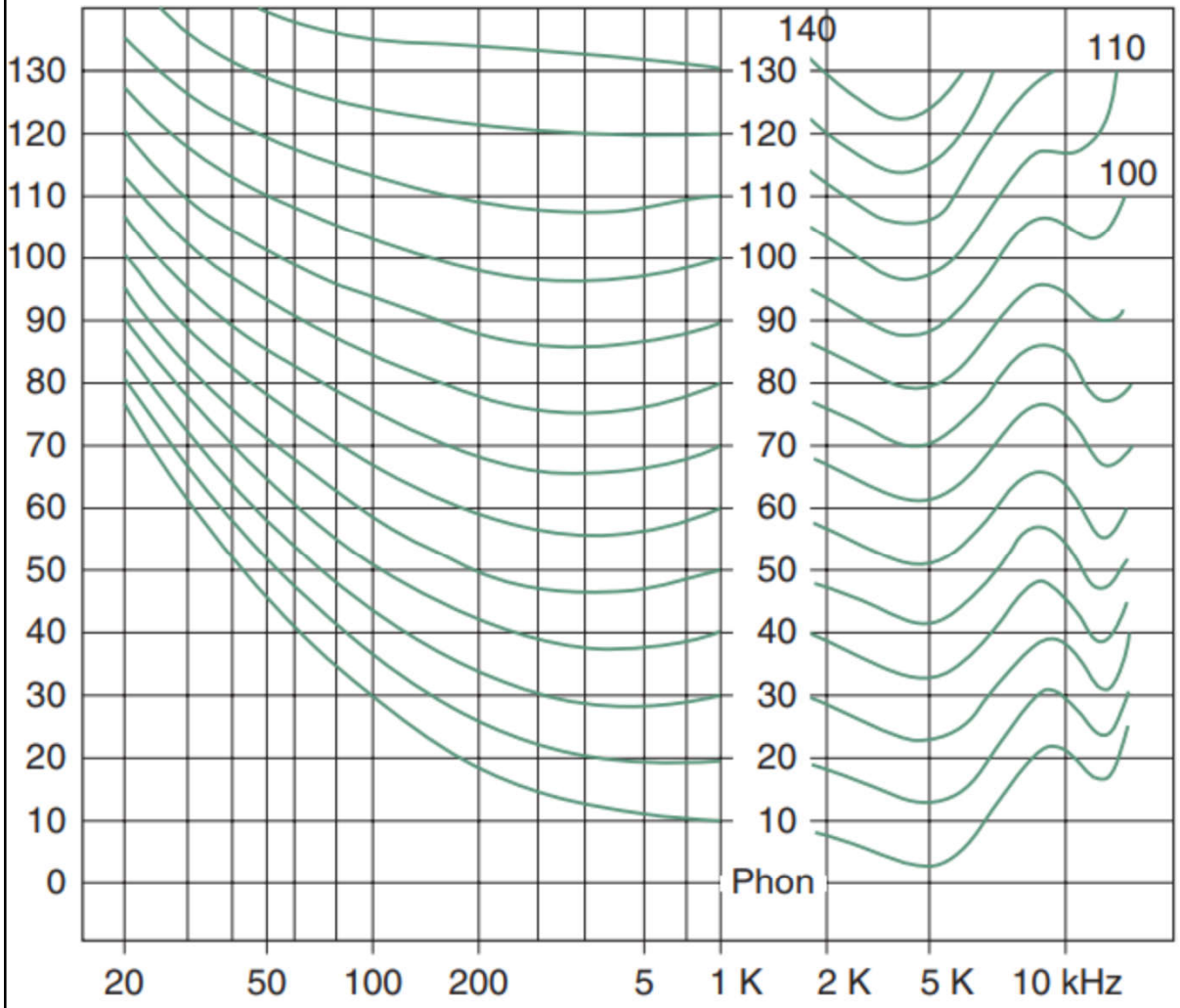
(Source: http://www.new-learn.info/packages/mulcom/comfort/visual/quality/content.html)

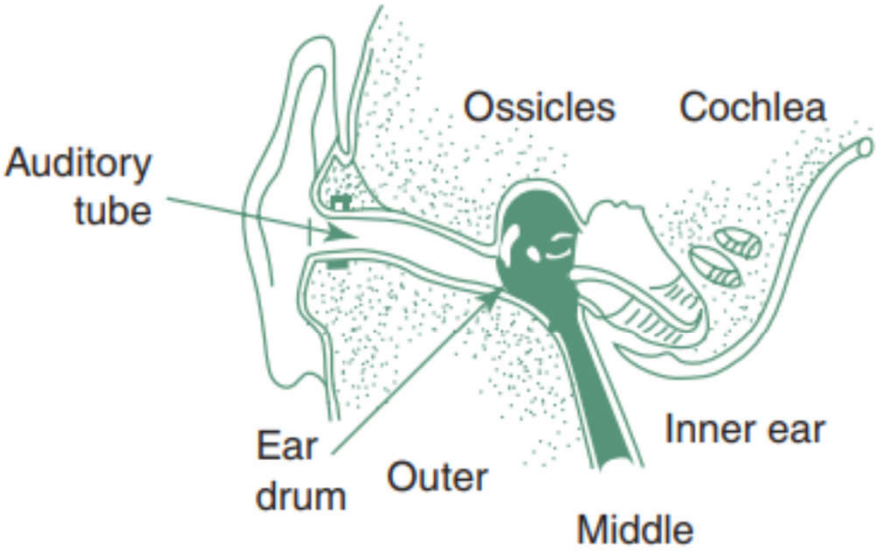
Considerations for lighting design

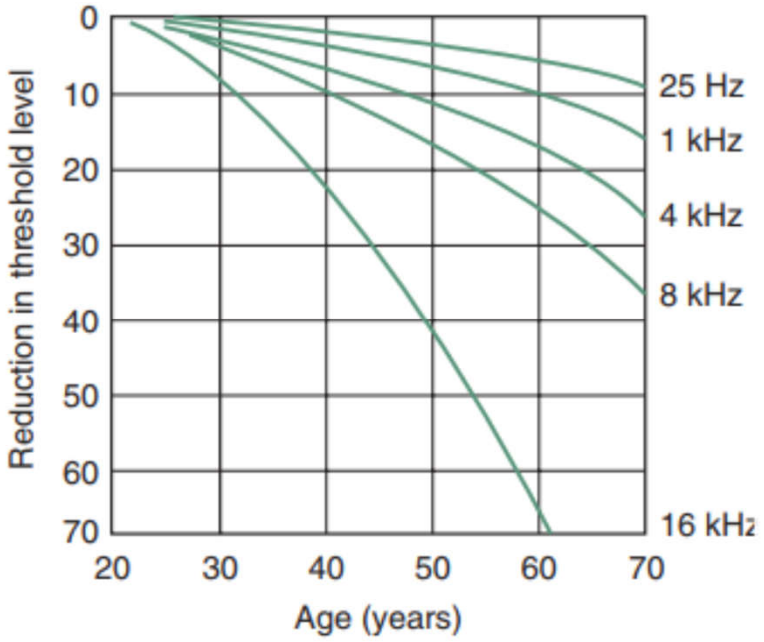


(Source: The SLL Lighting Handbook)

Human ear and equal loudness contours





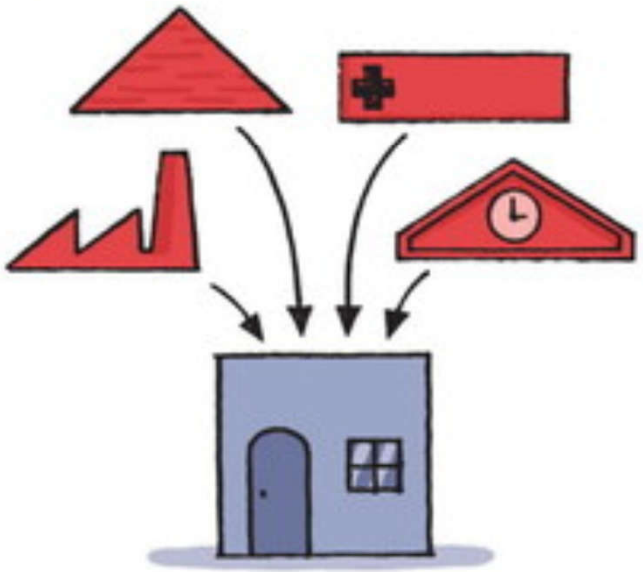


(Source: Szokolay S. V., 2008. *Introduction to Architectural Science: the Basis of Sustainable Design*, Second edition.)

Designing for acoustic comfort

To design acoustically comfortable buildings, it is important to take into account the needs of the occupants, as well as a variety of external and architectural factors:

The activities to be performed,



the types of noise to be managed,

interior...

or exterior

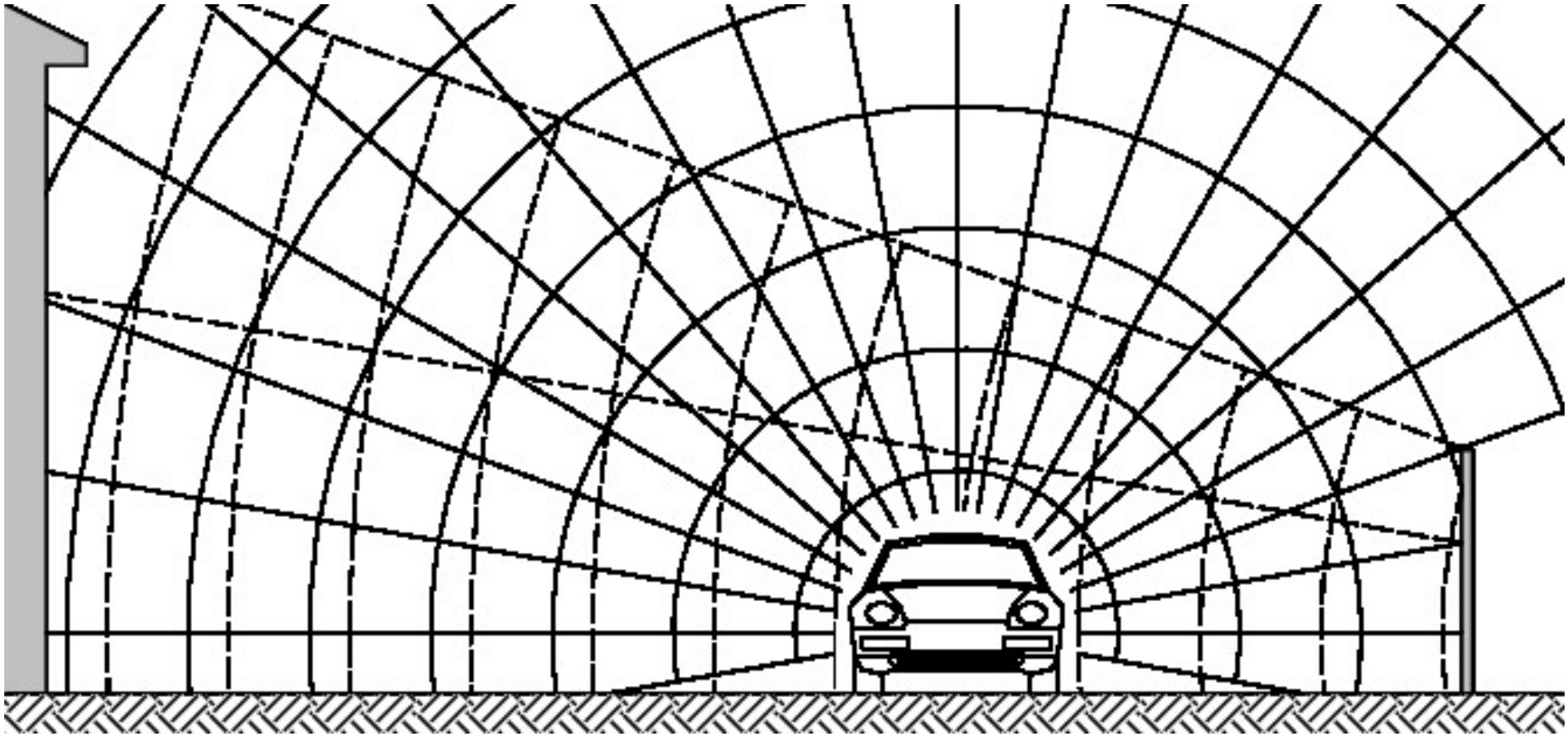
the spectrum of noise to be managed,

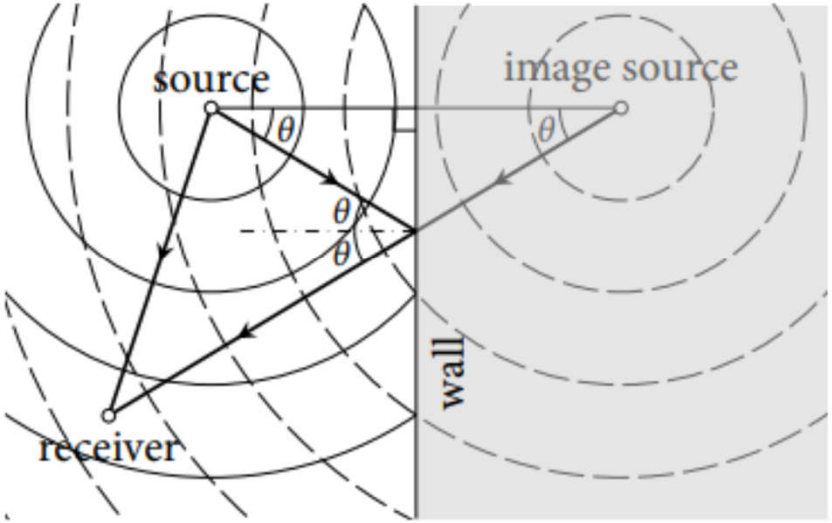
the construction system and materials...

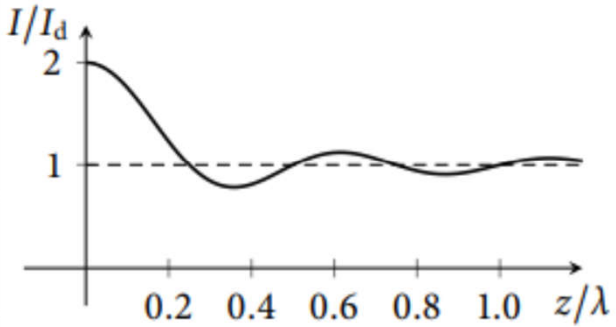
However, sound is difficult to predict. Computer simulations are very useful but cannot replace on-site testing and the experience of an acoustic engineer.

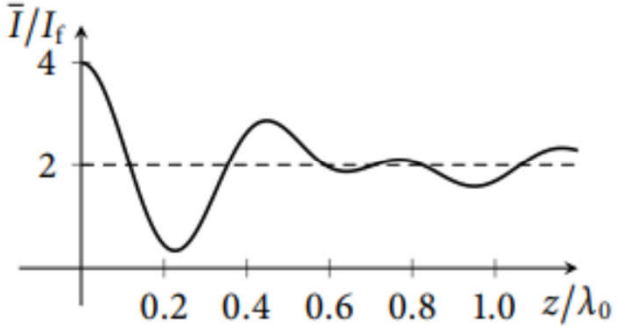
(Source: https://www.archdaily.com/909793/basic-principles-of-acoustics-why-architects-shouldnt-leave-it-all-to-consultants)

Sound/acoustics in built environment





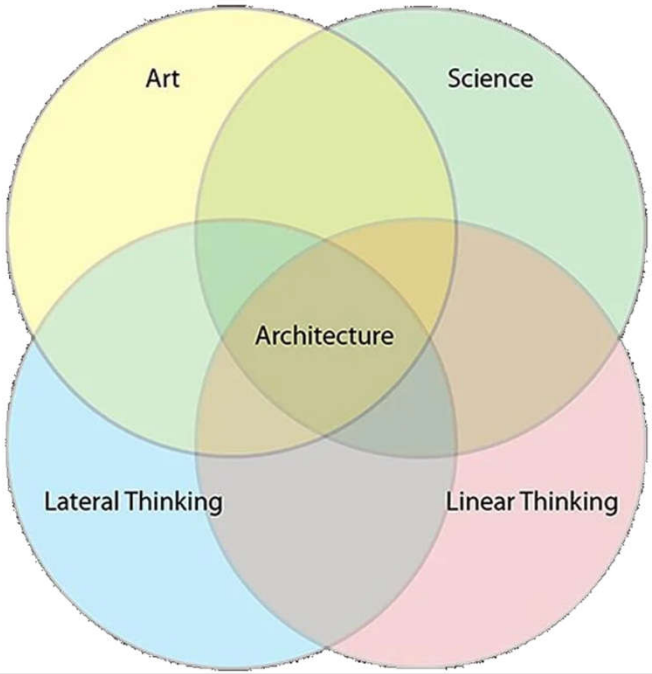




(Source: Pinterić M., 2021. *Building Physics: From physical principles to international standards*, Second Edition, Springer, Cham, Switzerland.)

Science principles

- Architecture is the art and science of building
  - Require understanding of human physiology, climatology & physics of building elements
  - Using science to understand & improve the built environment
- Related terms or areas:
  - Architectural science
  - Building science
  - Building physics



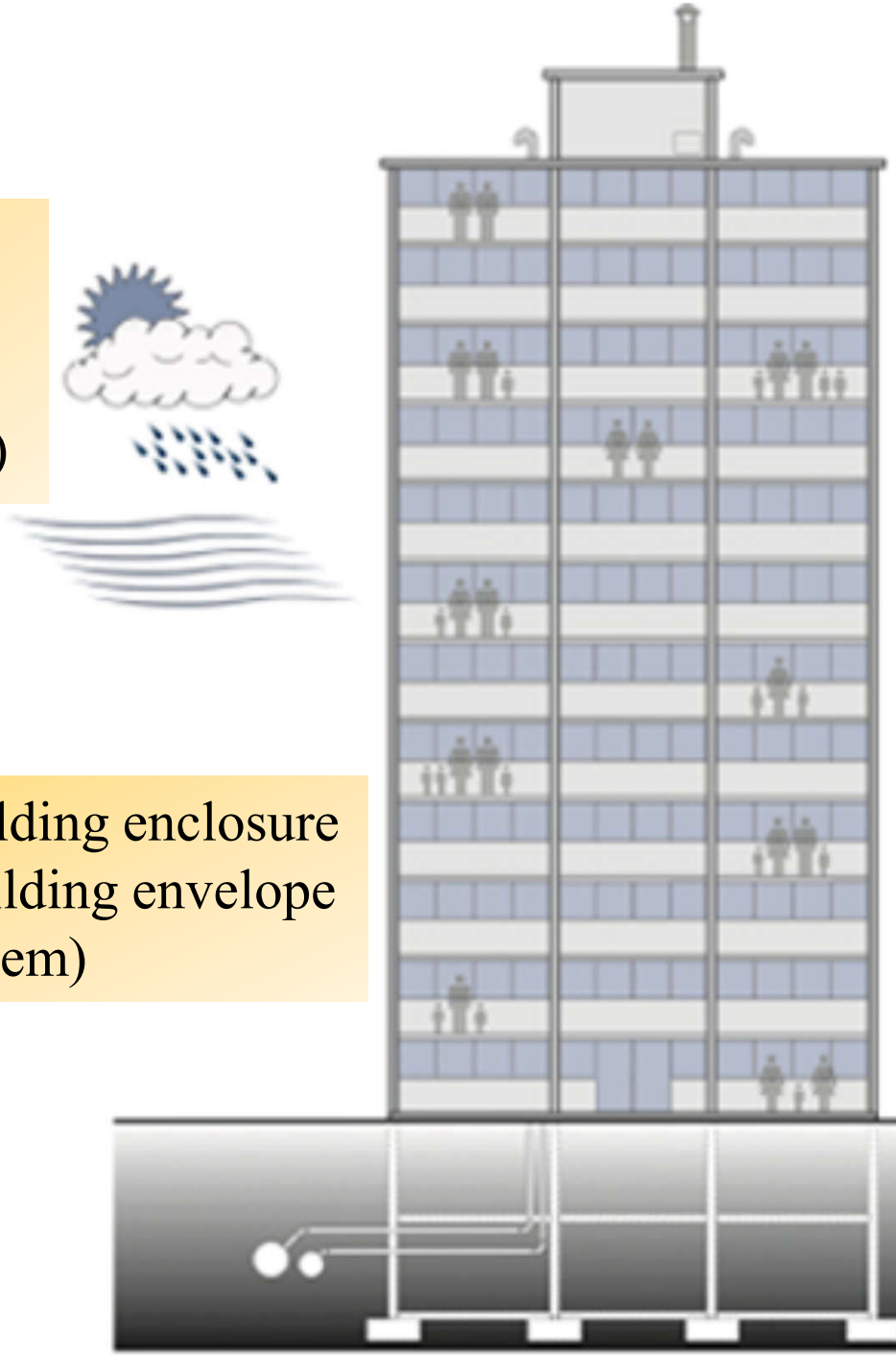
Science principles

- Building Science Concepts
  - It is a field of knowledge that draws upon physics, chemistry, engg., architecture, and the life sciences
  - Understand the physical behaviour of *the building as a system* and how this impacts energy efficiency, durability, comfort & indoor air quality
  - Apply empirical techniques to the effective solution of design problems
  - Harmonization of the building elements is the key to well-performing buildings

(Source: Building Science Concepts (WBDG) https://www.wbdg.org/resources/building-science-concepts)

The building as a system (with sub-systems & other elements)

External environment (weather & micro-climate)



Building services (electrical/mechanical systems)

Inhabitants (humans, animals, and/or plants, etc.)

Building enclosure (building envelope system)

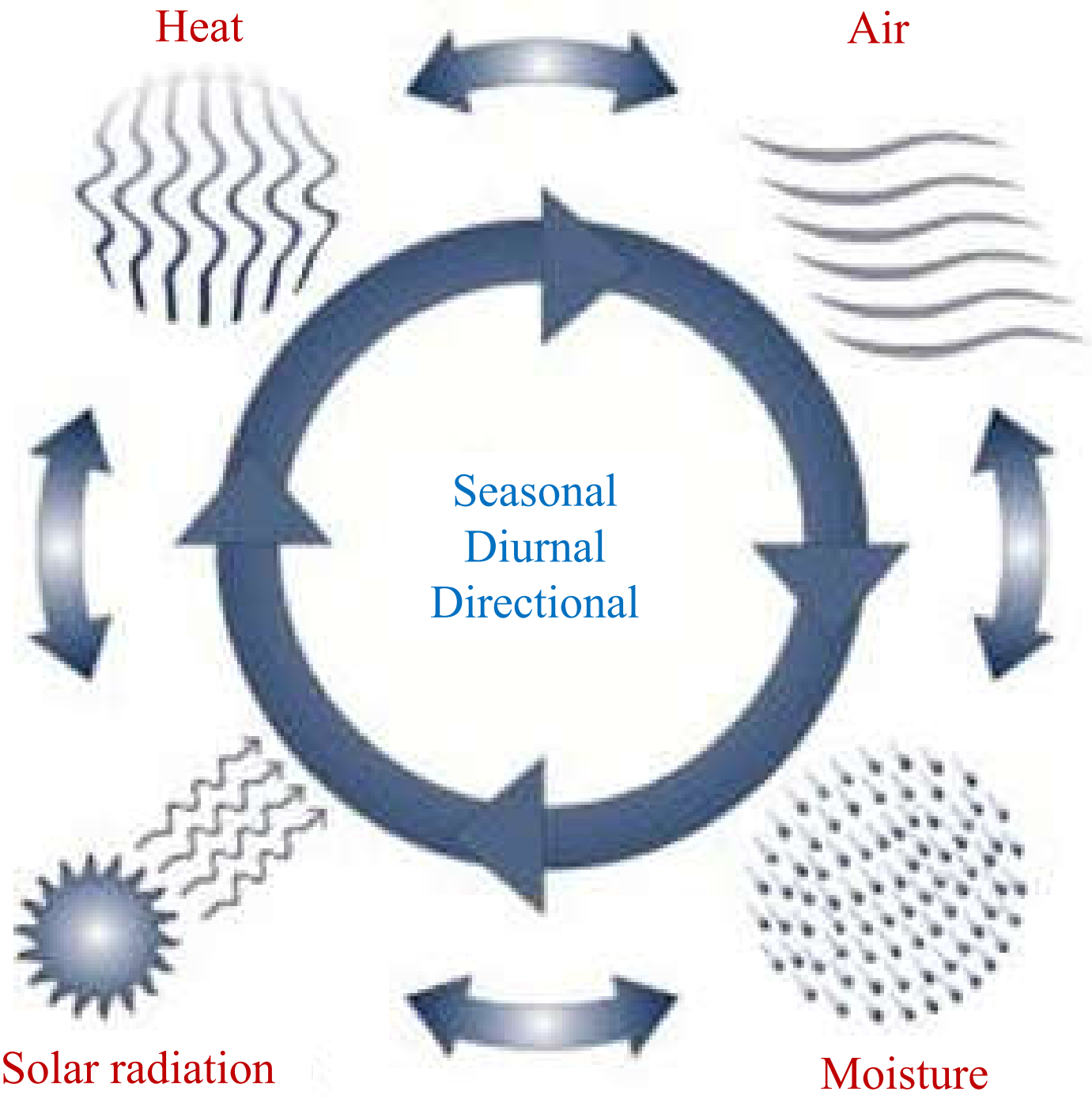
Site, with its landscape and services infrastructure

(Source: Building Science Concepts (WBDG) https://www.wbdg.org/resources/building-science-concepts)

Science principles

- Physical forces affecting the building as a system
  - Heat Flow - the conductive, convective, and radiative flow of heat
  - Air Flow - the air flow across and within the building enclosure due to air leakage and ventilation
  - Moisture Flow - the flow of water and vapour across and within the building enclosure
  - Solar Radiation - the influence of insulation on the opaque and transparent enclosure components

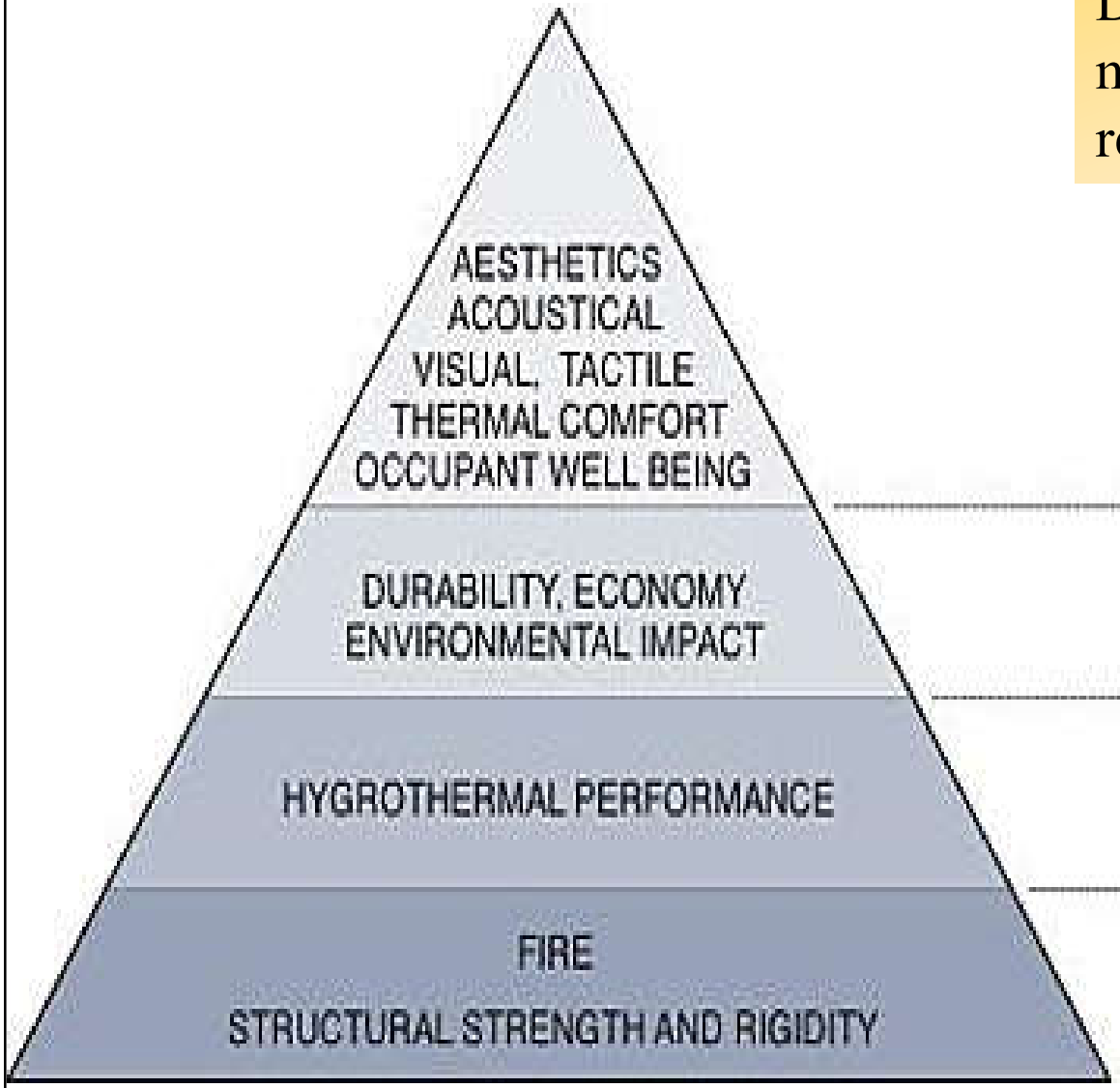
Physical mechanisms driving the behaviour of the building as a system



(Source: https://www.wbdg.org/resources/building-science-concepts)

Building science hierarchy of performance requirements

Do you know what are the most important performance requirements? Why?



AESTHETICS
Aesthetic considerations may be applied to building envelope alternatives that satisfy the preceding criteria.

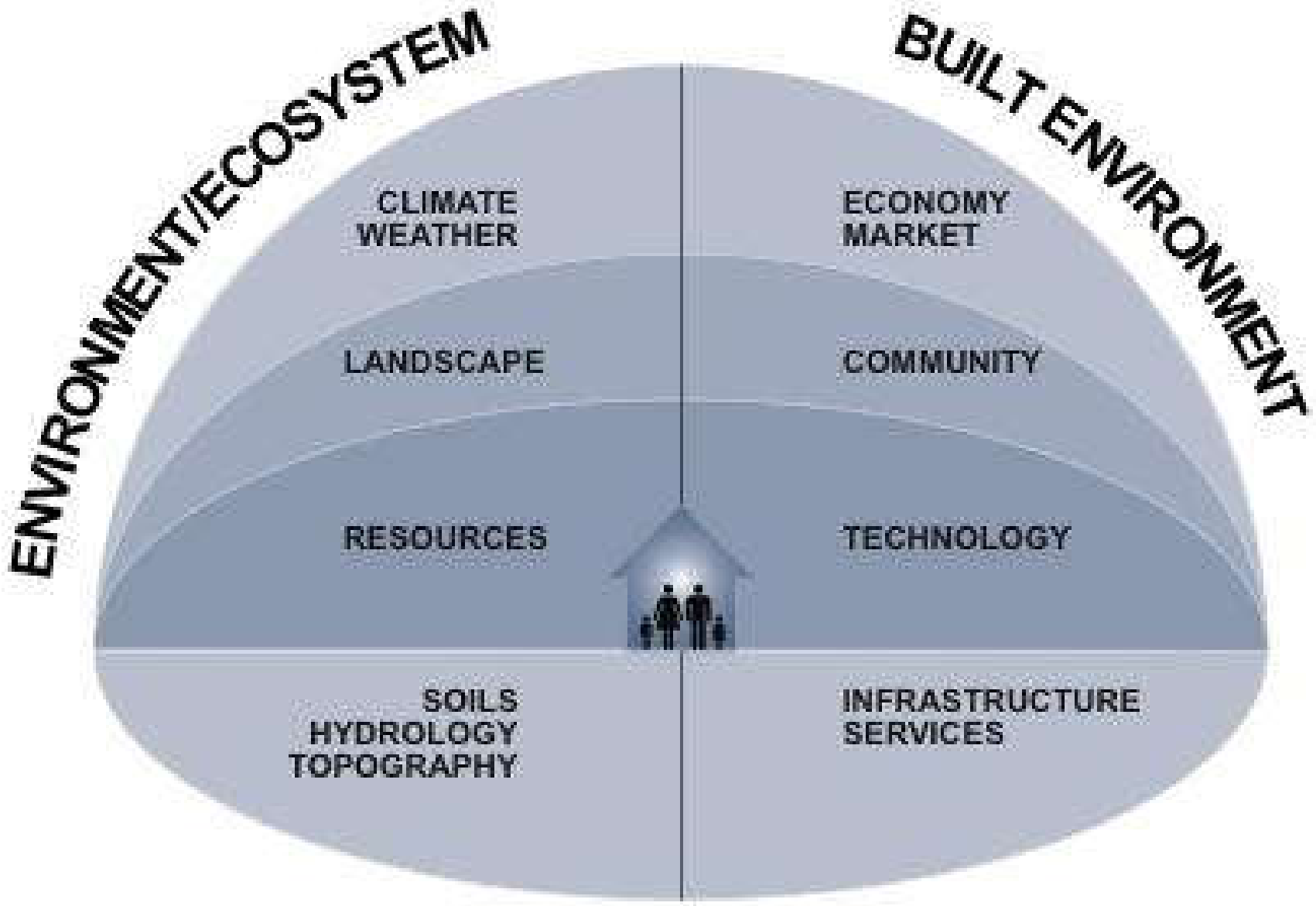
SUSTAINABILITY
Hygrothermal performance, along with the selection of materials and methods, influence sustainability.

ENVIRONMENTAL SEPARATION / MODERATION
Control of heat, air, moisture and solar radiation passively influence the quality of indoor environment.

HEALTH AND SAFETY
Minimum requirements for health and safety represent a necessary but insufficient condition for high performance.

(Source: Building Science Concepts (WBDG) https://www.wbdg.org/resources/building-science-concepts)

Contemporary context for building performance objectives

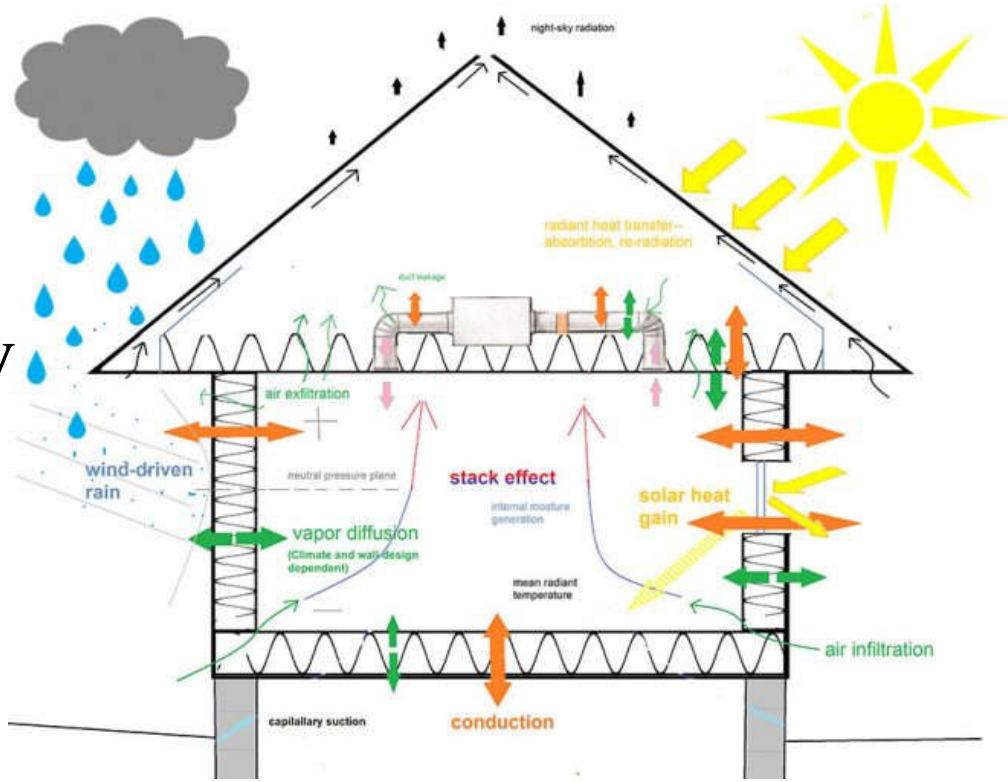


The assessment of building performance objectives involves numerous interfaces between the building, its occupants, and the natural & built environment.

(Source: Building Science Concepts (WBDG) https://www.wbdg.org/resources/building-science-concepts)

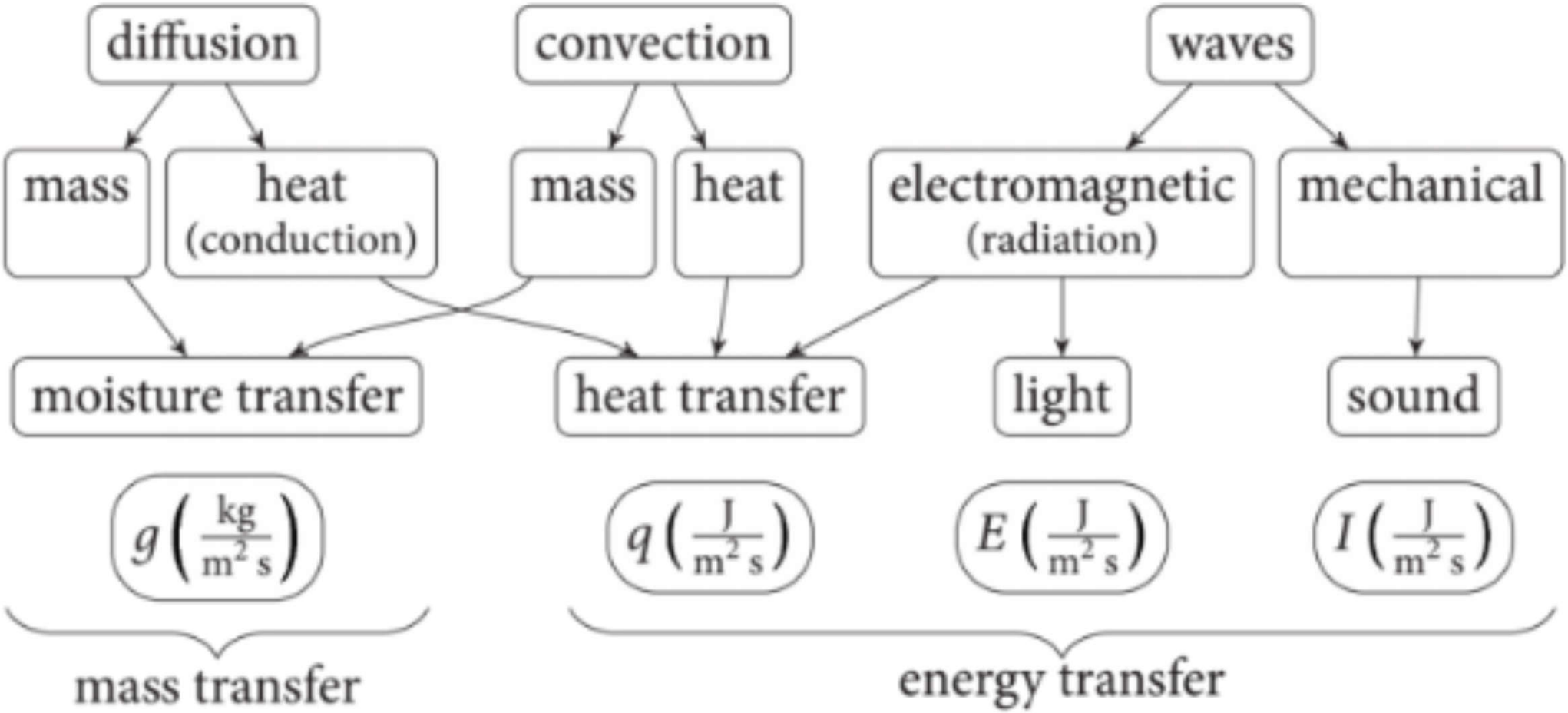
Science principles

- Building engineering physics: major aspects
  - Thermal performance
  - Acoustics
  - Air movement
  - Climate
  - Construction technology
  - Building services
  - Control of moisture
  - Lighting



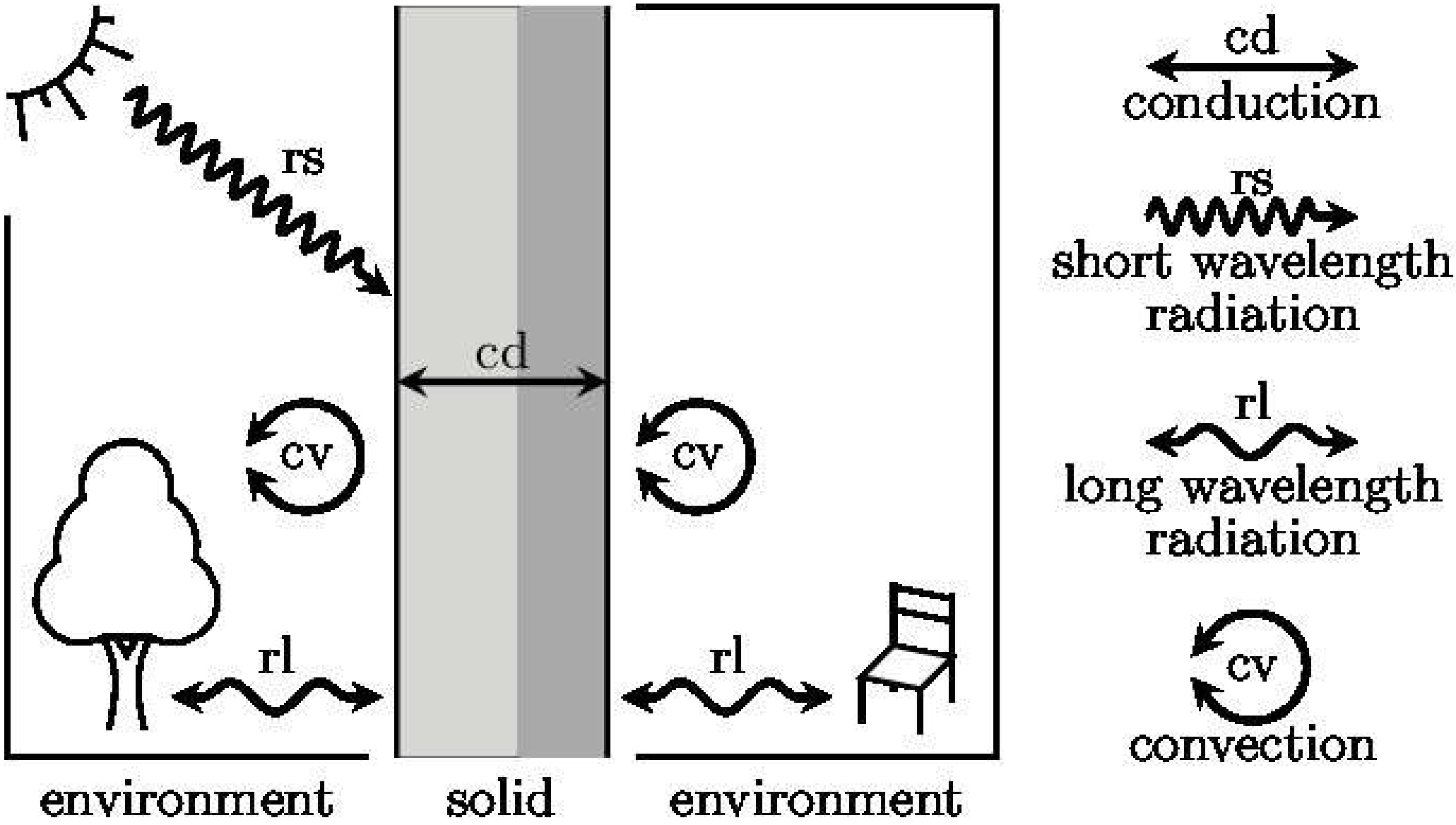
Overall physical principles and building physics phenomena for mass and energy transfer

$$\text{intensity} = \frac{\text{amount of entity}}{\text{area} \times \text{time}} \left(\frac{\text{X}}{\text{m}^2\,\text{s}} \right).$$



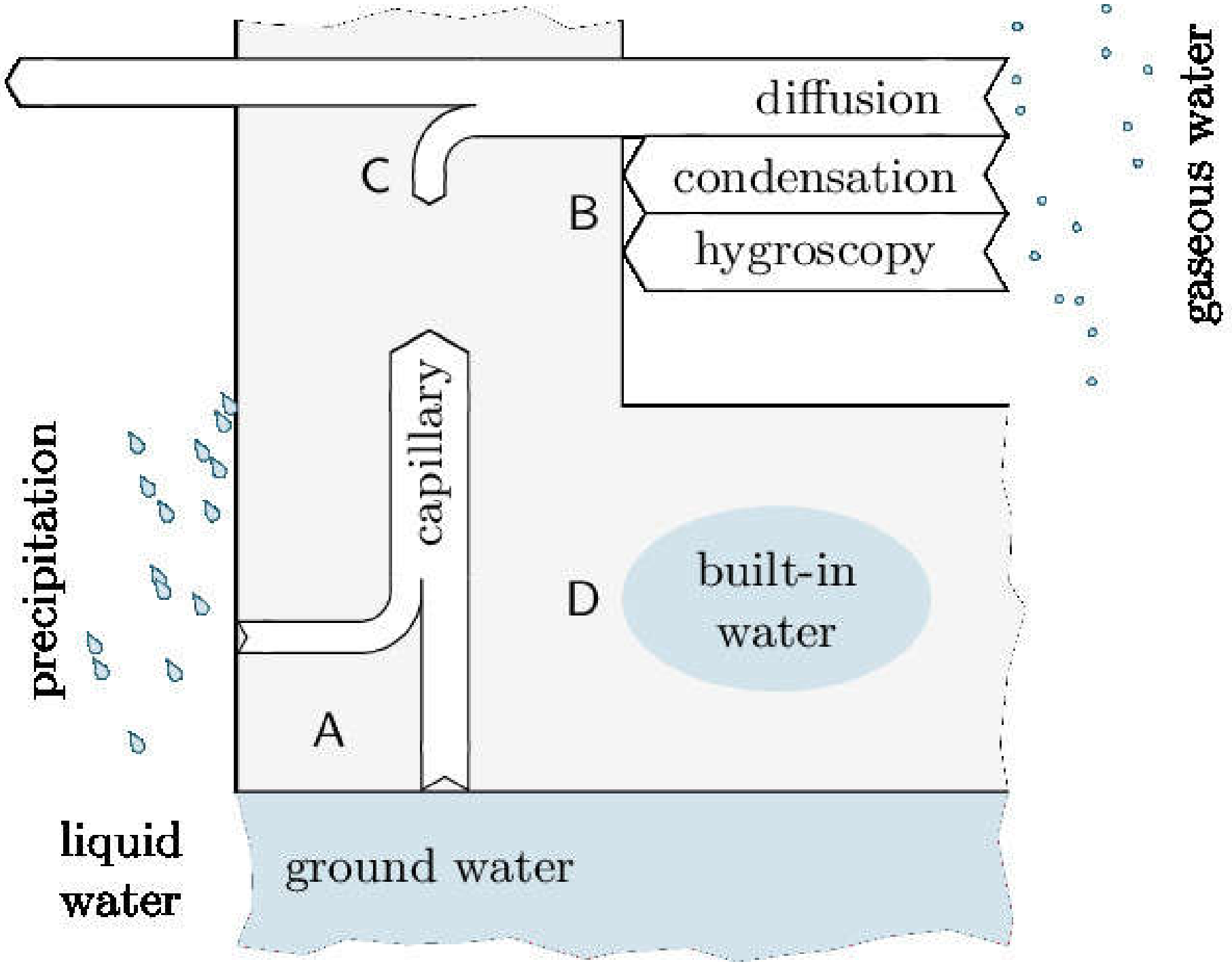
(Source: Pinterić M., 2021. *Building Physics: From physical principles to international standards*, Second Edition, Springer, Cham, Switzerland.)

Heat transfer in buildings



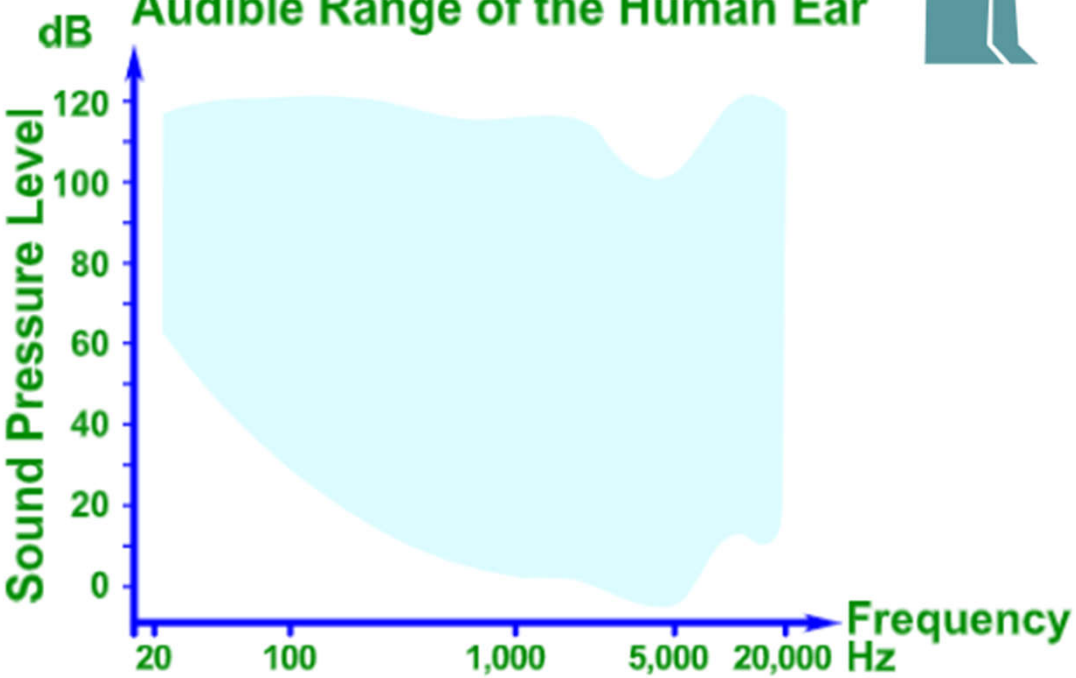
(Source: Pinterić M., 2021. *Building Physics: From physical principles to international standards*, Second Edition, Springer, Cham, Switzerland.)

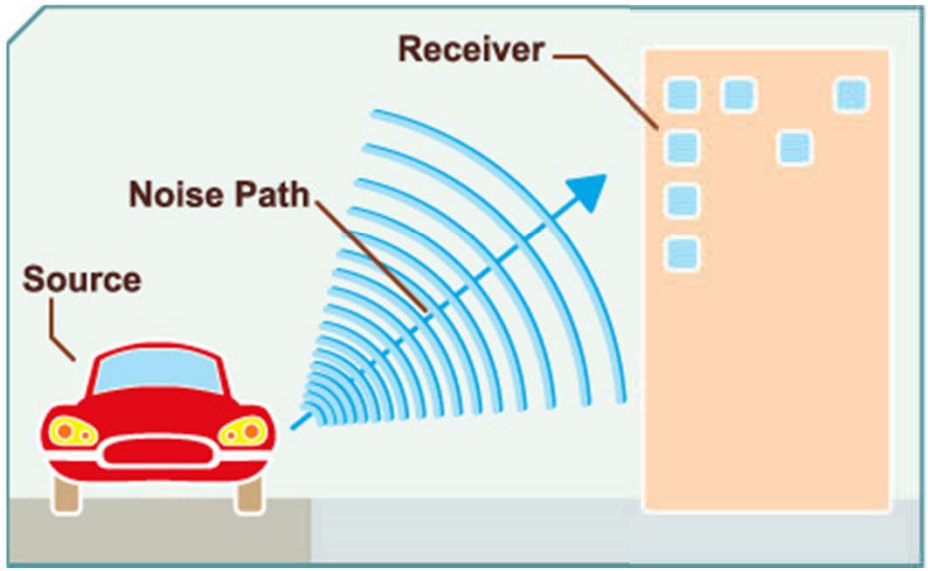
Moisture transfer in buildings

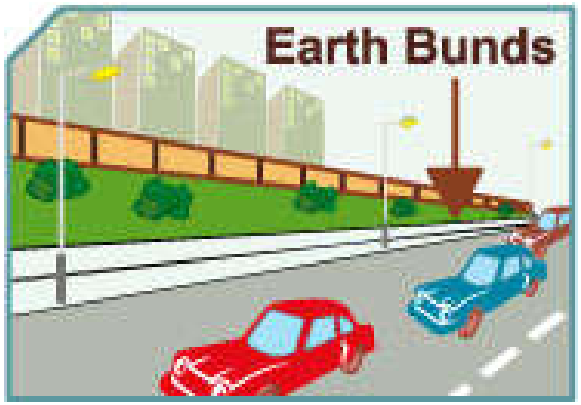


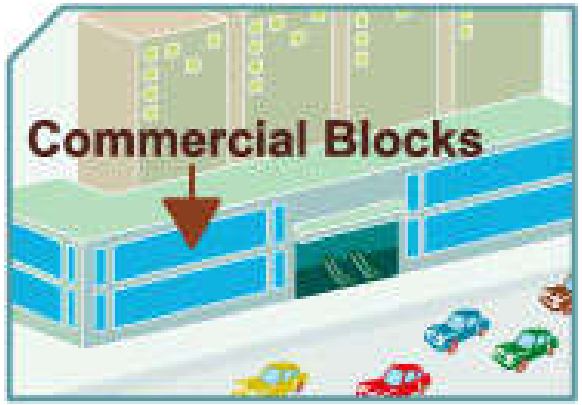
(Source: Pinterić M., 2021. *Building Physics: From physical principles to international standards*, Second Edition, Springer, Cham, Switzerland.)

Noise control principles & typical measures









(Source: Environmental Noise 環境噪音 https://www.epd.gov.hk/epd/noise_education/)

Engineering fundamentals

- Understand the fundamentals is important for thoughtful design
- Key fundamentals of engineering that influence the building design:
  - Laws of thermodynamics
  - Heat transfer
  - Fluid mechanics
  - Energy conversion

Engineering fundamentals

- Laws of thermodynamics
  - First Law: Energy cannot be created or destroyed
  - Second Law: All processes irreversibly increase the entropy of a system and its environment
    - Must use energy carefully and effectively
- Heat transfer
  - Conduction, $Q = U\,A\,\Delta T$
  - Convection (natural & forced convection)
  - Radiation, $Q = \varepsilon\,\sigma\,A\,(T_1^4 - T_2^4)$

Engineering fundamentals

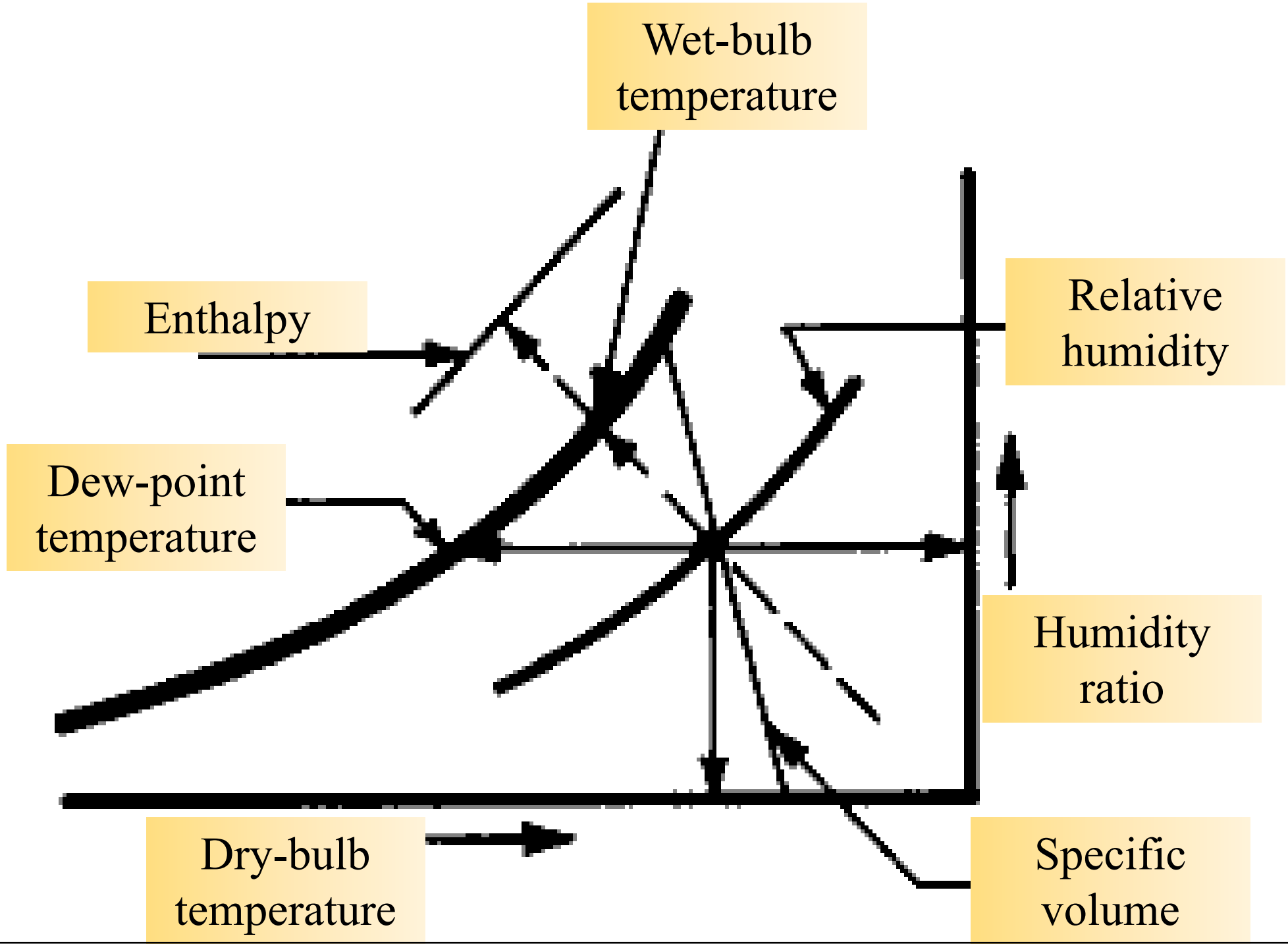
- Fluid mechanics
  - Fluid flow and systems
    - Bernoulli equation: $\frac{p}{\rho g} + \frac{v^2}{2g} + z = \text{constant}$
  - Hydraulic machines, e.g. pumps, fans
- Energy conversion
  - Power generation and distribution
  - Cogeneration, combined heat and power (CHP)
  - Recovery of energy, system efficiencies
  - Mass transfer, latent heat

Engineering fundamentals

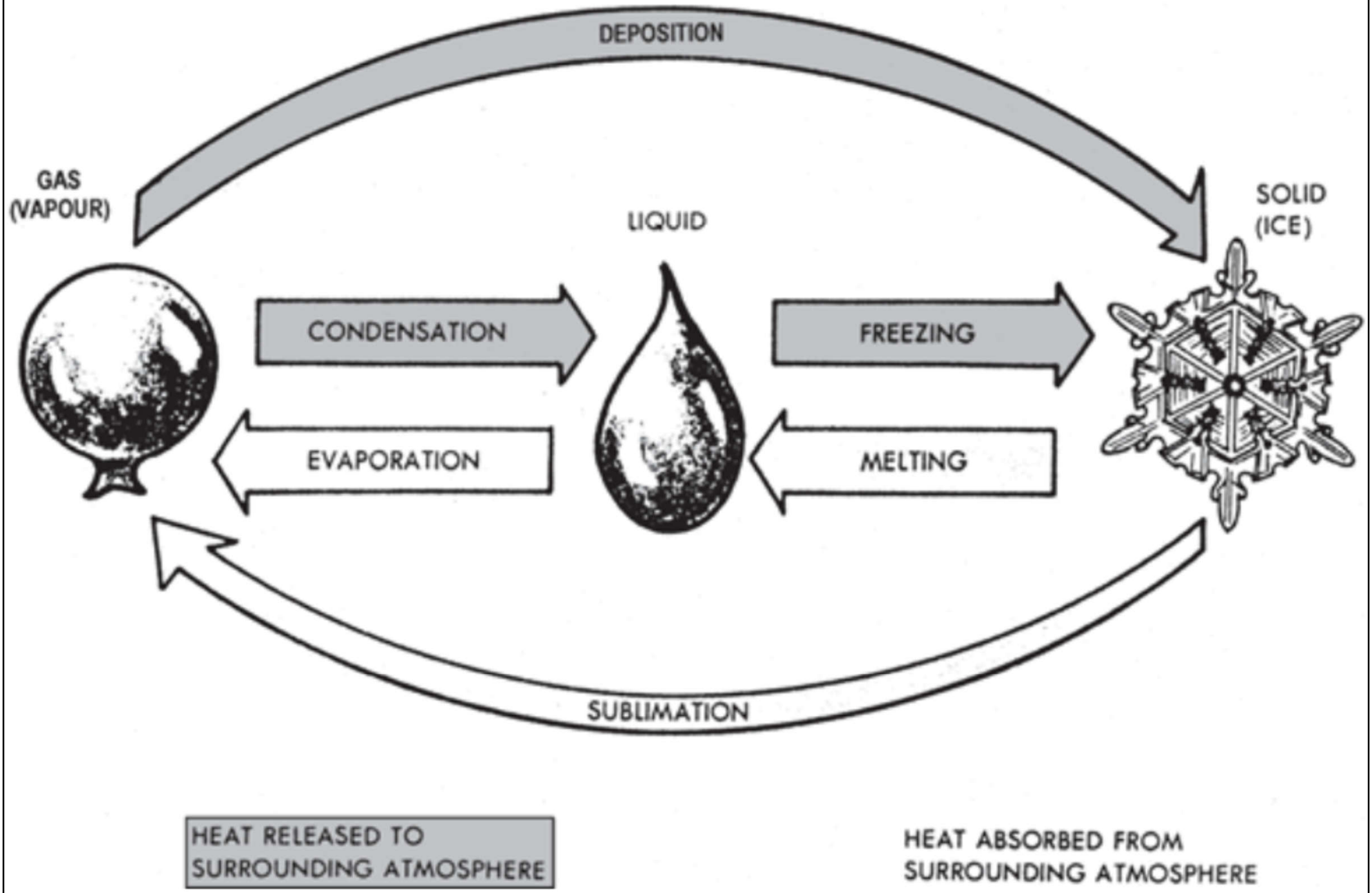
- Psychrometry (測濕學)
  - The measurement or study of the thermodynamic properties of moist air (dry air + water vapour)
    - The Greek term psuchron (ψυχρόν) meaning "cold" and metron (μέτρον) meaning "means of measurement"
  - Moist air properties:
    - Ideal gas laws: Dalton's law of partial pressures
    - Standard atmospheric pressure = 101.325 kPa
    - Saturated vapour pressure: Max. pressure of water vapour that can occur at any given temperature

(See also: Psychrometrics - Wikipedia http://en.wikipedia.org/wiki/Psychrometrics)

Major parameters on a psychrometric chart

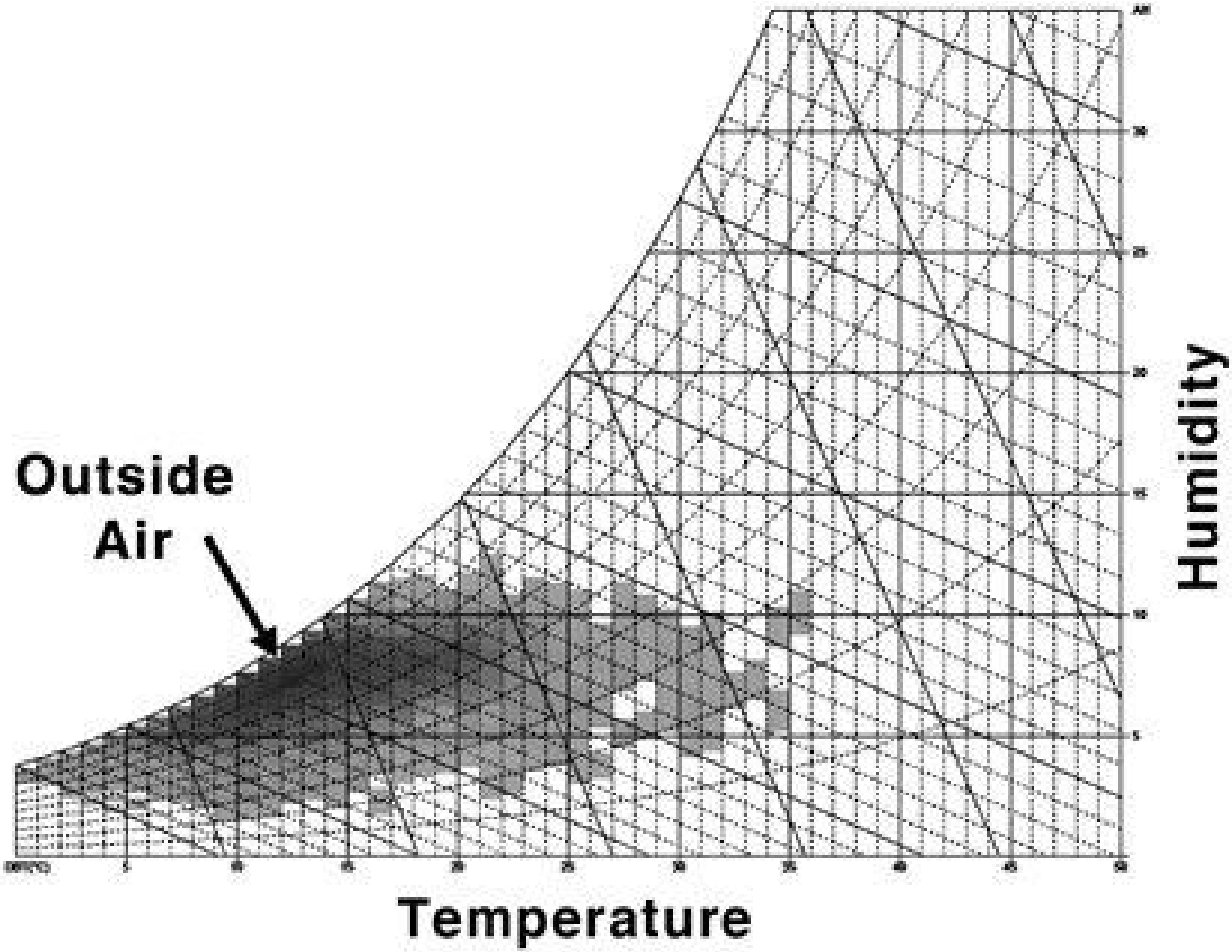


Phase change processes for H_2O



(Source: Gatley, D. P., 2013. *Understanding Psychrometrics*, 3rd ed.)

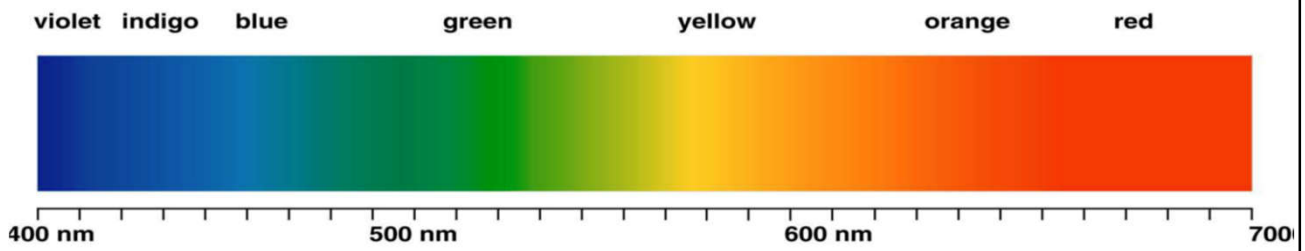
Analysis of outside air (climatic) conditions using a psychrometric chart



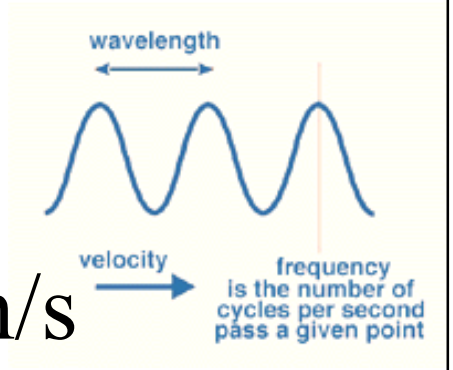
(Source: https://knowledge.autodesk.com/support/revit-products/getting-started/caas/simplecontent/content/psychrometric-charts-part-1.html)

Engineering fundamentals

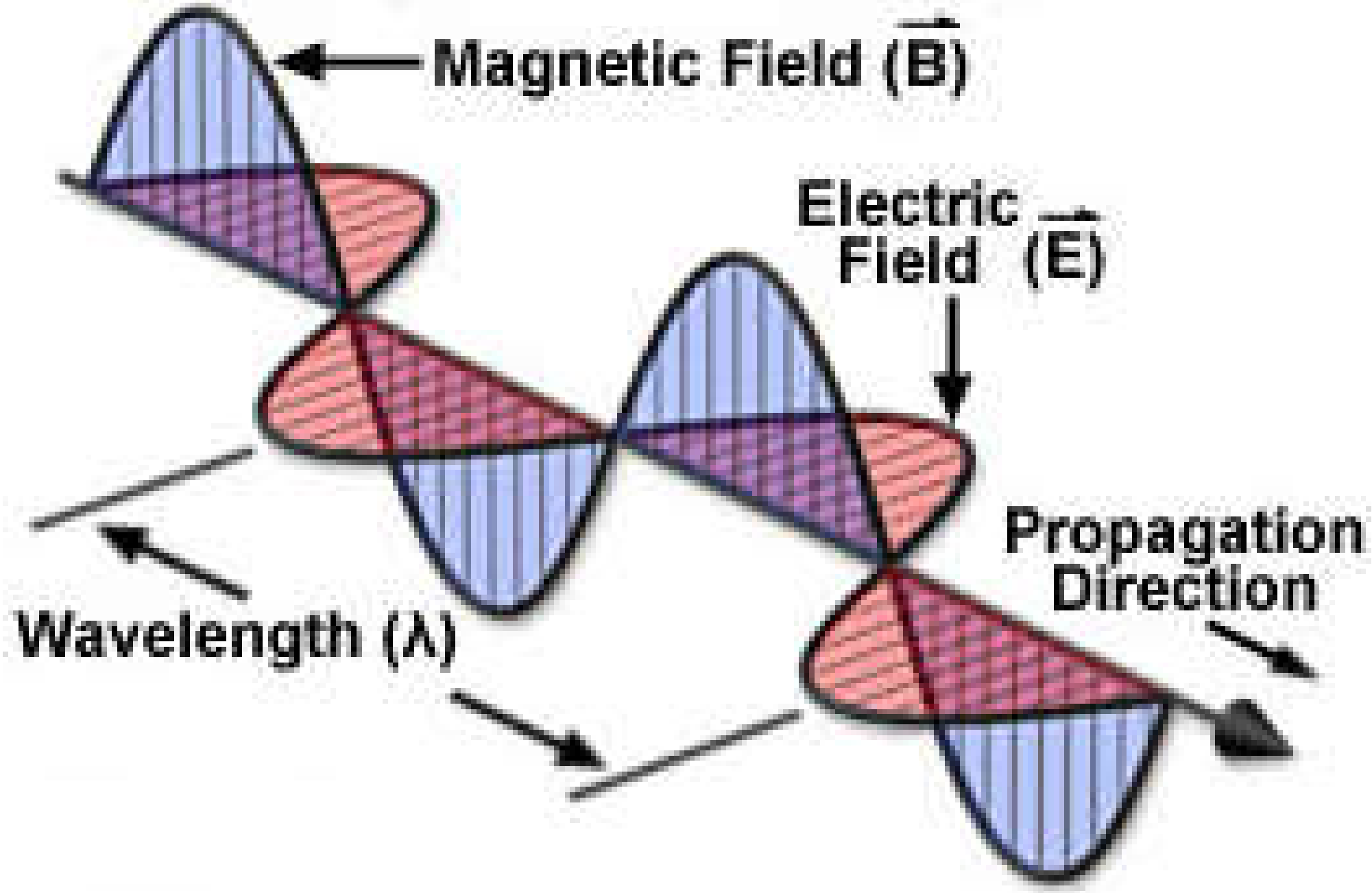
- Electromagnetic spectrum
  - Visible light (380 to 760 nm)
    - Mr. ROY G. BIV (Red, Orange, Yellow, Green, Blue, Indigo, Violet)



  - Ultraviolet (100 to 380 nm)
  - Infrared (760 to 1,000,000 nm)
- Speed of light (in air) = 299 702 547 m/s
  - = (wavelength, metres) x (frequency, Hertz)



Basic properties of electromagnetic wave



(Source: https://www.olympus-lifescience.com/en/microscope-resource/primer/lightandcolor/electromaghome/)

Quality characteristics of lighting

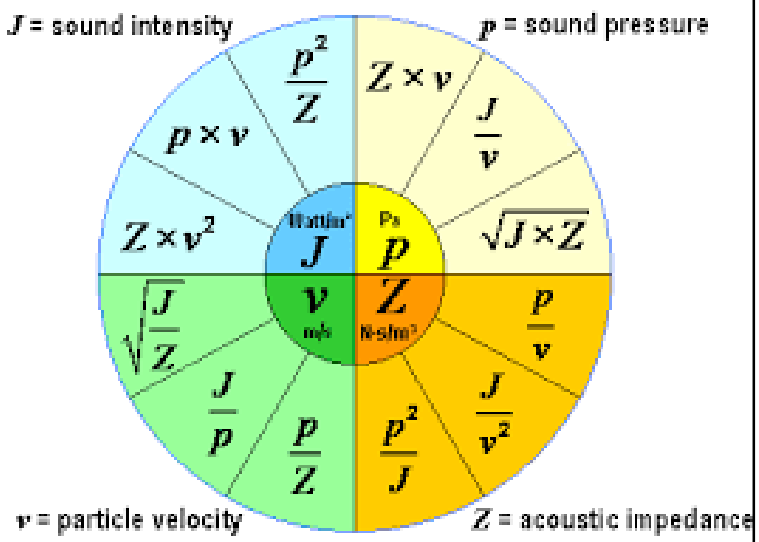
Traditional quality criteria:	**New quality criteria:**
– Sufficient illumination level – Harmonious brightness distribution – Glare limitation – Avoidance of reflections – Good modelling – Correct light colour – Appropriate colour rendering	– Changing lighting situations – Personal control – Energy efficiency – Daylight integration – Light as an interior design element

(Source: The Lighting Handbook (Zumtobel) http://www.zumtobel.com/PDB/teaser/EN/lichthandbuch.pdf)

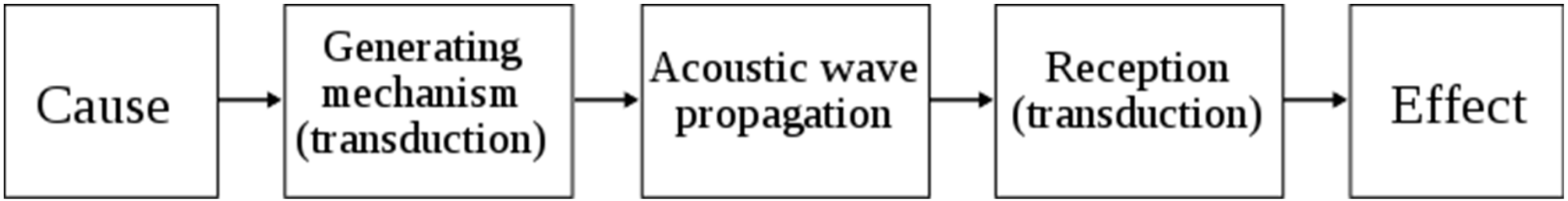
Engineering fundamentals

- Aural environment (sound)
  - Human hearing fundamentals
  - Architectural acoustics
  - Engineering noise control
  - Vibration & structural acoustics

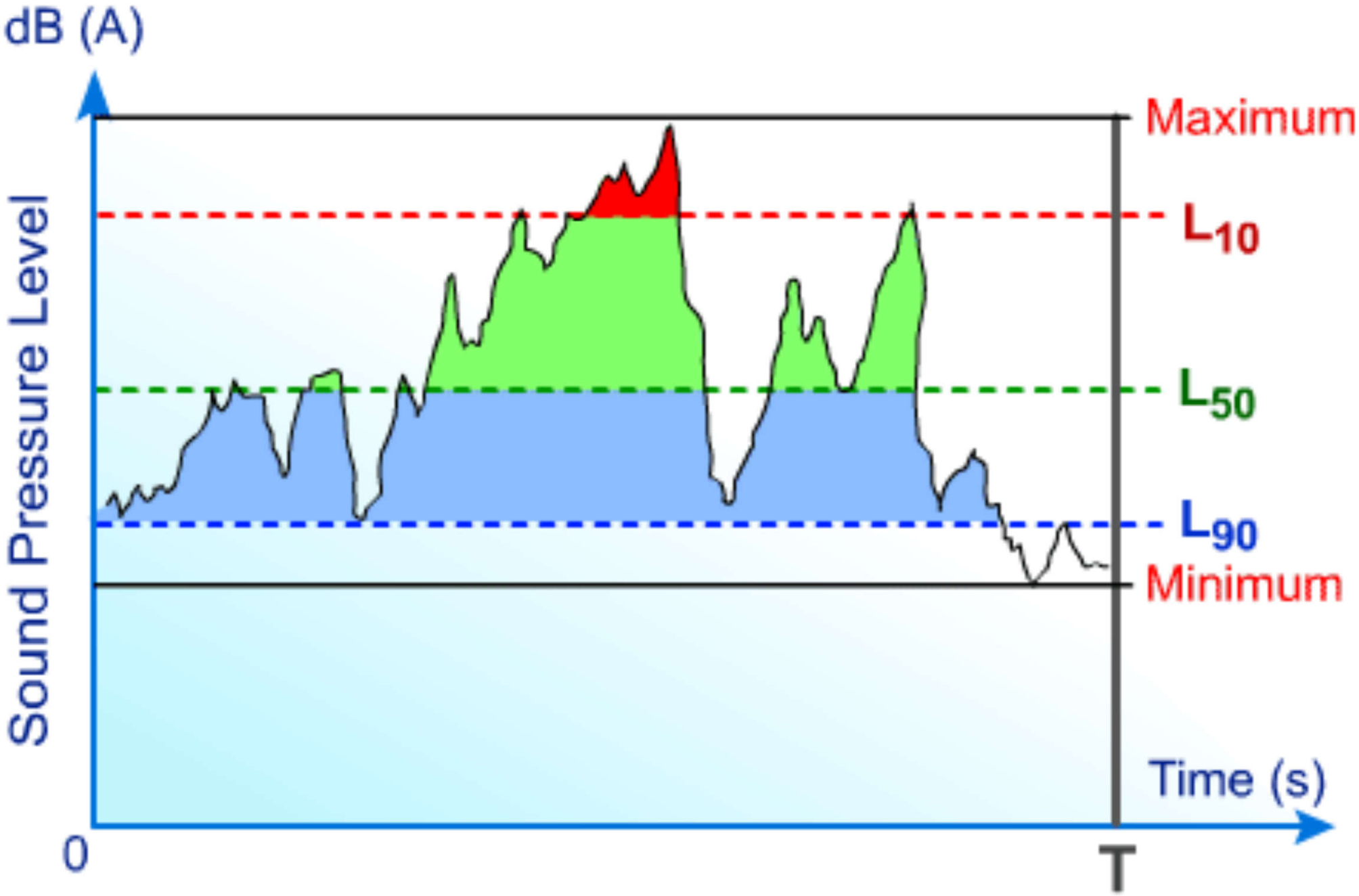
$$SPL_{(total)} = 10\log_{10}\sum_{i=1}^{n}10^{(SPL_i)/10}$$



$$L_p = 20\log_{10}\left(\frac{p_{\text{rms}}}{p_{\text{ref}}}\right) \qquad c = \sqrt{1/(\beta_s \rho)}$$

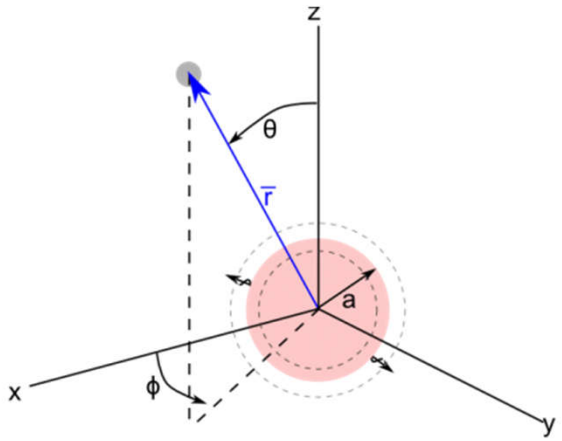


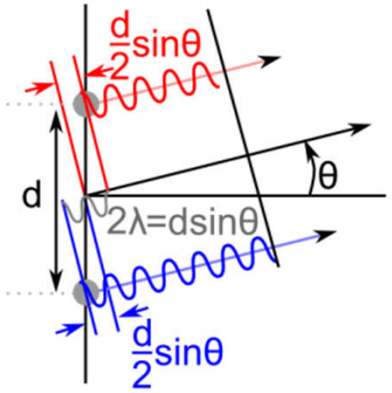
Sound pressure level and noise descriptors L_{10}, L_{50} & L_{90}



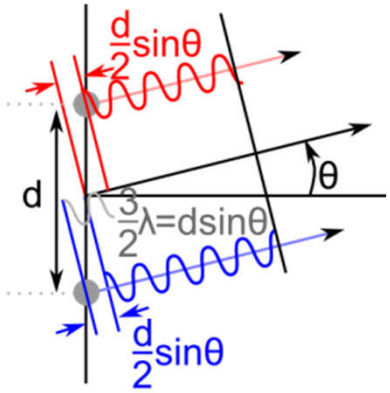
(Source: Environmental Noise 環境噪音 https://www.epd.gov.hk/epd/noise_education/)

Noise control and mitigation

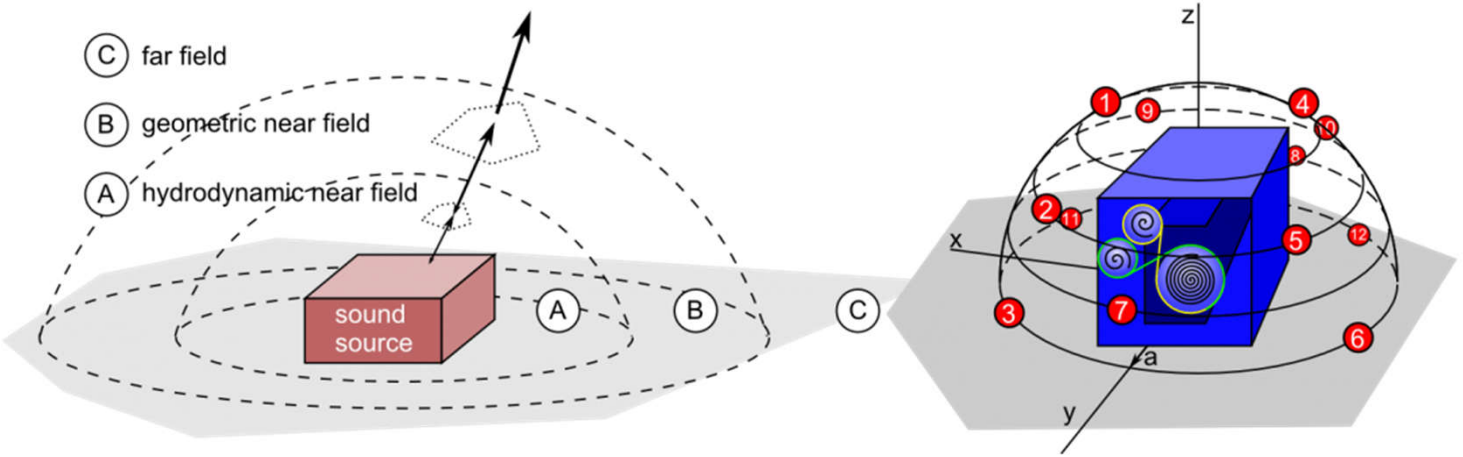


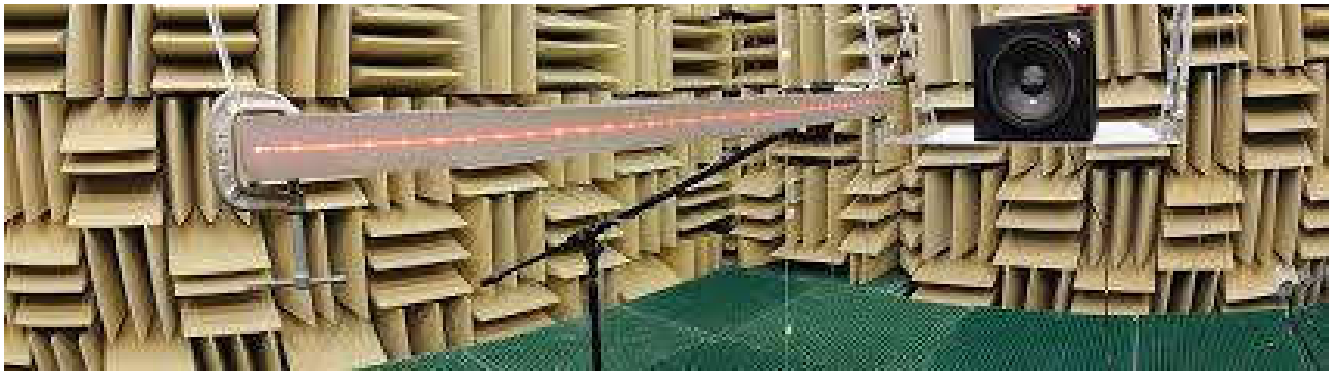


constructive interference



destructive interference





Further Reading

- Built environment - Wikipedia
  https://en.wikipedia.org/wiki/Built_environment
- Building Science Concepts
  https://www.wbdg.org/resources/building-science-concepts
- Human comfort in buildings - Designing Buildings Wiki
  https://www.designingbuildings.co.uk/wiki/Human_comfort_in_buildings
- Videos:

  - Introduction to Built Environment (11:34) https://youtu.be/tlsJwhWmtA0
  - 01_Designing A Building For Comfort (5:22) https://youtu.be/bKO3ZstpThM
  - 02 Thermal Comfort (6:41) https://youtu.be/BTdiimklSqo
  - 03 Acoustic Comfort (6:02) https://youtu.be/ZAIRH1aZ668
  - 04 Visual Comfort (7:56) https://youtu.be/fsjVlzIV1DQ