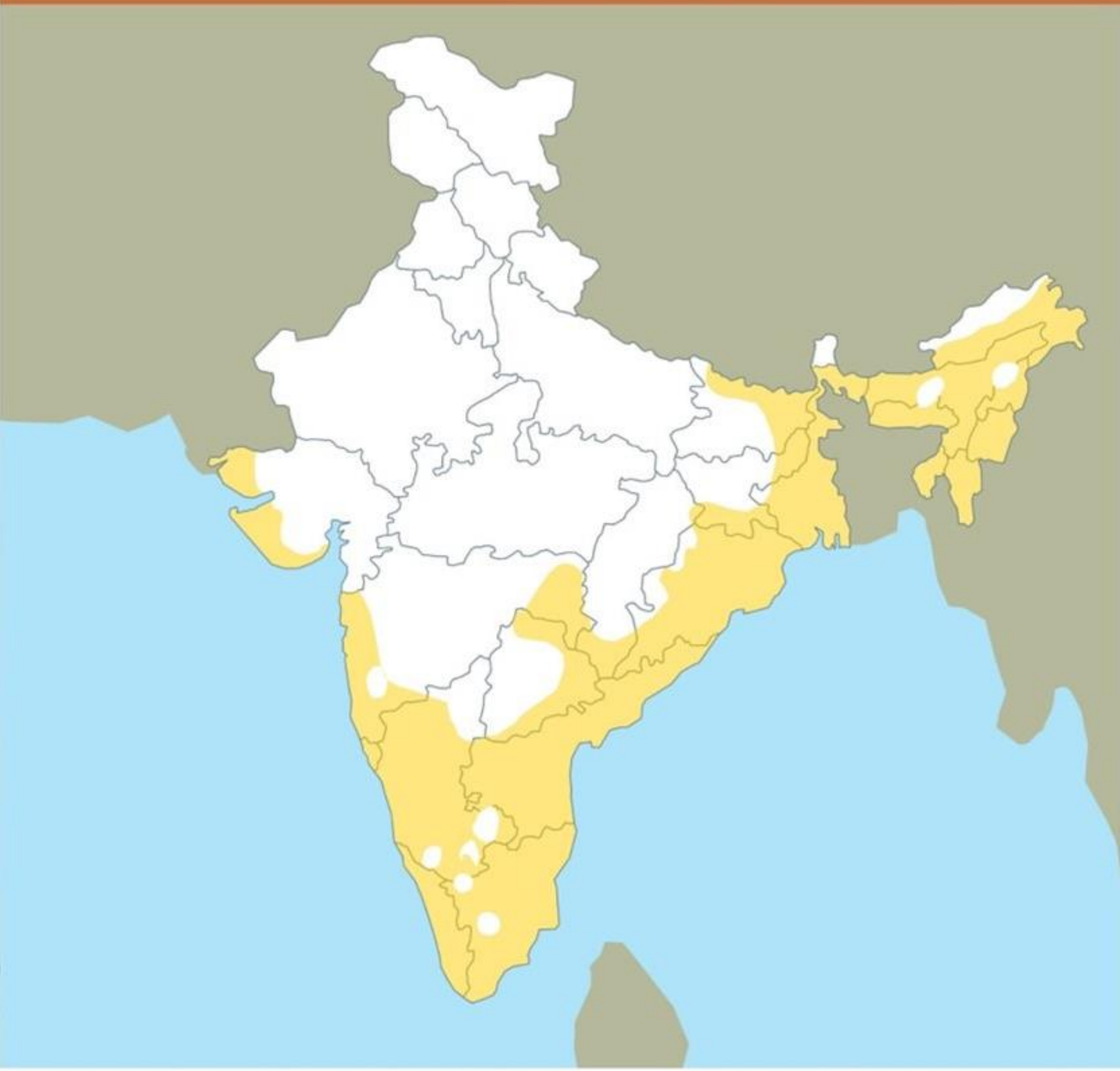
Design Guidelines for Thermally Comfortable Homes in Warm-humid Climate



Knowledge partners

Foreword

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Message by the Minister

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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 I 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.

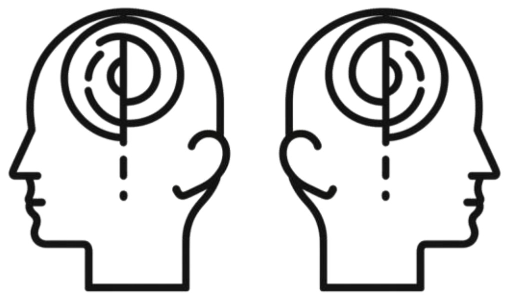
giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

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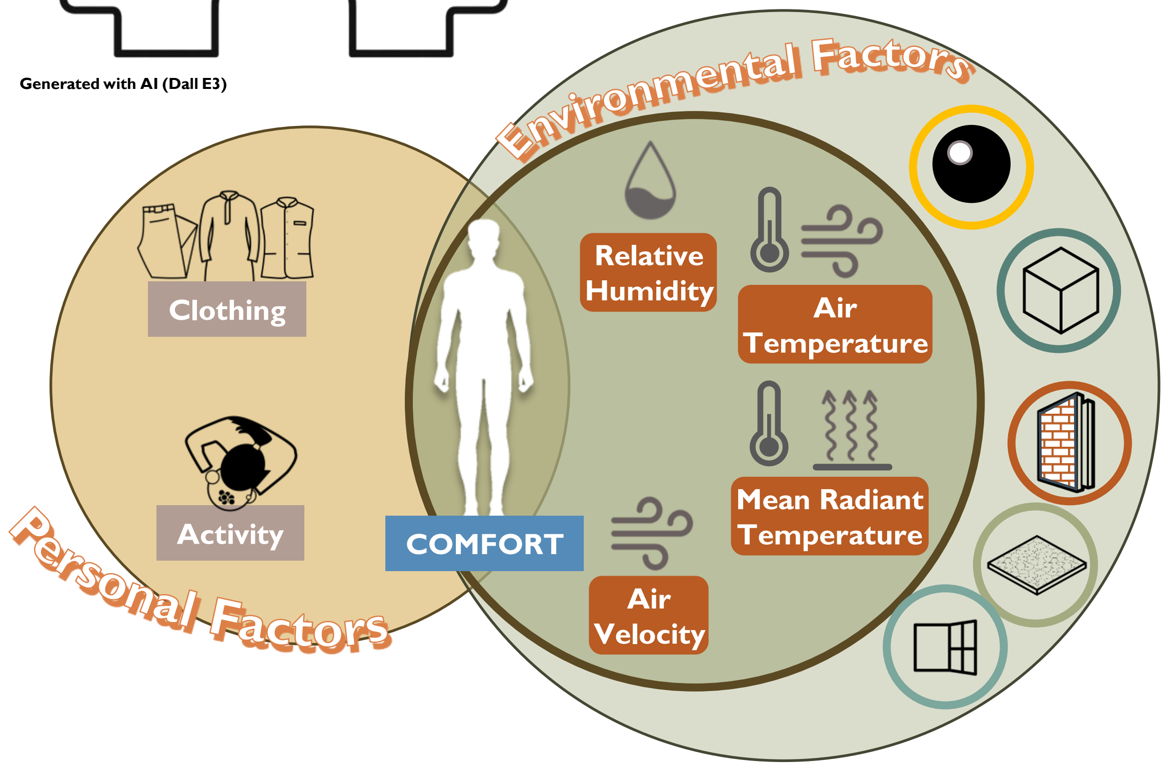
ISO 7730 defines thermal comfort as '…that condition of mind which expresses satisfaction with the thermal environment.'



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.

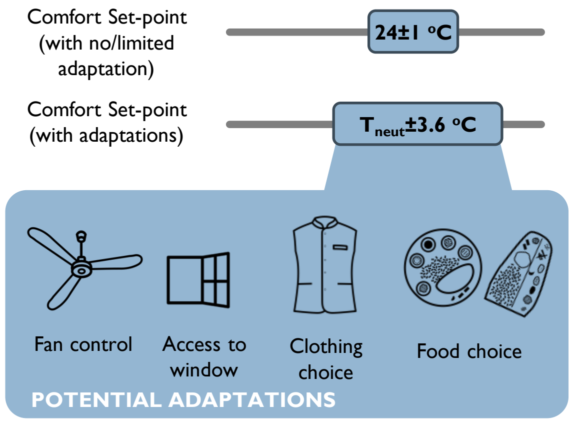
B Physiological response to discomfort

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.

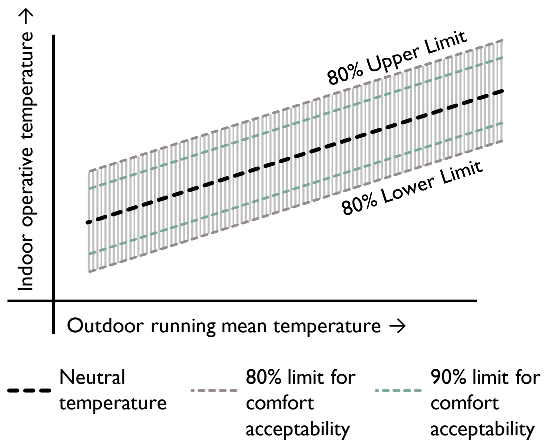
Vasodialtion and Sweating   Vasoconstriction and Shivering



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).



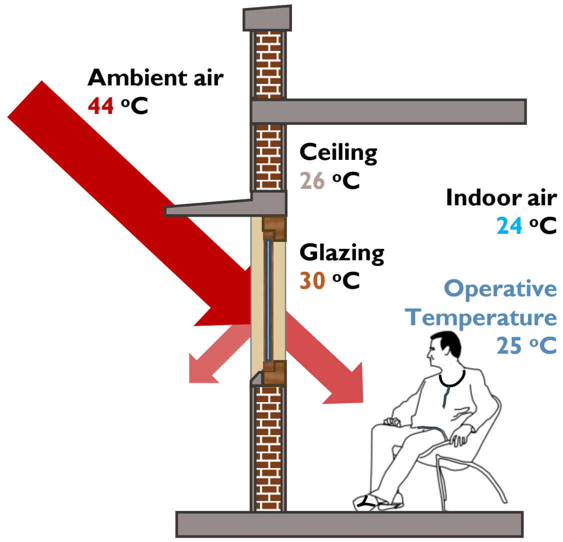
D Measuring thermal comfort

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.

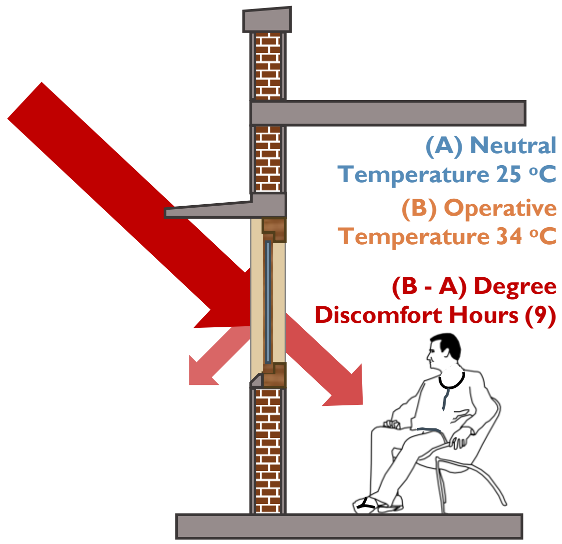


Metric – Degree Discomfort Hour (DDH)

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.

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



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 Warm-humid climate

B Seasonal characteristics

27 - 32°C

Day-time mean-max temperature range

21 - 27°C

Night-time mean-min temperature range

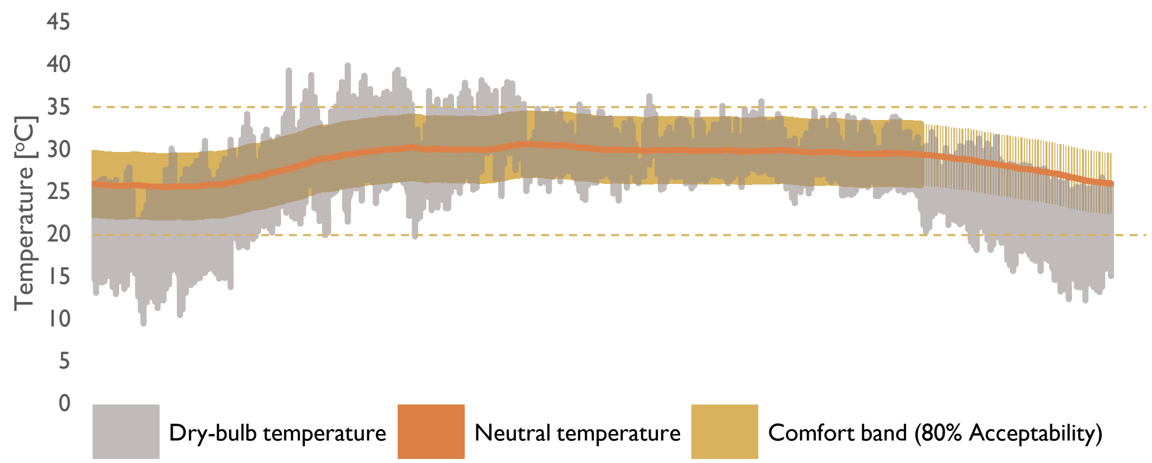
55 - 100%

Typical humidity range

Warm-humid climate is characterised hot, sticky conditions nearly throughout the year. The narrow diurnal and annual range also point to vey little seasonal variation throughout the year. Sky conditions are typically cloudy throughout the year. This implies diffused solar radiation and limited potential of night-sky cooling. While radiation is diffused, it is still harsh, and combined with high humidity it is a significant cause for discomfort.

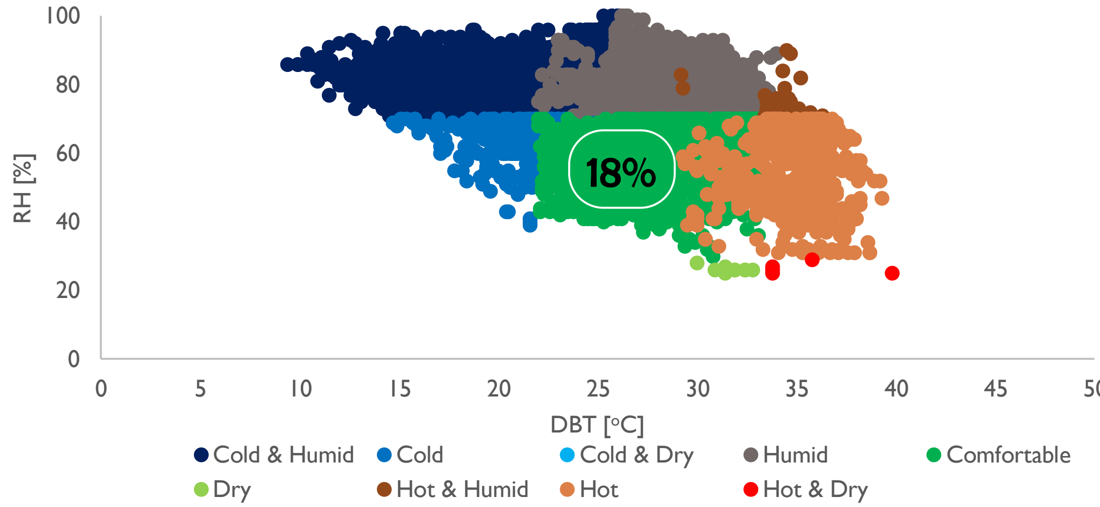
High humidity is known to affect durability of materials. Mold and algal growth, rotting of organic materials, and rusting/oxidation of metallic materials are typical concerns. Because of constant humidity and high vapour pressure, vapour diffusion through the envelope can lead to degradation of materials. This can impact health of building occupants. Careful choice of materials and incorporating judiciously placed vapour barrier are important design considerations.
Insects also thrive in these climates and this can deter occupants from using windows for ventilation. Insect screens can be integrated with windows to ensure use of windows for ventilation.
It is important to keep these considerations in mind while designing for thermal comfort and overall well being.

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 19 and 35°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.



The warm-humid climate can provide comfortable conditions for only about 18% hours in a year. Relative Humidity exceeds 70% for more than 70% of the occupiable hours.

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

From a thermal comfort point of view, the human body finds it difficult to reject heat in a warm-humid environment as there is negligible difference between the air and skin temperature. Therefore the opportunities for achieving comfort are limited to allowing breeze to not only pass through the window but also across the body surface of the occupants. To improve the effectiveness of ventilation, other strategies to avoid solar gains must be adopted as well. Judicious use of shading and low thermal mass in structure can complement natural ventilation,

1 **Enhanced natural ventilation**
Almost constant wind direction is a characteristic feature of warm-humid climate and this can be leveraged to enhance natural ventilation.
- Aligning building openings to prevailing wind direction (**see D**).
- Larger window-openings may be required for enhanced ventilation
- Since, by nature, warm-humid climate is endemic to coastal areas there is potential to leverage sea-breeze that flows from sea to land during the day and in the opposite direction during the night. Sea breeze is significant until 100 km from the coastline.

Due care must be taken while sizing and orienting windows. While windows can enhance ventilation they can bring in heat too.

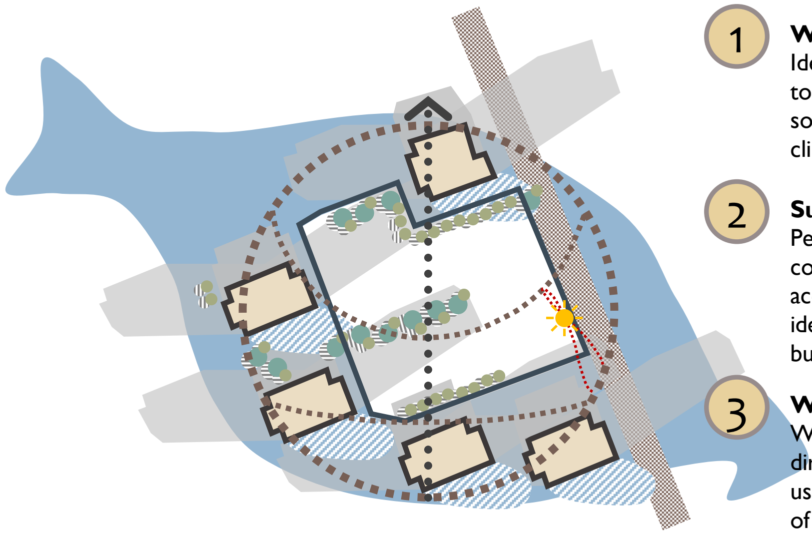
2 **Shaded windows with shutters**
While this isn't a climatic opportunity, it complements enhanced natural ventilation by limiting solar gains.
Owing to cloud cover, there is significant diffused radiation implying the requirement for adequate and practical shading.
- Shading has its limitations and must be augmented with external movable shutters that can cut-off all radiation when not desirable while still allowing ventilation. External shutters with venetian blinds are one example of external movable shades that cut-off radiation while still allowing ventilation.

3 **Low thermal mass**
Since day-night temperature difference is marginal, it becomes difficult to expel the heat trapped in the structure throughout the day. Low thermal mass avoids this build-up. The breeze flowing through the built mass in turn has to carry away lesser heat from the built mass.

03

Passive design features for thermal comfort

A Site context: Microclimate, siting & orientation

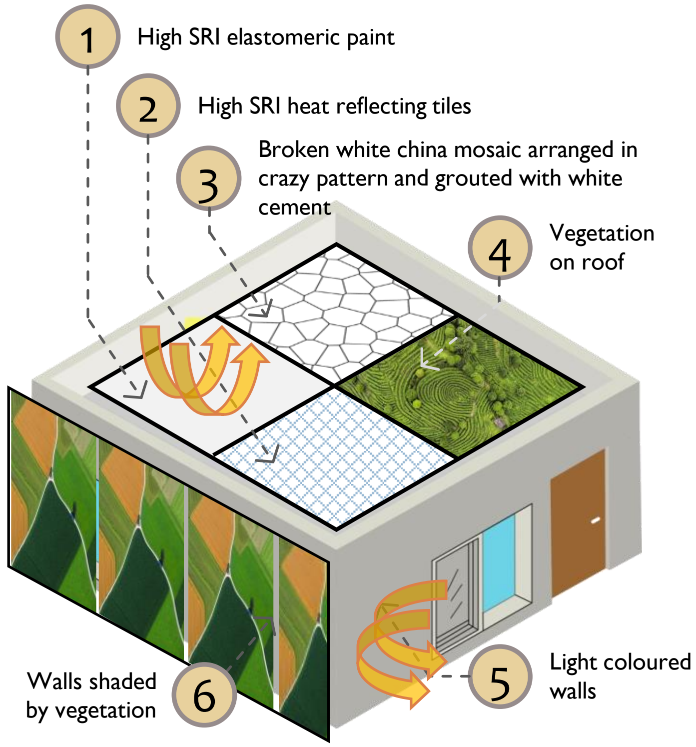


1. **Weather data for site location**
Identify periods of year the building is likely to experience discomfort. Prioritize passive solutions for these time periods. (See climate section.)

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 Mitigating urban heat islands – reflective roof and wall surfaces



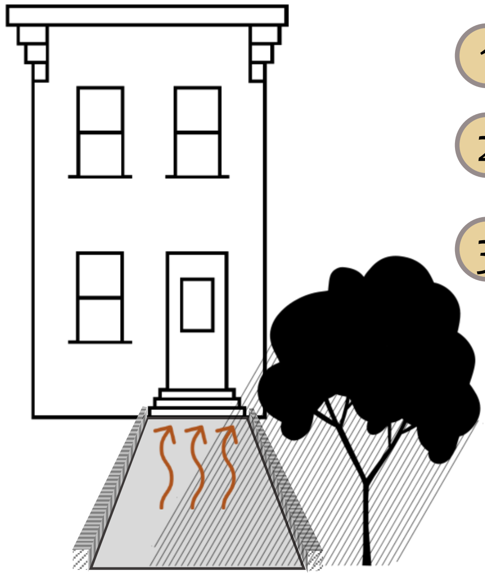
***Cool* Roofs and *Cool* Walls**
Reflective and emitting exterior surfaces have the potential of reducing surface temperatures by 4-5°C. This in turn can reduce the amount of heat being transferred to indoor spaces. This can also enhance the overall microclimate by mitigating urban heat islands.

Exposed roof surfaces may be treated with either:

1. High SRI elastomeric paint
2. Heat reflecting tiles
3. Broken white china mosaic grouted with white cement
4. Vegetation on walls and roof surfaces have an effect similar to reflective and emitting surfaces. Landscaping uses soil media which has the potential of providing insulation as well.

Exposed wall surfaces may be painted with heat reflective paints.

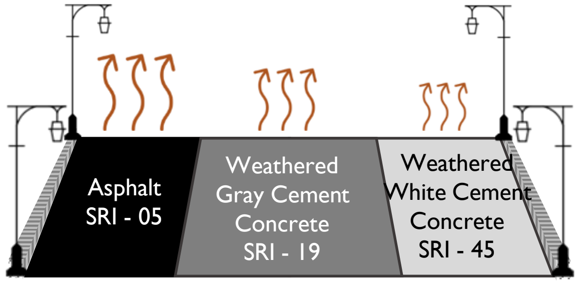
B2 Mitigating urban heat islands – reducing paved surfaces



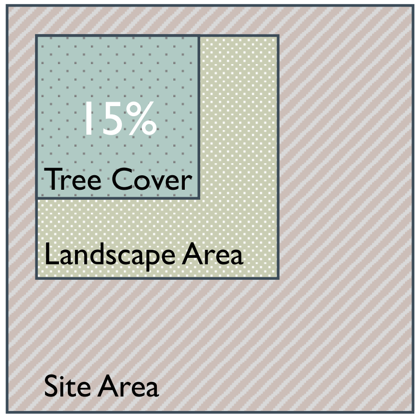
1 **Reduce hard paved areas**
Replace hard paved areas with landscape as much as possible.

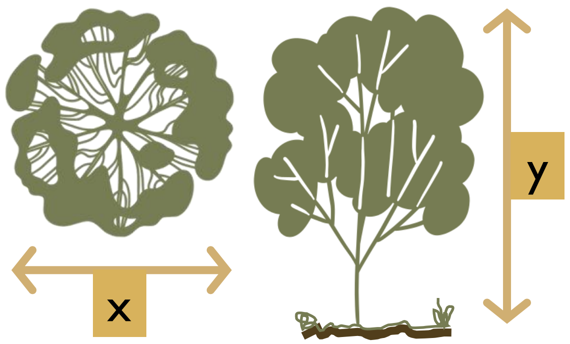
2 **Shade paved areas**
Plan paved areas such that they are shaded by buildings or vegetation for most parts of the day. Cover paved areas with temporary structures.

3 **Use reflective and emitting surfaces for pavements**
Provide at least 50% of hard paved areas with materials having SRI 50 or greater.



B3 Mitigating urban heat islands – minimum tree cover





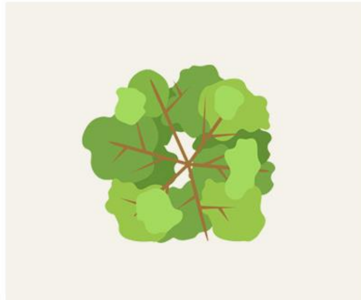
Trees moderate the microclimate by reflecting radiation, evapotranspiration and by providing shade. This leads to reduction in ambient temperatures and overall improvement in thermal comfort.

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.

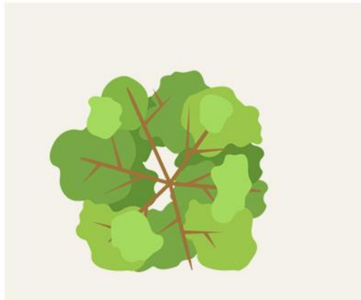
B3-1 Tree canopy area of common Indian trees

Neem (Azadirachta Indica)
Crown Dia: 10-20m
Tree Height: 15-30m

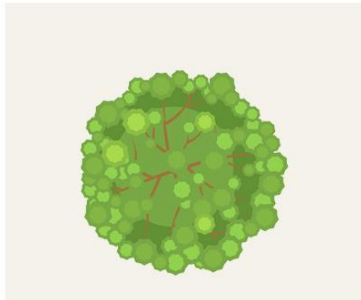


Gulmohar (Delonix Regia)
Crown Dia: 8-12m
Tree Height: 15-20m

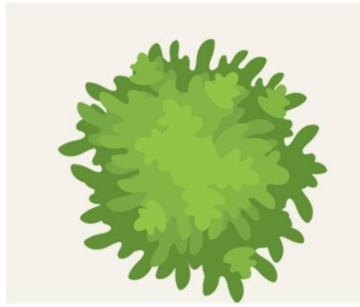
Mango (Mangifera Indica)
Crown Dia: 15-20m
Tree Height: 35-40m



Pipal (Ficus Religiosa)
Crown Dia: 10-15m
Tree Height: 8-15m



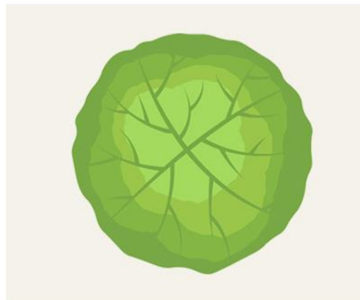
Indian Almond Tree (Terminalia Catappa)
Crown Dia: 10-15m
Tree Height: 15-23m



Arjuna Tree (Terminalia Arjuna)
Crown Dia: 15-23m
Tree Height: 15m

Golden-Shower (Cassia Fistula)
Crown Dia: 8-10m
Tree Height: 8-15m

Banyan (Ficus Benghalensis)
Crown Dia: 23m
Tree Height: 15m



Pride of India (Lagerstroemia Speciosa)
Crown Dia: 15-23m
Tree Height: 10-15m

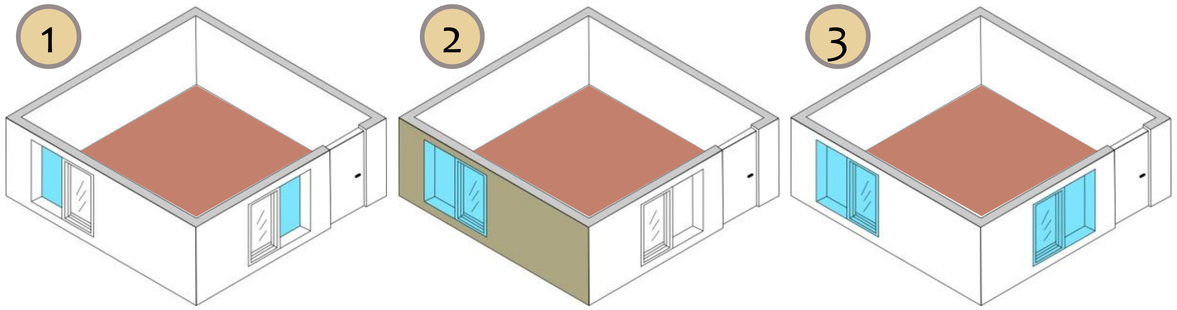
Dense Foliage

Medium-dense Foliage

Light-dense Foliage

C Opening ratios for regulating ventilation & heat gains

1 2 3



$\text{Openable Window Area}/\text{Carpet Area} \geq 1/6$

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

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

Perform check for each external wall with windows

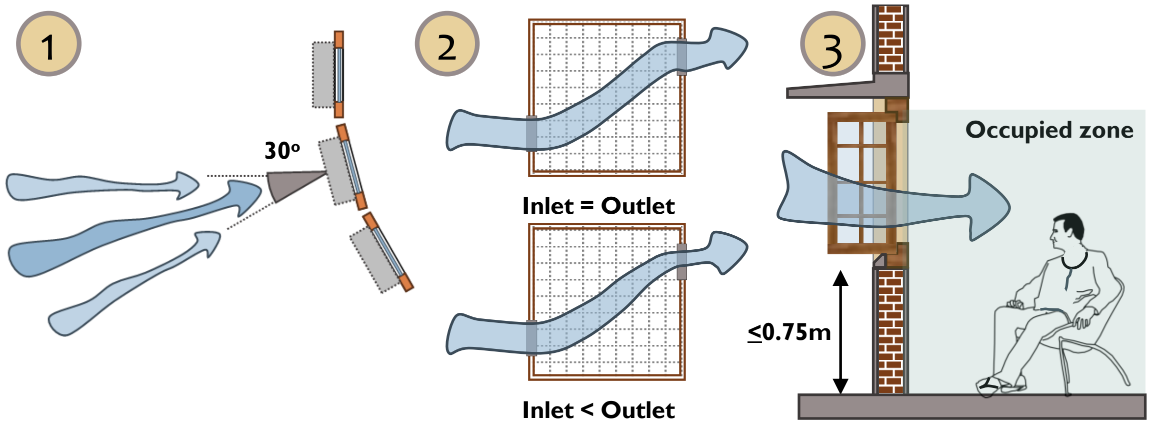
Operable window area ratio
At least 1/6th of window area serving habitable spaces should be openable. This will ensure all habitable spaces are adequately ventilated.
Windows serving habitable spaces must open to the exteriors.

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

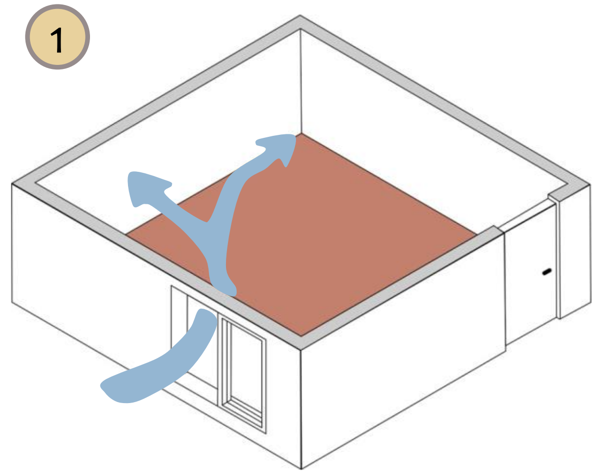


Window orientation
Windows facing the windward side function as air inlets. Orient inlet windows within 30° of the prevalent wind direction to maximize the effectiveness of natural ventilation.

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.

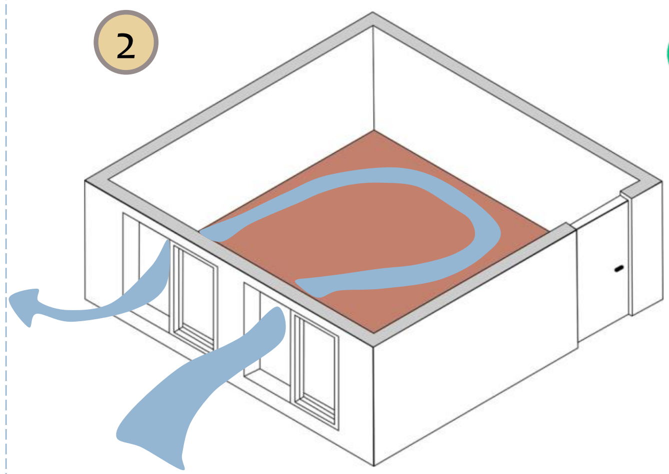
1



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.

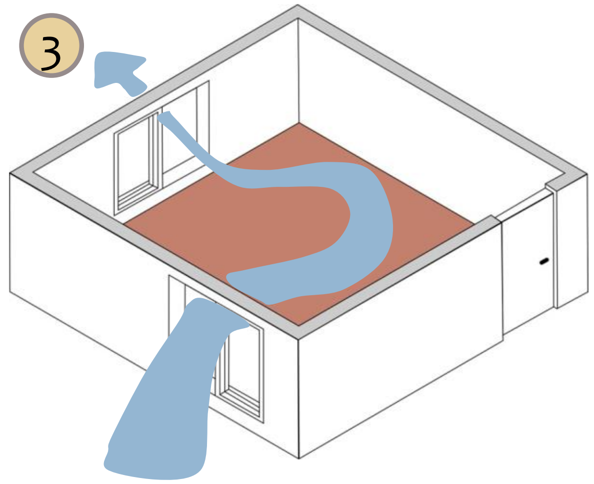
2



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.

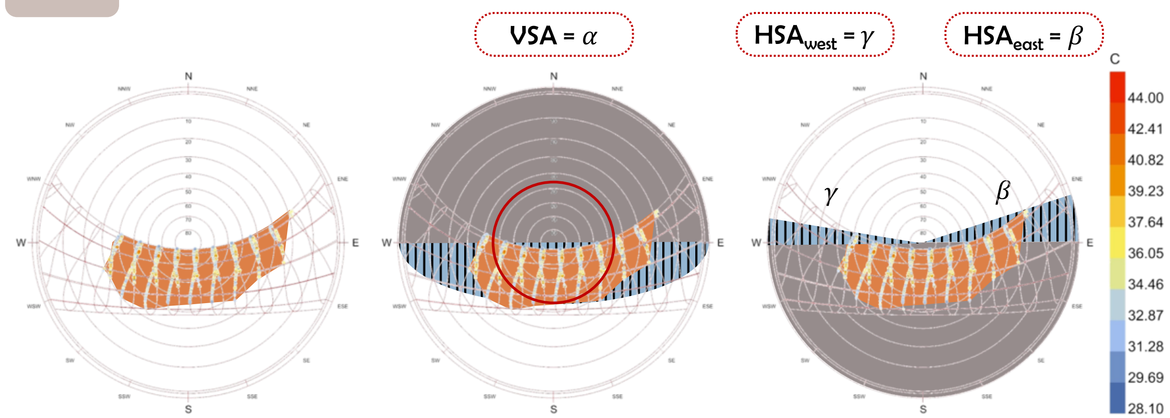
3



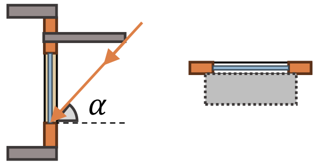
Level A++

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..

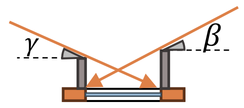
E Window shading for limiting thermal gains



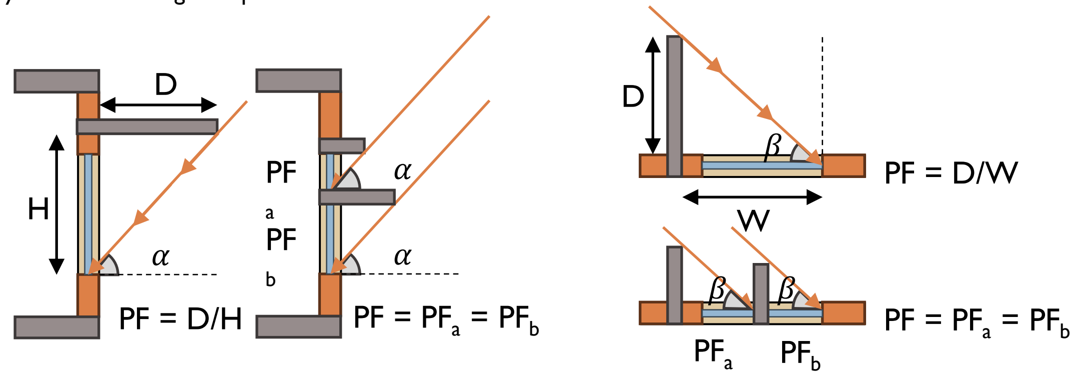
Designing for shading – When to shade?
Design for shades whenever ambient temperature exceeds 28 °C and global horizontal radiation exceeds 315 kWh/m².
A stereographic chart is a useful tool for superimposing solar path and weather data to identify time of the year when shading is required.



Stereographic chart showing overhang for south facing facade



Stereographic chart showing side fins for north facing facade

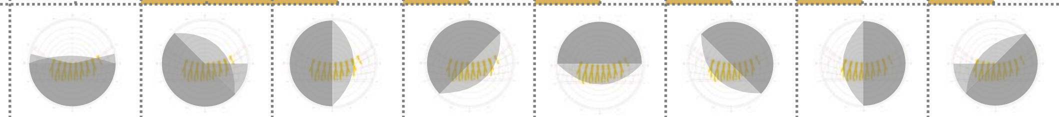
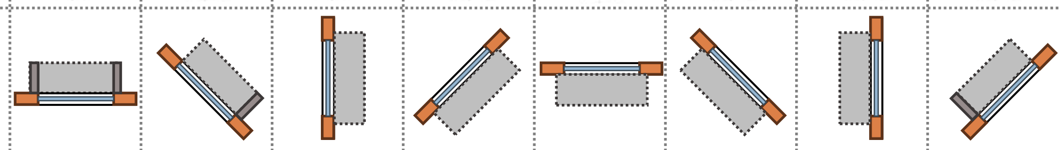
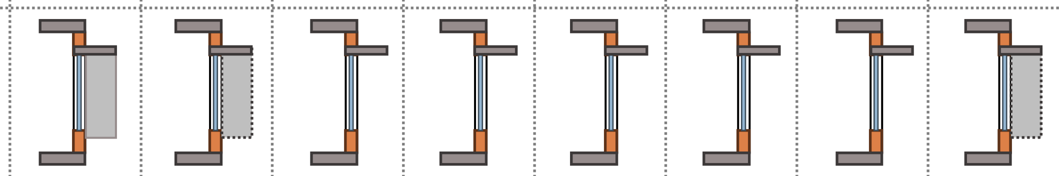


Designing for shading – How to shade?
Read projection factors for your climate and latitude from the Shading factor tables. While shading is the primary defense against solar gains, it may not be practical to design a single shade. Take cues from the image above on distributing overhangs and fins into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

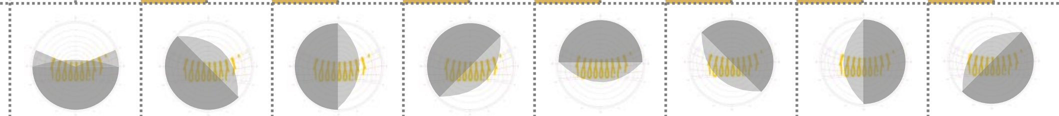
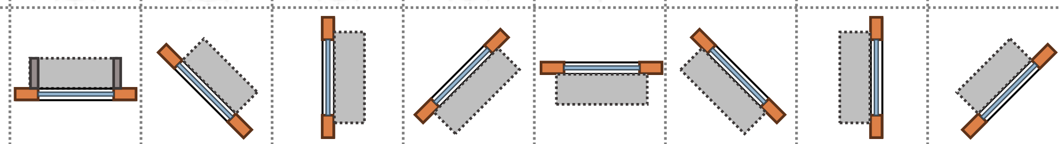
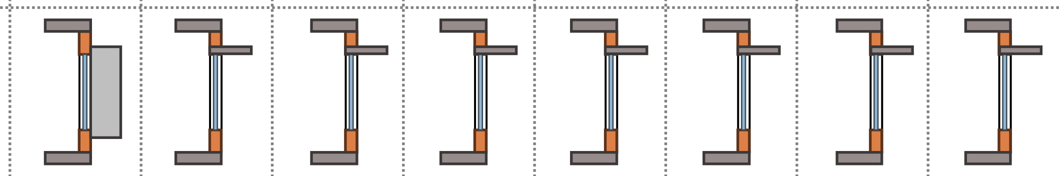
Overhang Projection Factor
Projection factor or (**PF**) is the ratio of the depth of the overhang (i.e. **D**) to the distance of cill from the base of the overhang (i.e. **H**).

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**).

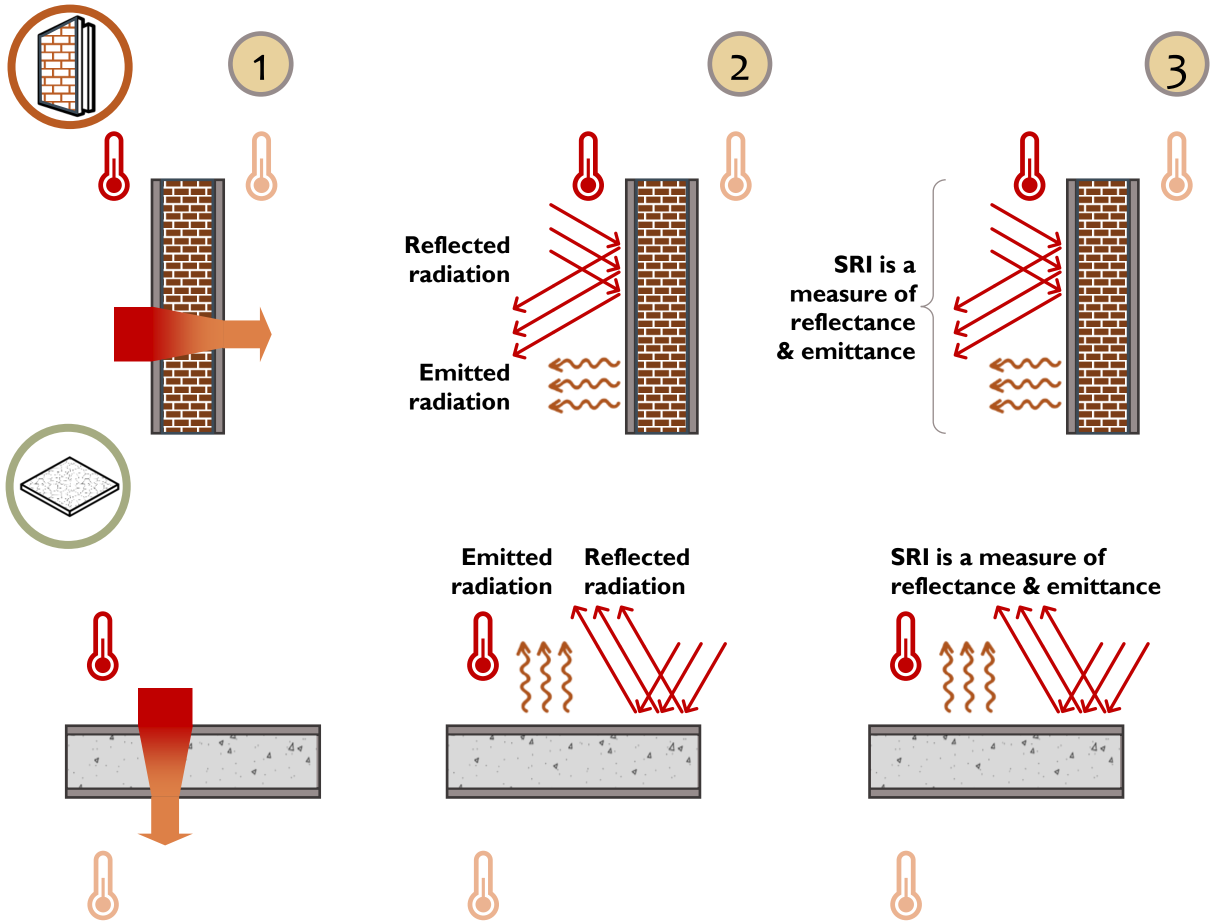
Window shading factors for locations in Warm-humid climate over >23.5° N

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
	Either		*Either*												*Either*	
Projection Factors	0.47	L-0.21	1.00	-	1.00	-	1.00	-	1.00	-	1.00	-	1.00	-	1.00	L-1.00
		R-0.21		R-1.00		-		-		-		-		-		-
Shadow mask																
Section through window – Plan view																
Section through window- Elevation view																

Window shading factors for locations in Warm-humid climate over ≤23.5° N

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
	Either															
Projection Factors	0.58	L-0.41	1.00	-	1.00	-	1.00	-	1.00	-	1.00	-	1.00	-	1.00	-
		R-0.41		-		-		-		-		-		-		-
Shadow mask																
Section through window – Plan view																
Section through window- Elevation view																

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.

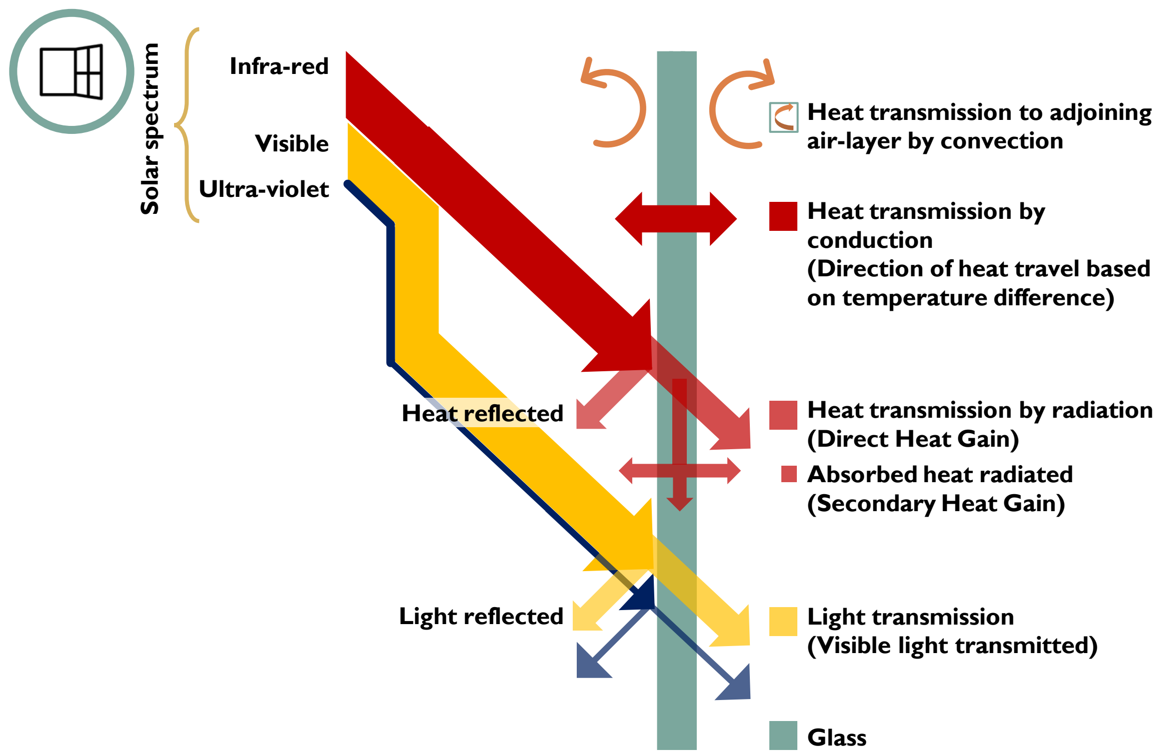
Reflectance & Emittance
As solar radiation strikes an opaque surface, a part of it gets absorbed, while the rest gets reflected. The portion absorbed by the surface is 'emitted' out as long-wave infra-red radiation. The reflected component is termed as 'Reflectance' and the emitted component is termed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

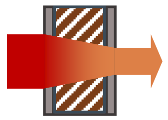
Visible Light Transmittance (VLT)
VLT is a measure of light entering into the space through the glazing. It is a unitless metric and expressed as a number between 0 and 1.

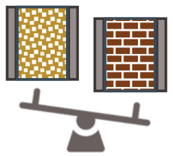
VLT is the fraction of light in the visible spectrum transmitted through the glass. VLT is arrived at after weighting for sensitivity of the human eye.

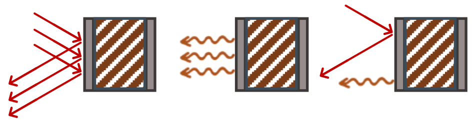
Performance tests for U-factor, SHGC and VLT for glazing and glazing assemblies (U-factor)
ISO-9050 provides methods for testing glass for, U-factor, Solar Heat Gain Coefficient (SHGC) and Visible Light Transmittance (VLT).
ISO 12576-1 provides test methods for testing complete glazing construction assemblies,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





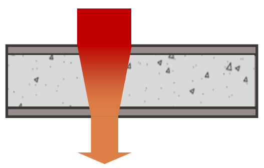


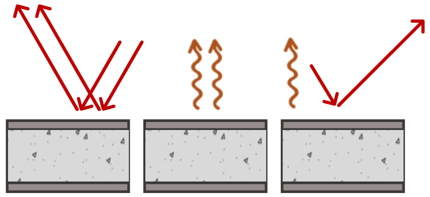
	Light-weight assembly	Medium/Heavy-weight assembly
Density (kg/m³)	≥800	<800
Level A	0.80	1.00 or lower
Level A+	0.60	0.80 or lower
Level A++	0.40	0.45 or lower

Reflectance	0.60 or higher
Emittance	0.75 or higher
SRI	29 or higher

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

Roof assembly





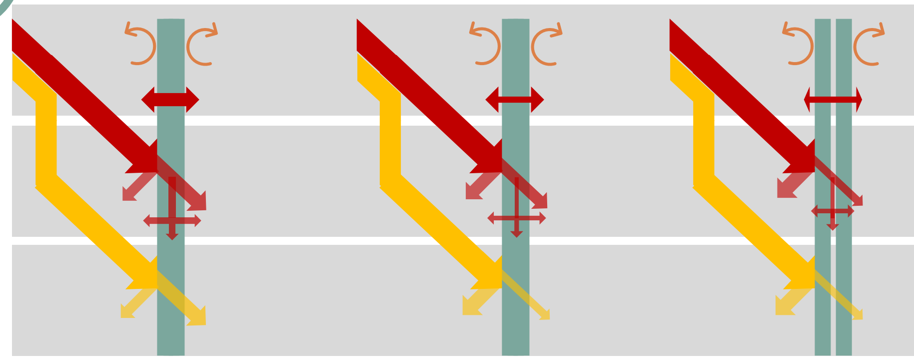
	U-factor in W/m²K
Level A	0.75 or lower
Level A+	0.45 or lower
Level A++	0.25 or lower

Reflectance	0.70 or higher
Emittance	0.75 or higher
SRI	78 or higher

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

G2 Key performance requirements: Glazing assembly

Glazing assembly

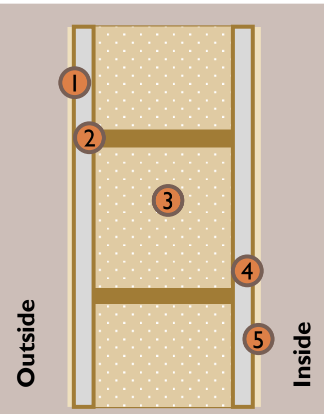


	Level A	Level A+	Level A++
U-factor	5.7 or lower	4.8 or lower	2.8 or lower
SHGC	0.6 or lower	0.4 or lower	
VLT	0.3 or higher		

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

Glazing frame type to reduce thermal bridging and air leakage

Windows are a potential thermal bridge, i.e. source of uncontrolled thermal exchange between the indoor space and the external environment. In naturally ventilated buildings, metal frame with thermal break, wooden and vinyl window frames minimize bridging losses. In air-conditioned buildings, it is especially important to eliminate thermal bridges to minimize cooling/heating losses. Wood and vinyl are preferred in conditioned buildings 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.

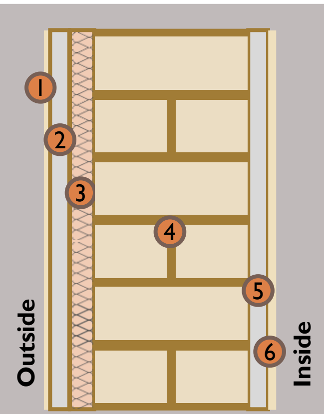


AAC Block Wall

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



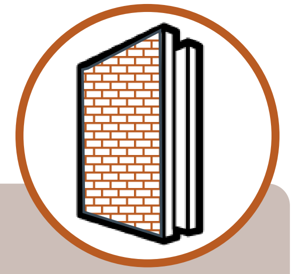
Fly ash brick wall with external insulation

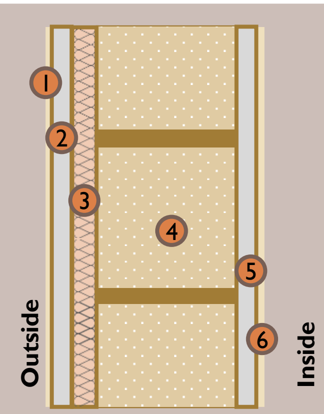
1. Exterior paint
2. Cement plaster/base Coat (over reinforcing mesh)
3. Rigid insulation board applied with adhesive and held in place with PVC fasteners
4. Fly-ash block work
5. Internal plaster
6. Interior paint

Fly ash brick 230 mm
Expanded Polystyrene 25 mm
285 mm thick | 0.89 W/m²K

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

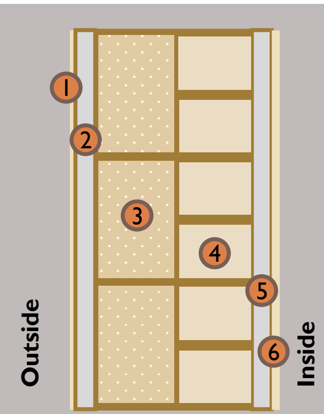




AAC Block Wall with external insulation

1. Exterior paint
2. Cement plaster/base coat (over reinforcing mesh)
3. Rigid insulation board applied with water based adhesive and held in place with PVC fasteners
4. AAC block work
5. Internal plaster (GI chicken wire mesh over block-work and structure joints)
6. Interior paint

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



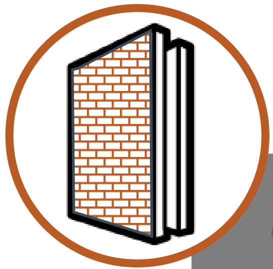
Fly ash brick wall faced with AAC block outside

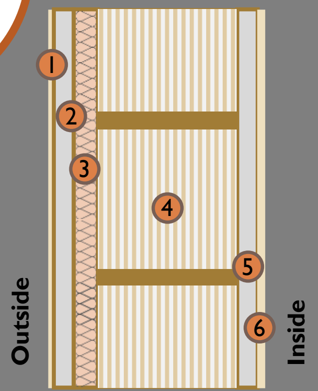
1. Exterior paint
2. Cement plaster
3. AAC block work
4. Fly-ash block work
5. Internal plaster
6. Interior paint

Fly ash brick 115 mm
AAC block 150 mm
295 mm thick | 0.88 W/m²K

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

H1 Performance bundles – Wall



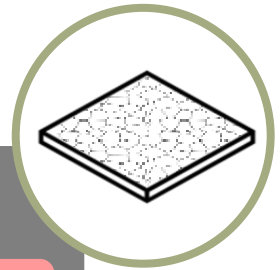


Solid concrete block with external insulation

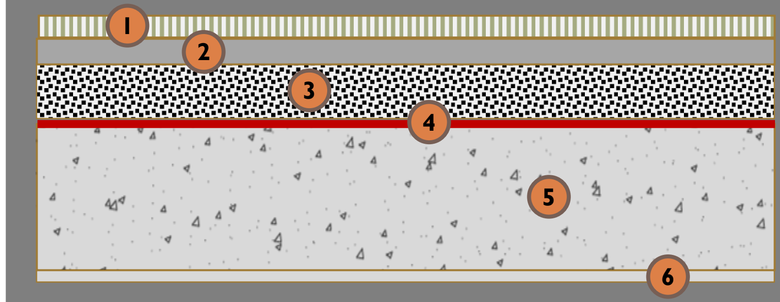
1. Exterior paint
2. Cement plaster/base coat (over reinforcing mesh)
3. Rigid insulation board applied with water based adhesive and held in place with PVC fasteners
4. Solid concrete block work
5. Internal plaster
6. Interior paint

Solid concrete block 200 mm	
Extruded Polystyrene 25 mm	
255 mm thick	0.81 W/m²K
Solid concrete block 200 mm	
Polyurethane Foam 25 mm	
255 mm thick	0.77 W/m²K
Solid concrete block 200 mm	
XPS/PUF 50 mm	
285 mm thick	~0.45 W/m²K

H2 Performance bundles – Roof



Outside



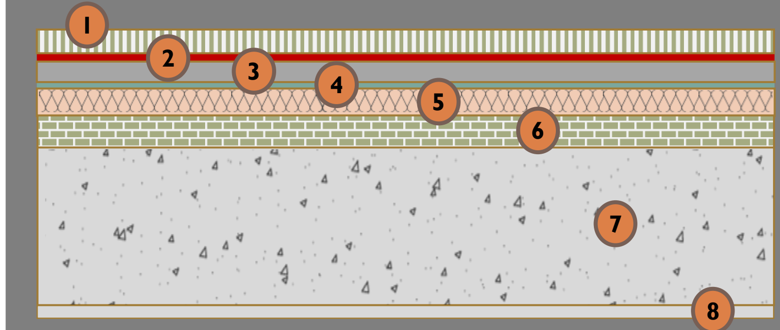
Inside

Foam concrete insulation over RCC slab. Roof assembly finished with broken white china mosaic.

1. Broken china mosaic (white tiles grouted with white cement) 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 over RCC slab. Roof assembly finished with broken white china mosaic.

1. Broken china mosaic (white tiles grouted with white cement) applied with cement mortar
2. Water proofing layer
3. Cement screed with welded mesh
4. Polythene sheet/Geo-textile membrane
5. Rigid insulation board applied with water-based adhesive
6. Brick-bats/Plain Cement Concrete (PCC) laid to slope
7. RCC slab (as/structural design)
8. Internal plaster

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

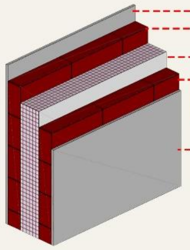
*Replace Brick-bat coba/PCC in #6 with foam concrete – laid to slope.

H3 High thermal performance bundles – Alternative materials for wall construction Level A++

Compressed Stabilised Earth Block | **Rammed Earth** | **Autoclave Aerated Concrete Block** | **Fly Ash Brick**

With Rice Husk Insulation

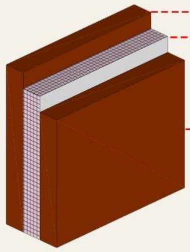
Compressed Stabilised Earth Block



U-Value : 0.38W/(m².K)

Thickness : 285mm

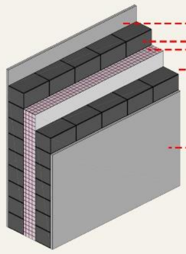
Rammed Earth



U-Value : 0.385W/(m².K)

Thickness : 300mm

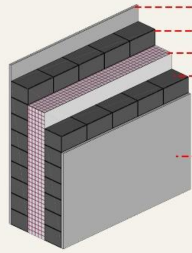
Autoclave Aerated Concrete Block



U-Value : 0.389W/(m².K)

Thickness : 275mm

Fly Ash Brick

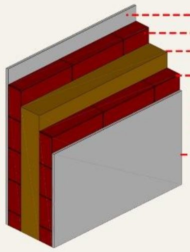


U-Value : 0.392W/(m².K)

Thickness : 285mm

With Saw Dust Insulation

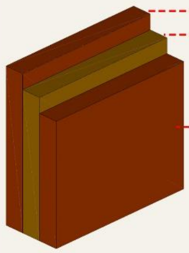
Compressed Stabilised Earth Block



U-Value : 0.38W/(m².K)

Thickness : 285mm

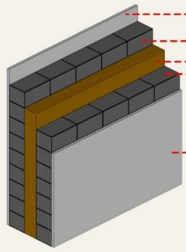
Rammed Earth



U-Value : 0.385W/(m².K)

Thickness : 300mm

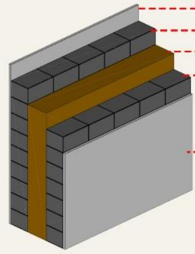
Autoclave Aerated Concrete Block



U-Value : 0.389W/(m².K)

Thickness : 275mm

Fly Ash Brick

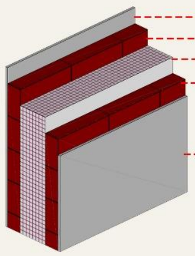


U-Value : 0.392W/(m².K)

Thickness : 285mm

With Jute Fibre Insulation

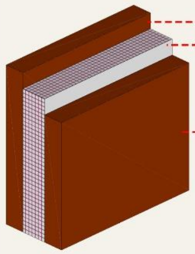
Compressed Stabilised Earth Block



U-Value : 0.37W/(m².K)

Thickness : 325mm

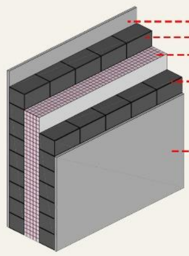
Rammed Earth



U-Value : 0.388W/(m².K)

Thickness : 330mm

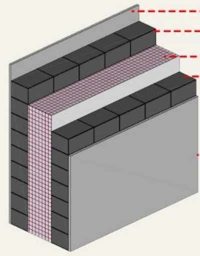
Autoclave Aerated Concrete Block



U-Value : 0.393W/(m².K)

Thickness : 295mm

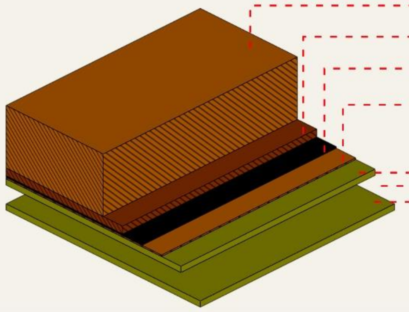
Fly Ash Brick



U-Value : 0.391W/(m².K)

Thickness : 320mm

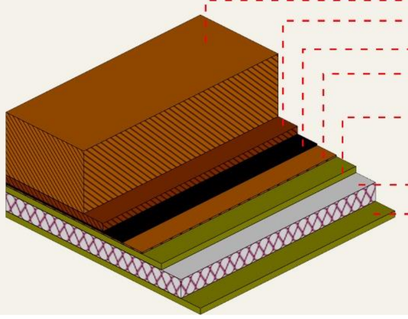
Level A++
Straw Thatch Roof



U-Value : 0.234 W/(m².K)

Thickness : 335mm

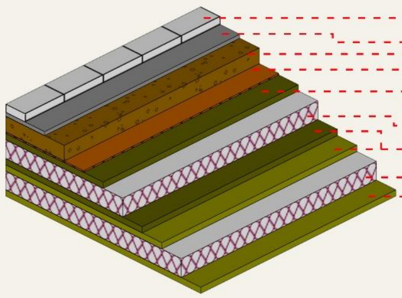
Level A++
Straw Thatch Roof with Coir Insulation



U-Value : 0.176 W/(m².K)

Thickness : 335mm

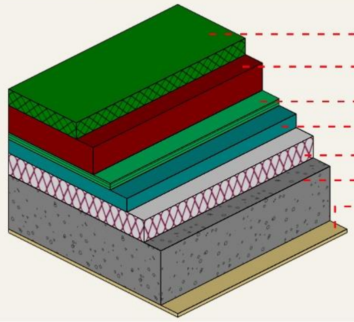
Level A++
Bamboo Mud Slab with Coir Insulation



U-Value : 0.25 W/(m².K)

Thickness : 293mm

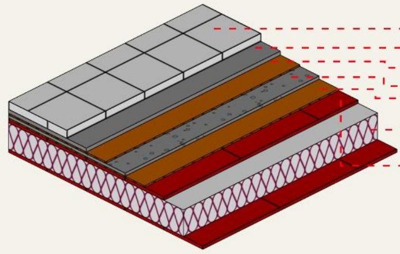
Level A++
Green Roof with Coir Insulation



U-Value : 0.25 W/(m².K)

Thickness : 527.7mm

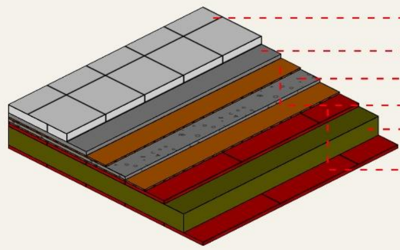
Level A+
Terracotta Tile RCC Filler Slab with Coir Insulation



U-Value : 0.356 W/(m².K)

Thickness : 183.1 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

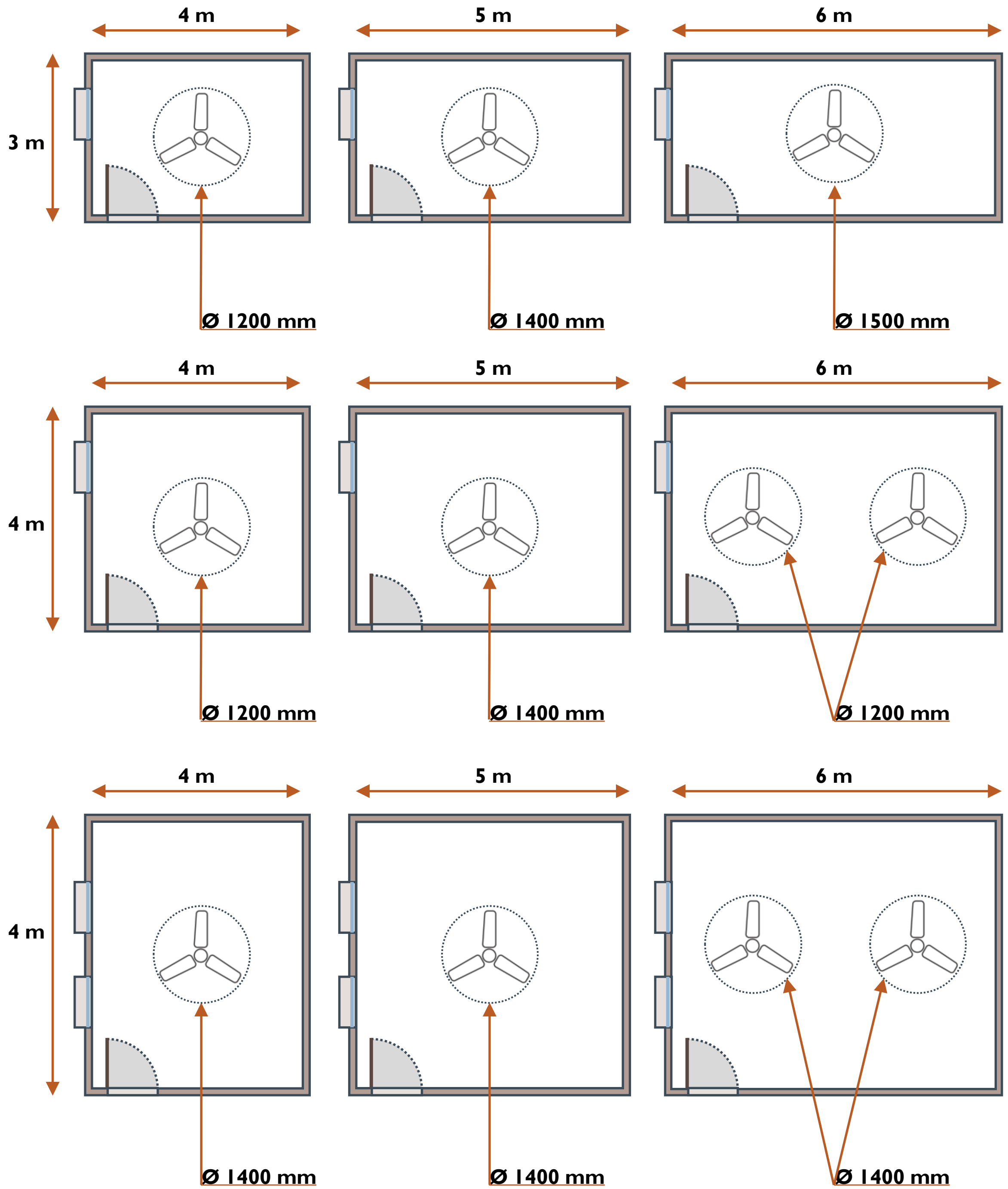
Material	Conductivity {W/mK}	Density {kg/m³}	Source
AAC Block	0.184	642	Source: CBERD-MNRE
Rammed Earth Wall	0.58	1,540	Source: Gupta P., et al.
Solid Concrete Block	1.411	2,350	Source: SP-41
Fly Ash Brick	0.856	1,650	Source: Gourav K., et al.
CSEB	1.026	1,700	Source: Balaji N.C., et al.
Cellular/ Foam 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)	>78 (SRI (Deemed))

04

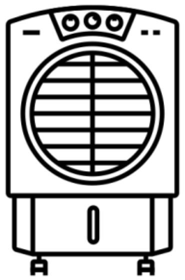
Low-energy active comfort systems for thermal comfort

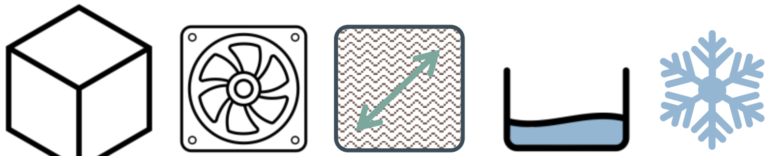
A-1 Design recommendations for ceiling fans (size & numbers)



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

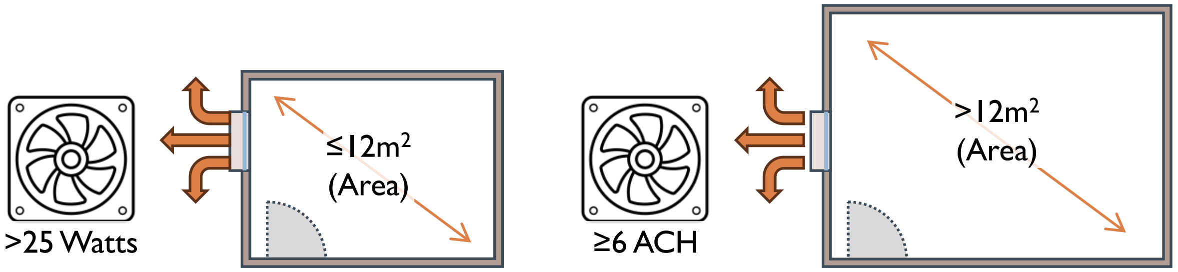
Source: SP-41
(Subject to revision as per Star labelling requirements for desert cooler)

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.

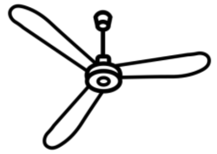
A-3 Design recommendations for exhaust fans in kitchen, bath and lavatories



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

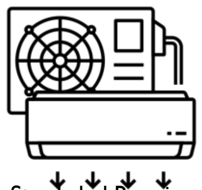
Ceiling Fan



Sweep size (mm)	Min. Service value (CMM/Watt) Level A	Min. Service value (CMM/Watt) Level A+	Min. Service value (CMM/Watt) Level A++
> 1200	4.1	4.6	5.1
<= 1200	5.0	5.5	6.0

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

Split-type Air Conditioner (Variable Speed)

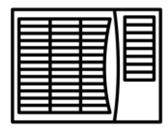


Cooling Watts	ISEER
<10,465	5.0

Default temperature setting of 24ºC

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

Unitary-type Air Conditioner (Variable Speed)

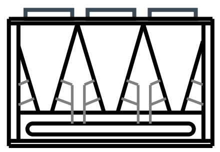


Cooling Watts	ISEER
<10,465	3.5

Default temperature setting of 24ºC

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

Air Cooled Chiller



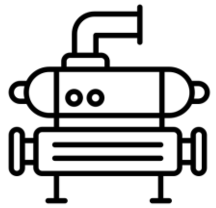
Cooling kW	Min COP*	ISEER
<260	2.4	4.4
>=260	2.6	4.7

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

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

Source: BEE

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)

Prepared by:
Environmental Design Solutions Pvt Ltd
Wuppertal Institut
Hunnarshala Foundation

Published (November 2023)

Contact:
Govinda Somani (govinda.somani@giz.de)
Anamika Prasad (anamika@edsglobal.com)

Disclaimer:
This guidebook is prepared for the Ministry of Housing Affairs (MoHUA) and the Deutsche Gesellschaft fur Internationale Zusammenarbeit (GIZ) GmbH. This report is part of the *"Development of Thermal Comfort Action Plan 2050 and Thermal Comfort Performance based Design Standard cum Guidelines for Affordable Housing in India."* project under the *Climate Smart Buildings Program* funded by GIZ India.

This guidebook has been prepared for the purpose of assisting professionals in the construction industry in designing and developing thermally comfortable homes. This guidebook is an outcome of the best efforts and technical judgement of the authors. The authors do not accept any duty, liability, or responsibility to any person or entity in relation to this guidebook.

Suggested Citation
MoHUA, GIZ, EDS, WI, HF, *Design Guidelines for Thermally Comfortable Homes in Warm-humid Climate* (2023)

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Project implemented by the GIZ for the Ministry of Housing and Urban Affairs

Ministry of Housing and Urban Affairs
Government of India

Knowledge partners EDS, Wuppertal Institut & Hunnarshala Foundation