Design Guidelines for Thermally Comfortable Homes in Cold Climate

Knowledge partners

Foreword

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Message by the Minister

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Message by Secretary

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Message by GIZ

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About the program

The Pradhan Mantri Awas Yojana (PMAY) is a flagship initiative of the Government of India that aims to provide affordable housing for all. The PMAY(U) scheme has surpassed the milestone of sanctioning 1 Crore dwelling units out of which 64 lakh homes have already been completed. This phenomenal success over the past 7 years has led to the extension of this mission to 2024. As the mission takes rapid strides towards development, the Government of India recognizes that these homes are going to remain with us over the next 6 decades. This presents the nation with a unique opportunity to build climate-resilient and thermally comfortable homes that avoid the need for cooling/heating and associated energy use. This will not only mitigate the stress on our environment and infrastructure, but also enhance the affordability and liveability of these homes.

The vision of this program is to achieve thermally comfortable, and affordable homes through passive design measures, locally available and low embodied energy material coupled with best available technologies in construction. To meet this vision this program has developed:

Building on strong Indo-German ties, the Ministry of Housing and Urban Affairs, Government of India and GIZ on behalf Federal Ministry of Economic Cooperation and Development (BMZ), Germany have joined hands. Under this cooperation, GIZ is providing technical assistance to the Ministry of Housing and Urban Affairs, Government of India in realizing the opportunity of shaping India's unbuilt housing stock to be responsive and resilient to climate change.

Ministry of Housing and Urban Affairs
Government of India

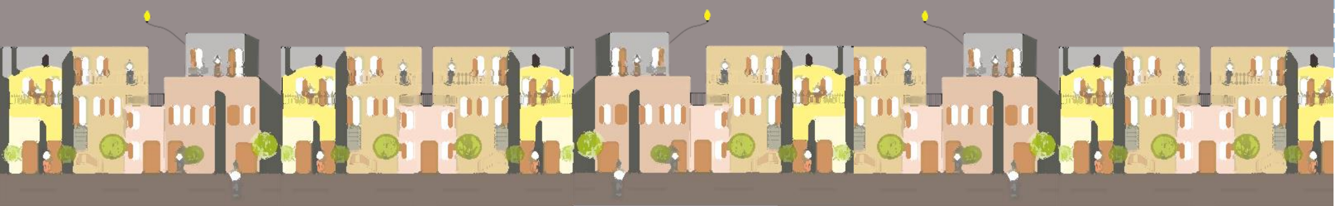
The Ministry of Housing and Urban Affairs is the apex authority of Government of India at the national level to formulate policies, sponsor and support programme, coordinate the activities of various Central Ministries, State Governments and other nodal authorities and monitor the programmes concerning all the issues of housing and urban affairs in the country.

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

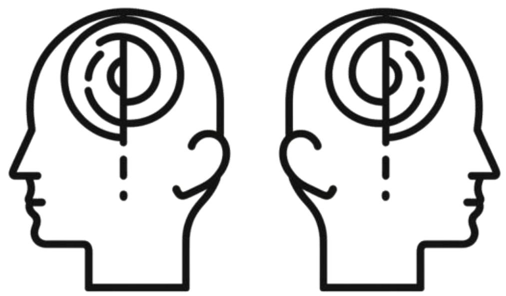
For over 60 years, the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH has been working jointly with partners in India for sustainable economic, ecological, and social development.
The Government of India has launched numerous important initiatives to address the country's economic, environmental and social challenges, and GIZ is contributing towards this transition.

01

Fundamentals of thermal comfort



A What is thermal comfort?



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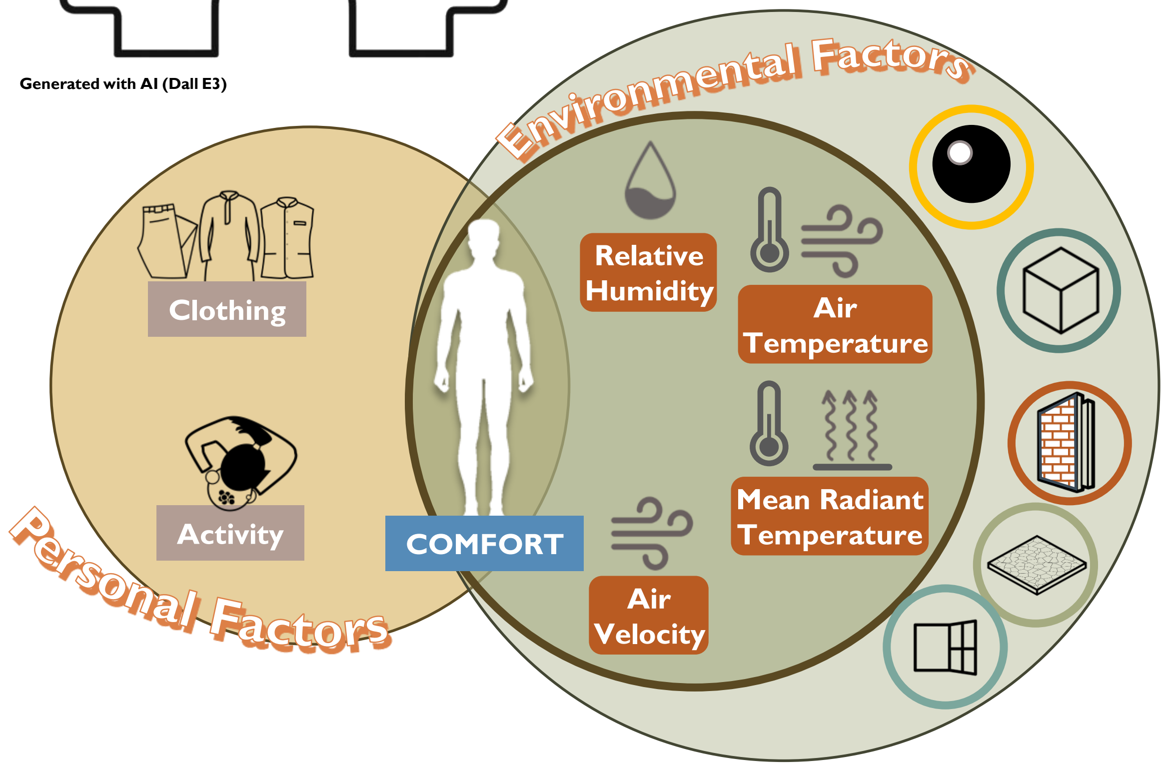
ISO 7730 defines thermal comfort as '…that condition of mind which expresses satisfaction with the thermal environment.'



Thermal Comfort is influenced by Personal and Environmental factors.
The personal factors are determined by occupant behaviour, i.e,

- the kind of activity that is being performed - running, sitting, walking, cooking, etc., and,
- the type of clothing – thick and insulating (like woolens) or light and breathable (say light cotton fabric)

The environmental factors on the other hand represent the *'behaviour'* of the occupants' environment i.e.,

- the moisture holding capacity of the air,
- the air temperature,
- the temperature of objects surrounding the occupant (expressed as mean radiant temperature)
- the velocity of air that the occupant is in contact with.

While both factors are critical to achieving thermal comfort, it is the indoor environmental factors that can be controlled by the designer through passive design. Prudence in building orientation, design of form and building envelope, and choice of materials impact Thermal Comfort.

B Physiological response to discomfort

The human body maintains its core temperature between 36.5 and 37.5 °C (or 97.7 and 99.5 °F). This thermo-regulatory mechanism comes under stress in extreme conditions.

When the body is exposed to hot environment, the human thermoregulatory system tries to cool down the body through two mechanisms – 'vasodilation' and 'sweating'. Under vasodilation, the blood vessels expand to increase blood flow near the skin, in turn increasing the rate at which the body can expel heat. Sweating is an evaporative cooling mechanism employed by the body. The cooling sensation felt on the skin when sweat evaporates is because sweat absorbs body heat to evaporate.

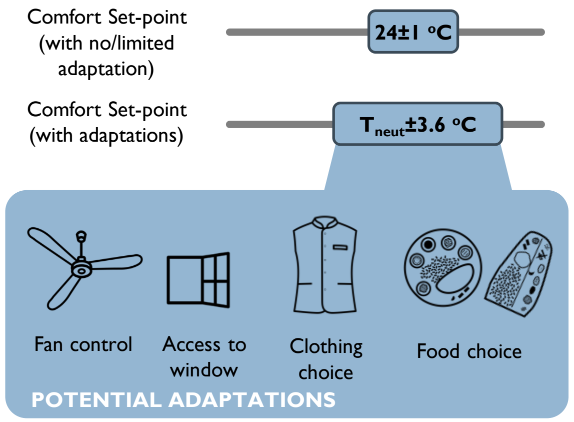
Similarly, the human body employs mechanisms for keeping warm when the body is exposed to cold environment. To keep warm, the blood vessels narrow (or vasoconstrict) to reduce blood flow to the skin. This means internally generated heat not lost to the skin as readily. In addition to vasoconstriction, the human body produces involuntary movement in skeletal muscles, also known as shivering to stay warm.

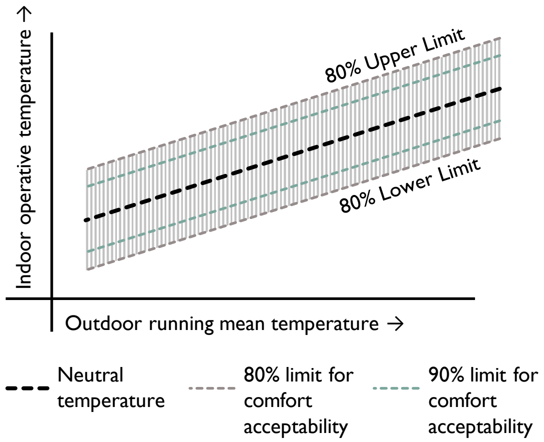
Vasodialtion and Sweating   Vasoconstriction and Shivering

C Adaptive thermal comfort

Thermal comfort is fraught with subjectivity and has been widely researched over the last few decades. In terms of understanding thermal comfort, one approach has been to observe physiological response and thermal perception of people in controlled environment. Fanger Comfort Model, Pierce Two-node Model, and KSU Two-node Model are examples of this approach.

Another approach, that deviates from the first approach, recognizes the ability of the human body to adapt, albeit within limits, to existing conditions based on past thermal experience and contextual factors. This approach moves away from tightly controlled mechanically conditioned buildings that operate in narrow comfort bands, to naturally ventilated or mixed-mode buildings that operate on broader and flexible comfort bands. Although suited to unconditioned buildings, this approach does not preclude mechanical conditioning solutions. This approach uses statistical analyses of thermal comfort response obtained from diverse building occupants spread over time (seasons) and space (geography), and complemented with measurement of key environmental parameters (at the time of survey).





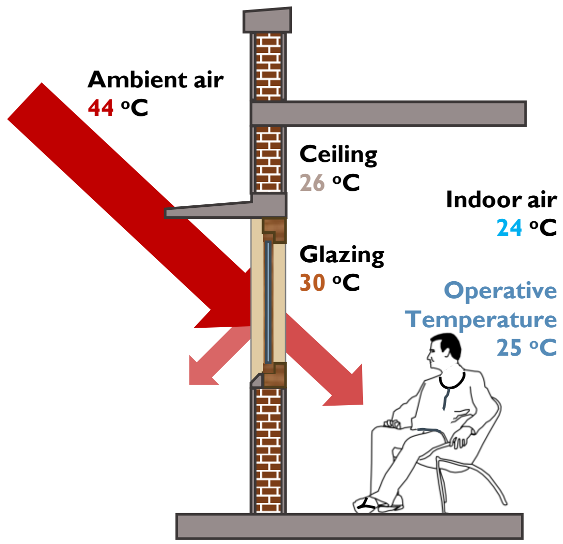
D Measuring thermal comfort

Index - Indoor Operative Temperature

There are more than 40 indices to measure thermal comfort (indoor and outdoor). The Indoor Operative Temperature is one of the simpler metrics that is also utilised by the adaptive comfort model for determining acceptable temperature ranges.

For better understanding, it is important to distinguish operative temperature from air temperature. For example, you may be in a space with seemingly comfortable temperature, but a nearby radiative source may be causing you thermal discomfort. The indoor operative temperature accounts for the radiative component (along with air temperature) and air velocity to a degree, to better approximate thermal expectations. It is because of this, operative temperature can serve better for control of building systems (say window, ceiling fan or mechanical systems operation).

The Indoor operative temperature takes into account; the air temperature, mean radiant temperature and air speed. At air velocities less than 0.2 m/sec (or 40 feet per minute), the operative temperature is the mean of dry bulb temperature and mean radiant temperature.

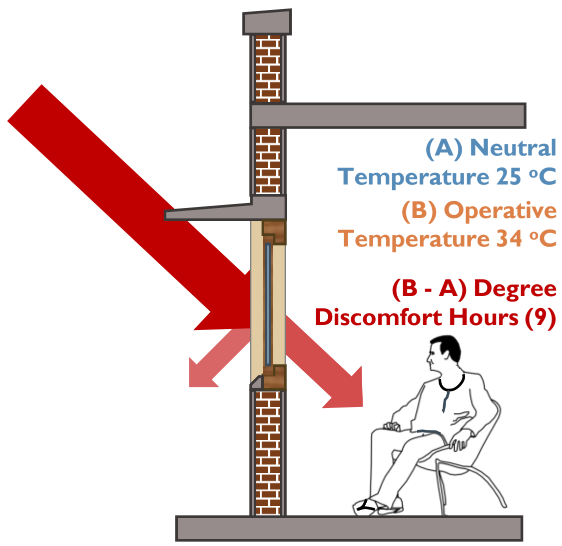


Metric – Degree Discomfort Hour (DDH)

Indoor operative temperature also presents an opportunity to measure discomfort severity. Discomfort severity is measured in terms of 'Degree Hours', i.e. the deviation from desired temperature at a given hour. For example, if the desired (or neutral) temperature at a given hour is 25°C and the operative temperature is 34°C, then the operative temperature exceeds thermal expectations for that hour by 9 degree-hours. Cumulating discomfort for each hour annually provides an annualized metric for discomfort.

Summer discomfort (due to overheating) is typically reported as a positive quantity, and winter discomfort is reported as a negative quantity. Therefore, cumulating Discomfort Degree Hours over seasons lends itself as a seasonal metric as well. However, for reporting annual discomfort, only absolute values of degree discomfort must be computed.

$$DDH = \sum_{i=1}^{8760} \left| T^{i}_{neut} - T^{i}_{op} \right|$$

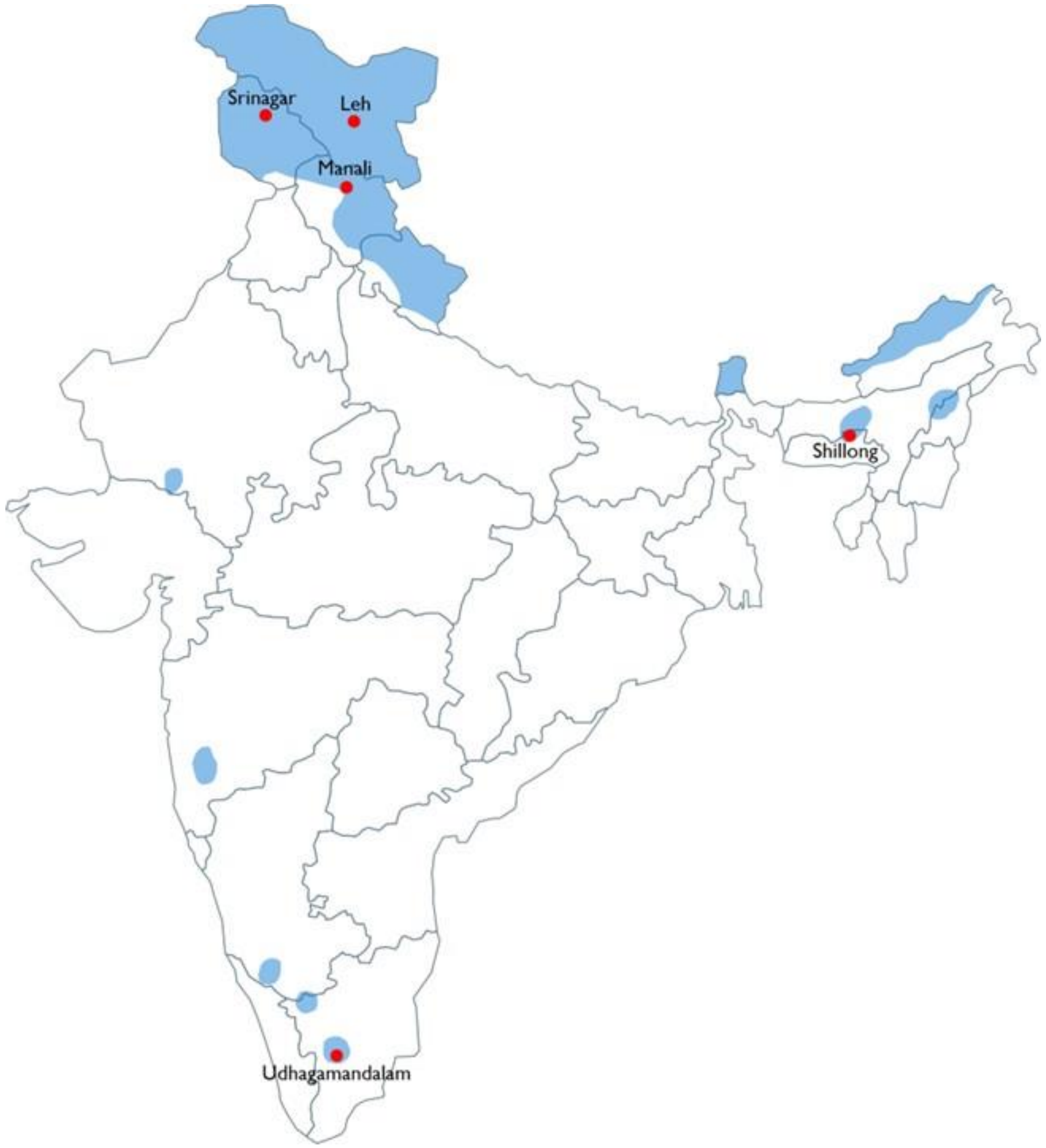


Note: Neutral temperature represents a state when occupants' thermal vote is neutral, i.e., neither feeling hot nor cold, or in other words, feeling comfortable.

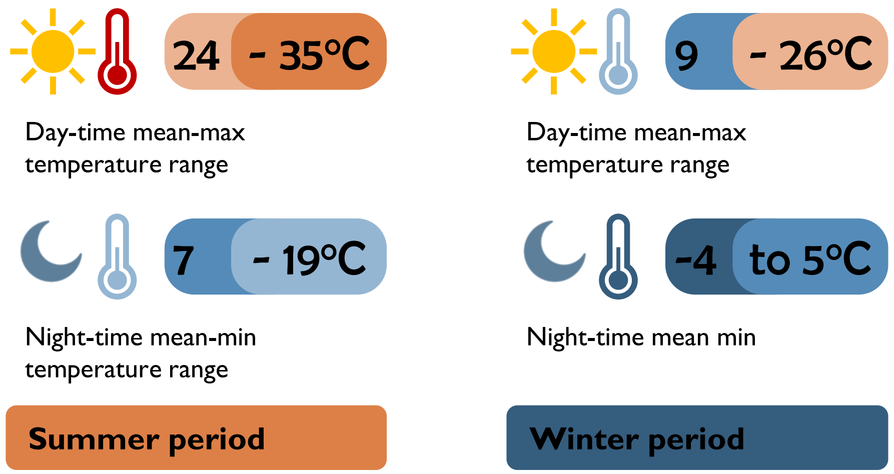
02

Climate and its characteristics

A Some of the major cities in Cold climate



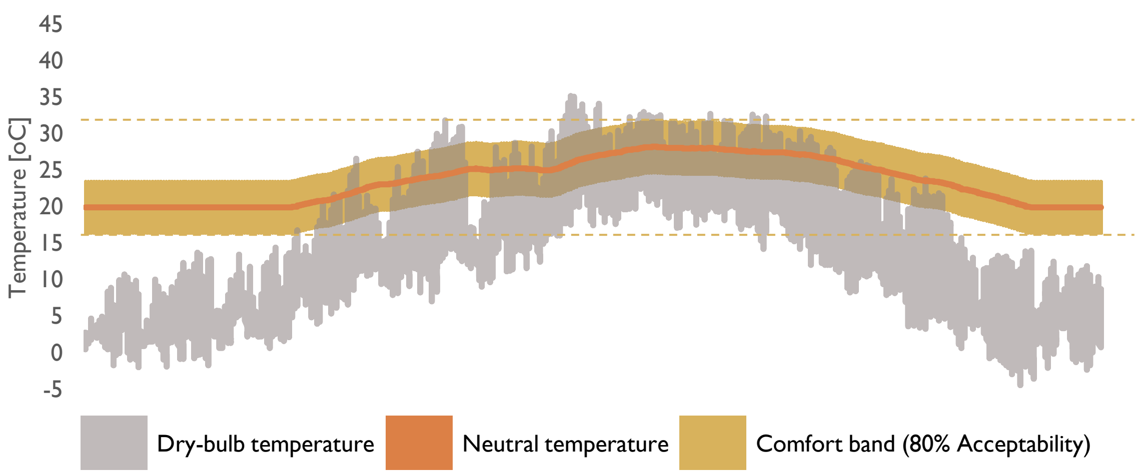
B Seasonal characteristics



Note: Statistics compiled from Srinagar's climate. Assumed Oct – Mar as winter period, and May – Aug summer period.

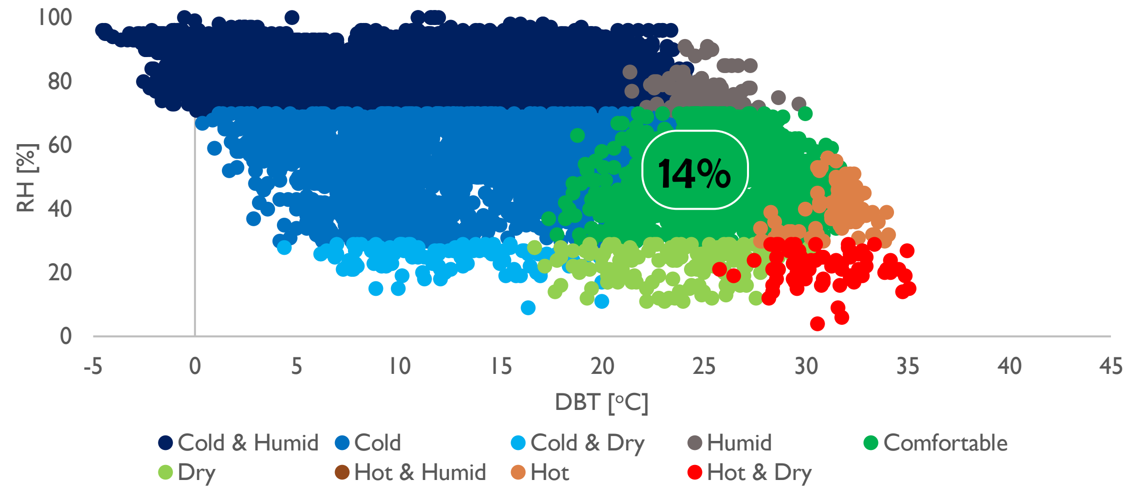
Cold climate is characterised by harsh winters and mild summers. The diurnal variation in temperatures can exceed 20°C implying that cold discomfort can occur even in warm season.

C Thermal comfort potential



80% acceptability criterion defined by the adaptive comfort model indicates that the comfort band (inclusive of adaptations such as clothing, ceiling fan operation, etc.) lies between 16 and 32°C dry-bulb temperature.

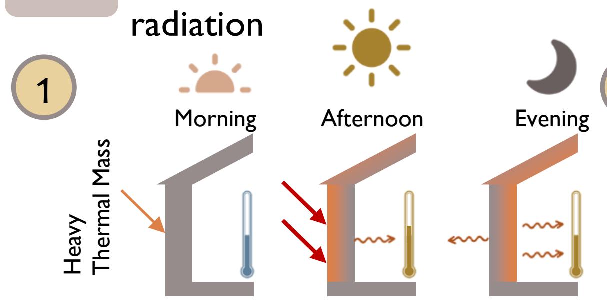
Note: Comfort assessments are an outcome of the application of an adaptive comfort model derived from scientific studies in the Indian residential context.



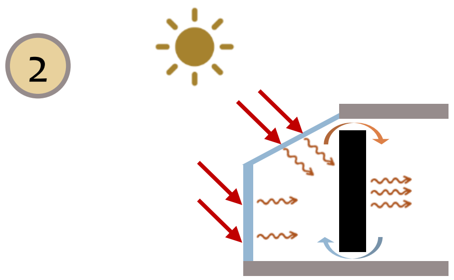
Cold climate can provide comfortable conditions for about 14% hours in a year. In terms of severity, interventions in the built environment are required for cold and cold-humid conditions. While summer discomfort is negligible, care must be taken to avoid direct radiation which can lead to overheating in summers.

Note: Comfort assessments are an outcome of the application of an adaptive comfort model derived from scientific studies in the Indian residential context.

D Climatic opportunities: Diurnal range and high intensity solar radiation



Solar radiation incident on the wall surface gets absorbed by the structure during day-time. The stored heat gets radiated indoors to counter cold discomfort during the evenings.



South facing spaces that receive abundant and un-hindered sun light during the winters can be used to create a glass enclosure (solarium/sunspace) to trap solar radiation during day-time.

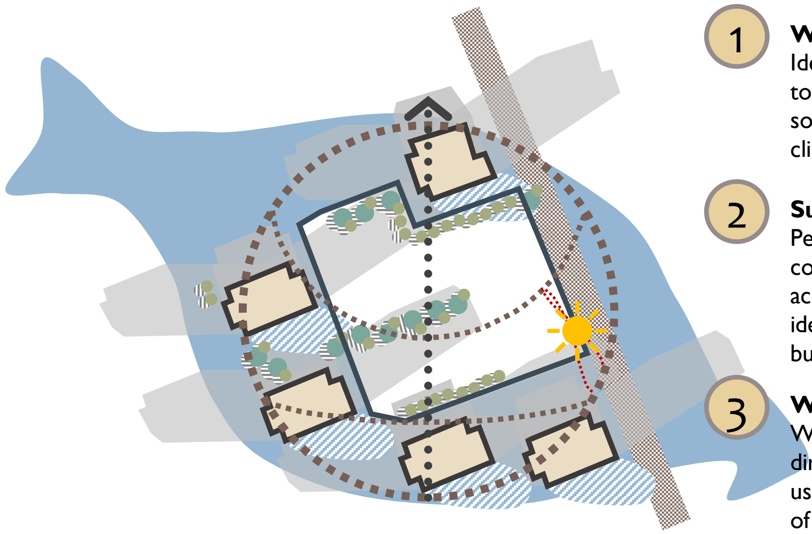
Thermal mass
Building materials with high capacity to store heat, dampen the impact of external temperatures to maintain comfortable conditions indoors. Thermal mass is feasible when diurnal range or difference in daily maximum and minimum temperature exceeds 6°C. For cold climate, a time lag of around 8 hours brings in heat indoors at night when it is most required. Since roof absorbs the most radiation during day time, it plays a significant role in storing heat and radiating it inside during the night.
It is also advisable that a the surface finish is darker (with low albedo) to promote heat absorption and storage.

Solarium/sun-space
Geographies in cold climate are typically located in higher altitudes that see clear skies. This implies ample availability of high intensity solar radiation for heating. A solarium/sun-space is essentially a glass enclosure that traps direct solar radiation as long-wave infrared during the sunshine hours. This is further used to heat a dark coloured absorptive surface with heavy thermal mass. This surface absorbs heats up during the day and emits heat during night to provide relief from cold. Sun-spaces are effective when they receive unhindered direct solar radiation and should therefore be planned on the south side.

03

Passive design features for thermal comfort

A Site context: Microclimate, siting & orientation

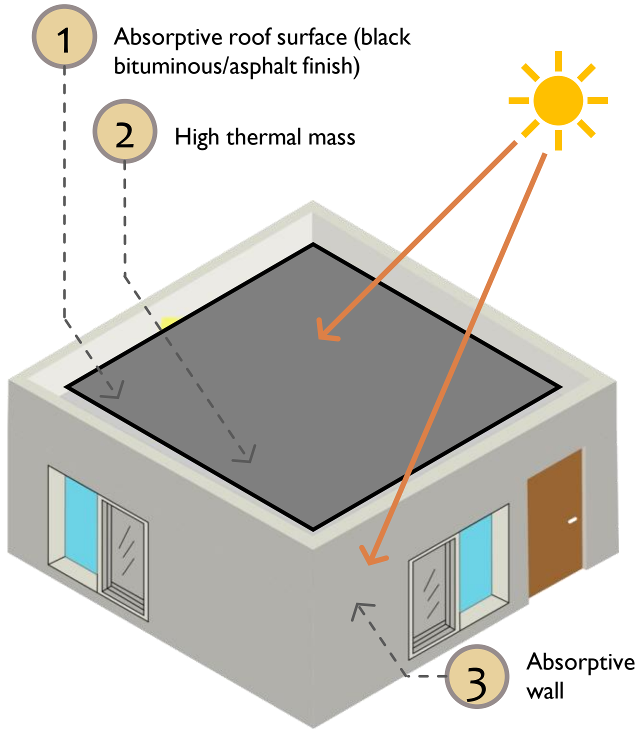


1. **Weather data for site location**
Identify periods of year the building is likely to experience discomfort. Prioritize passive solutions for these time periods. (See climate section.)

2. **Sun path and solar radiation analyses**
Perform sun-path studies of existing context (including trees) to identify solar access on site. This can be useful in identifying buildable zones, and shaping building form.

3. **Wind analysis**
Wind studies (based on predominant wind direction during discomfort periods) can be used to identify natural ventilation potential of the site.

B1 Absorptive roof and wall surfaces

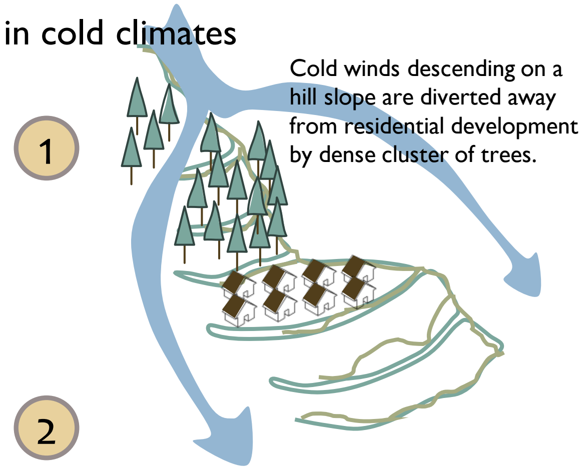


Absorptive Roofs and Walls
Dark coloured (or absorptive surface) that have high thermal inertia can raise internal temperatures by 3°C. This in turn can stave off cold discomfort.
Absorptive surfaces ((i.e. low albedo value) and low emittance have the potential to store more heat during the day-time and transfer stored heat during the night-time.

B2 Landscape for thermal comfort in cold climates

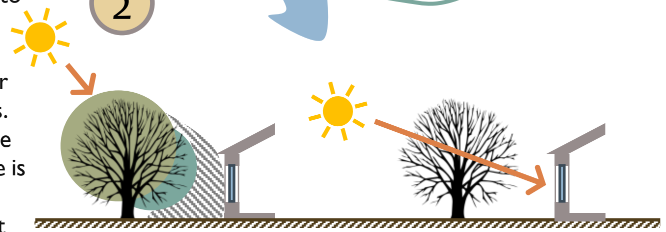
Colder climate in India is typically restricted to high altitudes. The tree ecosystem in these hilly regions, especially the Himalayas, is of paramount significance. Not only do these serve as carbon sinks, but they are also key in maintaining the structural integrity of the terrain.

Judicious planning of trees plays a key role in improving thermal comfort. In extreme cold weather, hill slopes often experience a rapid descent of cold dense air, also known as katabatic winds. Tree clusters have the potential to act as a barrier and provide protection to the down-wind residential development.



Cold winds descending on a hill slope are diverted away from residential development by dense cluster of trees.

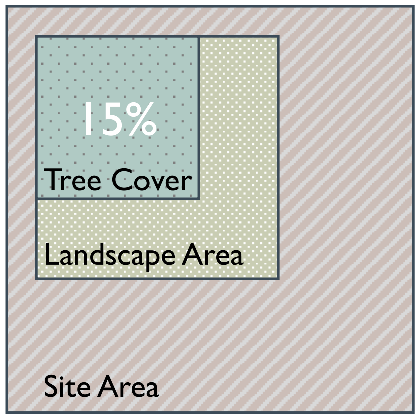
Owing to high intensity radiation, dwellings in colder regions can experience overheating during summers. Deciduous tree species with their dense foliage, have the ability to provide shade in summers (when there is overheating risk). In winters these tree species shed their leaves and allowing sunlight through to protect from cold discomfort.

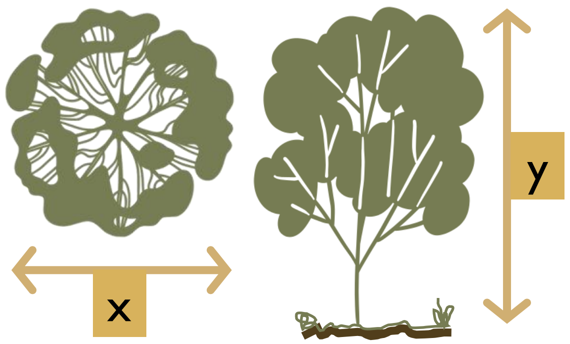


Deciduous trees provide shade in Summers

Deciduous trees shed leaves in Winters allowing sun to penetrate

B3 Maintaining minimum tree cover





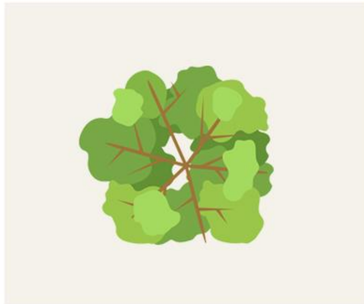
Trees moderate the microclimate by reflecting radiation, evapotranspiration and by providing shade. They can also provide barrier to cold winds. This can facilitate favourable microclimate for achievement of thermal comfort.

Tree canopy area requirements

Maintaining a minimum tree canopy area (x) can mitigate urban heat islands. For fulfilling tree canopy area requirements, the landscape design must consider native tree species that mature to a height (y) of 6 ft (or 2m) or greater. Trees with high foliage density should be preferred as they provide shade. Some native tree species are identified in B3-1.

⚠ While a higher tree canopy is desirable, it may lead to high humidity that could adversely impact thermal comfort outcomes. Similarly, while high foliage density is desirable, its impact on the built environment during winter months must be taken into account. Due care must be practiced while selecting tree species.

B3-1 Tree canopy area of common Indian trees in cold climate

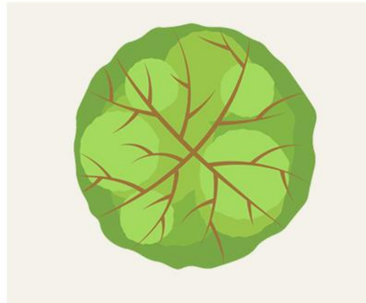


Aralu (Ailanthus Glandulosa)
Crown Dia : 2.5 to 9.6 m
Height at Maturity: 4.3 to 14 m

Teak (Tectona grandis)
Crown Dia : 10 to 11 m
Height at Maturity: 13 to 45 m

Mango Tree-(*Mangifera Indica*)
Crown Dia : 15 to 20 m
Height at Maturity: 35 to 40 m

Jangli Toot / Paper Mulberry (Broussonetia Papyrifera)
Crown Dia : 8 to 10 m
Height at Maturity: 6 to 18 m



Indian Horse-chestnut (Aesculus Indica)
Crown Dia: 10 to 15 m
Height at Maturity: 15 to 23 m

Devdar (Cedrus deodara)
Crown Dia: 6 to 14 m
Height at Maturity: 15 to 25 m

Himalayan poplar (Populus ciliate)
Crown Dia: 3 to 5 m
Height at Maturity: 18 to 24 m

Chinar Tree (Platanus Orientalis)
Crown Dia: 15 to 21 m
Height at Maturity: 21 to 30 m

Himalayan birch (Betula utilis)
Crown Dia: 5 to 8 m
Height at Maturity: 8 to 15 m

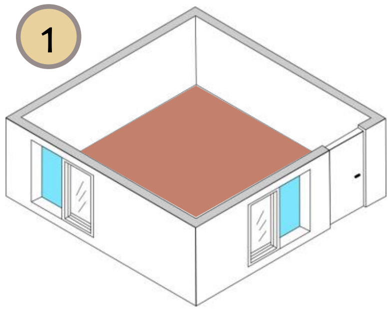
Dense Foliage

Medium-dense Foliage

Light-dense Foliage

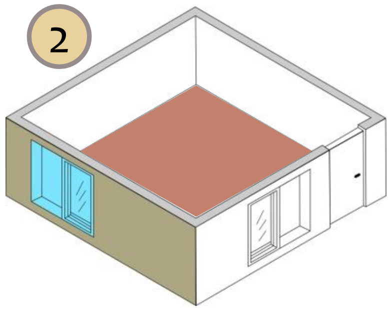
C Opening ratios for regulating ventilation & heat gains

1



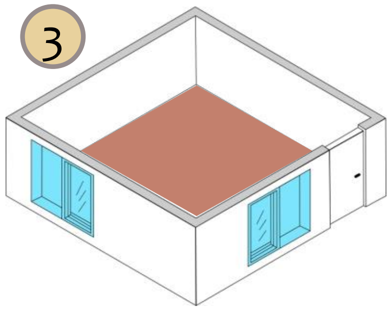
$\frac{\text{Openable Window Area}}{\text{Carpet Area}} \geq \frac{1}{12}$

2



$\frac{\text{Window Area}}{\text{Wall Area}} \leq \frac{1}{4}$

3



$\frac{\text{Window Area}}{\text{Carpet Area}} \leq \frac{2}{5}$

*Perform check for each external wall with windows

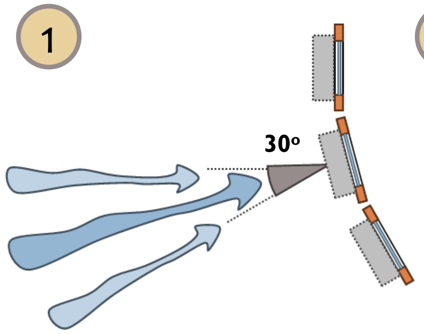
Operable window area ratio
At least 1/12th of window area serving habitable spaces should be openable. This will ensure all habitable spaces are adequately ventilated.
Windows serving habitable spaces must open to the exteriors.

Window to wall area ratio
No wall should have window exceeding 1/4th of its area.
Large windows have the potential to cause hot pockets within a room due to direct radiation.

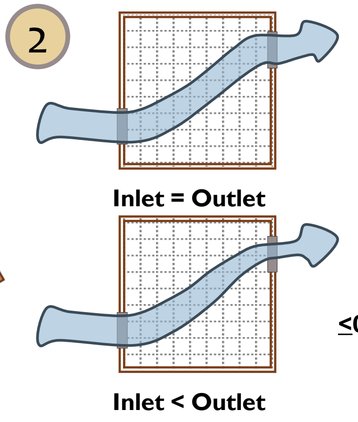
Operable window to wall area ratio
Overall window opening area should not exceed 40% of overall carpet area. Limiting glazing area avoids excessive heat gains and losses in the space.

D Window openings for enhanced ventilation

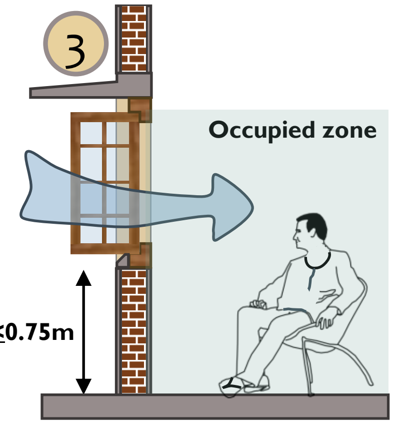
1



2



3

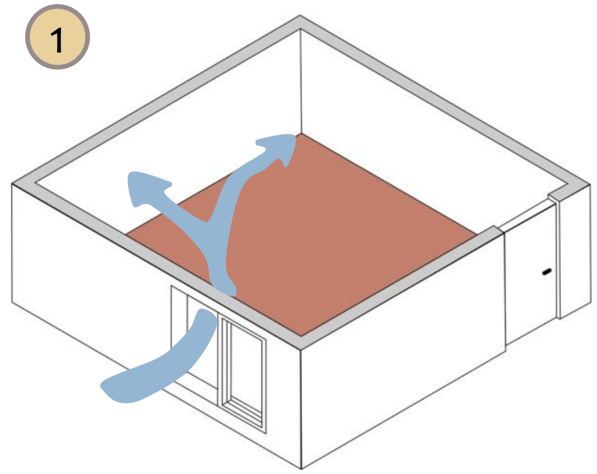


Window orientation
Windows facing the windward side function as air inlets. Orient inlet windows within 30° of the prevalent wind direction to maximize the effectiveness of natural ventilation.

Window size distribution
Inlet windows shall be equal to or larger than the outlet windows to enhance air movement within the indoor space.

Window cill height
Window cill height at 0.75 m is ideal for the seated position.
Judicious planning of window heights enables air movement in the occupied zone.

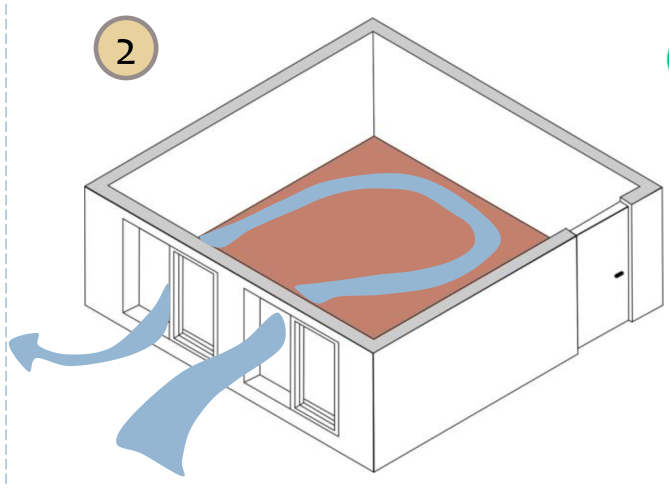
1



Level A

Single-sided ventilation
A window placed on a single external wall provides ventilation and, access to daylight and views. It is necessary that this window opening is unobstructed.
Compared to no windows, a single window provides significant improvement to quality of space.

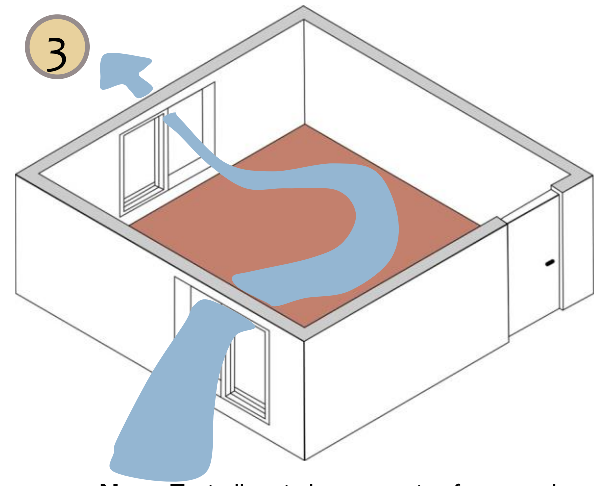
2



Level A+

Single sided ventilation: Openings distributed on a single side
Distributing windows on single side not only improves ventilation performance, but also daylight performance.

3

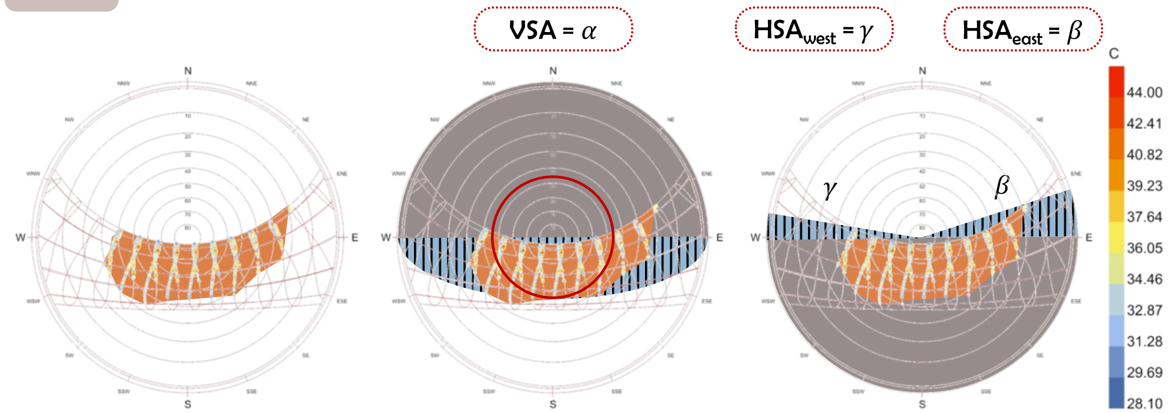


Level A++

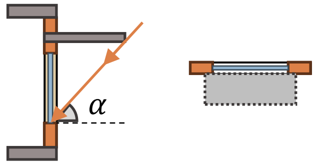
Two (or more)-sided ventilation: Windows on adjacent walls
Placing windows on two or more walls improves ventilation performance compared to single-sided ventilation,
Further, placing windows diagonally across is expected to provide best ventilation performance..

Note: Typically, window operation for natural ventilation in cold climate will be restricted to short periods. In Cold climate, the intent is to harvest solar gains to stave off cold discomfort. In summer, however, harvesting solar gains may lead to overheating. Natural ventilation then comes in handy to expel the unwanted gains. Due care must be taken to properly seal windows.

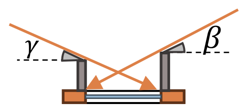
E Window shading for limiting thermal gains



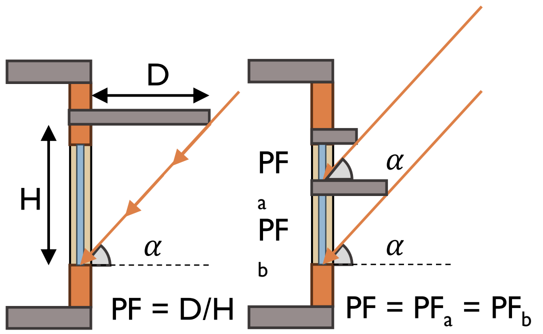
Designing for shading – When to shade?
Design for shades whenever ambient temperature exceeds 28 °C and global horizontal radiation exceeds 315 kWh/m².
A stereographic chart is a useful tool for superimposing solar path and weather data to identify time of the year when shading is required.

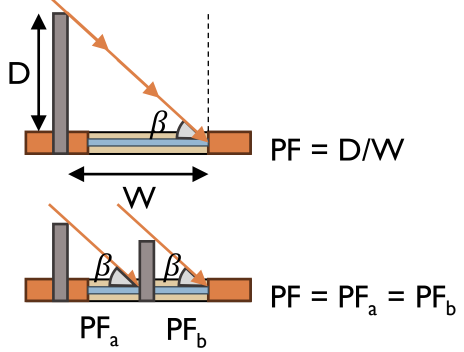


Stereographic chart showing overhang for south facing facade



Stereographic chart showing side fins for north facing facade



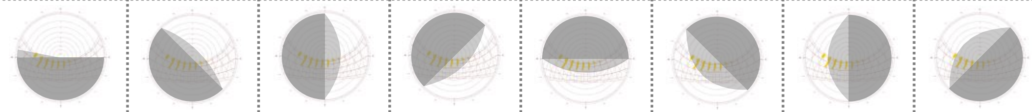
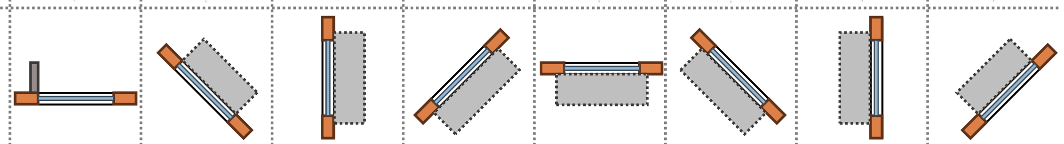
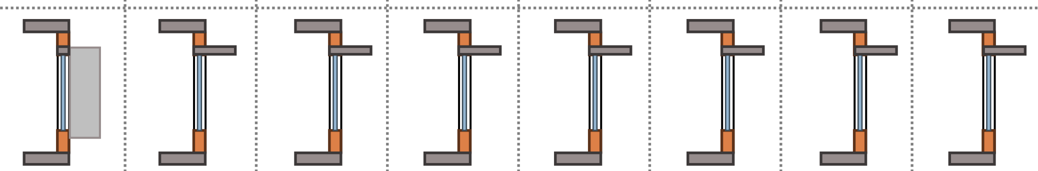


Designing for shading – How to shade?
Read projection factors for your climate and latitude from the Shading factor tables. While shading is the primary defense against solar gains, it may not be practical to design a single shade. Take cues from the image above on distributing overhangs and fins into multiple elements (while maintain the projection factor) for designing practical shading devices.

Overhang Projection Factor
Projection factor or (**PF**) is the ratio of the depth of the overhang (i.e. **D**) to the distance of cill from the base of the overhang (i.e. **H**).

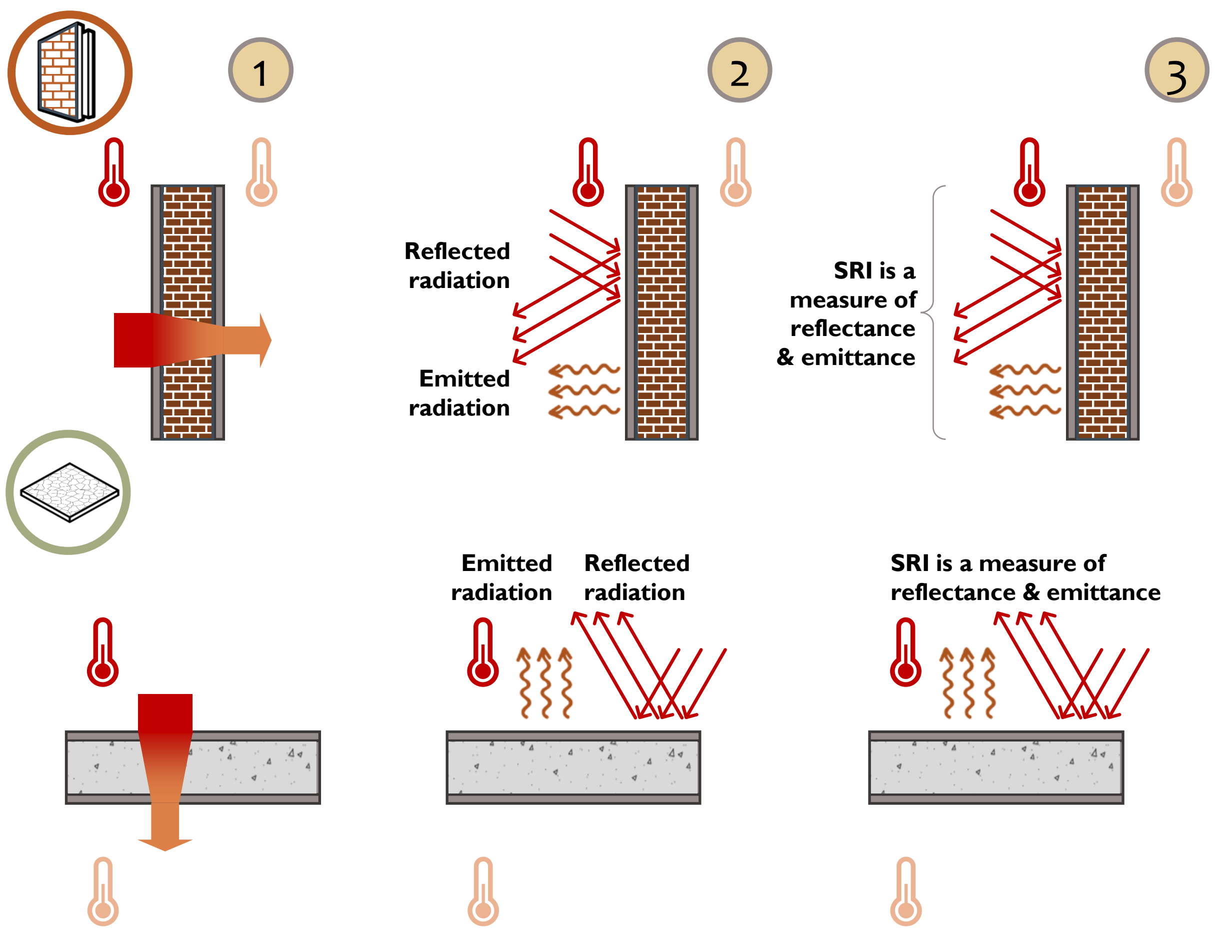
Fin Projection Factor
Projection factor or (**PF**) is the ratio of the depth of the fin (i.e. **D**) to the distance of the furthermost edge of the window from the base of the fin (i.e. **H**).

Window shading factors for locations in Cold climate

Orientation	0°		45°		90°		135°		180°		225°		270°		315°	
Shade type	O-H	Fin	O-H	Fin	O-H	Fin	O-H	Fin	O-H	Fin	O-H	Fin	O-H	Fin	O-H	Fin
Projection Factors	-	L-0.18 / -	0.47	- / -	0.84	- / -	0.70	- / -	0.70	- / -	1.00	- / -	1.00	- / -	1.00	- / -
Shadow mask																
Section through window – Plan view																
Section through window- Elevation view																

Note:
1. External movable shades are not required for buildings in cold climate.
2. Shading factors have been developed for cities above 23.5° N only due to unavailability of weather files for latitudes below 23.5° N. In absence of weather files below 23.5° N, same shading factors may be applied.

F1 Key performance parameters: Opaque assemblies – Wall & Roof



Thermal Conductance (U-factor)
U-factor of an opaque construction assembly is a measure of heat conducted through a unit area of material for 1°C temperature difference.

ISO 6946 provides method for testing thermally homogeneous (including assemblies with air layers) assemblies. It also provides an approximate method for evaluating inhomogeneous layers.

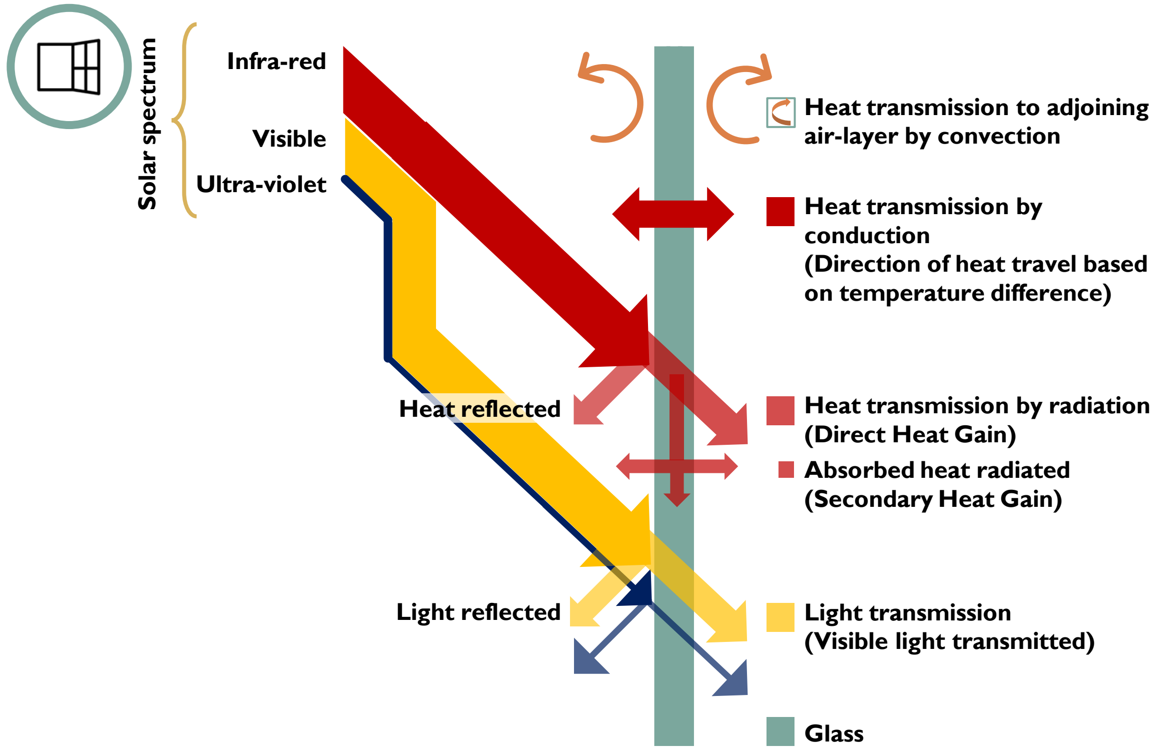
Reflectance & Emittance
As solar radiation strikes an opaque surface, a part of it gets absorbed, while the rest gets reflected. The portion absorbed by the surface is 'emitted' out as long-wave infra-red radiation. The reflected component is termed as 'Reflectance' and the emitted component is termed as 'Emittance'. Both are expressed as a ratio between 0 and 1.

For external wall surfaces, the test procedures for evaluating reflectance and emittance are detailed out in Wall Product Rating Program Manual CRRC-2.

Solar Reflective Index (SRI)
Solar reflective index is a metric that combines the effect of a material's ability to reflect incident solar radiation as well as its ability to emit thermal radiation.

The SRI value of a product shall be tested as per ASTM E 1980. This standard defines the method to determine the solar reflectance, the thermal emittance and the subsequent calculation for SRI.

F2 Key performance parameters: Transparent Assemblies - Glazing



1

Thermal Conductance (U-factor)
The thermal conductance of glass is the amount of non-solar heat (i.e. heat flow via conduction and convection) transmitted through a glazing of unit area for 1°C temperature difference.

U-factor may also be used to represent the thermal conductance across a glazing construction assembly, i.e. glass along with frame, spacer material and other components.

2

Solar Heat Gain Coefficient (SHGC)
SHGC is a measure of heat transmitted through the glazing via radiation. It is a unitless metric and expressed as a number between 0 and 1.

SHGC is the fraction of solar heat gain radiated through the glazing either directly or after absorption.

3

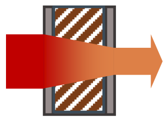
Visible Light Transmittance (VLT)
VLT is a measure of light entering into the space through the glazing. It is a unitless metric and expressed as a number between 0 and 1.

VLT is the fraction of light in the visible spectrum transmitted through the glass. VLT is arrived at after weighting for sensitivity of the human eye.

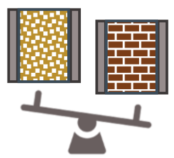
Performance tests for U-factor, SHGC and VLT for glazing and glazing assemblies (U-factor)
ISO-9050 provides methods for testing glass for, U-factor, Solar Heat Gain Coefficient (SHGC) and Visible Light Transmittance (VLT).
ISO 12576-1 provides test methods for testing complete glazing construction assemblies, i.e. glass along with frame, sash, shutter, etc. for U-factor, SHGC and VLT.

G1 Key performance requirements: Opaque assemblies – Wall & Roof

Wall assembly



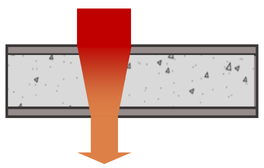
U-factor in W/m²K



	Light-weight assembly	Medium/Heavy-weight assembly	
Density (kg/m³)	≥800	<800	
Level A	0.80	0.85	or lower
Level A+	0.60	0.50	or lower
Level A++	0.35	0.35	or lower

Note: Level A++ is a mandatory if the residential building is mechanically air-conditioned.

Roof assembly



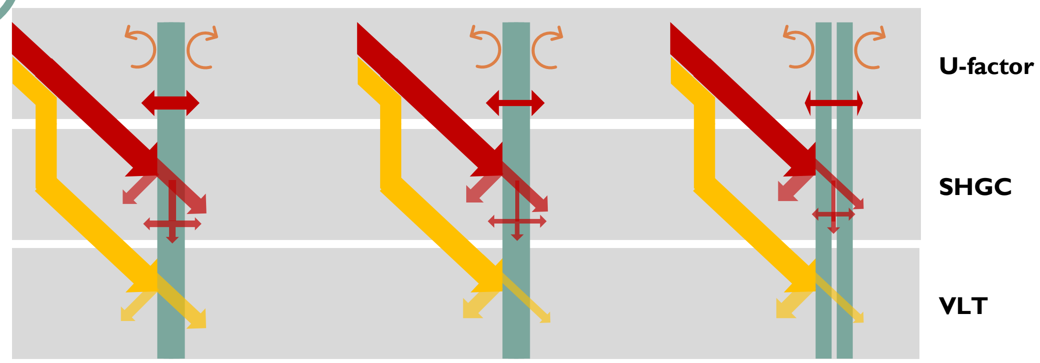
U-factor in W/m²K

Level A	0.75	or lower
Level A+	0.45	or lower
Level A++	0.25	or lower

Note: Level A++ is a mandatory if the residential building is mechanically air-conditioned.

G2 Key performance requirements: Glazing assembly

Glazing assembly



	Level A	Level A+	Level A++
U-factor	3.8 or lower	2.8 or lower	1.8 or lower
SHGC	0.7 or lower	0.6 or lower	
VLT	0.3 or higher		

Note: Level A++ is a mandatory if the residential building is mechanically air-conditioned.

Glazing frame type to reduce thermal bridging and air leakage

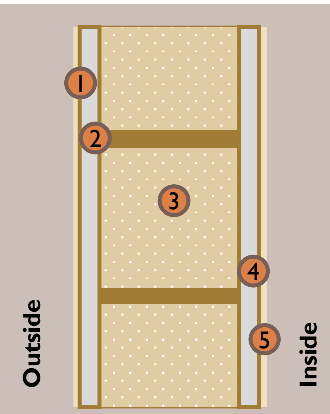
Wooden frame

Vinyl frame

Windows are a potential thermal bridge, i.e. source of uncontrolled thermal exchange between the indoor space and the external environment. In air-conditioned buildings, it is especially important to eliminate thermal bridges to minimize cooling/heating losses.

Wood and vinyl are preferred glazing assemblies as these are relatively less conducting. For all frame types, weatherstripping between sash and window frame, and caulk between window frame and structure are essential to effectively seal the windows and reduce uncontrolled air leakage.

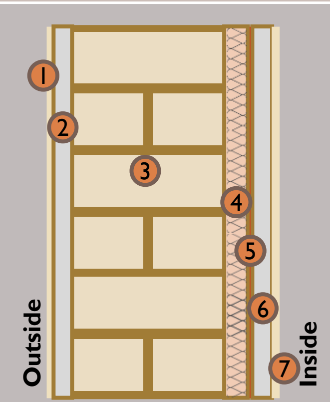
H1 Performance bundles – Wall



AAC Block Wall

1. Exterior paint
2. External cement plaster (GI chicken wire mesh over block-work and structure joints)
3. AAC block work
4. Internal cement plaster
5. Interior paint

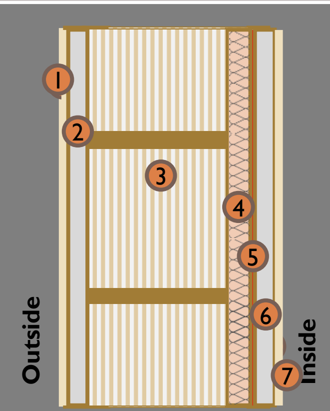
AAC Block work 200 mm		
230 mm thick	0.78 W/m²K	
AAC Block work 300 mm		
330 mm thick	0.55 W/m²K	



Fly ash brick wall with internal insulation

1. Exterior paint
2. Cement plaster/base Coat (over reinforcing mesh)
3. Rigid insulation board applied with adhesive and held in place with PVC fasteners
4. Cement plaster (for smooth finish to aid adhesion with rigid insulation board)
5. Fly-ash block work
6. Internal plaster
7. Interior paint

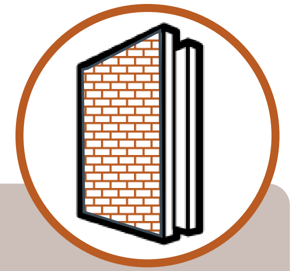
Fly ash brick 230 mm	
XPS/PUF 25 mm	
285 mm thick	~0.75 W/m²K
Fly ash brick 230 mm	
XPS/PUF 50 mm	
315 mm thick	~0.45 W/m²K
Fly ash brick 230 mm	
XPS/PUF 75 mm	
335 mm thick	~0.31 W/m²K

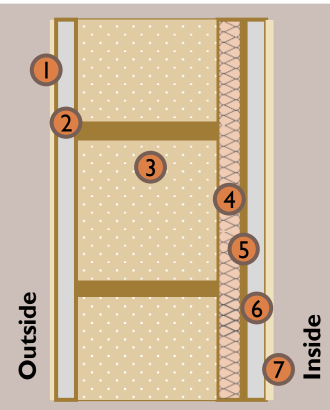


Solid concrete block with internal insulation

1. Exterior paint
2. External cement plaster
3. Solid Concrete Block
4. Rigid insulation board applied with water based adhesive and held in place with PVC fasteners
5. Vapour barrier (polythene sheet or any other suitable material)
6. Gypsum plasterboard
7. Interior paint

Solid concrete block 200 mm	
XPS/PUF 25 mm	
255 mm thick	~0.81 W/m²K
Solid concrete block 200 mm	
XPS/PUF 50 mm	
285 mm thick	~0.45 W/m²K
Solid concrete block 200 mm	
XPS/PUF 50 mm	
285 mm thick	~0.31 W/m²K

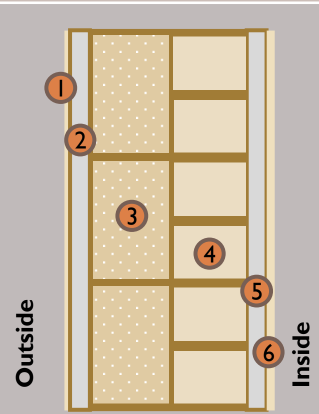




AAC Block Wall with internal insulation

1. Exterior finish (as/design)
2. External cement plaster (GI chicken wire mesh over block-work and structure joints)
3. AAC block work
4. Rigid insulation board applied with water based adhesive and held in place with PVC fasteners
5. Vapour barrier (polythene sheet or any other suitable material)
6. Gypsum plasterboard
7. Interior paint

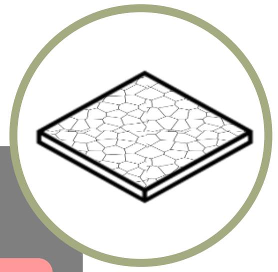
AAC Block work 150 mm	
XPS/PUF 50 mm	
230 mm thick	~0.34 W/m²K



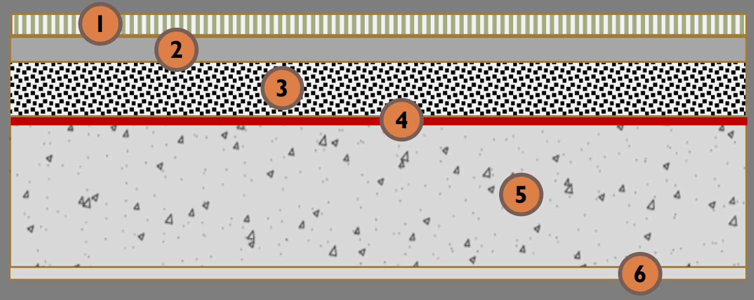
Fly ash brick wall faced with AAC block outside

1. Exterior paint
2. Cement plaster
3. AAC block work
4. Fly-ash block work
5. Internal plaster
6. Interior paint

Fly ash brick 75 mm	
AAC block 200 mm	
305 mm thick	0.73 W/m²K



Outside



Inside

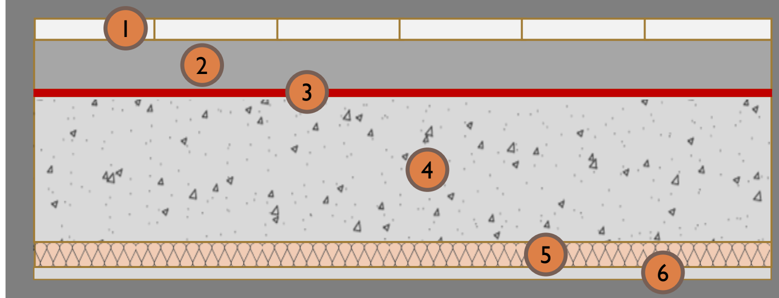
Foam concrete insulation over RCC slab.

1. Tiles applied with cement mortar
2. Plain Cement Concrete (PCC) screed laid to slope
3. Foam concrete
4. Waterproofing layer
5. Reinforced Cement Concrete (RCC) slab (as/structural design)
6. Internal plaster

Foam concrete 75 mm
RCC slab as/design
~280 mm thick | ~0.73 W/m²K

Foam concrete 150 mm
RCC slab as/design
~355 mm thick | ~0.41 W/m²K

Outside



Inside

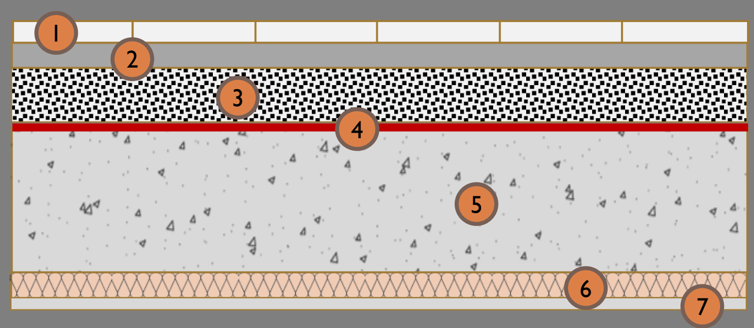
Rigid foam insulation installed under RCC slab.

1. Finishing surface (tiles, stone, etc.) applied over cement mortar
2. Plain Cement Concrete (PCC) screed laid to slope
3. Water proofing layer
4. Reinforced Cement Concrete (RCC) slab (as/structural design) thoroughly cleaned of all dust, dirt and loose particles with wire brush
5. Rigid insulation board applied with adhesive, held in place with screws and joints sealed with tape.
6. Internal plaster applied over reinforcing mesh

PUF/XPS 25 mm
RCC slab as/design
~280 mm thick | ~0.73 W/m²K

PUF/XPS 50 mm
RCC slab as/design
~305 mm thick | ~0.45 W/m²K

Outside



Inside

Foam concrete insulation and rigid foam insulation installed under RCC slab.

1. Finishing surface (tiles, stone, etc.) applied over cement mortar
2. Plain Cement Concrete (PCC) screed laid to slope
3. Foam concrete
4. Waterproofing layer
5. Reinforced Cement Concrete (RCC) slab (as/structural design)
6. Rigid insulation board applied with adhesive, held in place with screws and joints sealed with tape.
7. Internal plaster

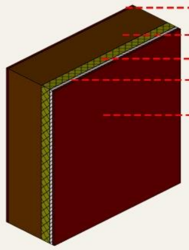
PUF/XPS 25 mm
Foam Concrete 100mm
RCC slab as/design
~330 mm thick | ~0.38 W/m²K

PUF/XPS 75 mm
Foam Concrete 100mm*
RCC slab as/design
~305 mm thick | ~0.45 W/m²K

H3 High thermal performance bundles – Alternative materials for Wall Construction

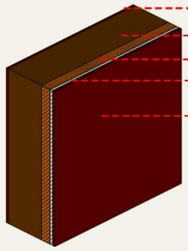
Level A+

Rammed Earth Wall



U-Value : 0.66 W/(m².K)

Thickness : 291 mm

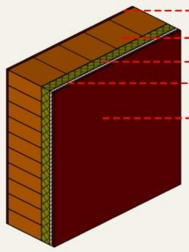


U-Value : 0.60 W/(m².K)

Thickness : 291 mm

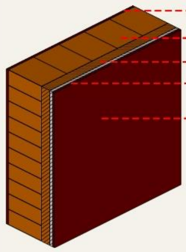
Level A+

CSEB Wall



U-Value : 0.72 W/(m².K)

Thickness : 291 mm

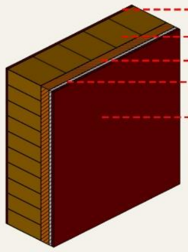


U-Value : 0.66 W/(m².K)

Thickness : 291 mm

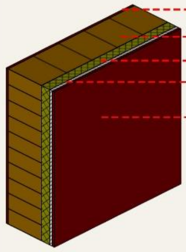
Level A+

Adobe Block Wall



U-Value : 0.76 W/(m².K)

Thickness : 291 mm



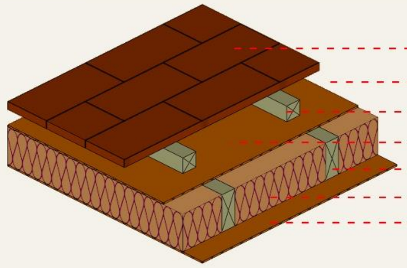
U-Value : 0.69 W/(m².K)

Thickness : 291 mm

H3 High thermal performance bundles – Alternative materials for Roof Construction

Level A+

Pine Shingle Roof Insulated with Jute Fibre

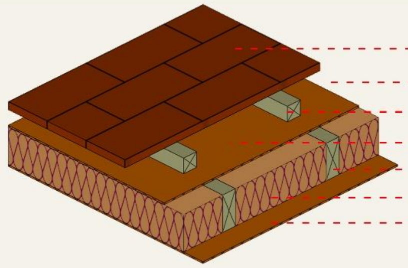


U-Value : 0.363 W/(m².K)

Thickness : 207 mm

Level A+

Pine Shingle Roof Insulated with Straw

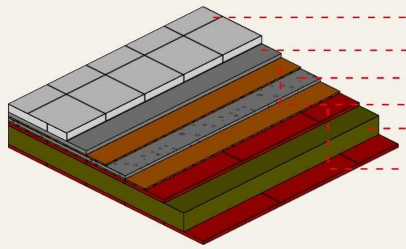


U-Value : 0.331 W/(m².K)

Thickness : 207 mm

Level A

Terracotta Tile RCC Filler Slab with Rice Husk Insulation



U-Value : 0.57 W/(m².K)

Thickness : 158.1 mm

H5 Key material specifications

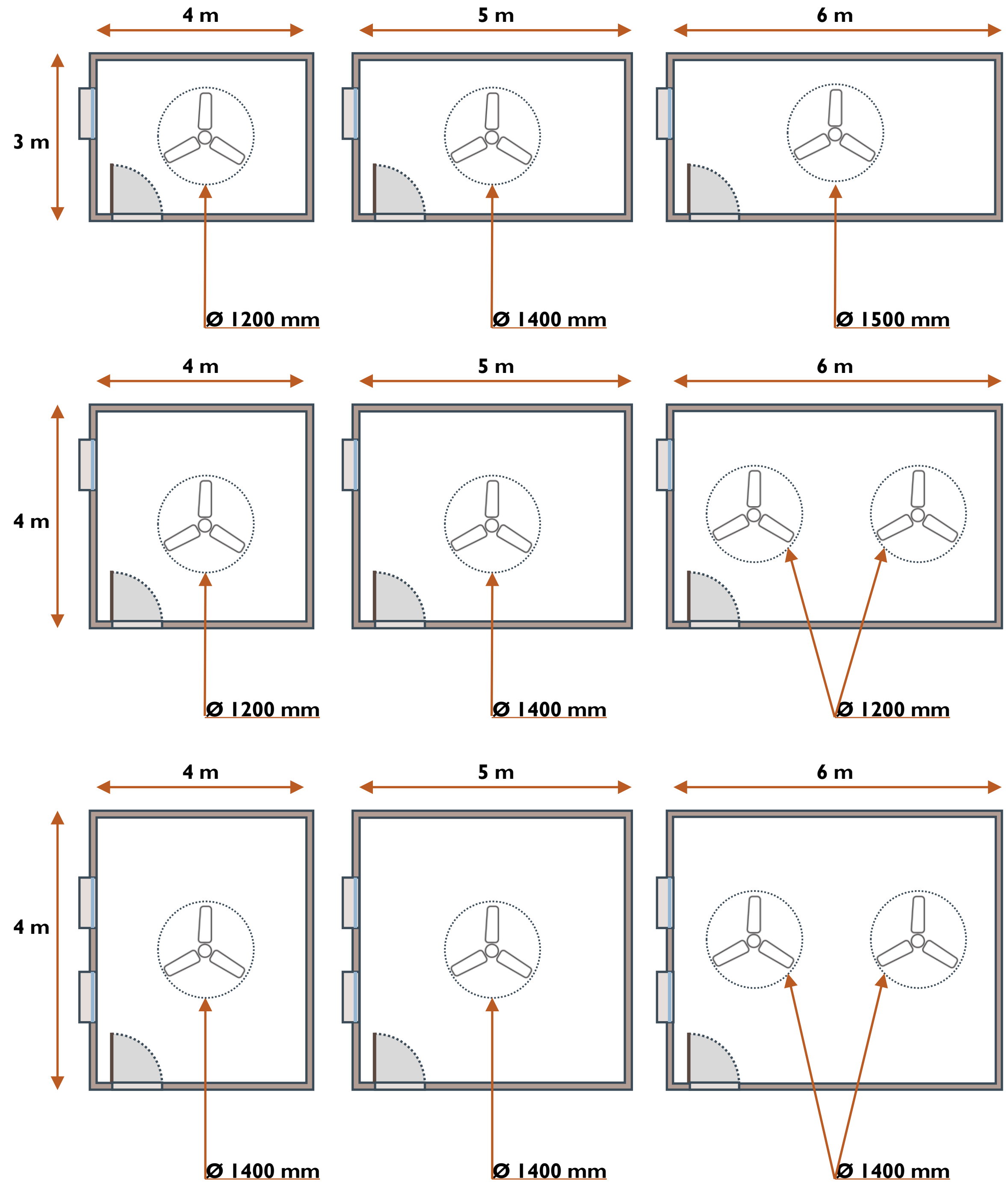
Material	Conductivity {W/mK}	Density {kg/m^3}	Source
AAC Block	0.184	642	Source: CBERD-MNRE
Rammed Earth Wall	0.58	1,540	Source: Gupta P., et al.
Solid Concrete Block	1.411	2,350	Source: SP-41
Fly Ash Brick	0.856	1,650	Source: Gourav K., et al.
CSEB	1.026	1,700	Source: Balaji N.C., et al.
Cellular/ Foam Concrete	0.188	704	Source: SP-41
Burnt Clay Brick	0.811	1,820	Source: SP-41
Adobe Block	0.75	1,731	Source: SP-41 (Mud-brick)
Reinforced concrete	1.580	2,288	Source: SP-41
PUF [Polu Urethane Foam]	0.026	38-42	ASHRAE Handbook (Fundamentals)
Jute Fibre	0.067	329	Source: SP-41
XPS [Extruded Poly-Styrene]	0.029	34-36	ASHRAE Handbook (Fundamentals)
Saw Dust	0.051	188	Source: SP-41
Rockwool (unbonded)	0.043	150	Source: SP-41
Rice Husk	0.051	120	Source: SP-41

Material	SRI
Exterior Paint (Wall/Roof)	>78
Heat Reflective Tiles (Wall/Roof)	>78
White China Mosaic (Grouted in white cement)	SRI (Deemed) >78

04

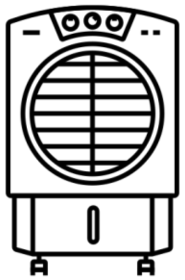
Low-energy active comfort systems for thermal comfort

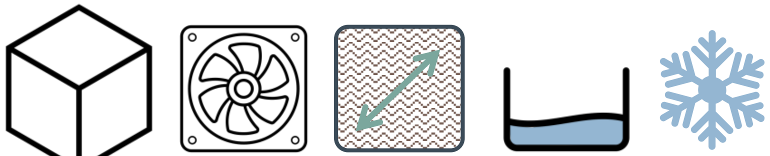
A-1 Design recommendations for ceiling fans (size & numbers)



Source: SP-41

A-2 Design recommendations for sizing desert coolers





Space Volume (m³)	Fan Dia (mm)	Cooling Pad Area (m²)	Water Tank (litres)	Cooling Capacity (Tons)
30-50	300	1.3	40	1.0
40-60	400	1.9	60	1.2
80-120	450	2.1	80	2.0

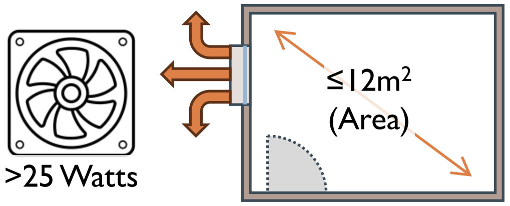
Source: SP-41
(Subject to revision as per Star labelling requirements for desert cooler)

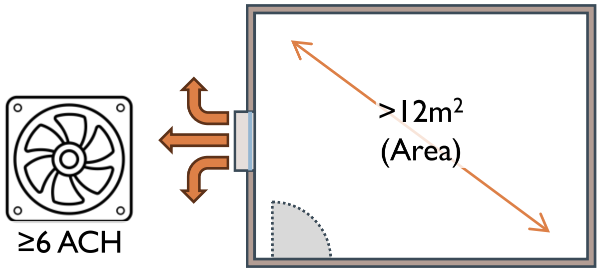
The desert/swamp cooler is a cost-effective and energy efficient alternative for cooling during hot-dry periods. The cooling capacity of the desert cooler is dependent upon air flow and effective area for heat exchange. Cooling efficiency is expressed as

$$Cooling\ efficency = \frac{T_{db} - T'_{db}}{T_{db} - T_{wb}} \times 100$$

T_{db} is is dry bulb temperature at the inlet, T_{db}' is dry bulb temperature at the outlet and T_{wb} is the wet bulb temperature at the inlet.

A-3 Design recommendations for exhaust fans in kitchen, bath and lavatories

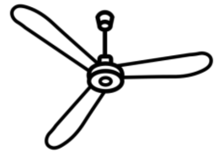




All kitchen, bath and lavatory spaces must maintain minimum ventilation to maintain health and hygiene. These spaces shall have provision to directly exhaust air outside.

B Star labelled equipment and minimum efficiencies

Ceiling Fan



Level A

Sweep size (mm)	Min. Service value (CMM/Watt)
> 1200	4.1
<= 1200	5.0

Level A+

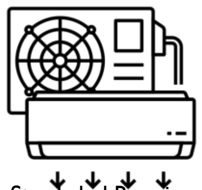
Sweep size (mm)	Min. Service value (CMM/Watt)
> 1200	4.6
<= 1200	5.5

Level A++

Sweep size (mm)	Min. Service value (CMM/Watt)
> 1200	5.1
<= 1200	6.0

Star Label Requirements for Ceiling Fan. (Validity until December 31, 2024)

Split-type Air Conditioner (Variable Speed)

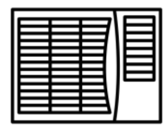


Cooling Watts	ISEER
<10,465	5.0

Default temperature setting of 24°C

Star Label Requirements for 5 Star Air Cooled Chiller (Validity until December 31, 2023)

Unitary-type Air Conditioner (Variable Speed)

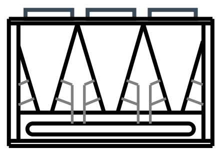


Cooling Watts	ISEER
<10,465	3.5

Default temperature setting of 24°C

Star Label Requirements for 5 Star Air Cooled Chiller (Validity until December 31, 2023)

Air Cooled Chiller

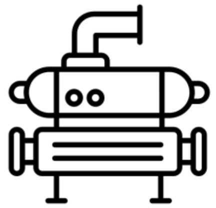


Cooling kW	Min COP*	ISEER
<260	2.4	4.4
>=260	2.6	4.7

Star Label Requirements for 5 Star Air Cooled Chiller (Validity until December 31, 2025)

*Minimum COP for Air Cooled Condenser (for 100% load)

Water Cooled Chiller



Cooling kW	Min COP*	ISEER
<260	4.2	6.6
<530	4.7	7.4
<1050	5.0	8.2
<1580	5.2	8.7
>=1580	5.6	9.0

Star Label Requirements for 5 Star Water Cooled Chiller (Validity until December 31, 2025)

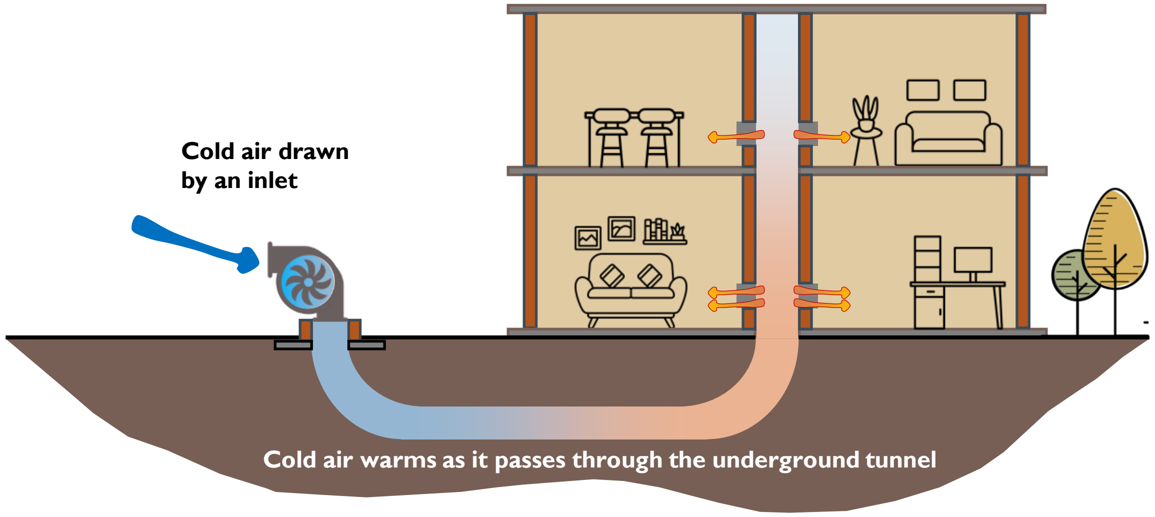
*Minimum COP for Water Cooled Condenser (for 100% load)

Source: BEE

C-1 Low-energy systems: Earth-to-air heat exchange

Earth-air tunnel
Sub-surface temperatures beyond 3m depth, tend to hover around the annual mean temperature. This provides an opportunity to exchange heat with ambient air (in both winters and summers) for achieving thermal comfort indoors.

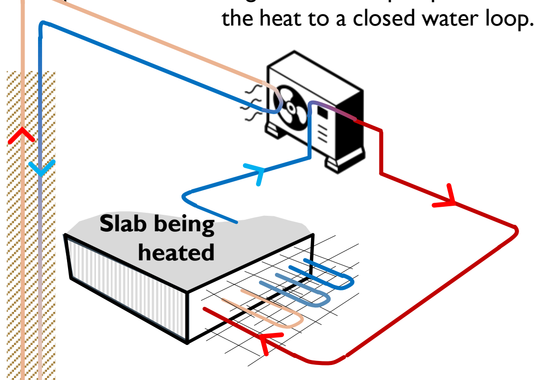
Winter operation
Cold ambient air is drawn in via fans and pushed through an underground tunnel. As the air passes through the underground tunnel, it absorbs heat from the warmer earth encasing the tunnel. This warmer air can be used as pre-heated air for reducing load on mechanical systems for heating



C-2 Geo-thermal heat-pump coupled with radiant heating

A geothermal heat-pump (or ground source heat pump) coupled with structure embedded distribution system for radiant heating has 3 key components,
(1) the ground loop,
(2) the heat pump, and,
(3) hot-water distribution system embedded in the structure.
This system delivers efficiency on 3 counts, energy efficient heating technology, passive heating through geothermal principles, and efficient heat distribution systems.
Pre-heated water from ground loop feeds into the heat –pump thereby reducing the load on the heat pump.
This heating load is further reduced as the heat is delivered through a radiant slab which does not require achieving temperatures as high as required by other conventional heating systems.
Typically the pipes for ground loop are buried vertically. For residential projects where land is available, the ground loop pipes can be laid horizontally underground (in slinky configuration upto 2m depth) as well.

Heat Pump
exchanges heat with the ground loop. The compressor uses pre-heated input from ground loop. The heated refrigerant in heat pump transfers the heat to a closed water loop.

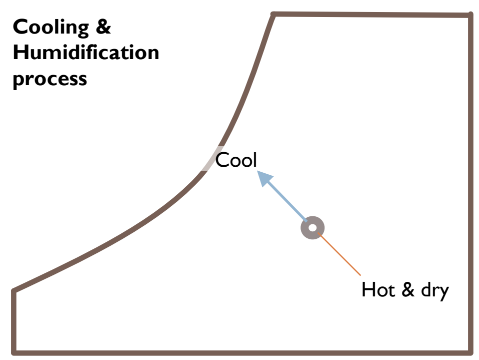


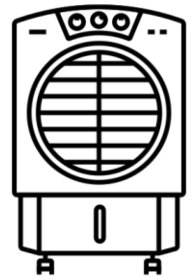
Ground loop
Pipes buried underground exchange heat with the earth

Water loop embedded in structure
Heated water from the heat pump cycles through the slab to warm the structure.

C-3 Low-energy systems: Evaporative cooling

Direct evaporative cooling
Water has high heat capacity and can readily absorb heat from the ambient air.
Evaporation implies water changes its state from liquid to vapor. This change of state is an energy intensive process. In this case the heat energy held by the air during hot-dry conditions is consumed in the evaporation process leading to cool air.



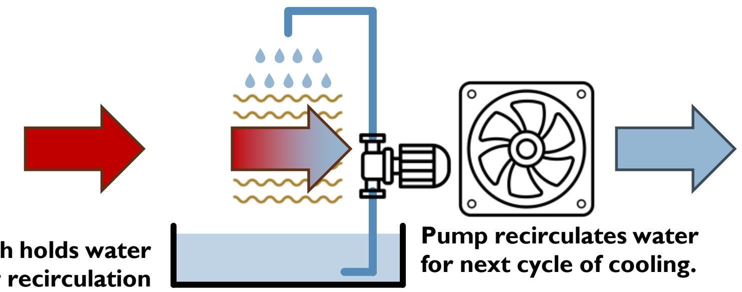


Desert/Swamp Cooler

1 Hot air passes over wet filter media

2 Hot-air loses heat to water and cools down

3 Cooled air delivered indoors via fan

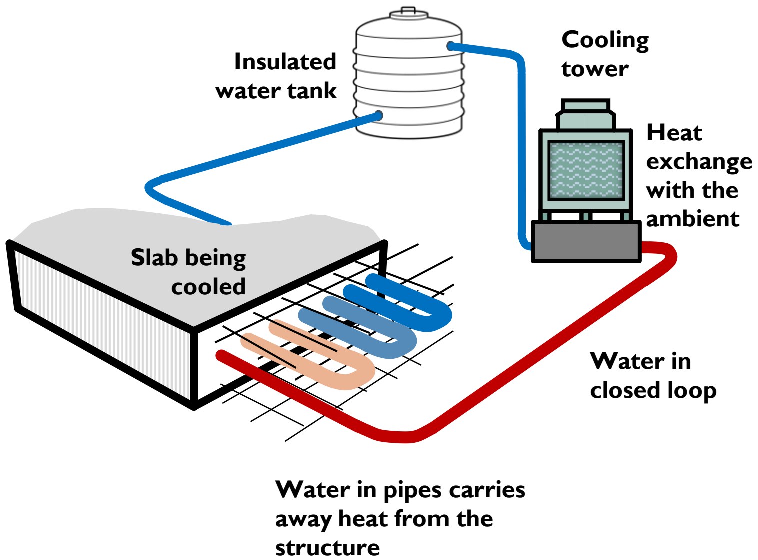


Trough holds water for recirculation

Pump recirculates water for next cycle of cooling.

Desert/Swamp coolers provide effective cooling during summer using this principle. A powerful exhaust fan draws in hot-dry air from the outside. This air passes over wet filter media losing its heat in the process. The same exhaust fan delivers this cool air indoors.

C-4 Low-energy systems: Indirect evaporative cooling



Structure cooling system
The structure of the building is often heavy thermal mass. This thermal mass has the capacity to absorb and retain heat for long periods. The retained heat is released indoors causing discomfort during summer months.
Structure cooling system embeds a network of pipes through the structural system. This network of pipes carries cool water that draws heat from the structure. This pipe carrying warm water (or heat from the structure) exits the structure and expels the heat outside to an air or water medium (cooling tower in the schematic here). The water in closed loop keeps cycling through the structure till there is heat to be removed.

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