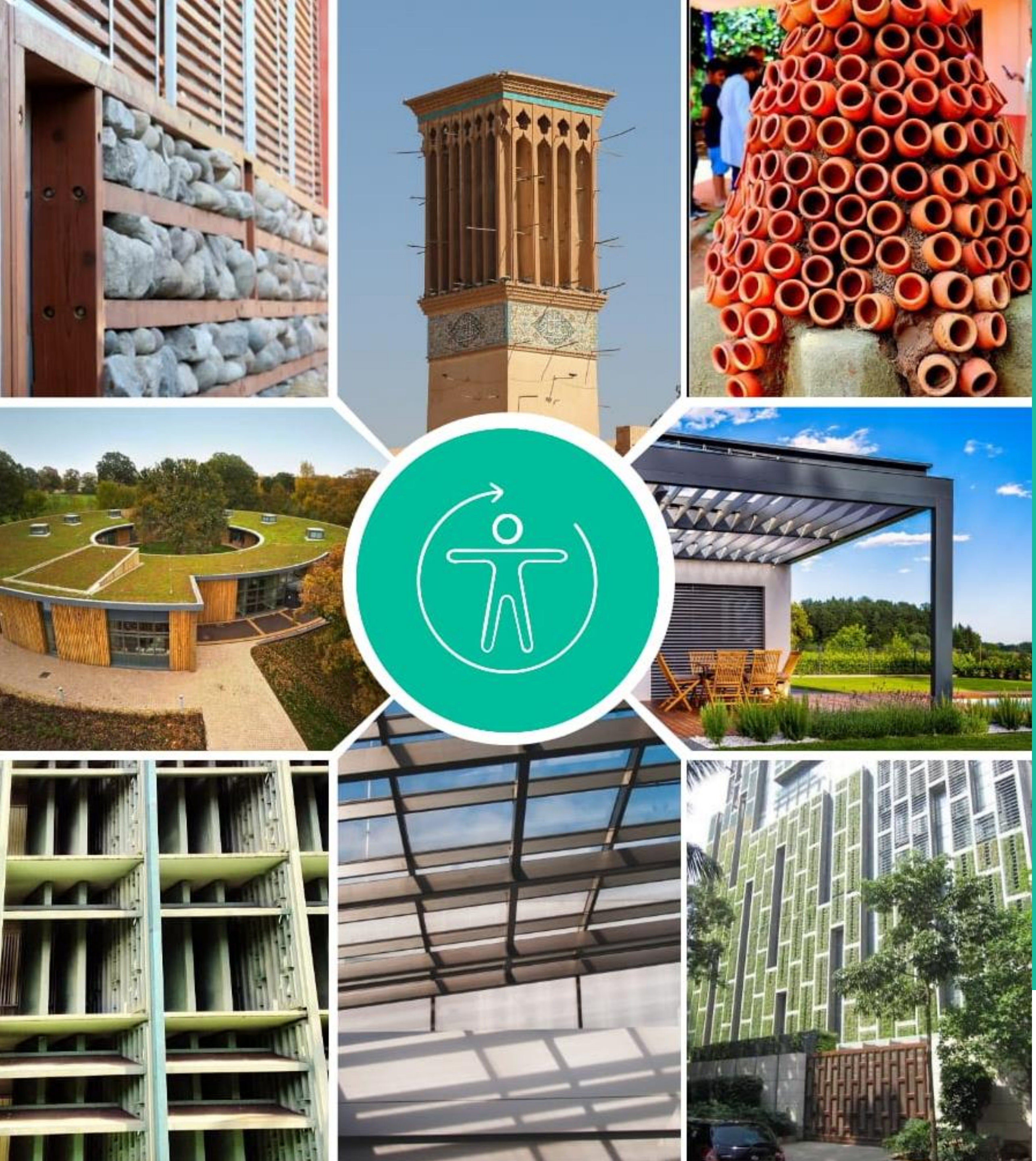
ASIA LOW CARBON BUILDINGS TRANSITION PROJECT

Life Cycle Assessment for Transitioning to a Low-Carbon Economy



2.1 Understanding Building Envelope

November 2024

Supported by:

Federal Ministry for Economic Affairs and Climate Action

INTERNATIONAL CLIMATE INITIATIVE

on the basis of a decision by the German Bundestag

WHAT WILL YOU LEARN?

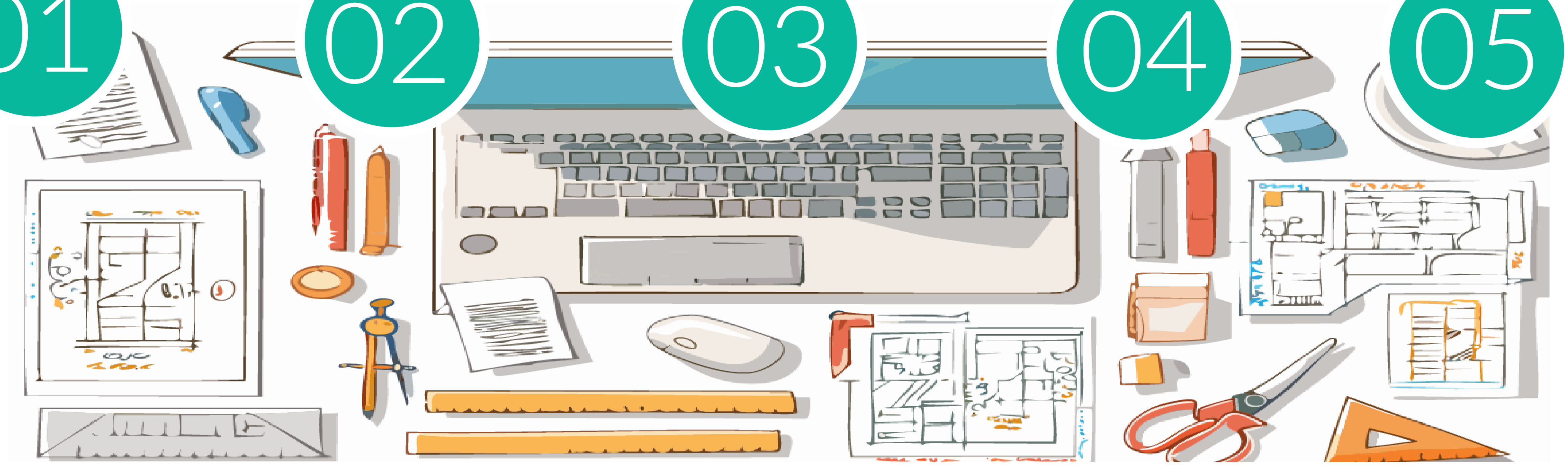
01 Challenges in Building Design

02 Basics of Building Physics

03 Thermal Properties of Building Materials

04 Thermal Properties of Fenestration

05 Key Takeaways



Building Design

Challenges

BUILDING DESIGN

Challenges: HOT versus COLD climates

Hot Climates

- External surfaces (roof and walls) absorb heat from solar radiation
- Heat transfer through thermal conduction to inner surfaces
- Increased discomfort from internal heat sources and reliance on fans and air conditioning systems

Cold Climates

- Heat loss through roofs, walls and windows
- Ventilation requirements and infiltration losses lead to excessive heating needs
- Higher energy costs and reduced thermal comfort

BUILDING CONDITIONS

Commercial versus residential

COMMERCIAL BUILDINGS

- Mostly air-conditioned
- Narrow band of expected comfort
- Mostly daytime occupancy
- Air-conditioning used for longer duration and may be used throughout the year
- Heat loads in the building may have equal or more contribution from internal loads, i.e., from occupants and equipment

RESIDENTIAL BUILDINGS

- May or may not be air-conditioned
- Broader band of expected comfort
- Mostly nighttime occupancy
- Air-conditioning used intermittently during the day and mainly in summer
- Heat loads in the building dominated by external loads i.e., those from the building envelope

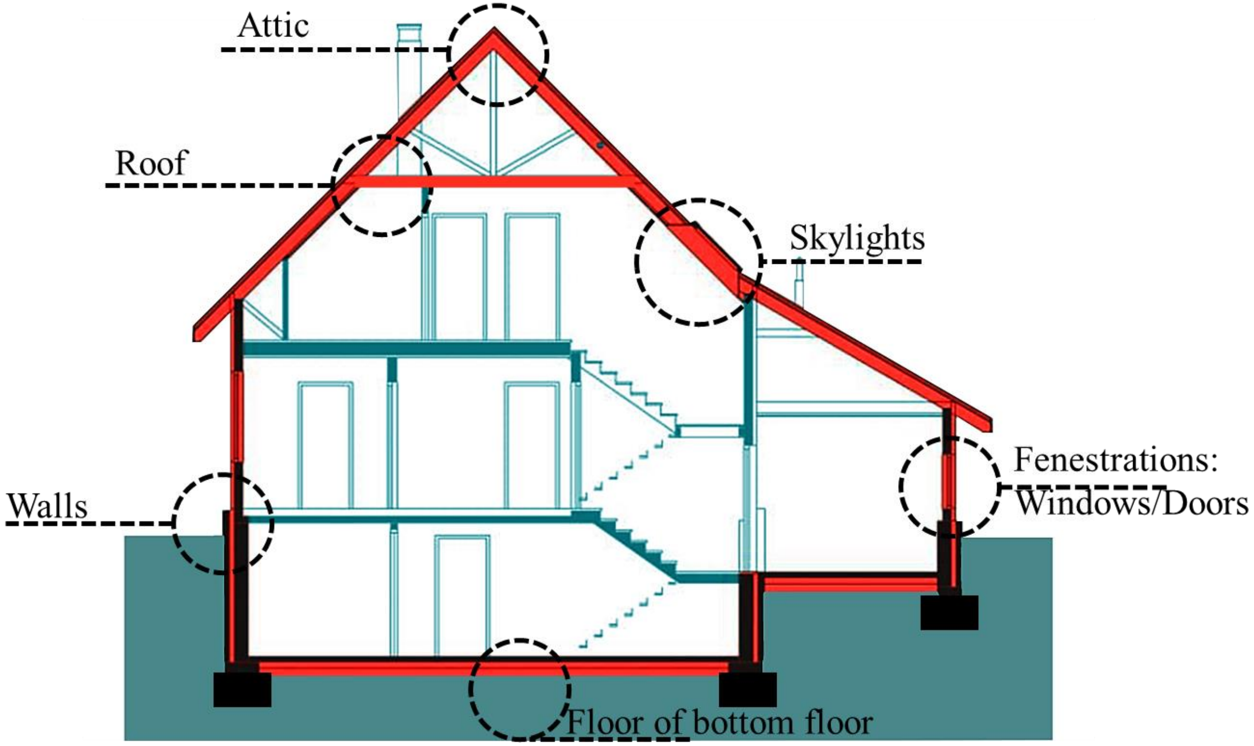
Building Physics

Building Envelope and Heat Transfer

BUILDING ENVELOPE
Components

Separates exterior from interior environments

Components:
- External walls
- Roof
- Windows
- Doors
- Foundation
- Floor



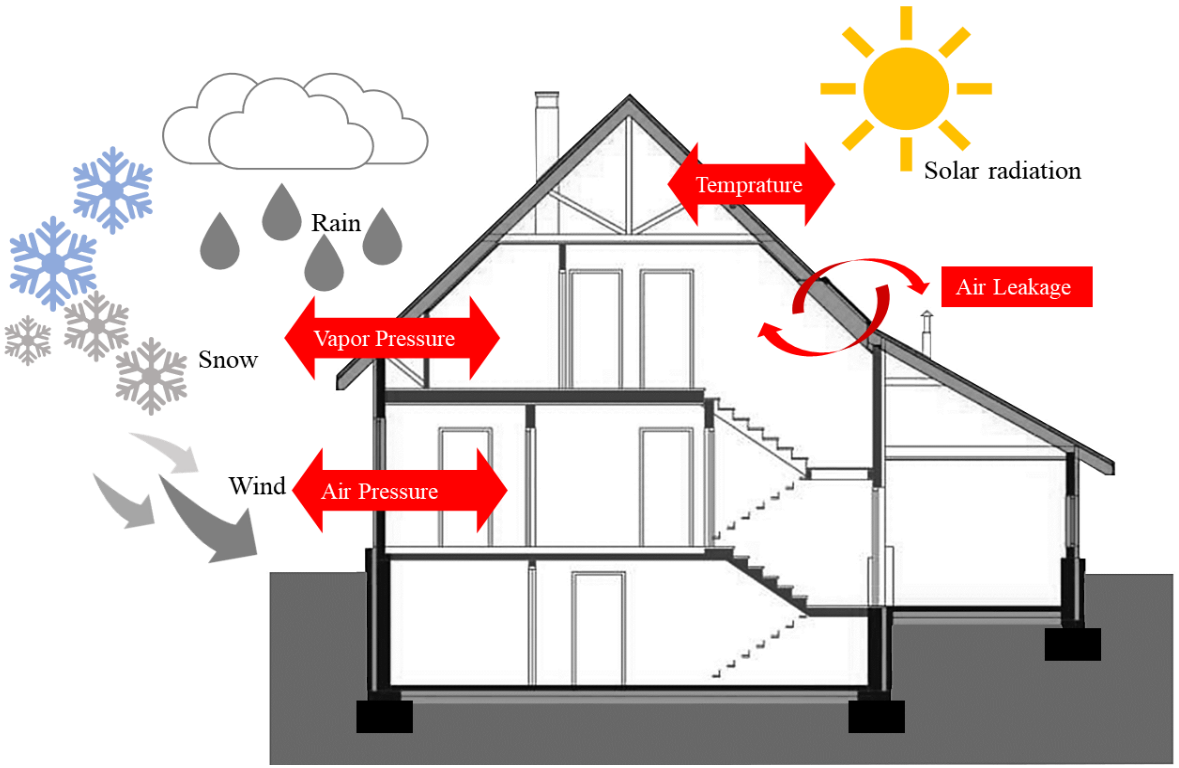
Components of a building envelope

Source: Building Energy Efficiency in Nepal (BEEN) Project, 2024

BUILDING ENVELOPE

Role and importance

- Physical protection
- Protection from rain and noise
- Light control
- Indoor climate regulation

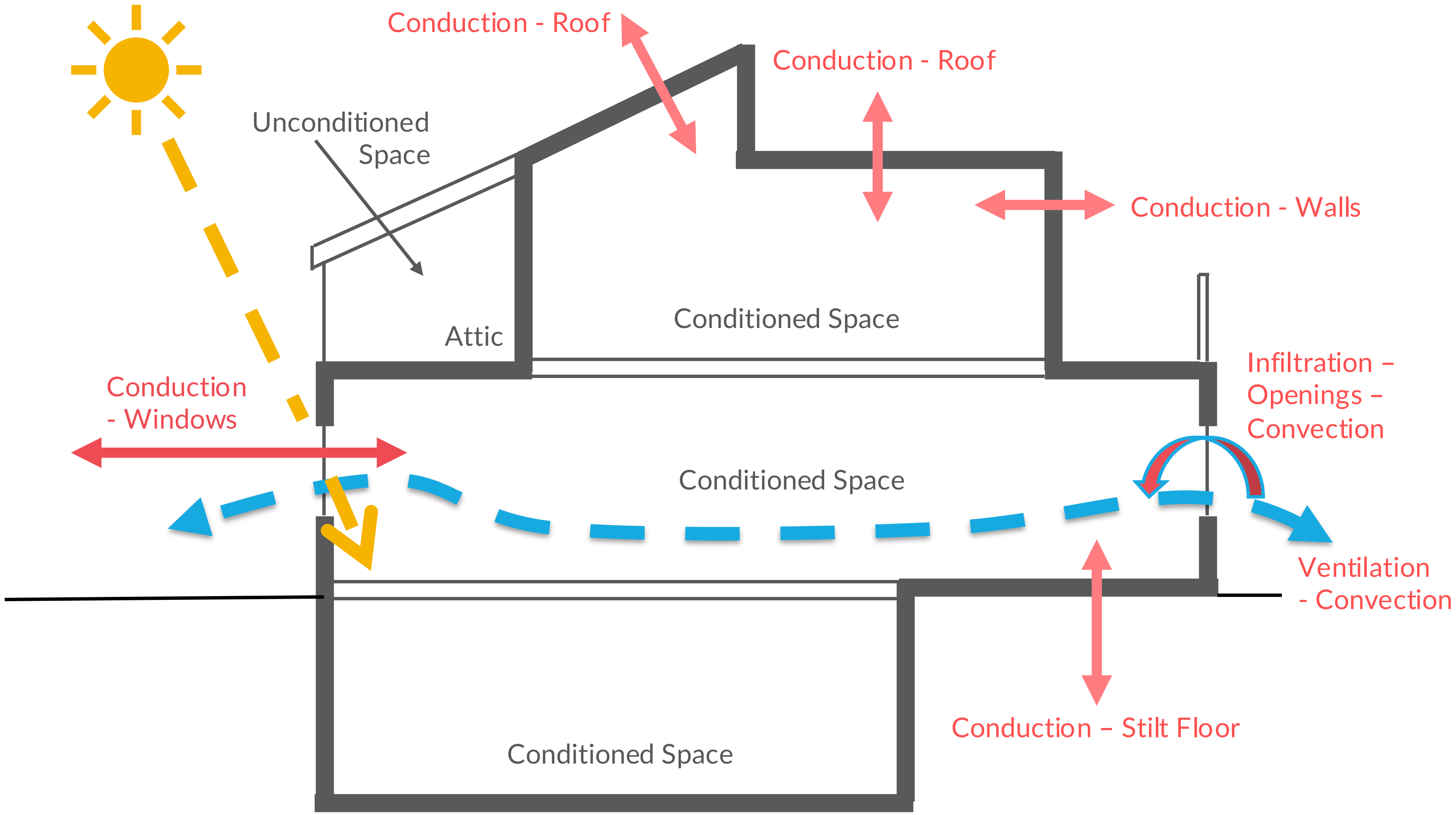


Protection from external elements through building envelope

Source: Building Energy Efficiency in Nepal (BEEN) Project, 2024

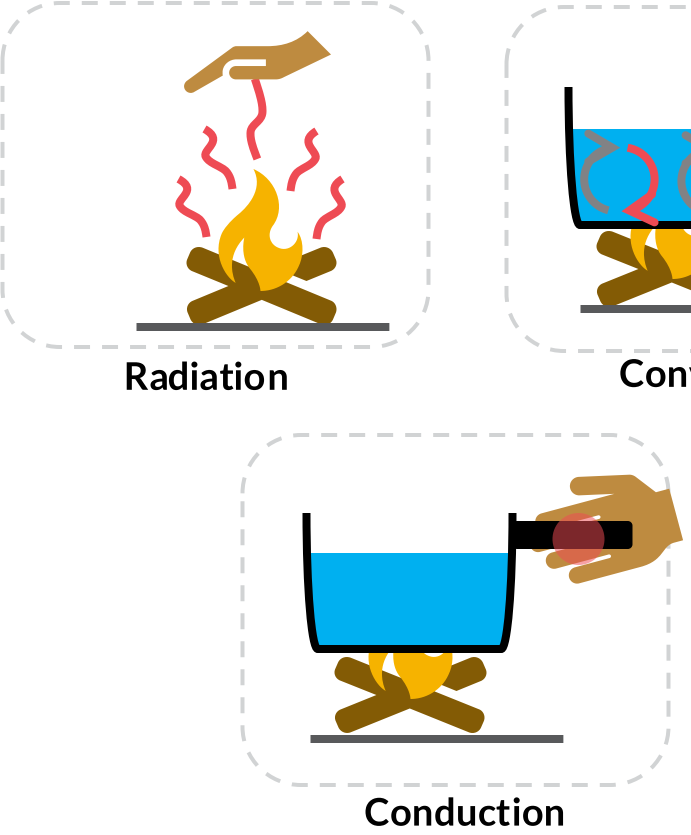
HEAT EXCHANGE IN BUILDINGS

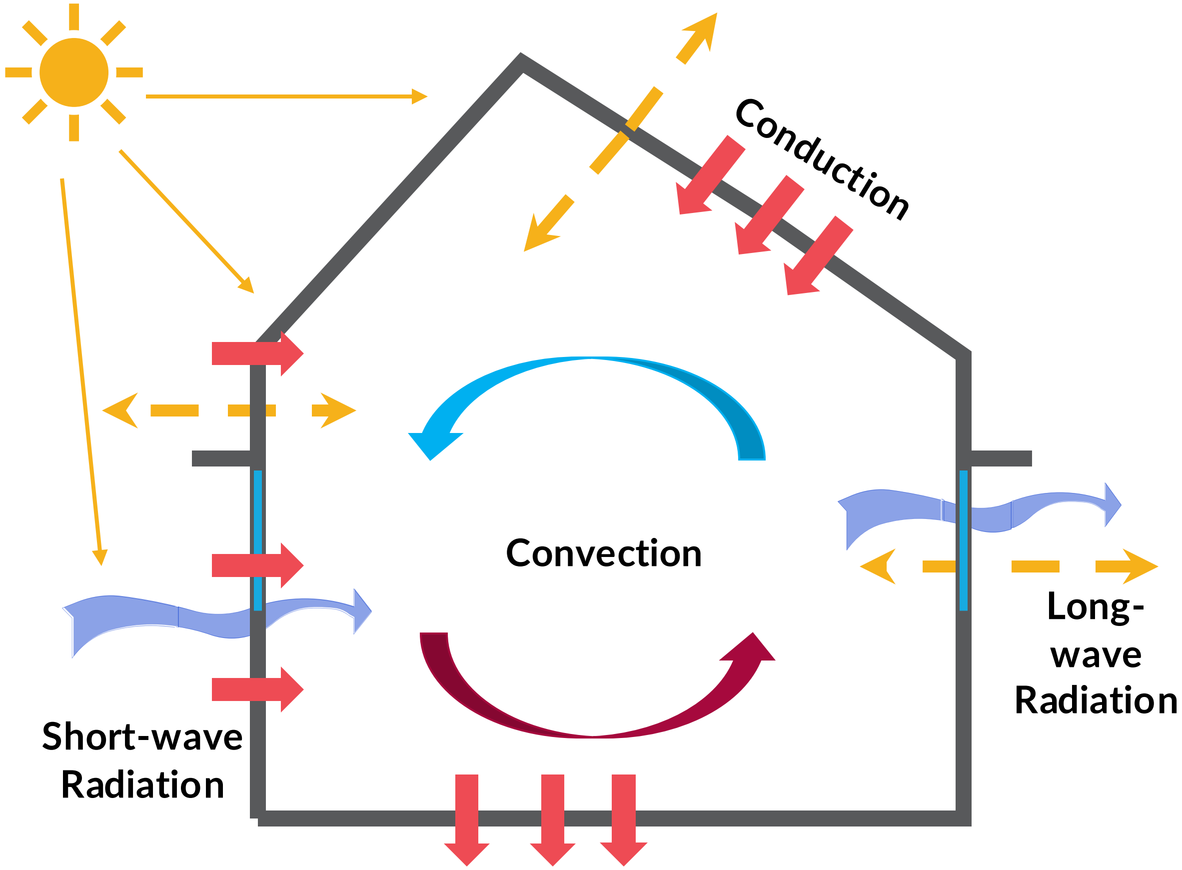
Role of building envelope



HOW HEAT TRAVELS?

Modes of heat transfer



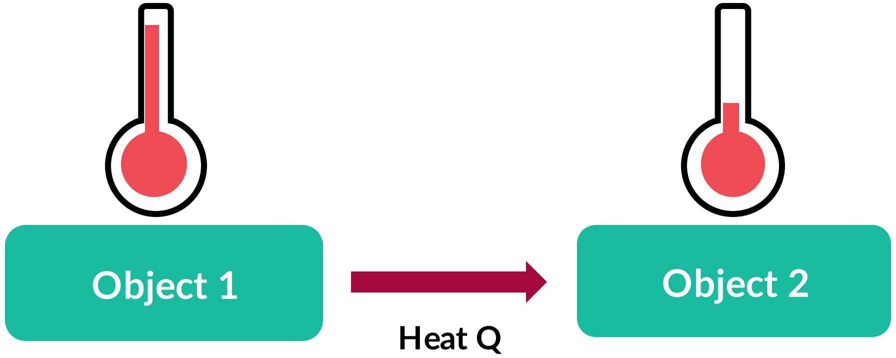


Source: Building Energy Efficiency in Nepal (BEEN) Project, 2024

HEAT TRANSFER

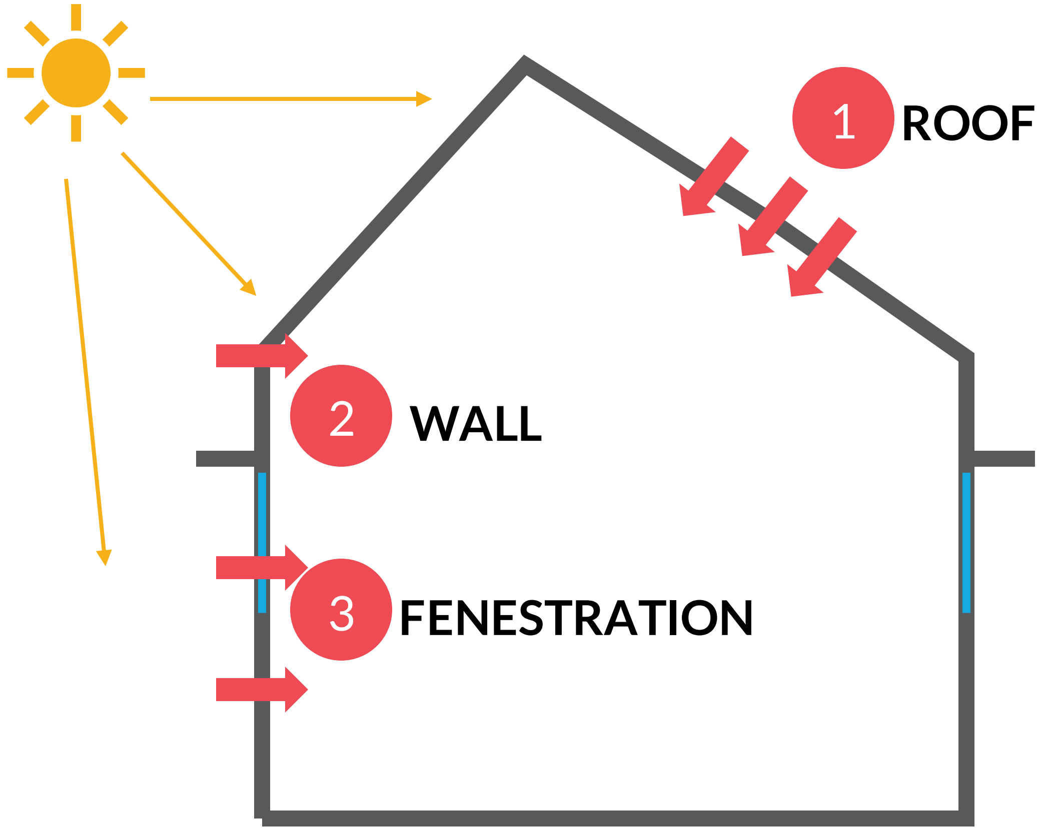
Always from higher temperature to lower temperature

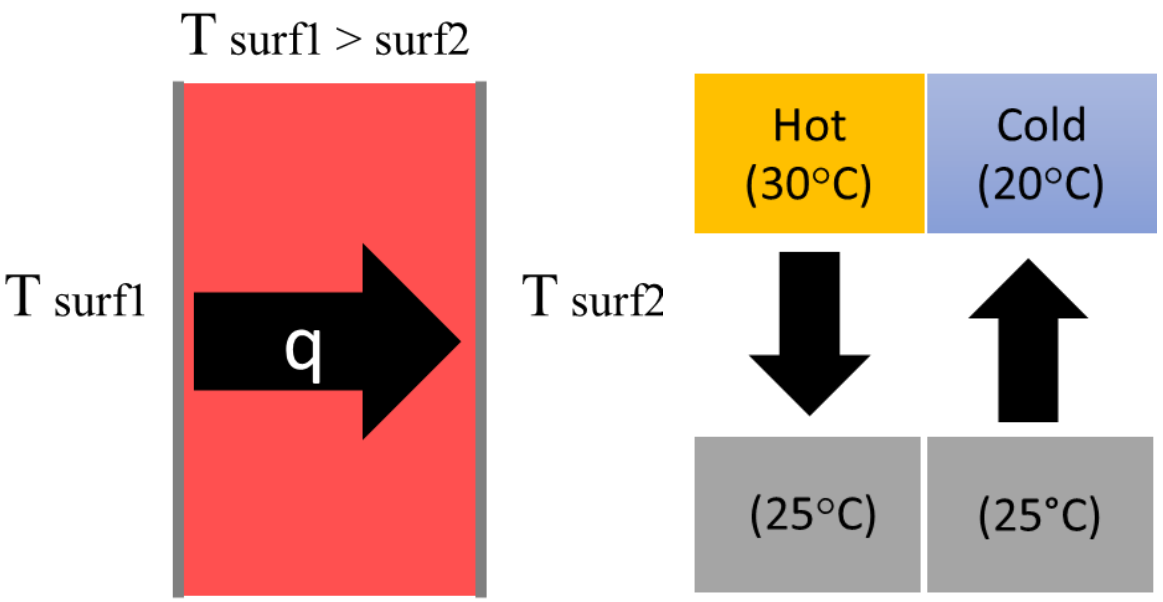
- Heat flows from a hot body to a cold body
- Heat is thermal energy
- Heat is transferred between bodies at different temperatures
- The measurement unit of heat is joule (J); kilowatt-hour (kWh) is also commonly used
- 1 joule corresponds to 0.278 x 10^{-6} kWh
- 1 kWh corresponds to 3.6 MJ (mega joules)



CONDUCTION

Heat diffusion through solids: Hot to cold

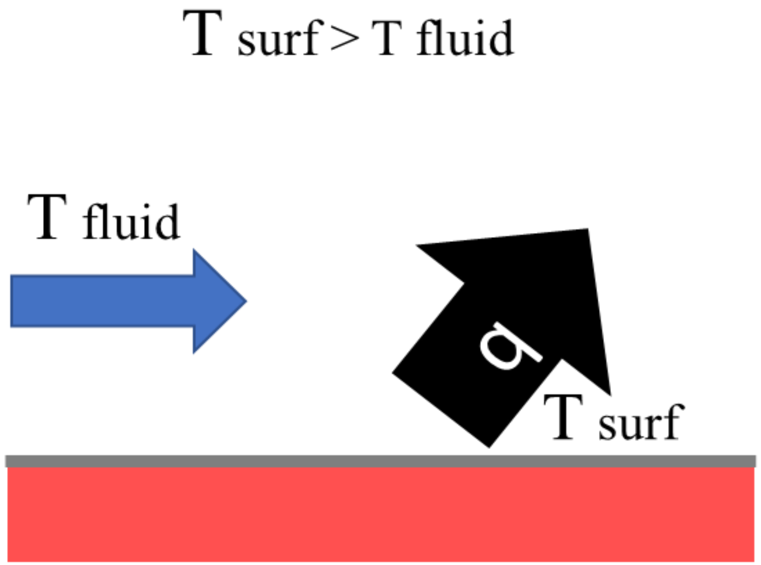


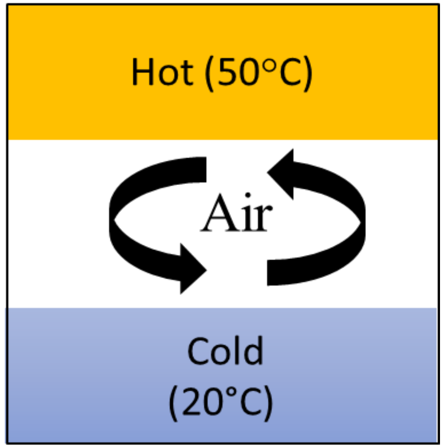


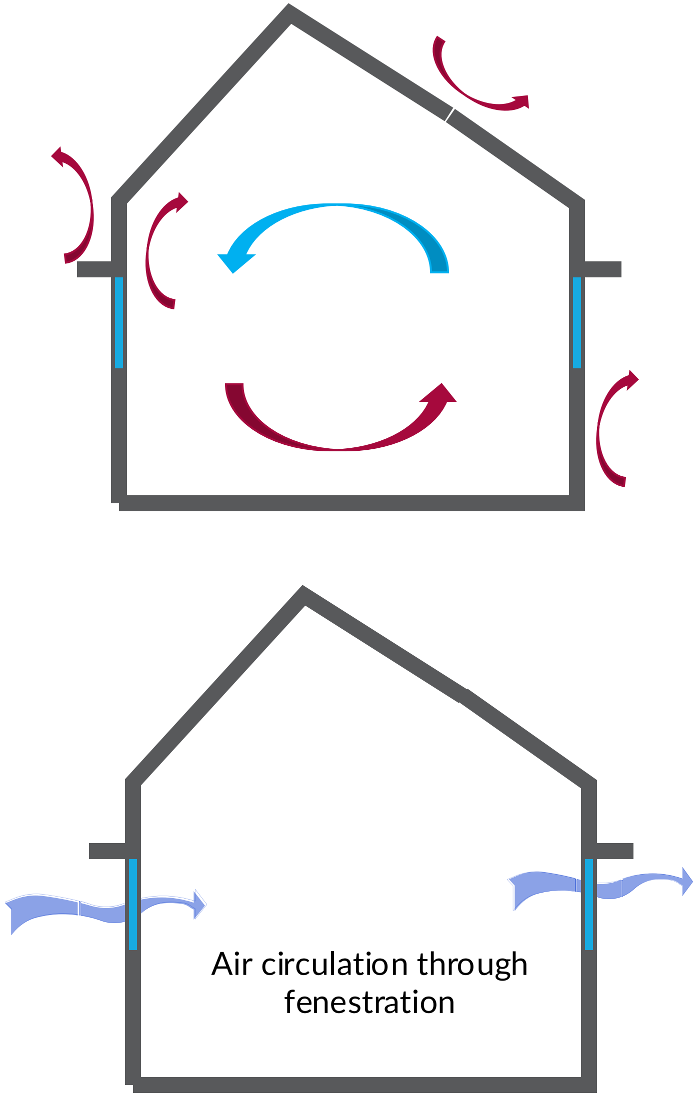
Source: Building Energy Efficiency in Nepal (BEEN) Project, 2024

CONVECTION

Heat transfer by fluid movement



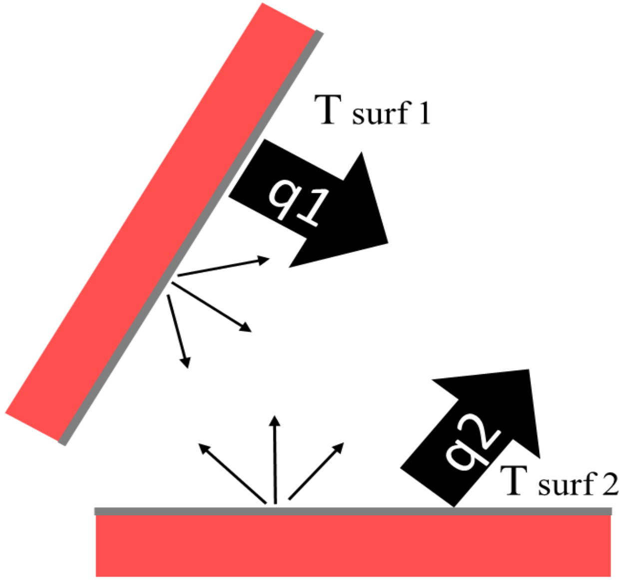


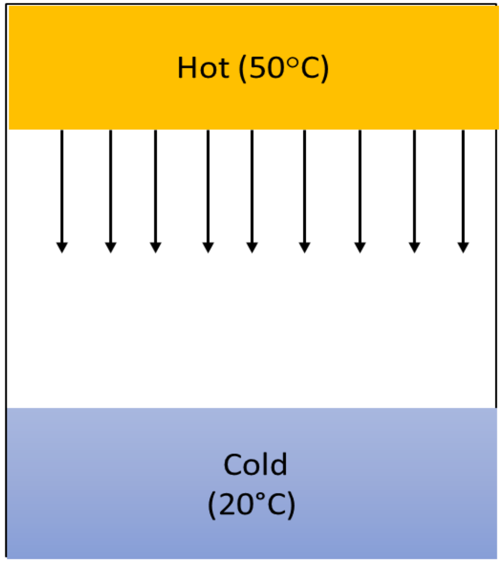


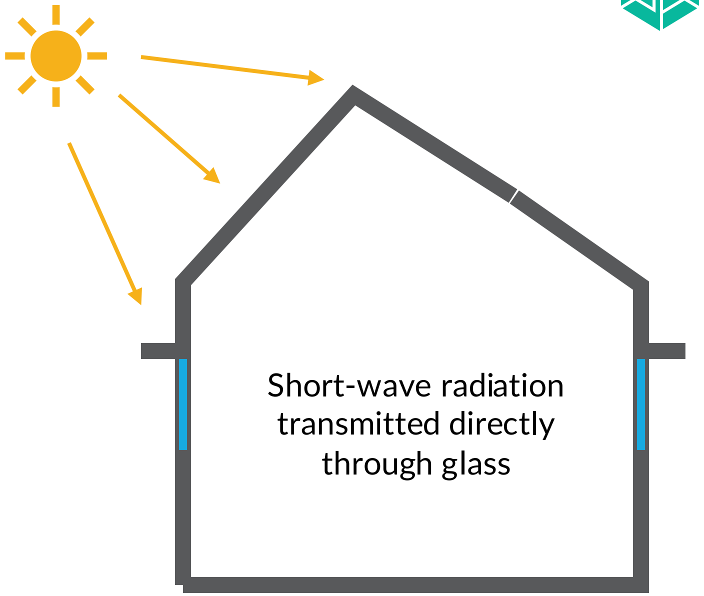
Source: Building Energy Efficiency in Nepal (BEEN) Project, 2024

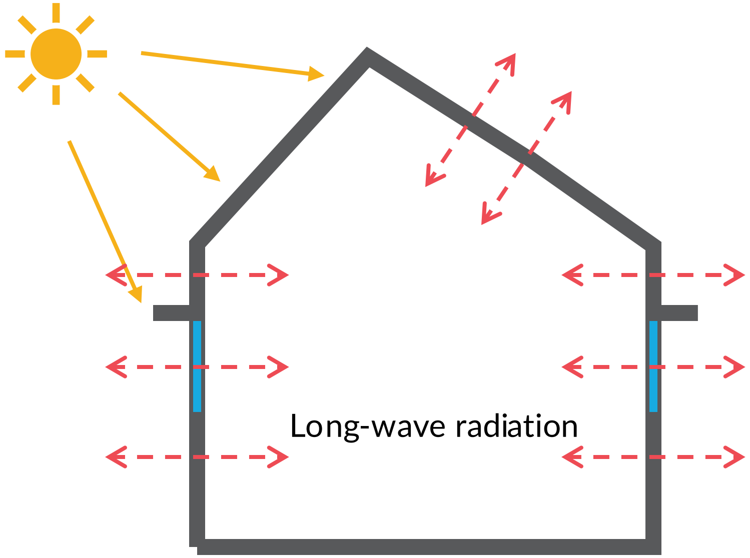
RADIATION

Heat transfer via electromagnetic waves









Source: Building Energy Efficiency in Nepal (BEEN) Project, 2024

Building Materials

Thermal Properties

Image source: https://www.bricknbolt.com/blogs-and-articles/construction-guide/building-material-density-importance-construction

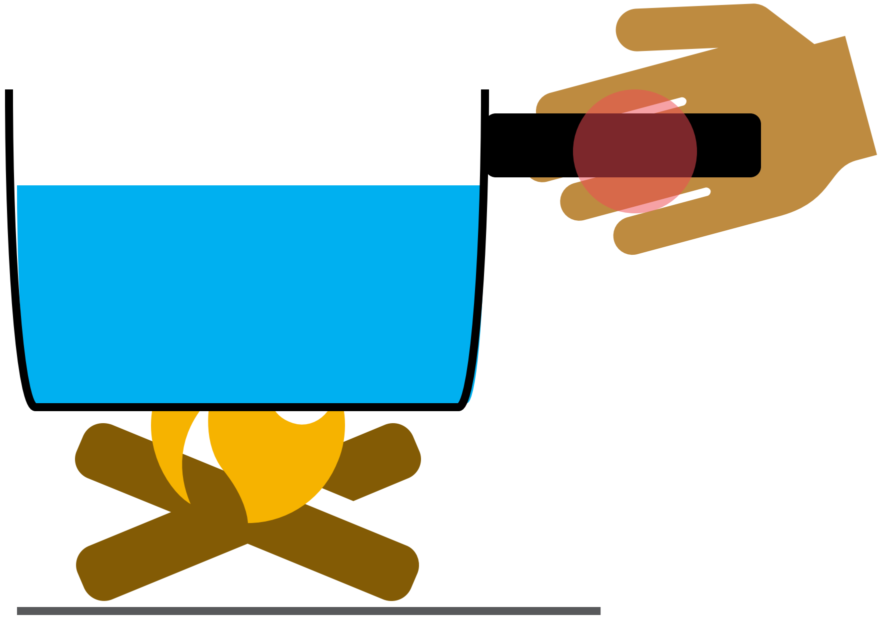
THERMAL CONDUCTION

Understanding parameters

Thermal Conduction (K-value)
Low K-value = **good insulation**

Thermal Resistance (R-value)
High R-value = **good resistance**

Thermal Transmittance (U-value)
Low U-value = **low heat transfer**



THERMAL PROPERTIES

Walls and roofs

- Reflectance and emissivity, combined as Solar Reflective Index (SRI)
- Thermal conductivity and transmittance (ability to conduct heat)
- Thermal mass (ability to absorb and store heat)

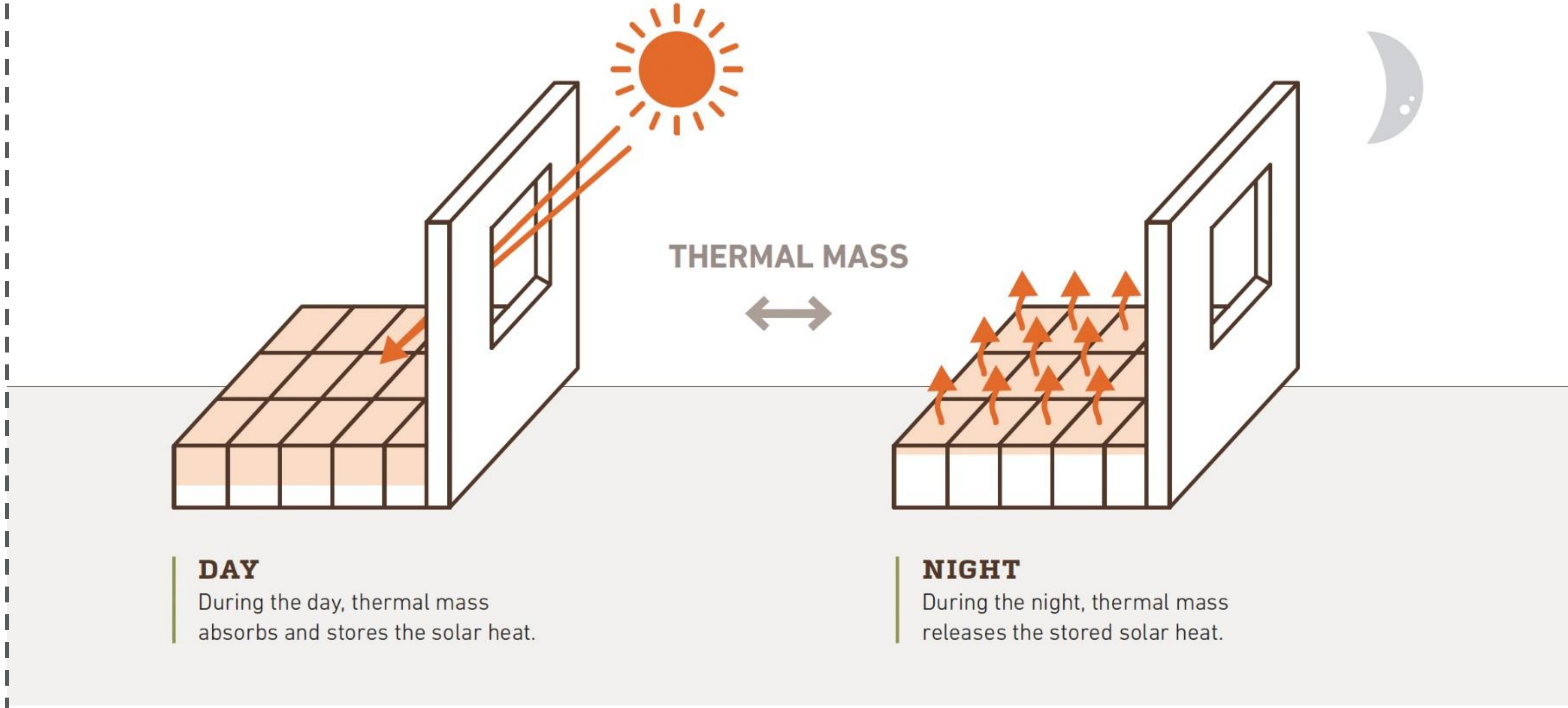
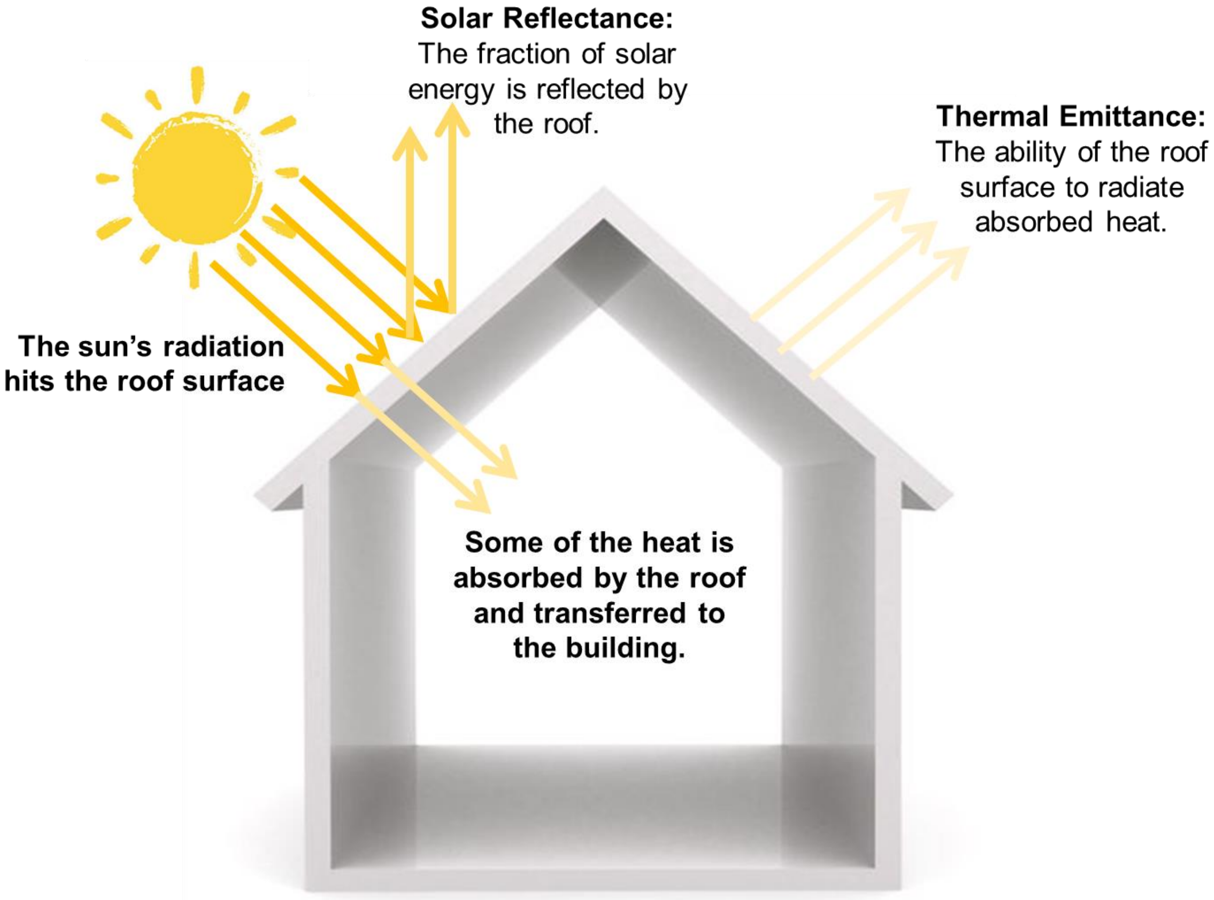


Image source: https://www.echelonmasonry.com/2018/06/29/capitalizing-on-thermal-mass-to-improve-efficiency-in-construction/

SOLAR REFLECTIVE INDEX

SRI: Combination of solar reflectance and thermal emittance

- Calculated value that combines solar reflectance and thermal emittance into one number
- SRI can be used as an indicator of how hot the material is likely to become when solar radiation is incident on the surface
- SRI values for most materials fall between 0 and 100, although values outside of this range is possible
- High SRI roof and wall finishes are beneficial in warm and hot climates

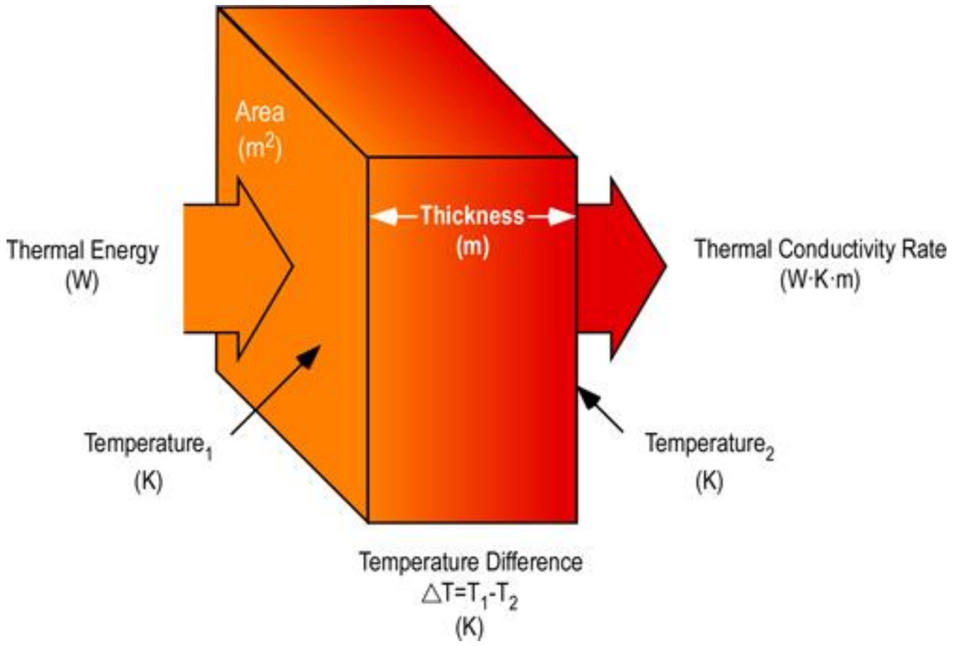


Source: Building Energy Efficiency in Nepal (BEEN) Project, 2024

THERMAL CONDUCTIVITY

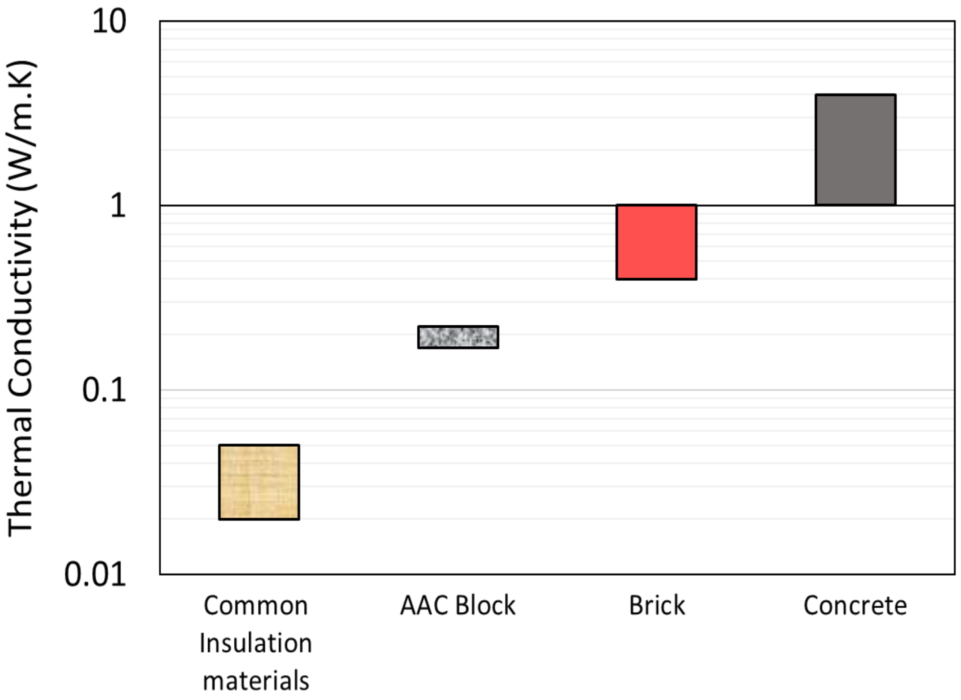
K-value

Measured in watts per meter-degree kelvin (W/m.K)



Heat transferred in unit time, through unit area ($1m^2$) of homogenous material, of unit thickness (1m) of the material, with the two surfaces of the material differing by one unit of temperature (1°K)

Thermal conductivity of common building materials



Source: Building Energy Efficiency in Nepal (BEEN) Project, 2024

THERMAL TRANSMITTANCE

U-value

Heat transmission, in unit time through unit area of a material or construction and the boundary air films, induced by unit temperature difference between the environments on either side

The unit of U-value is W/m^2.K

$$U = \frac{1}{R_{si} + R_{se} + \frac{t_1}{k_1} + \frac{t_2}{k_2} + \cdots + \frac{t_n}{k_n}}$$

R_{si} is the interior surface film thermal resistance, m^2.K/W

R_{se} is the exterior surface film thermal resistance, m^2.K/W

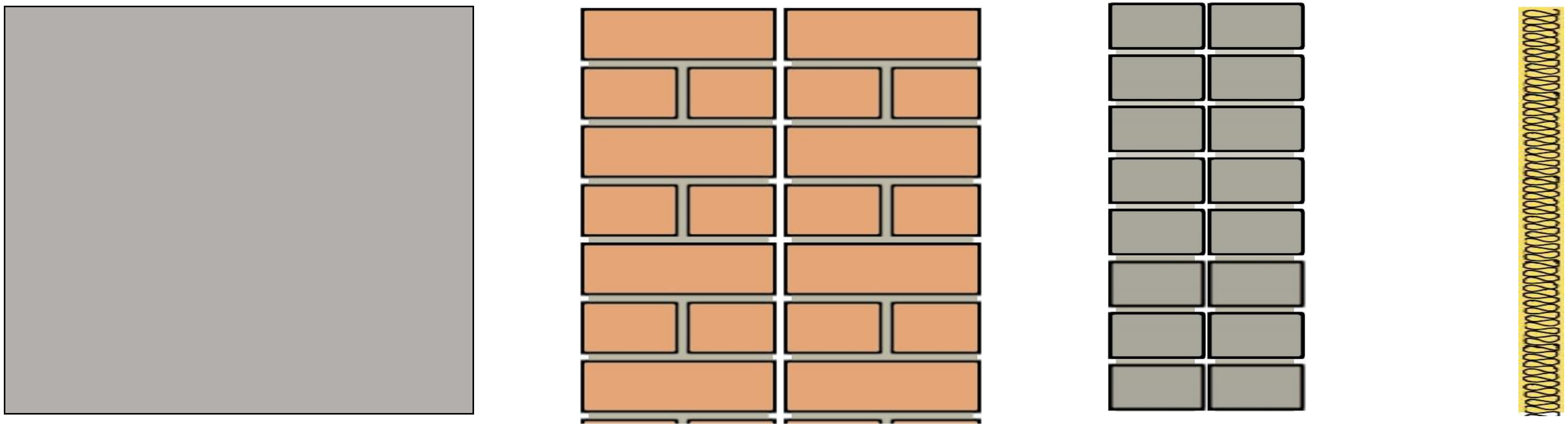
t is the thickness of material (in meters)

k is the thermal conductivity of material, W/(m.K)

Source: Building Energy Efficiency in Nepal (BEEN) Project, 2024

MATERIAL THICKNESS

For U-value of 0.40 W/m^2.K



RCC
3.7m thick

Brick
1.8m thick

AAC
0.42m thick

XPS
0.08m thick

Source: Building Energy Efficiency in Nepal (BEEN) Project, 2024

MATERIAL THICKNESS

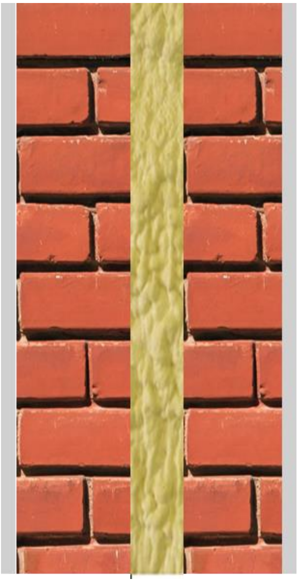
For different wall assemblies

Hollow Brick Wall

Total thickness: 230mm
U-value: 1.85 W/m^2.K

Autoclaved Aerated Concrete (AAC) Wall

Total thickness: 230mm
U-value: 0.96 W/m^2.K



Cavity Wall with Insulation

Total thickness: 255mm
(with 25mm mineral wool insulation)
U-value: 0.74 W/m^2.K

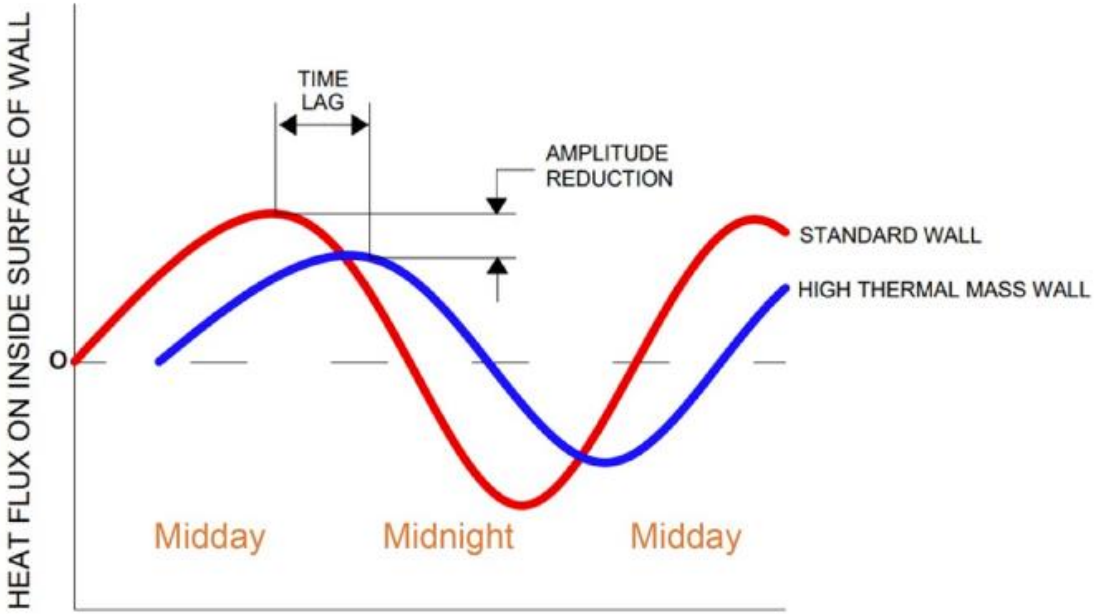
Source: UNEP, Compendium of Passive Cooling Strategies in Cambodia (draft)

THERMAL MASS

Heat capacity of a material

- Thermal mass is the property of a **building's mass** that enables it to store heat, providing 'inertia' against temperature fluctuations
- Scientifically, thermal mass is **equivalent to heat capacity** – the amount of heat to be supplied to a given mass of a material to produce a unit change in its temperature
- The unit of measurement is joule per kelvin (J/°K)
- The use of materials with high thermal mass is most advantageous where there is a big difference in outdoor temperatures from day to night

Depending on the climate, building usage and comfort requirement, a higher OR lower thermal mass should be preferred



Impact of thermal mass on heat exchange

Source: Building Energy Efficiency in Nepal (BEEN) Project, 2024

Image source: https://decarbhealthcare.com/guidebook/542

THERMAL BRIDGES

Pathways for heat or cold transmission

Description:

- Pathways for heat or cold to cross from inside to outside
- Reduce insulation effectiveness and can cause condensation

Minimization techniques:

- Using external insulation
- Installing thermal breaks in metal frames
- Fixing prefab insulated panels over frames
- Using less conductive framing materials (e.g., timber, UPVC)

Source: Building Energy Efficiency in Nepal (BEEN) Project, 2024

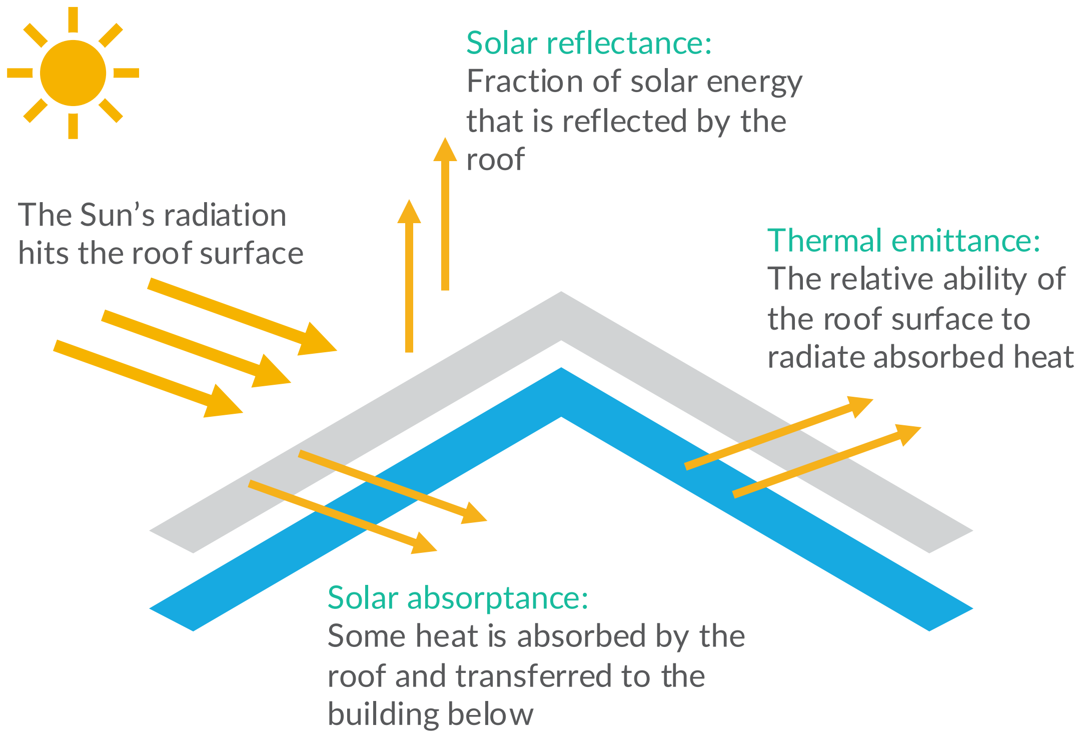
SOLAR RADIATION

Components of solar radiation

- **Solar reflectance**: Energy reflected back to the atmosphere
- **Solar absorptance**: Energy absorbed by the roof and transferred to the building's interior
- **Solar emittance**: Absorbed solar energy radiated back to the atmosphere

Standard white surface (reflectance 0.80, emittance 0.90): SRI = 100	Standard black surface (reflectance 0.05, emittance 0.90): SRI = 0

Roofs attract solar radiation almost throughout the day and need to be protected more than the walls



Source: ECBC User Guide, July 2009

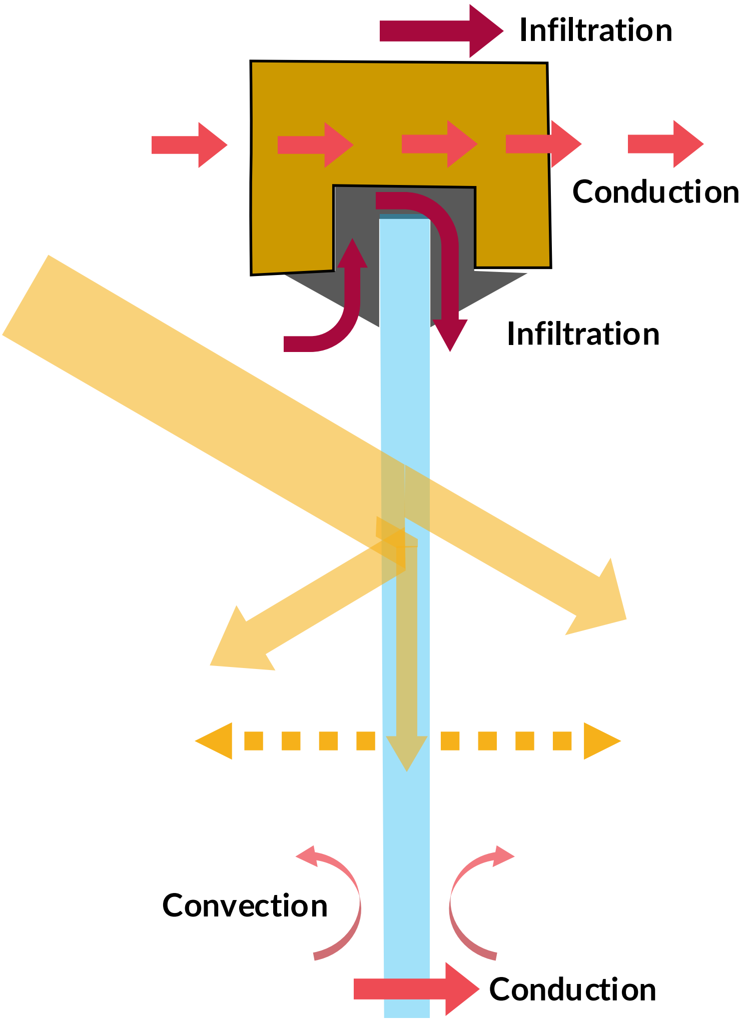
Fenestration

Thermal Properties

FENESTRATION

Heat transfer

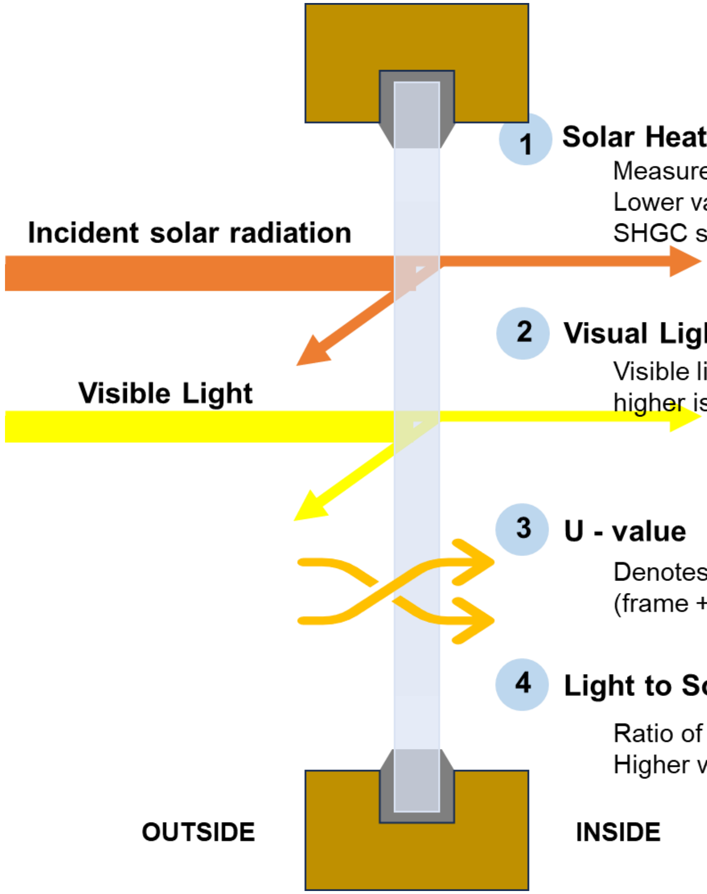
- In a building, fenestration comprises both opaque and solid elements (such as wood, aluminum, etc.) and non-opaque or transparent elements (i.e., glass). Between the two, a significant amount of heat transfer occurs through the glass
- In addition to conduction, heat transfer occurs through infiltration, i.e., unintentional air entering a space through the cracks and gaps in the fenestration elements. This is part of the air exchange process



Source: Building Energy Efficiency in Nepal (BEEN) Project, 2024

GLAZING

Key parameters



1 **Solar Heat Gain Coefficient (SHGC)**

Measure of solar heat transmitted through the window.
Lower value – lesser is the solar heat gain.
SHGC should be lower for warm climates & higher for cold climate.

2 **Visual Light Transmission (VLT)**

Visible light that passes through the glazing .The higher VLT, the higher is daylight penetration.

3 **U - value**

Denotes conduction heat gain through the glazing unit (frame + glazing). Lower U value, less heat is conducted.

4 **Light to Solar Gain Ratio (LSG)**

Ratio of VLT to SHGC.
Higher value is better for daylight harvesting.

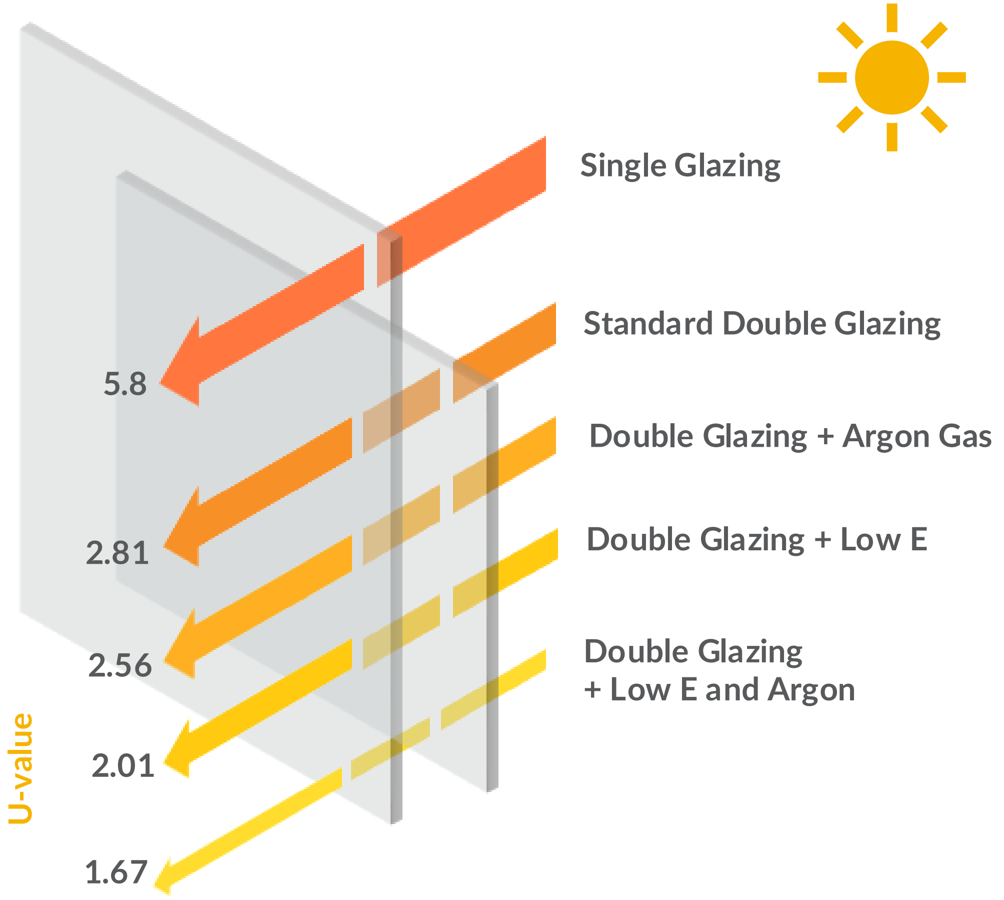
Source: Building Energy Efficiency in Nepal (BEEN) Project, 2024

GLAZING

U-value

- In the United States, values are normally given for NFRC / ASHRAE winter conditions of 0°F (-18°C) outdoor temperature, and for 70°F (21°C) indoor temperature, with 15 mph of wind speed, and no solar load
- U-values are often quoted for windows and doors
- In the case of a window, for example, the U-value may be expressed for the glass alone or for the entire window assembly, which includes the effect of the frame and the spacer materials

Heat Transfer – Fenestration U-value

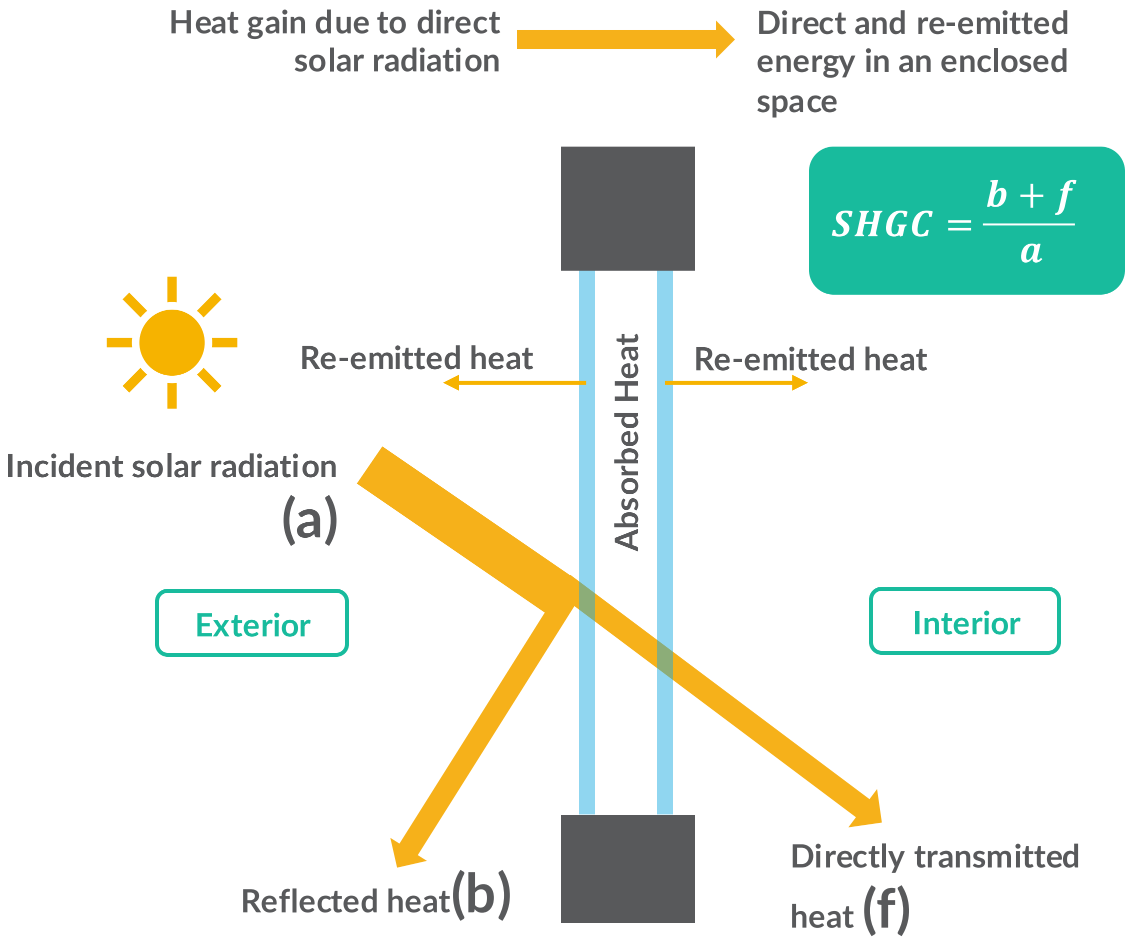


Source: USAID ECO-III Tip Sheets

SOLAR HEAT GAIN COEFFICIENT

SHGC – unshaded

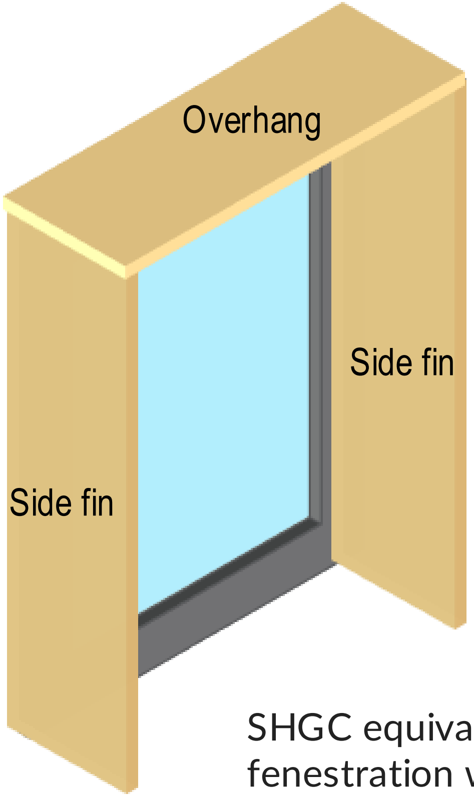
- SHGC is the ratio of solar heat gain that passes through fenestration to the total incident solar radiation that falls on the fenestration
- Lower SHGC means lesser heat transfers into the building through the window
- In hot climates, SHGC is more significant than U-value



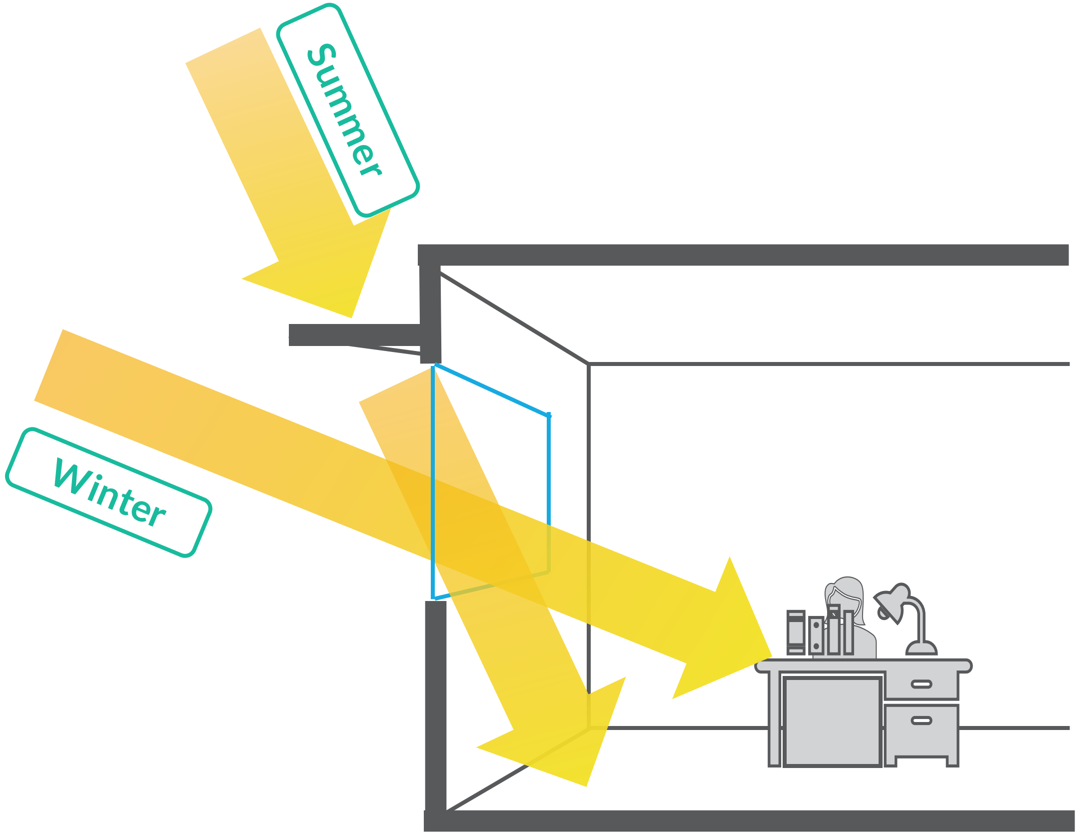
Source: USAID ECO-III Tip Sheets

EFFECT OF SHADING

SHGC equivalent



SHGC equivalent is the SHGC of a fenestration with a permanent external shading projection (overhang and side fins)



External shading devices impact the SHGC of a fenestration by impacting the solar radiation incident on the window. The impact of the shading device on the unshaded SHGC results in SHGC equivalent

Source: Building Energy Efficiency in Nepal (BEEN) Project, 2024

EXTERAL SHADING VS. INTERNAL SHADING

SHGC equivalent

- Internal shading does not prevent heat from entering the building
- With internal curtains the effective SHGC is around **0.75** (with 6 mm clear glass)
- In case of external shading the heat get reflected from outside the window
- With good external shading the effective SHGC is around **0.18** (with 6 mm clear glass)

Up to four times reduction in window solar gains with external shading as compared to internal shading

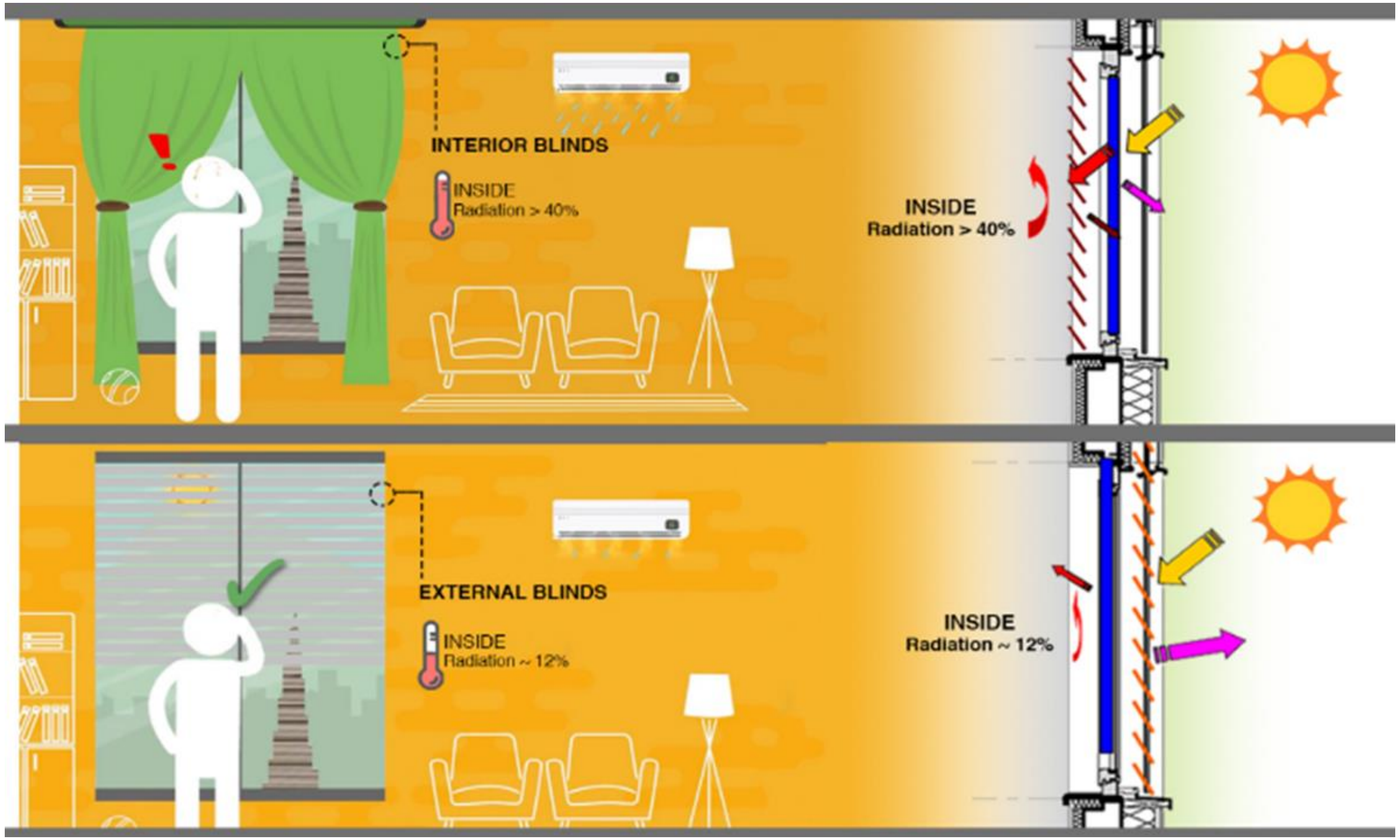


Illustration of external vs. internal shading

Source: Ministry of Power, Government of India, 2022b

GLAZING

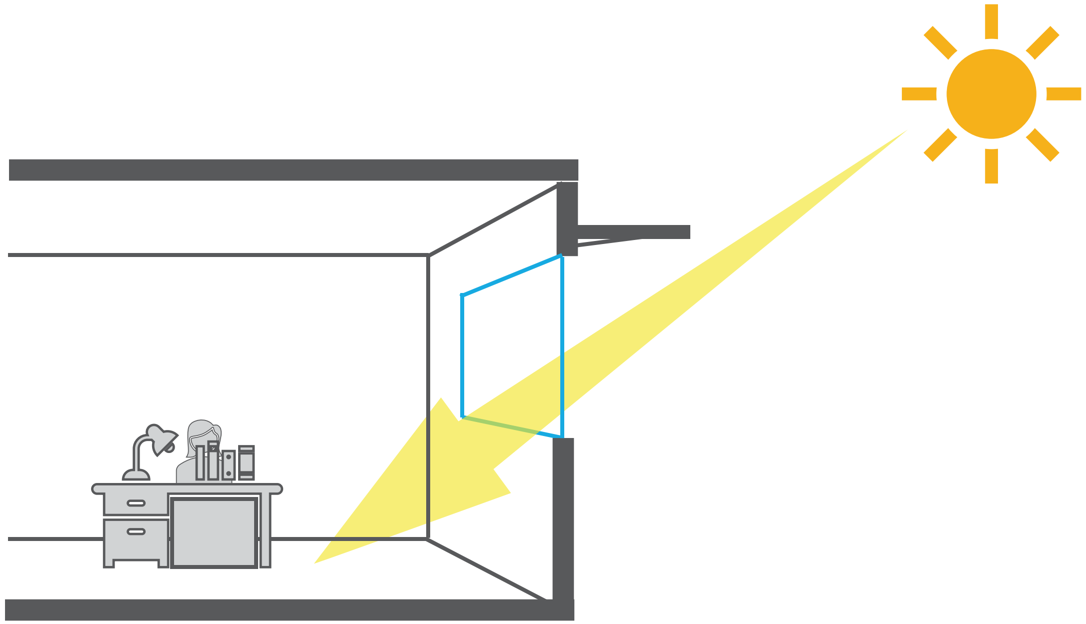
Visible light transmittance (VLT)

VLT is the fraction of visible light transmitted through the glazing

- Affects daylight and visibility
- Varies between 0 and 1

Typically, the lower the SHGC, the lower the VLT

- Higher insulating property glass will reduce daylight



Source: USAID ECO-III Tip Sheets

GLAZING

Minimum illuminance level required

- ASHRAE provides recommendations for minimum illuminance levels in different areas through its standards, particularly **ASHRAE 90.1** and **IES Lighting Handbook** (in collaboration with the Illuminating Engineering Society)

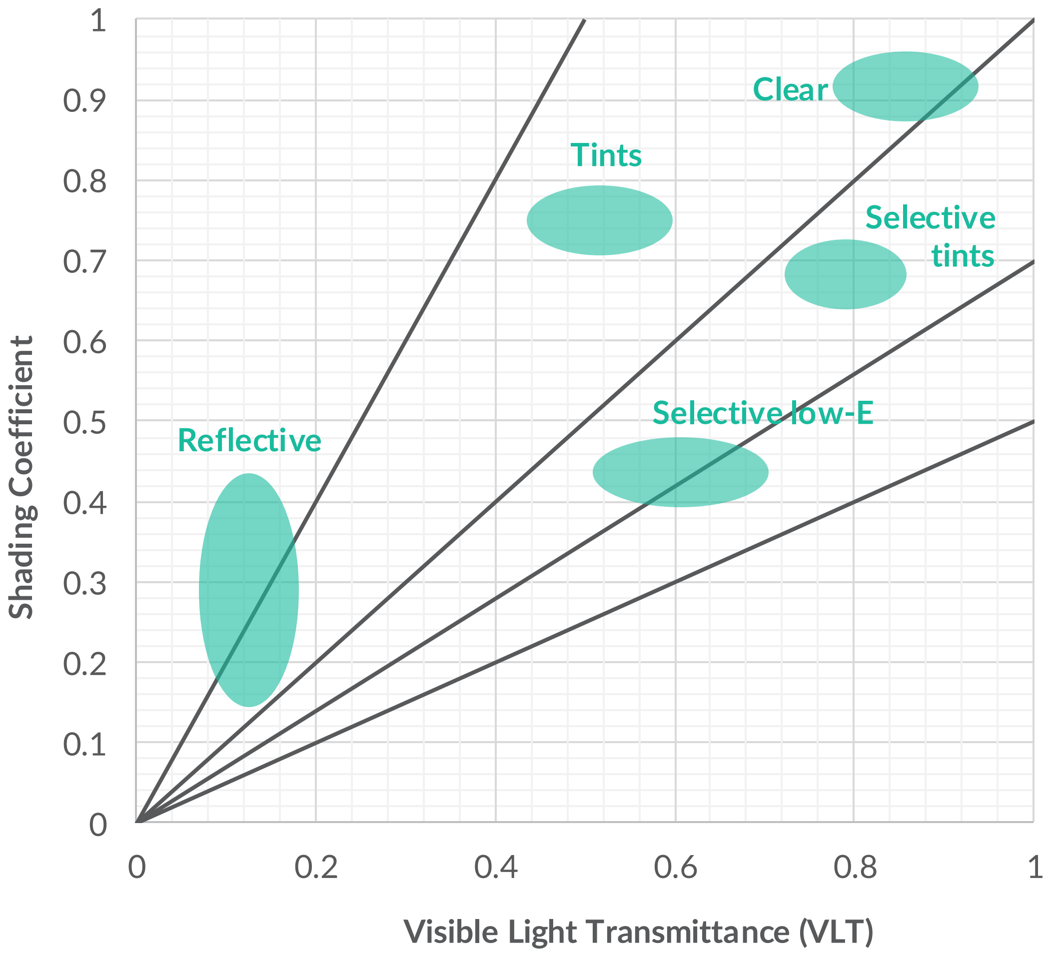
- These standards are widely referenced in building codes for energy efficiency and lighting quality

- The table shows some typical illuminance levels suggested by ASHRAE and IES for various types of spaces (measured in lux)

Area	Minimum illuminance levels
General Office Areas	300–500 lux
Conference Rooms	300–500 lux
Reception Areas	300 lux
Classrooms	300–500 lux
Laboratories	500 lux
Lecture Halls and Auditoriums	200–300 lux
Warehousing and Storage Areas	100–300 lux
Restaurants (Dining Areas)	100–300 lux

RELATION OF SHADING COEFFICIENT AND VLT

- The graph depicts that, for clear glass, the VLT is very high, and the shading coefficient is also high, leading to heat and glare
- As selective metallic oxides are applied on clear glass (either as soft or hard coat), the glass performance improves
- Depending on the need, a balance between VLT and shading coefficient must be managed
- **For larger floor plates, VLT is not very significant, as daylight cannot penetrate more than 6–7m from perimeter**
- **For such large buildings, shading coefficient plays a major role in reducing heat gains through glazing**



Source: USAID ECO-III Tip Sheets

Building Heat Transfer Values

RTTV and OTTV

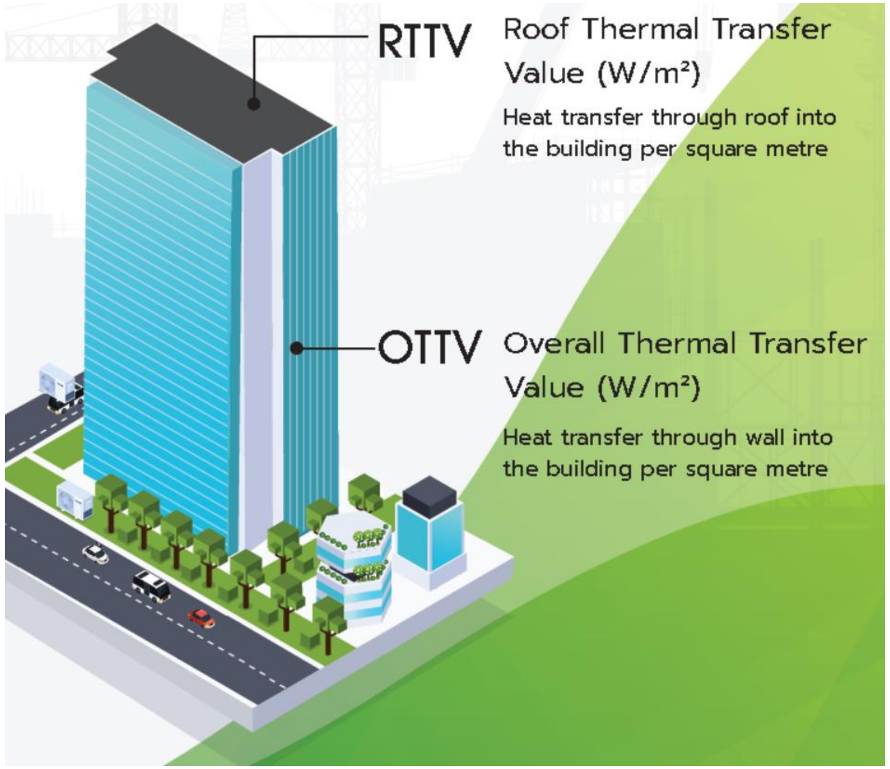
ROOF THERMAL TRANSFER VALUE

RTTV: Metric for heat transfer

- **Roof thermal transfer value (RTTV)** is a metric used to quantify heat transfer through a building's roof structure. It is commonly used in tropical and subtropical climates, where the roof is a primary source of heat gain in buildings
- RTTV is measured in **W/m²** and helps evaluate the roof's thermal performance, contributing to the building's overall energy efficiency
- **RTTV considers:**
  - **Direct solar radiation:** Heat absorbed by the roof due to sunlight
  - **Thermal conductivity:** The ability of the roof materials to conduct heat
  - **Surface temperature differentials:** The temperature difference between the inside and outside surfaces of the roof

$$RTTV = (a \times (1 - SKR) \times U_r) + (b \times SKR \times U_s) + (c \times SKR \times SC \times CF)$$

- RTTV: roof thermal transfer value (W/m²)
- SKR: skylight ratio of roof (skylight area/gross area of roof)
- U_r: Thermal transmittance of opaque roof (W/m².K)
- U_s: Thermal transmittance of skylight (W/m².K)
- SC: Shading coefficient of skylight
- CF: Solar correction factor for roof (based on the orientation and slope)
- a, b, c = multiplying factors determined based on the specific country/location



Source: Building and Construction Authority, Government of Singapore

ROOF THERMAL TRANSFER VALUE

RTTV: Sample calculation

For example, one building located in Singapore with the total roof (flat roof) area of 250m², containing 50m² of skylight. The technical specification of the roof construction materials are as follows:

- A_r=200m², U_r=0.5 W/m²·K
- A_s=50 m², U_s=3 W/m²·K
- SC=0.5,
- CF= 1 (flat roof)
- SKR= 0.2

Calculation of RTTV:

$$RTTV=(a\times(1-SKR)\times U_r)+(b\times SKR\times U_s)+(c\times SKR\times SC\times CF)$$

Multiplier factors values for Singapore:

a = 12.5
b = 4.8
c = 485

Breaking it down:

Opaque roof contribution: 12.5×0.8×0.5 = 5 W

Skylight conduction: 4.8×0.2×3 = 2.88 W

Skylight solar heat gain: 485×0.2×0.5×1 = 48.5 W

$$RTTV = 5 + 2.88 + 48.5 = 56.38\ W/m^2$$

The RTTV value of this roof is **56.4 W/m²**. This value should be below the prescribed limits mentioned in the national building energy efficiency code

Source: Building and Construction Authority, Government of Singapore

OVERALL THERMAL TRANSFER VALUE

OTTV: Metric for heat transfer

- **Overall thermal transfer value (OTTV)** is a widely-used metric to assess the thermal performance of the building envelope, particularly in tropical and subtropical climates. It measures the average rate of heat transfer into a building through its external walls, windows, and other opaque and transparent façades
- OTTV is expressed in **W/m²** and evaluates the thermal efficiency of external walls and fenestration systems in terms of heat gain
- **Key components of OTTV:**
  - **Wall heat conduction:** Heat transfer through the opaque portion of walls
  - **Glass heat conduction:** Heat transfer through windows and glazing systems
  - **Solar heat gain through windows:** Heat from solar radiation entering through glazed surfaces

$$\text{OTTV} = \boldsymbol{a}(1 - \boldsymbol{WWR})\boldsymbol{U_w} + \boldsymbol{b}(\boldsymbol{WWR})\boldsymbol{U_f} + \boldsymbol{c}\,(\boldsymbol{WWR})(\boldsymbol{CF})(\boldsymbol{SC})$$

- OTTV: Overall thermal transfer value (W/m^2)
- WWR: Window-to-wall ratio (fenestration area / gross area of external wall)
- U_w: Thermal transmittance of opaque roof ($W/m^2.K$)
- U_f: Thermal transmittance of fenestration ($W/m^2.K$)
- SC: Shading coefficient of fenestration
- CF: Solar correction factor for fenestration (based on the orientation and slope)
- a, b, c = multiplying factors determined based on the specific country/location

Source: Building and Construction Authority, Government of Singapore

OVERALL THERMAL TRANSFER VALUE

OTTV: Sample calculation

For example, taking a building with the following specifications:

- **Wall (opaque)**
  - Area of wall (A_w) = 50m²
  - Thermal transmittance of wall material (U_w) = 1.5W/m²·K
- **Window (glazing)**
  - Area of window (A_f) = 10m² (On north façade)
  - Thermal transmittance of glazing (U_f) = 5.0W/m²·K
  - Shading coefficient (SC) = 0.8
  - Window-to-wall ratio (WWR) = 0.2
  - CF = 0.8
- **Multiplier factors values for Singapore:**

  a = 12
  b = 3.4
  c = 211

$$\text{OTTV} = a(1 - WWR)U_w + b(WWR)U_f + c\,(WWR)(CF)(SC)$$

Wall heat transfer:
12 x 0.8 x 1.5 = **14.4 W/m²**

Glazing heat transfer:
3.4 x 0.2 x 5 = **3.4 W/m²**

Solar heat gain through windows:
211 x 0.2 x 0.8 x 0.8 = **27 W/m²**

OTTV = 25 + 16.67 + 0.53 = **44.8 W/m²**

Source: Building and Construction Authority, Government of Singapore

Thank you!

For more information, visit us at https://ALCBT.GGGI.ORG
or scan the QR code below

IKI Independent Complaint Mechanism

Any person who believes they may be harmed by an IKI project or who wish to report corruption or the misuse of funds, can lodge a complaint to the IKI Independent Complaint Mechanism at IKI-complaints@z-u-g.org. The IKI complaint mechanism has a panel of independent experts who will investigate the complaint. In the course of the investigation, we will consult with the complainant so as to avoid unnecessary risks for the complainant. More information can be found at https://www.international-climate-initiative.com/en/about-iki/values-responsibility/independent-complaint-mechanism/.

www.gggi.org
@gggi_hq
@GGGIHQ

@GGGIHQ
@gggi_hq
@GGGIMedia

GGGI ASEAN Centre for Energy ACE EESL HEAT

Supported by:

Federal Ministry for Economic Affairs and Climate Action

IKI INTERNATIONAL CLIMATE INITIATIVE

on the basis of a decision by the German Bundestag