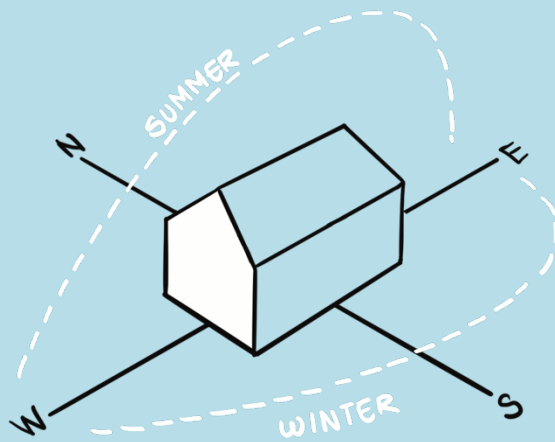


PASSIVE DESIGN GUIDELINES FOR THE TERAJ REGION



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Submitted to:

Lumanti Support Group for Shelter

Geography

Nepal is a landlocked country in South Asia, bordered by China to the north and India to the south, east, and west. Covering 147,516 sq. km, it falls within coordinates 28°N and 84°E, in the temperate zone north of the Tropic of Cancer. The country comprises three main regions: Himalayan, mid hill, and Terai. Mt. Everest, the highest point at 8,848 m, contrasts with the lowest point in the Terai plains at 60 m. The Terai region, occupying 17% of the land, ranges from 26-32 km in width and 60-305 m in altitude, draining south into India. The diverse topography includes Siwalik zone, Mahabharat range, Duns, Midlands, and mountainous areas, with the tree-line at 4,000 m and the snow line at 5,000 m. [1]

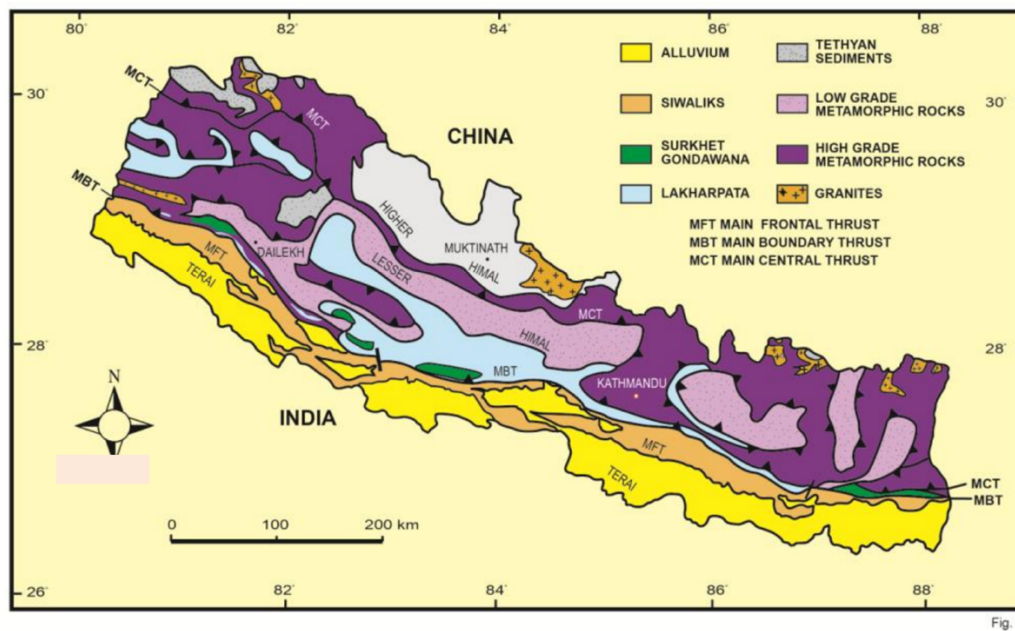


Figure 1 Geological map of Nepal [4]

Available Building Material

- The Terai Region's geology is mainly characterized by coarse, gravel, and finer sediments. [4]
- The rich fertile land is the basis for fertile agricultural land and dense Sal forest
- Abundantly available local material
 - Wood, thatch, other biogenic material, mud and sand

Climate

Climate zone classifications are derived from the Köppen-Geiger climate classification system, which divides climates into five main climate groups divided based on seasonal precipitation and temperature patterns. The five main groups are A (Tropical), B (Dry), C (Temperate), D (Continental) and E (Polar). As per Köppen climate classification Monsoon-influenced Humid Subtropical (Cwa) region covers most of the highly inhabited area of Nepal. [2]

Nepal's climate has two main seasons: Winter that lasts roughly from October to March and summer from April to September. Due to the fact that Nepal's climate is strongly influenced by the Monsoon the summer season can be subdivided into a hot and dry period (from April till mid-June) and a warm and rainy period (from mid-June till September) [3]

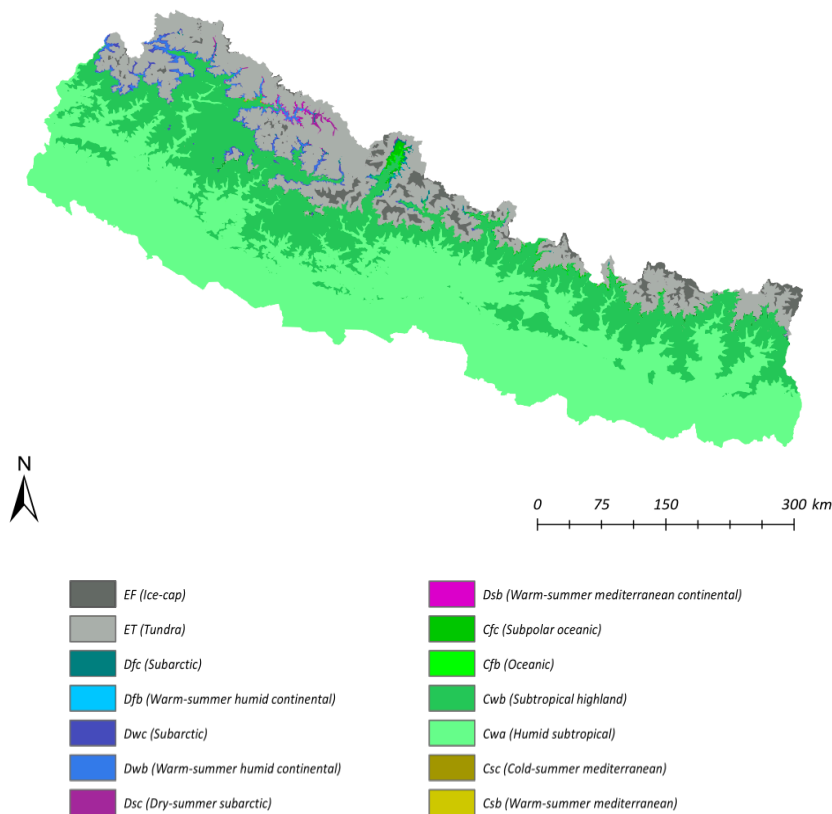


Figure 2 Köppen climate classification of Nepal (Wikipedia)

Climate responsive design strategies for Terai region

Per Givoni's psychrometric chart [5] and Mahoney table [6] the design strategies that could be best suitable for Terai region are

- **Mahoney table recommendation [7]**
 - January: Protection from cold
 - February: Air movement desirable
 - March: Thermal capacity (Thermal mass)
 - April: Thermal capacity and outdoor sleeping
 - May: Thermal capacity
 - June: Rain protection necessary and thermal capacity
 - July: Air movement essential and rain protection necessary
 - August: Air movement essential and rain protection necessary
 - September: Air movement essential
 - October: Air movement essential

Per the above finding proper ventilation, rain protection from shading and thermal mass are the recommended strategies.

- **Givoni's psychrometric chart recommendation [7]**
 - January: Solar passive heating
 - February: Solar passive heating
 - March: Thermal mass
 - April: Thermal mass with night ventilation
 - May: Ventilation, Thermal mass with night ventilation and Conventional dehumidification
 - June: Ventilation and Conventional dehumidification
 - July: Ventilation and Conventional dehumidification
 - August: Conventional dehumidification
 - September: Ventilation
 - October: Ventilation
 - November: Solar passive heating
 - December: Solar passive heating

MONTH	SOLAR PASSIVE HEATING	PROTECTION FROM COLD	VENTILATION	THERMAL MASS	THERMAL MASS WITH NIGHT VENTILATION	OUTDOOR SLEEPING	RAIN PROTECTION	CONVENTIONAL DEHUMIDIFICATION
January								
February								
March								
April								
May								
June								
July								
August								
September								
October								
November								
December								

Figure 3 Climate responsive design strategies per Mahoney's table and Givoni's psychrometric chart

Introduction

This supplemental document has been prepared to serve as a valuable resource for professionals engaged in designing for the Terai region. Recognizing the distinct climatic characteristics and environmental challenges of this region, this guide focuses on passive design techniques tailored specifically to maximize comfort and efficiency in architectural projects.

- **Target Audience:** Designed with architects, designers, and urban planners in mind, this document offers practical insights and actionable recommendations for incorporating passive design principles into building projects within the Terai region.
- **Content Overview:** Drawing upon a rich array of sources including recent research papers and published books, this document provides a curated compilation of proven passive design strategies. From optimizing building orientation to maximizing natural ventilation and shading, each guideline is backed by empirical evidence and real-world applicability. These insights collectively inform architects, designers, and planners on implementing passive design techniques tailored for the Terai region, enhancing sustainability and occupant comfort in architectural projects.

The intent is that these design principles serve as a valuable starting point for your design process, offering a solid foundation to begin creating environmentally conscious designs for low-cost housing. This collection of passive design strategies is not intended to be a comprehensive solution, but rather a promising starting point.

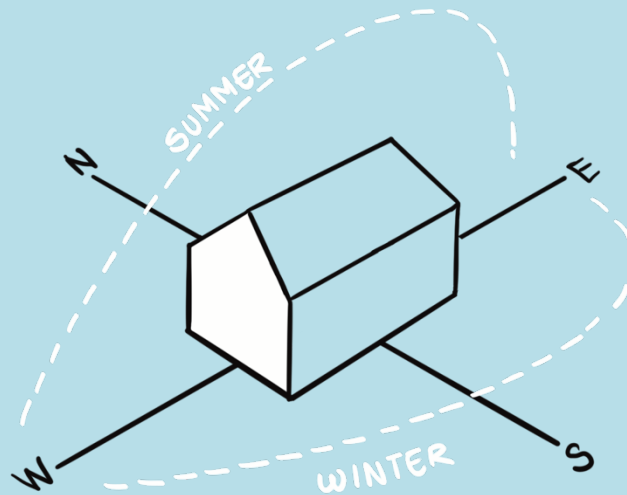
Possible Design Strategies

1. SITE ORIENTATION

Here are considerations for site orientation in such climates:

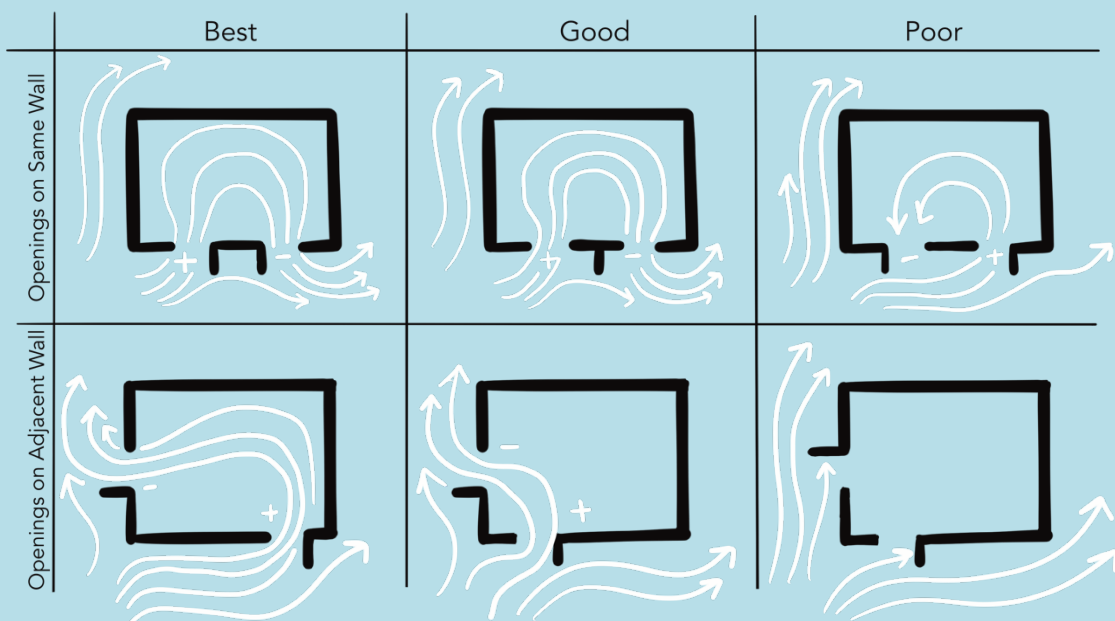
1.1. Solar Heat Gain

- Houses should be oriented north and south (long axis east-west) to reduce solar heat gains



1.2. Wind Direction [8]

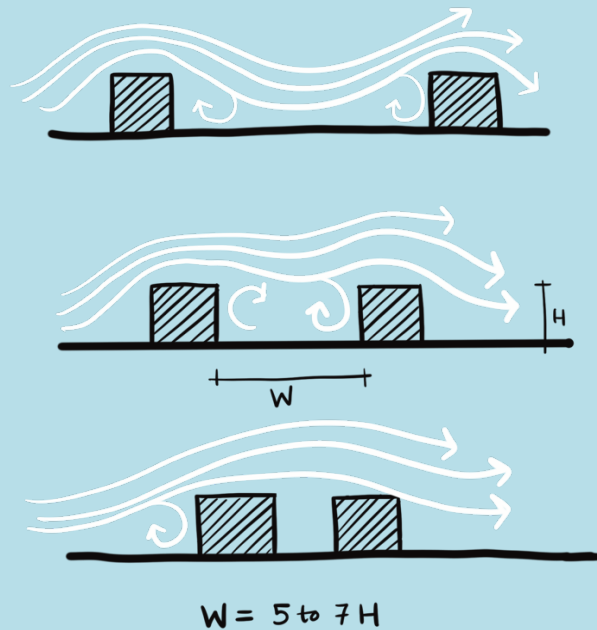
- Orient the building to capture prevailing winds for natural ventilation and cooling
- It causes higher pressure zones on the windward side and lower pressure zones on the lee side.



2. BUILDING LAYOUT

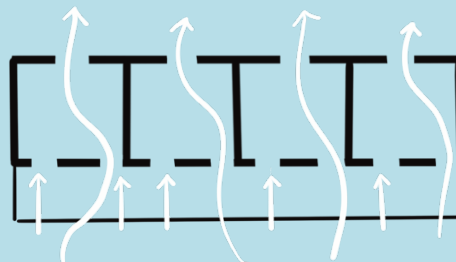
2.1. Dispersed Buildings [8]

- Buildings with wide open spaces preserve each building's access to breezes.
- Buildings in which cross-ventilation is important should be separated by a distance of **five to seven times** the building height to assure adequate airflow if they are directly behind one another [9]



2.2. Elongated Organizations [8]

- Thin plan room arrangements will have daylight available and opportunity for optimum ventilation for each space.



2.3. Courtyards

2.3.1. Breezy Courtyards [8]

- For proper ventilation courtyards should be low, wide and permeable
- Where ventilation is desired, a courtyard orientation 45° from the prevailing wind maximizes both wind in the courtyard and cross-ventilation in the building [8]

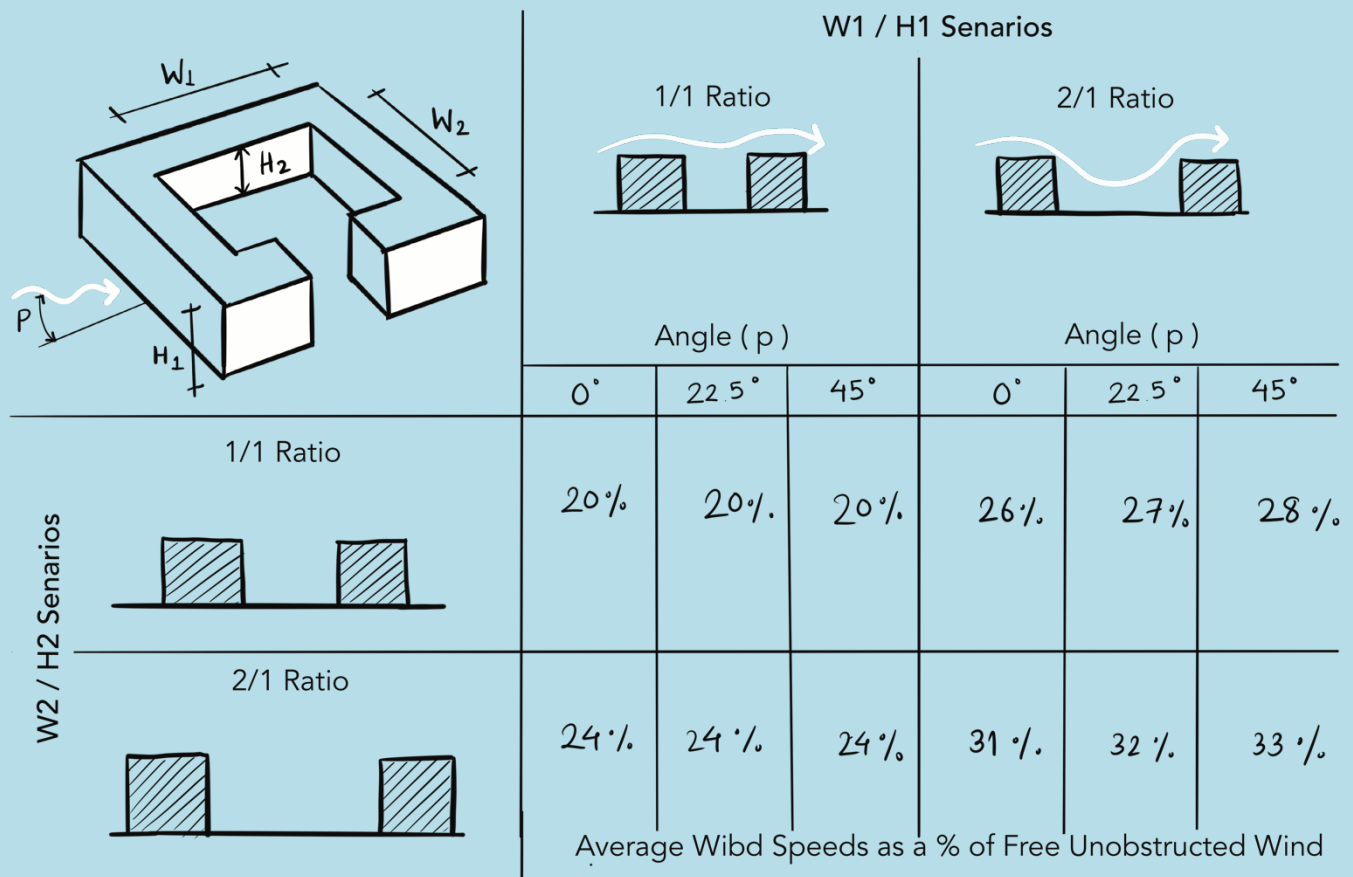


Figure 1 Sizing Courtyards for Ventilation [8]

2.3.2. Shady Courtyards

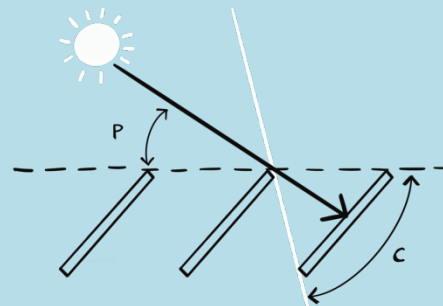
- Tall and narrow courtyards can be used as cold air sinks.



Figure 2 Shady Courtyard

2.4. Overhead Shade [8]

- A layer of overhead shades can protect outdoor spaces and buildings from the high sun.
- Louvers can be set at varying angles and orientations, as long as the cutoff angle (C) is greater than the profile angle (P).



Full Shade, $P < C$
Partial Shade, $P > C$

2.5. Planting and Vegetation [8]

- Planting can be used to reduce the ambient air temperature.
- The effect of shading from trees ranges from 15 to 35% of total cooling energy savings from trees.

2.6. Earth Edges [8]

- Earth can be used to shelter buildings from extremes of heat and cold and to meet a portion of the building's cooling needs.
- Earth sheltering reduces heat loss and heat gain in two ways: by increasing the resistance to heat flow of the walls, roof and floor and by reducing the temperature difference between inside and outside.



Sunken

Bermed

Partially Bermed

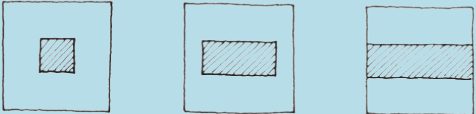
3. BUILDING ELEMENTS

3.1. Opening arrangement for Ventilation [8]

- Windows can be optimized to increase the rate of cross- ventilation in a room and to move air across occupants to increase their rate of cooling.

3.1.1. Opening Location

- When openings in a room are located in two walls, the average interior velocity is much higher, **35–65% of out- side air velocity**, because one opening will always be in a higher-pressure zone than the other.



	1/3	1/3	1/3	
	1/3	2/3	3/3	
	single opening	12-14%	13-17%	16-23%
	two openings in the same wall	----	22%	23%
	two openings in adjacent walls	37-45%	37-45%	40-51%
	two openings in opposite walls	35-42%	37-51%	47-65%

Figure 3 Average Interior Air Velocity as a % of the Exterior Wind Velocity [8]

3.1.2. Opening Height

- If the openings are all near the ceiling or all near the floor, the maximum velocity won't occur in the occupied zone, usually 0.3 to 1.8 m above the floor.
- If the openings are mid-height in the wall or if some are high and some are low, then higher velocities will occur in the occupied zone.

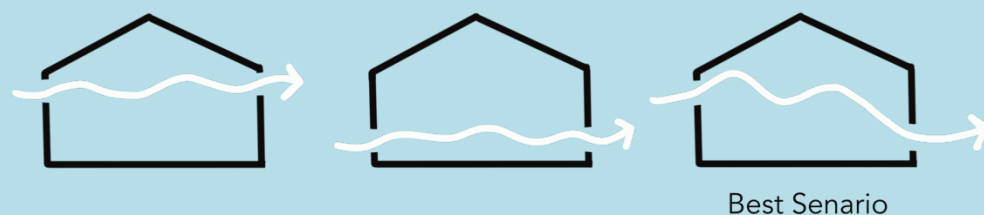


Figure 4 Opening Height

3.2. Ventilation Apertures [9]

- The rate of air flow in CROSS-VENTILATION ROOMS depends on the pressure difference between inlets and outlets (Melarango, 1982, p. 321)
- The maximum rate of ventilation occurs when the area of the inlets and outlets is large and the wind is relatively perpendicular to the window openings.

3.3. Thermal Mass

- Buildings with high levels of thermal mass can store excess daytime solar heat gains that can be used for heating a space on winter nights or can be flushed with cool night air in summer.
- Materials like concrete, brick, tiles, stones and rammed earth are the most common used thermal mass.

3.3.1. Placement of Thermal Mass

- It should be placed in an area that is not directly exposed to solar gain and also allows adequate ventilation and air flow at night to carry away stored energy without increasing internal temperatures.
- Placing mass in a ceiling location and secondarily, on walls is better than on the floor.



3.3.2. Sizing of Thermal Mass

In direct gain rooms,

- The masonry mass thickness should be 4 to 6 inches (100–150 mm) thick. [8]
- The surface area should be 3 to 6 ft² of mass per ft² of south facing glazing.

In other rooms,

- For mass located outside the sun-collecting room, the surface area should be 2-3 times larger than the surface area of mass that is directly coupled or located inside the sun-collecting room.

3.4. Optimum Opening Size [11]

Mathematically,

- Inlet window area = Airflow / Wind speed x WAF x WPF

Where,

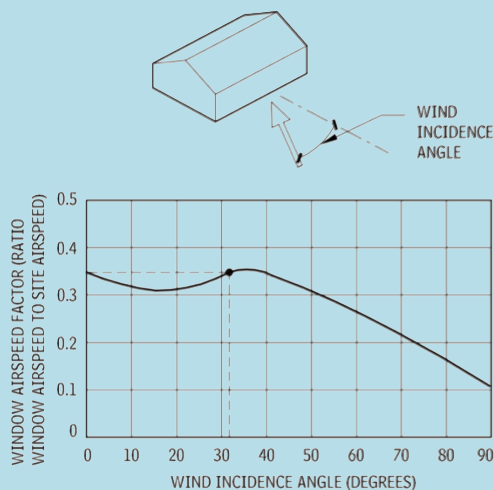
WAF: Window airspeed factor

WPF: Window porosity factor

Required airflow (CFM) = House volume x air changes per hr/60

- As a rule of thumb, an average of 30 air changes per hour should provide adequate structure cooling, maintaining air temperatures most of the time.

**EFFECTS OF WIND INCIDENCE ANGLE ON
AIRFLOW RATES**
12.8



POROSITY FACTORS
12.9

WINDOW TYPE	FACTOR
Fully open awning or projecting window	0.75
Awning window with 60% porosity insect screen	0.65
60% porosity insect screen only	0.85

3.5. Shading Devices [10]

3.5.1. Internal Shading Device

- Internal shading devices such as curtains, vertical blinds can reduce heat energy passing through a window.
- Light colored drapes or blinds lined with light colored materials are more effective than the dark colored shading devices.
- They are adjustable and allow occupants to regulate the amount of direct light entering their space

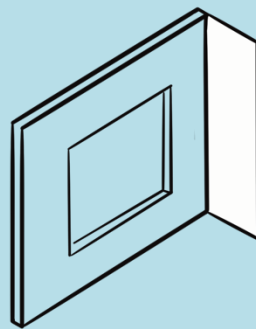
CONSTRUCTION TYPE	Shading Coefficient
1/8" Clear Glass, in & out	
Venetian Blinds Between (light/medium)	0.33/0.36
Venetian Blinds Inside (light/medium)	0.58/0.62
Louvered Sun Screen Between	0.43
Special Shaped Mirrored Louvers Between	0.25-0.59(1)
Opaque Roller Shade Inside (white/translucent/dark)	0.35/0.40/0.71
Draperies Inside	
open weave/dark color	0.62
semi-open weave/medium color	0.52
closed weave/light color	0.42
1/4" Heat Absorb. Glass Out, Clear Glass In	
Venetian Blinds Between (light/medium)	0.28/0.30
Venetian Blinds Inside (light/medium)	0.36/0.39
Louvered Sun Screen Between	0.37
Opaque Roller Shade Inside (white/translucent/dark)	0.22/0.30/0.40
Draperies Inside	
open weave/dark color	0.47
semi-open weave/medium color	0.41
closed weave/light color	0.35

(1) Varies with sun angle, Compagno, 1995, p. 74.

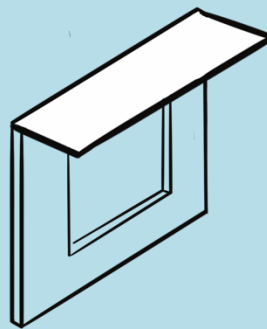
Figure 5 Internal Shading [8]

3.5.2. External Shading Device

- The east and west sides of a building are difficult to shade because of the low altitude of the rising and setting sun in the eastern and western skies.
- A building with long north and south facades and short east and west facades is much easier to shade.
- As a rule of thumb, the following assumptions apply
 - Horizontal shading: South face
 - Vertical shading or combination shading: East & West face



Vertical Shading



Horizontal Shading

3.5.3. Designing External Shading [10]

When attempting to shade a window two important shadow angles must be considered. These are the horizontal shadow angle (HSA) and vertical shadow angle (VSA).

Horizontal Shadow Angle (HSA)

It describes the performance of a vertical shading devices.

$HSA = \text{Azimuth angle (AZI)} - \text{Orientation of building façade (ORI)}$

Vertical Shadow Angle (VSA)

It describes the performance of a horizontal shading devices.

$VSA = \arctan (\tan (\text{altitude}) / \cos HSA)$

$\text{Overhang depth} = \text{Height} / \tan (VSA)$

$\text{Overhang width} = \text{Depth} / \tan (HSA)$

$\text{Fin Depth} = \text{Width} / \tan (HAS)$

The following steps may be used to determine the appropriate size of the shading devices:

- Determine the overheated period i.e. the dates and times when shading is desired

- Find the azimuth angle from appropriate sun path diagram.
- Use the appropriate sun path diagram (suitable for the location in question) to obtain the azimuth and altitude of the sun
- Use the equations above to determine HSA & VSA

3.6. Exterior Surface Color

- Light in hot climates to reflect radiation.
- To reduce the possibility of glare, use materials and surfaces that diffuse the sunlight.

Terminologies [8]

- Solar reflectance: Ability of material to reject solar radiation
- Infrared Emittance: Ability of material to release back to the environment, the heat that it absorbs
- Solar Reflectance Index: indicates the roof's ability to reject solar heat, and is the combined value of reflectivity and emittance. Standard black is zero (reflectance 0.05, emittance 0.90) and a standard white is 100 (reflectance 0.80, emittance 0.90)

Roofing Material	Solar Reflectance	Infrared Emittance	Temperature Rise	Solar Reflectance Index (SRI)
Metal				
Steel, galvanized	0.61	0.04	55 F (31 C)	46
Aluminum	0.61	0.25	48 F (27 C)	56
Siliconized polyester, white	0.59	0.85	37 F (21 C)	71
Tiles				
Metal, white	0.67	0.85	28 F (16 C)	82
Clay, red	0.33	0.9	62 F (34 C)	41
Concrete, red	0.18	0.91	77 F (43 C)	23
Cement, unpainted	0.25	0.9	70 F (39 C)	31
Concrete, light brown	0.42	0.9	53 F (29 C)	49
Fiber cement, earth brown	0.26	0.9	69 F (38 C)	28
Coatings				
White polymer	0.7-0.85	0.86-0.91	9-24 F (5-13 C)	88-107
Light yellow	0.79	0.91	16 F (9 C)	99
Gray	0.40	0.91	55 F (31 C)	47
Dark blue	0.12	0.91	83 F (46 C)	9
Aluminized	0.61	0.25	48 F (27 C)	56

Figure 6 Solar Reflectance Index of Roofing Materials

Note: For all buildings in hot climates, select materials with an SRI above 50 (LBL, 1999).

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- [11] Ramsey/Sleeper Architectural Graphic Standards, 10th Edition