Guideline for Sustainable Energy Residences in Sri Lanka

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Acknowledgement

Preparation of Guideline for Sustainable Energy Residences in Sri Lanka was undertaken as a supplementary measure under the provisions available to prescribe standards and regulations on building energy use in Sri Lanka. Section 36 (f) of the Sri Lanka Sustainable Energy Authority Act, No.35 of 2007 empowers Sri Lanka Sustainable Energy Authority (SEA) to specify and enforce limits for building on energy utilisation. This Guideline provides the essential knowledge and approaches to develop design concepts for residences with low energy use. This Guideline is meant for Sri Lankans embarking on a house construction project and all other stakeholders in the construction industry involved in house construction projects.

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For providing valuable guidance towards successful conclusion;

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Preamble

The present guideline for housing is focused on two aspects in the pursuit of comfortable housing in the Sri Lankan context: **Energy Efficiency and Sustainability**. 'Energy efficiency' strategies are those that lead to a comfortable home environment at the least level of energy expenditure. 'Sustainability' is to do so without compromising other people's as well as other generation's ability to do the same.

A critical strategy to achieve both these aims is to '**Design with Climate**,' that is, enhance the use of beneficial features of our climate while sheltering or protecting from its excesses for negative impacts. The most problematic of the 'climatic excess' in most of our context is the sun. Thermal comfort in tropical dwellings is largely about controlling the heat gain from the sun and its indirect effects without compromising its ability to provide daylight and also dealing with inherently humid conditions. And, controlling the heat gain depends on the choices we make related to three aspects of house design:

Shading
Ventilation
Materials

Given the geographical location of Sri Lanka (just a few latitude degrees north of the equator) the sun movements are within closed proximity to the zenith at noon causing high ambient temperatures throughout the year. Therefore avoiding sun and its effects should be the primary objective of climate-sensitive design in the Sri Lankan context.

However, excess heat gain is not the only climatic excess confronting us. Given our monsoonal location and island status, year-round high humidity is equally problematic. The only low-energy option to dispel the stifling heat made worse by excessive humidity is to ventilate the residence, but with care as to ensuring the ventilation comes from cooler and cleaner outdoors.

Finally, a certain degree of separation between the hot and humid outside and a comfortable inside is also needed in the tropical context. Here, the choices we make with regard to the building envelope (walls, floor and roof) is the key. Permeable but insulated envelope helps to maintain an adequate level of separation between the two, indoor and outdoor.

Even with all of the above, some level of energy expenditure for the attainment of comfort indoors is unavoidable in a tropical context. An easy option is to air condition the dwelling by active means but this may not be a sustainable option, both from an economic (cost of energy needed to operate the active air conditioning system) as well as environmental (consumption of excessive electrical energy which is likely to be generated using fossil fuel sources) points of view. A level of local generation of electrical energy could be an attractive option needed to meet the comfort requirements of dwellings. Solar Photovoltaic (PV) panels could be a potentially advantageous and attractive solution.

Sustainability of residences could be further enhanced by the frugal use of water. Although a tropical country blessed with high levels of water availability by international standards, rain availability throughout the year and across the whole island varies considerably and therefore, a means of capturing the excess rainwater would be a prudent option for Sri Lanka dwellings.

This guideline attempts to capture all of the above strategies in a systematic and easy-to-understand format. It presents the science underpinning sustainable and energy efficient residences but in a manner that is relevant to the Sri Lankan context, practically applicable and visually comprehensible manner. It is hoped that the widespread use of the present guidelines will lead to more comfortable indoor environments in Sri Lankan dwellings without excessive use of unsustainable energy forms of energy generation.

Contents

Notes

1. Sustainable Design - Climate and Thermal Comfort

1.1 Climate of Sri Lanka

The climate of where you live and build needs to be taken into consideration when planning a residence.

There can be significant differences in maximum and minimum temperatures, relative humidity and wind velocity in different climatic zones in Sri Lanka. Therefore, design should be specific to the particular conditions of the location (see Fig.1).

1.1.1 Classification

The location of Sri Lanka, is between 5° 55' to 9° 51' North latitude and between 79° 42' to 81° 53' East longitude -the climate of the island could be characterized as TROPICAL.

1.1.2 Topography

The central part of the Southern half of the island is mountainous. The remainder of the island is practically flat except for several small hills that rise abruptly in the lowlands. These topographical features strongly affect the spatial patterns of winds, seasonal rainfall, temperature, relative humidity and other climatic elements, particularly during the monsoon season.

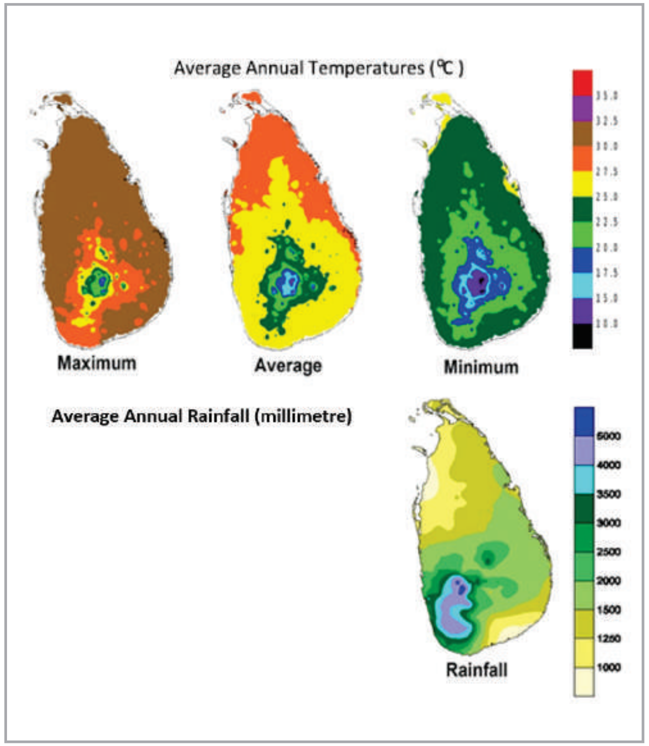


Fig | 1: Average Annual Temperature and Rainfall- Sri Lanka
(Source – www. meteo.gov.lk)

1.1.3 Rainfall

Rainfall in Sri Lanka has multiple origins. Monsoonal, convectional and expressional rain accounts for a major share of the annual rainfall. The mean annual rainfall varies from under 900mm in the driest parts (South-Eastern and North-Western) to over 5000mm in the wettest parts (Western slopes of the central highlands) (see Fig. 1)

1.1.4 Temperature

Regional differences observed in air temperature over Sri Lanka are mainly due to altitude, rather than to latitude. The mean monthly temperatures differ slightly depending on the seasonal movement of the sun, with some modified influence caused by rainfall. The mean annual temperature in Sri Lanka manifests largely homogeneous temperatures in the low lands and rapidly decreasing temperatures in the highlands. The mean annual temperature varies from 27^{o}C in the coastal lowlands to 16^{o}C at Nuwara Eliya, in the central highlands (1,900m above mean sea level)

1.2 Thermal Comfort

Thermal comfort is generally defined as that state of mind which expresses satisfaction with the thermal environment (ANSI/ASHRAE Standard 55-2013).

Thermal comfort is measured by considering following comfort variables

Air temperature (also called dry bulb temperature): the most common measure of thermal comfort

Mean radiant temperature. (a weighted equivalent temperature representing the radiation effects within the internal occupying space)

Air velocity: important in warm weather, as air moving relative to the skin increases heat loss by convection, lowering the perceived air temperature

Relative Humidity: representing the moisture content of the air is defined as relative humidity and may cause discomfort when above 70% or below 30%

Activity levels (metabolism): amount of metabolic heat generated by body due to human activities. Different types of activities (walking, sleeping, exercising, manual work, etc.) produce more or less heat

Thermal resistance of clothing (Clo value): Clothing we wear act as a barrier to heat exchanging with our bodies. The more clothing we wear (or more insulating they are) less heat will be lost from the body

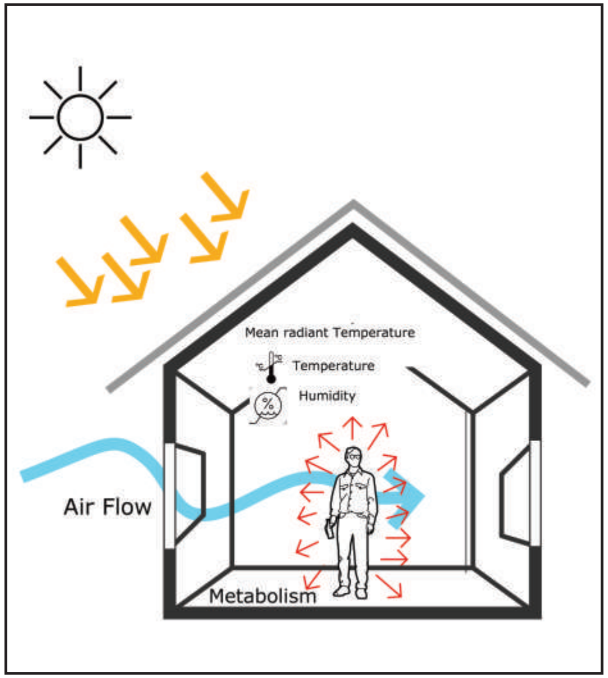


Fig | 2: Thermal Comfort Variables

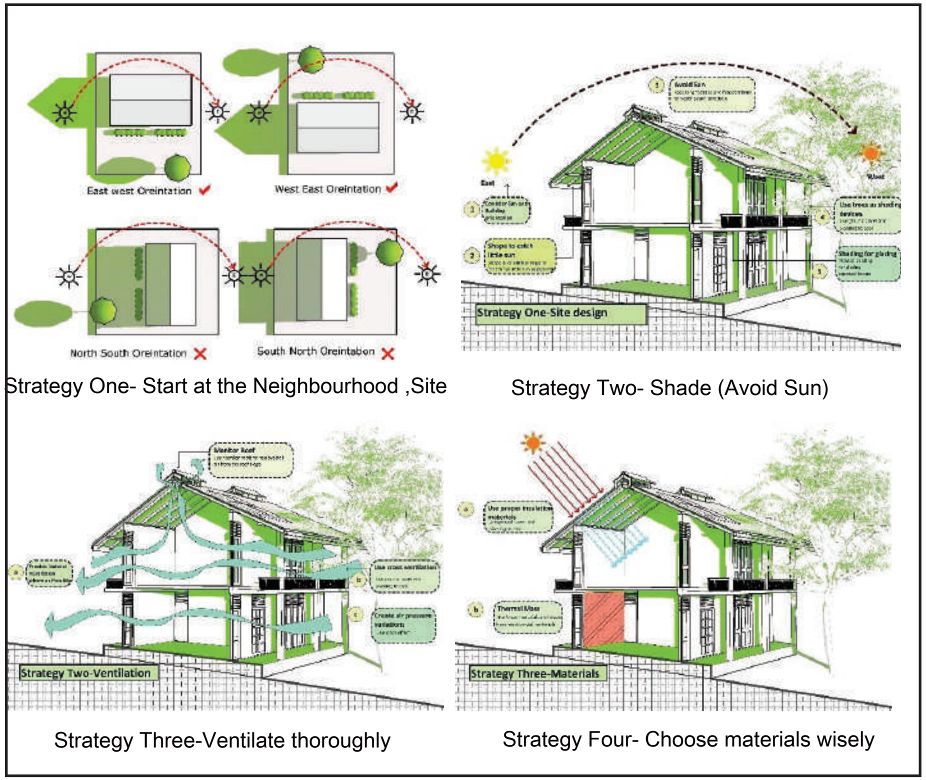
Building design affects the first four of these thermal comfort variables (see Fig. 2) (termed environmental factors), while the last two are behavioural (termed personal factors). An understanding of the effect of building design on thermal comfort would help optimise the design to achieve particular comfort levels.

1.3 Passive Design Strategies

Passive design is a method of improving your - indoor thermal comfort and thereby energy use - without using an active system such as electrical fans, cooling/heating based air conditioning systems, which are energy intensive. We present Four Key Passive Strategies you can use (see Fig. 3)

1. Strategy One- Start at the Neighbourhood/Site
    - a. Sun and building orientation
    - b. Laying out of streets/building plots

2. Strategy Three-Ventilate Thoroughly
    - a. Main wind directions and building siting
    - b. Building shell and openings



Strategy One- Start at the Neighbourhood ,Site

Strategy Two- Shade (Avoid Sun)

Strategy Three-Ventilate thoroughly

Strategy Four- Choose materials wisely

Fig | 3: Passive Design Strategies

3. Strategy Two -Shade (Avoid Sun)
    - a. Shading by external features
    - b. Shading by building features

4. Strategy Four- Select Materials Wisely
    - a. Insulation
    - b. Thermal mass
    - c. Colours of surfaces

1.3.1 Strategy One- Start at the Neighbourhood/Site

1.3.1.1 Sun and Building Orientation

Buildings cannot stand alone without its context. The city is a fabric of numerous buildings and vegetation around your land. Therefore, the understanding of such a context - both physical and climatic - is essential in order to build your energy efficient home.

a. Understanding the sun path diagram

The sun path diagram shows the location of the sun for a given time and day of a calendar year with respect to a particular site (see Fig. 4).

The values indicated around the circle are the azimuth, the horizontal angle the sun position makes with the North.

The concentric circles indicate the elevation angle, the vertical angle the sun makes with the horizon.

The path of the sun for a given day is represented by a curved horizontal line across the circle, with the top-most line representing the path of the sun on June 21 and the bottom-most line representing December 21.

Each point represents the sun position at that particular day and time with the azimuth angle and altitude.

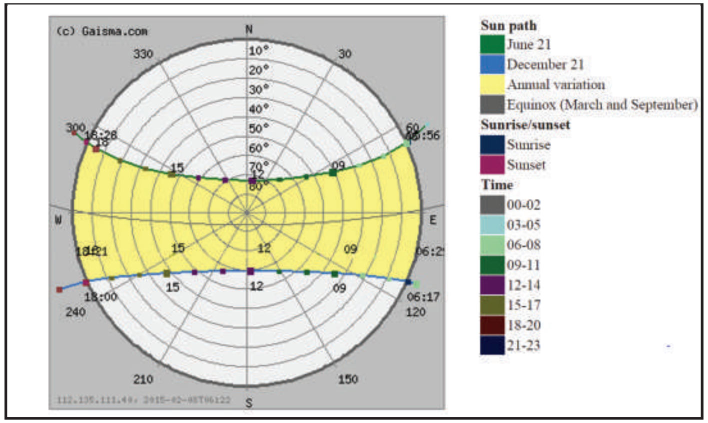


Fig | 4 : Colombo Sun Path Diagram
(Source – gaisma.com)

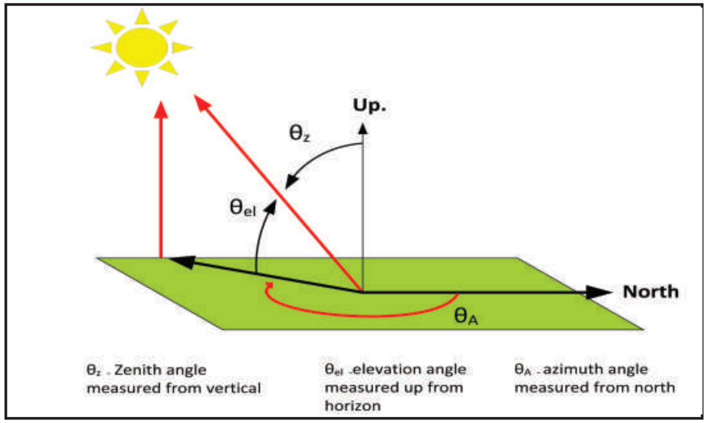


Fig | 5 : Solar Angels
(Source – pvpmg. Sandia.gov)

b. Sun path and building orientation

The sun's position relative to a particular to the geographical location of a site is a crucial factor to determine the heat gain of buildings and performance of solar energy systems. A sun path diagram displays seasonal and hourly positional changes of the sun as the earth rotates and orbits around the sun (See Fig. 6). In simple terms the sun path diagram could be related to the projection of the position of the sun at every moment on a horizontal plane at the location.

Design considerations;

Choose a site with good orientation to maximise the site's potential for passive cooling. For sites that are not ideally orientated, strategies to overcome challenges need to be adopted.

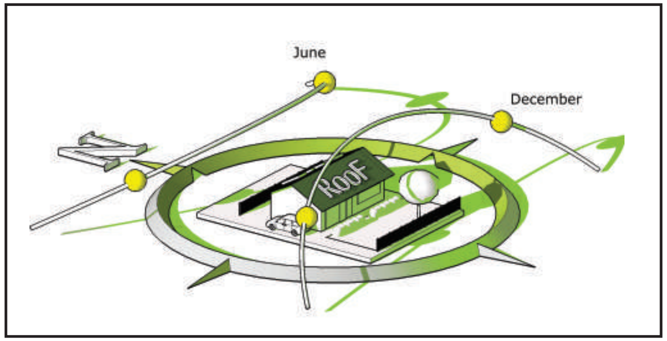


Fig | 6: Sun Path Diagram for Sri Lanka and the Best Building Orientation

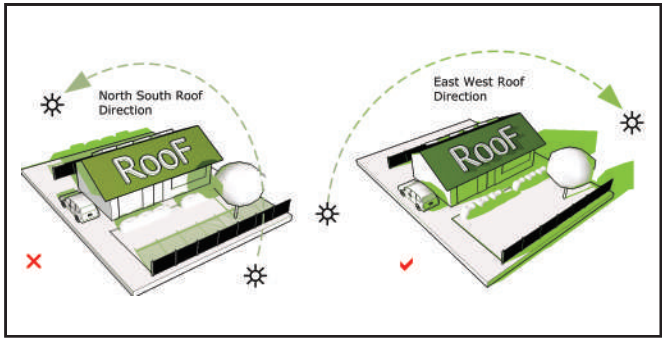


Fig | 7: East-West Orientation

In hot humid climates, the primary aim is to exclude direct sun by using trees and adjoining buildings to shade every façade year round while capturing and funnelling cooling winds.

In Sri Lanka East and the West is considered as the solar surface for your land or the house. The definition of solar surface is the surface which mostly affected by the direct sunlight. Facing smaller surfaces to the East and West is the effective way of excluding solar radiation. The solar exposure at a particular location would be the combination of the direct, sky diffused/scattered and ground reflected components of the sun at that point (see Fig. 7).

1.3.1.2 Laying Out of Streets/Building Plots

a. The orientation of streets

Affects the urban climate in several ways (see Fig. 8);

Wind conditions in the urban area as a whole;

Sun and shade in the streets and the sidewalks;

Solar exposure of buildings along the street;

Ventilation potential of the buildings along the street;

In a hot-humid climate the main objectives related to the street's layout are to provide maximum shade for pedestrians and minimum solar exposure of the buildings along the streets.

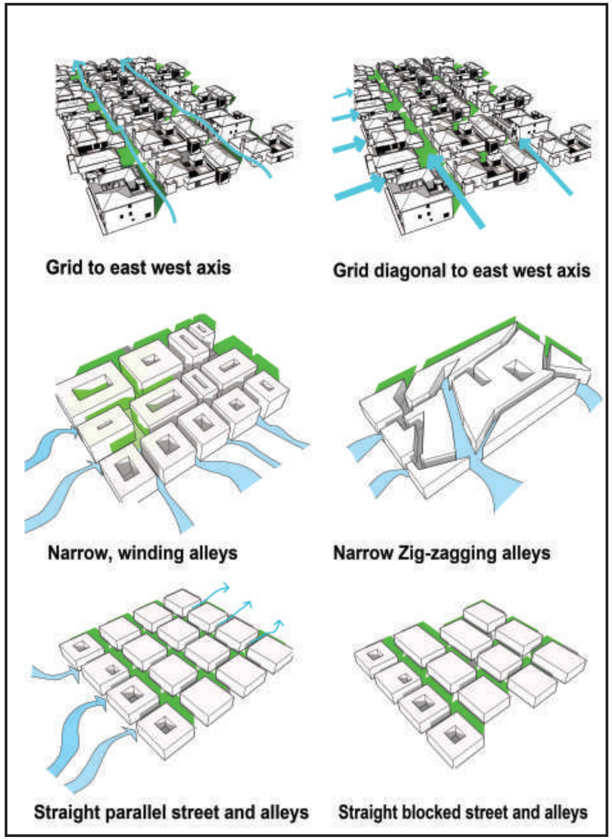


Fig | 8: Orientation of Streets Affectings Urban Micro-climate

In Narrow streets provide better shading by buildings for pedestrians on sidewalks than wide streets. However, shade for sidewalks can be provided even in wide streets by special details of the buildings or by vegetation

A North-South orientation of a street may result in an East-West orientation of buildings along and parallel to the street, which will cause unfavourable solar exposure for these buildings. From the solar exposure viewpoint an East-West street orientation is favourable (see Fig. 8).

Grids along and / or diagonal to east-west axis will offer effective spacing for wind penetration, while solar exposure needs consideration. Narrow spacing will provide better shading possibilities yet diminish the wind potential. Better spacing between building blocks rather than continuous blocks (as in the straight blocked street example) will allow better potential for wind

1.3.2 Strategy Two - Shade (Avoid Sun)

Minimising solar radiative heat gain can improve thermal comfort for building occupants. This helps reduce the demand for cooling, improving energy efficiency. Solar heat gain can be reduced by sensible building orientation (see Fig. 9), proper window design and adequate shading solutions. It is important to avoid direct solar radiation into the house.

a Shading by external features

Shading is most effective when placed externally, as it prevents solar heat from entering the building. External shading can consist of vegetation (trees), hard landscaping elements or neighbouring landforms and structures (see Fig. 10).

b Shading by building features

Well-designed shading solutions for walls and fenestration can reduce the energy required for cooling significantly (see Fig. 11).

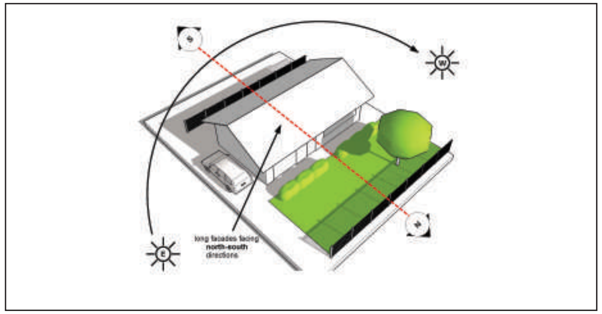


Fig | 9: Shape and Orient Buildings to "catch" as little Sun as possible

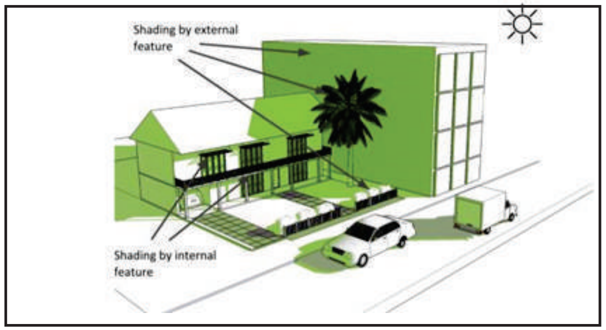


Fig | 10: Use of Neighbourhood Land Forms, Structures and Vegetation to Shade

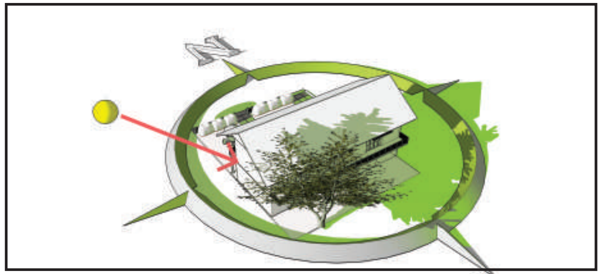


Fig | 11: Use of Ground cover and Planting for Cooling Effect

1.3.2.1 Shading by External Features

a. Use Neighbourhood land forms, structures and vegetation to shade (see Fig. 10) Tall trees with small leaf are best suited for shading a home. Planting such trees in perimeter lines can help two or more adjacent properties in shading.

b. Use ground cover and planting to cool.

Light colour paving can reflect solar radiation into the building. (see Fig. 11) Vegetation used intelligently can absorb and diffuse direct heat and promote evaporative cooling in both exterior and interior spaces

1.3.2.2 Shading by Building Features

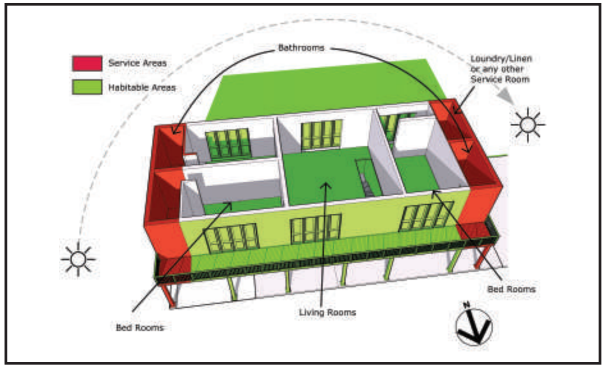


Fig | 12: Zone your House and Avoid Direct Heat Gain to Habitable Spaces

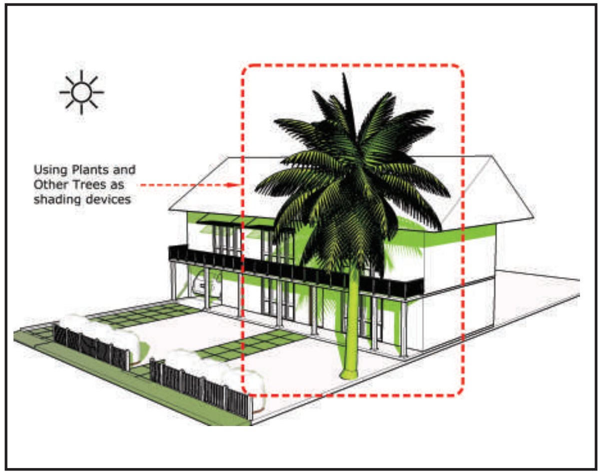


Fig | 13: Use Plants and other Trees as Shading Devices

a. Zone your house and avoid direct heat gain to habitable spaces;

Zoning your house carefully considering the sun's influence on the site and context is the first key strategy of planning your house. Therefore, the best ways to zone is to keep service areas, circulation, storage, parking and other seldom used areas oriented towards the east and west directions (see Fig. 12). Thus, Keeping spaces that used more frequently relatively cool

b. Provide shading for walls exposed to sun

Zoning cannot avoid all direct heat gain on a building, because of the sun movement throughout the day and year. Therefore, measures to avoid heat gain to walls that are exposed to direct solar radiation are important. Use deep roof eaves, verandas, overhangs, external vegetation to avoid the direct heat gain to walls that are exposed tothe sun (see Fig 13, 14, 15).

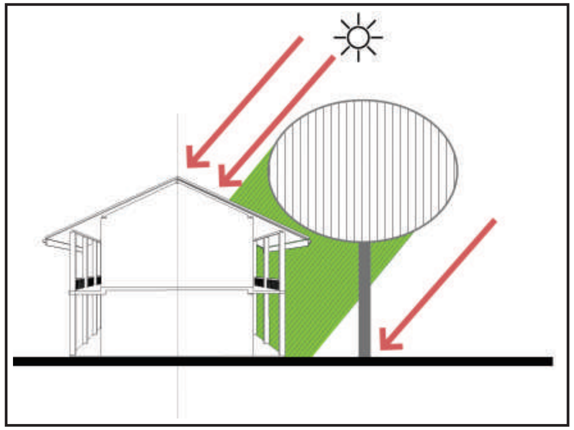


Fig | 14: Use Trees and Shade your Glazing

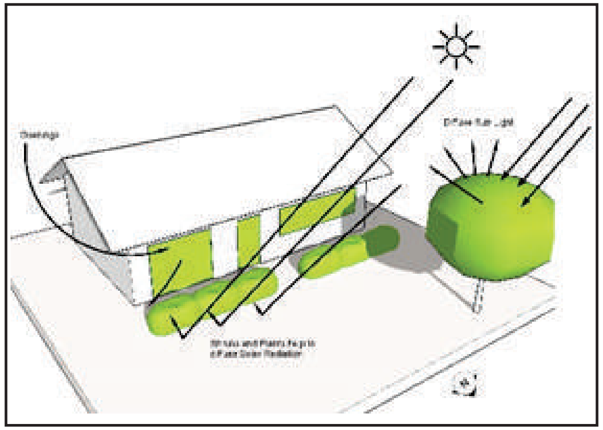


Fig | 15: Provide Shading for Walls exposed to Sun

c. Use green facades and green roofs to avoid heat gain to the building

Vegetation on flat roofs and walls absorb and diffuse solar radiation before it reaches the building envelope. The vegetation and its planting medium (earth) work as good insulators.

Planting next to the building skin used as screens also promote evaporative cooling, with the wind blowing through the plant screens before it reaches the openings and spaces of the building. (see Fig. 16, 17).

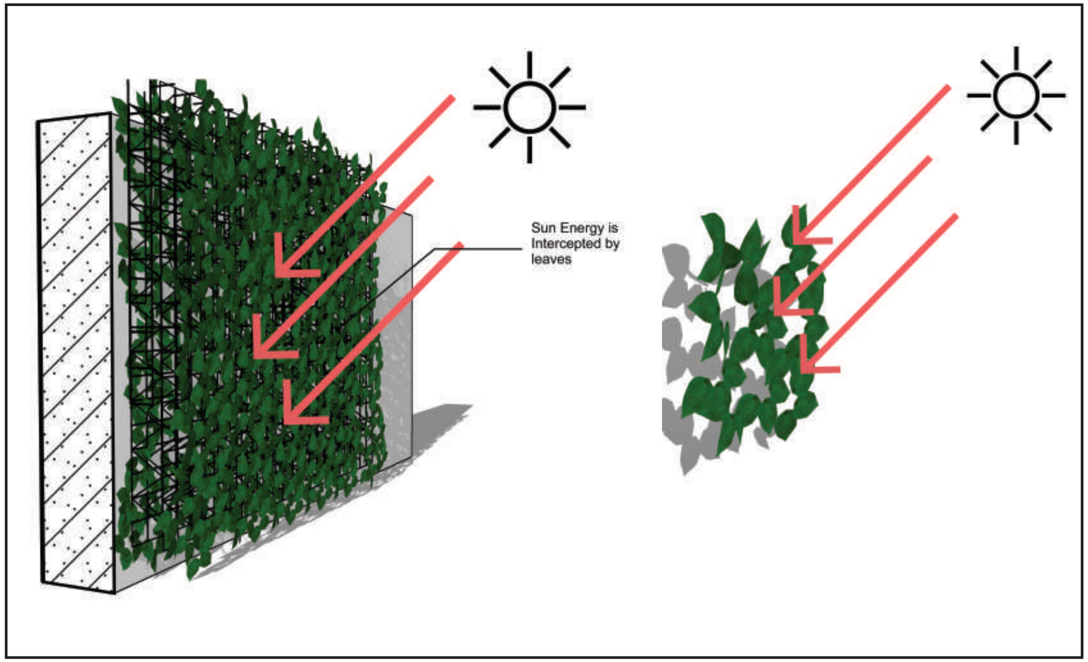


Fig | 16: Use Plants next to Building skin as Shading Devices

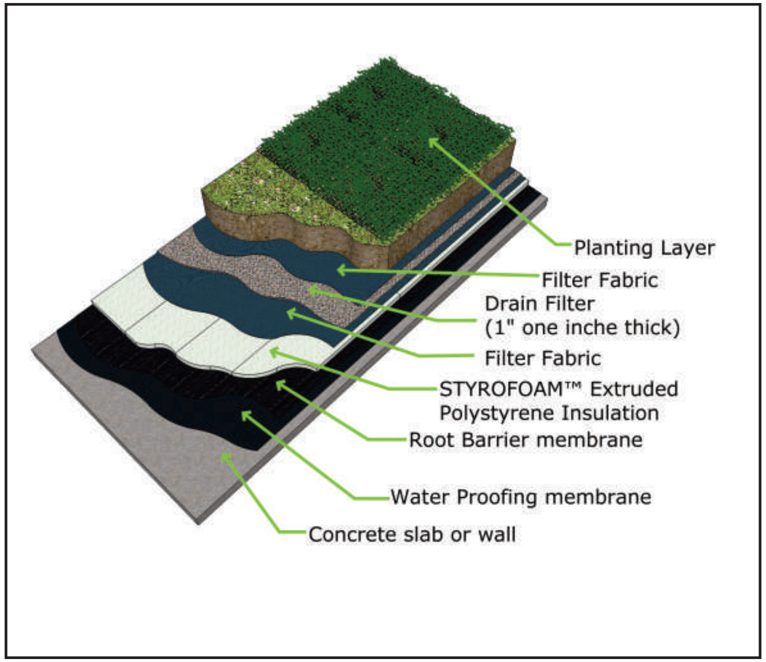


Fig | 17: Details of Green Roof Layers

d. Provide shading for glazing exposed to sun

Shading can be provided both externally and internally. External shading devices are crucial in avoiding heat coming through the windows. Internal shading devices slow down the transfer of heat.

I. External shading of fenestration

Use external shading devices in the form of horizontal, vertical and / or as a combination to exclude as much of the sun from reaching the interior. Fig 19 shows various shading device options. The sun's path and the orientation of the windows are essential for effective application.

ii. Internal shading devices

A combination of external and internal shading devices should be used. Internal devices reflect and diffuse radiation from reaching the occupants. Care must be taken to ensure ventilation, avoid trapping of the warm air within the space and integration of natural light. (see Fig. 18)

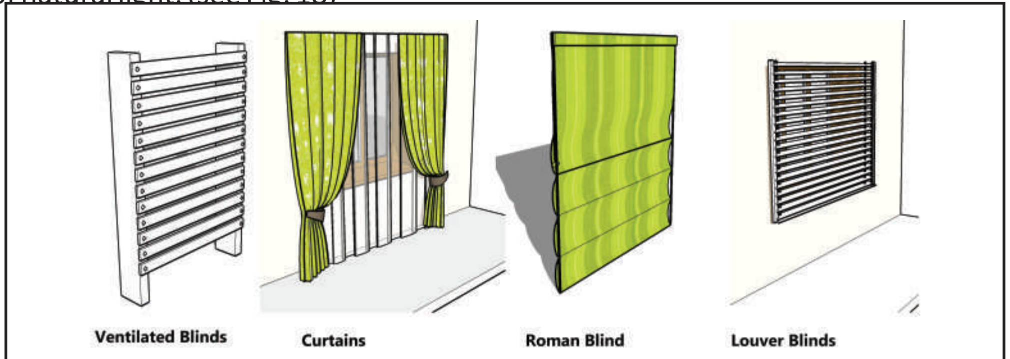


Fig | 18: Use Adjustable Shading Devices

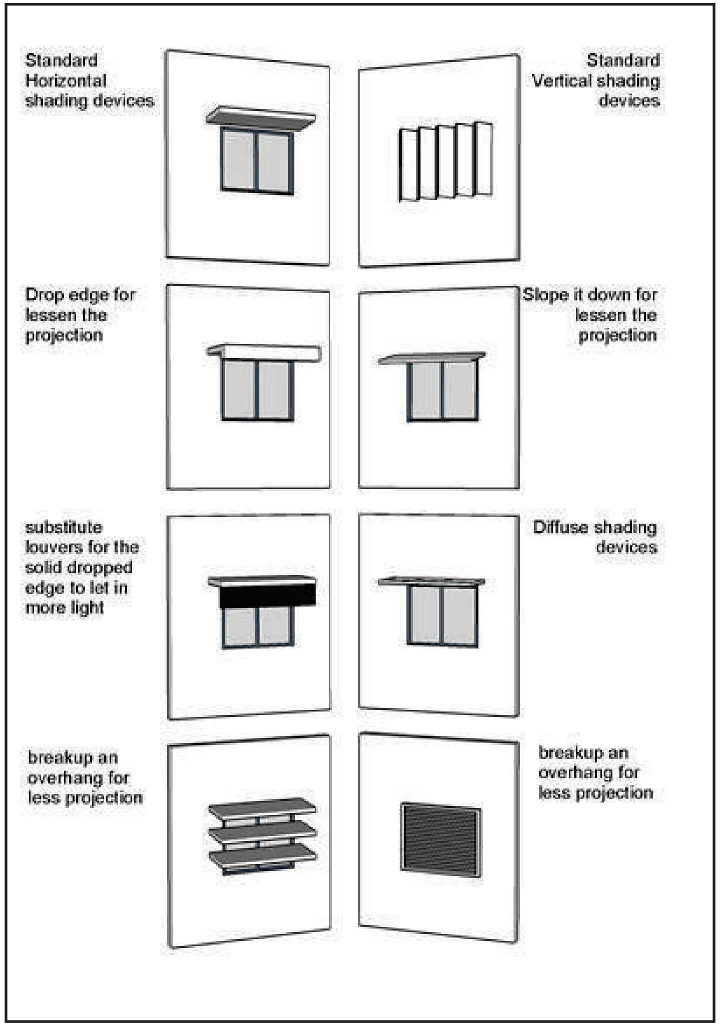


Fig | 19: Provide Shading for Glazing exposed to Sun

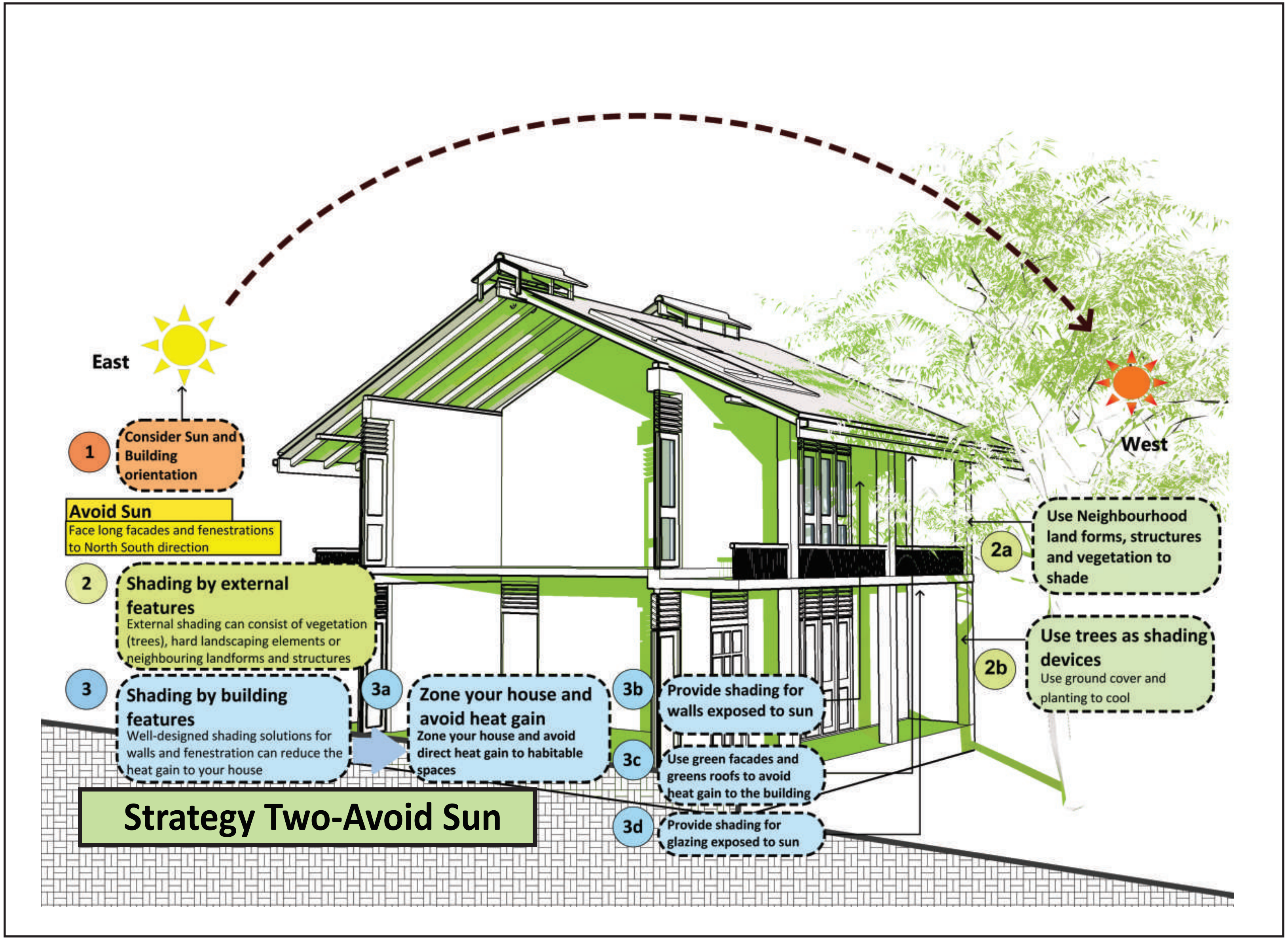


Fig | 20: Strategy Two - Avoid Sun

1.3.3 Strategy Three – Ventilate Thoroughly

1.3.3.1.Main Wind Directions and Building Siting

Passive ventilation strategies use natural airflow patterns around and within a building. For natural ventilation and natural air conditioning; wind and buoyancy caused by air temperature differences between the two spaces need to be created. Buildings can be designed in such a way to enhance these natural airflows and take advantage of them, thus enhancing thermal comfort and reducing energy use.

a. Main wind directions in Sri Lanka

The two main monsoons create the primary wind patterns across Sri Lanka - Wind from the North - East From December to February and wind from the South - West from May to September (see Fig 21.) wind moves due to the following factors described below'

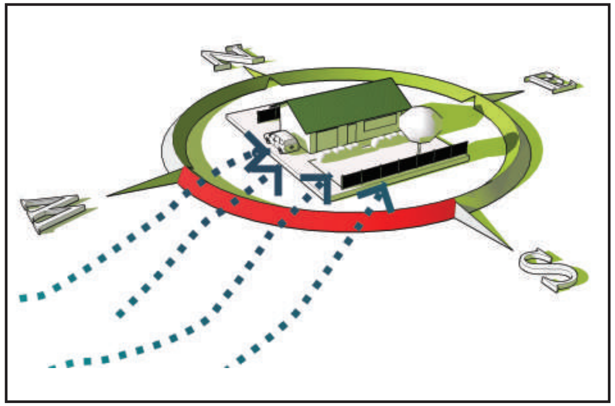


Fig | 21: Main Wind Directions in Sri Lanka

i Pressure difference (Cross Ventilation):

Cross ventilation uses the natural force of the wind (or local air pressure differences) to attract air into the building. When wind hits the windward facade, it creates a positive pressure on the facade. Similarly, as it flows away from the leeward facade, a region of lower pressure will be created. If windows are open in the building on both the windward and leeward side, air will be forced into the building, because of the pressure difference between the openings (see Fig. 22).

ii Temperature difference (Stack Effect)

Stack or buoyancy-driven ventilation relies on the air pressure difference between two spaces. The air inside the building and the outdoors to drive the flow or difference in temperature between two zones within the building itself. Warmer air is lighter than colder air. When there is a building full of warm air and it is exposed to an environment with cooler air, and two vertically spaced windows are opened, warmer air will escape through the opening and the colder air will enter the building through the lower window (see Fig. 22).

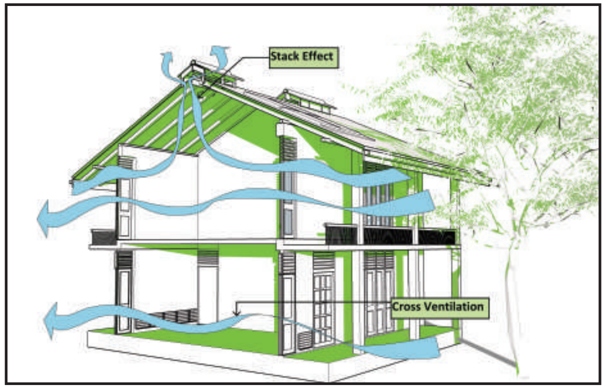


Fig | 22: Types of Ventilation

b. Orient buildings to “catch” maximum wind

It is important orient your building and openings towards the prevalent wind direction. For Sri Lanka the wind directions are North-East and South-West. Yet, in a highly built context this is not always the case. Therefore, local conditions need to be understood considering seasonal changes, prior to application. (see Fig. 21).

c. Use Neighbourhood land forms, structures and vegetation to increase exposure to wind

Neighbourhood influences on the wind direction and movement can be used in a positive manner. Careful placement of land forms, structures and vegetation (particularly trees) can sufficiently warp the ventilation stream into interior spaces, enhancing thermal comfort. (see Fig. 23 & 24)

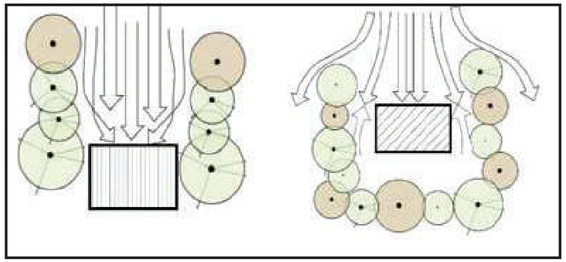


Fig | 23: Neighbourhood Vegetation to increase exposure to Wind

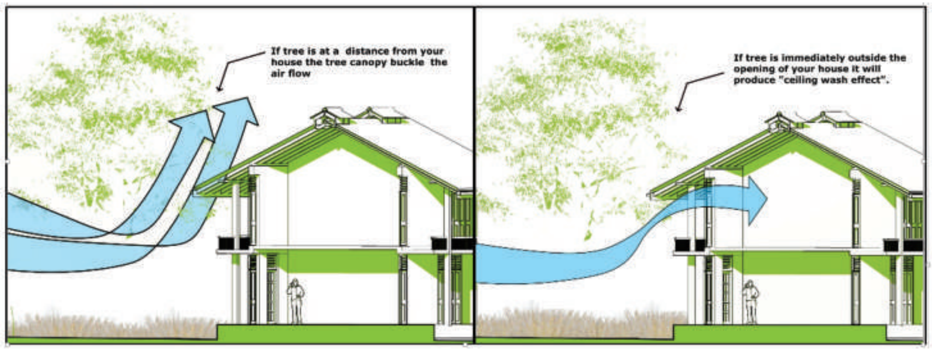


Fig | 24: Neighbourhood Vegetation to increase exposure to Wind

Fig. 25 shows the use of adjacent structures (pergola shaded courtyard) and surfaces (paving and vegetation), thus creating cooler and warmer areas to encourage cool air movement through the interior spaces.

Cool courtyard – pergola shaded, vegetated and /or water surface
Warm court – paving, sand, gravel

Where enclosed courtyards with water is used, care must be taken ensure air movement and thereby avoiding stagnation of humid air within interior spaces.

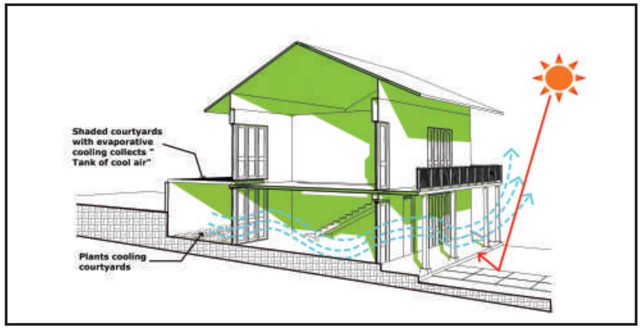


Fig | 25: Cool Courtyard – Pergola Shaded, Vegetated and /or Water Surface

1.3.3.2 Building Shell and Openings

The wind velocity determines the level of comfort at a given air temperature and humidity condition. The amount of air movement within an interior space is the function of the outside air velocity, the manner in which it strikes the openings (windows) and the size of the openings.

a. Shape & orient building shell and openings to "catch" maximum wind

It is important that openings are located, shaped and sized in a manner that they let in a maximum amount of air flow. Openings need to be located to ensure air moves past the occupants to be cooled. (see Fig. 26)

Decisions on where to place the openings and the shaping of it depends on the incoming air and the nature of the interior. Fig. 26 shows the effect on interior air flow with differing window configurations.

Consider excluding solar heat gain and enhancing daylight integration.

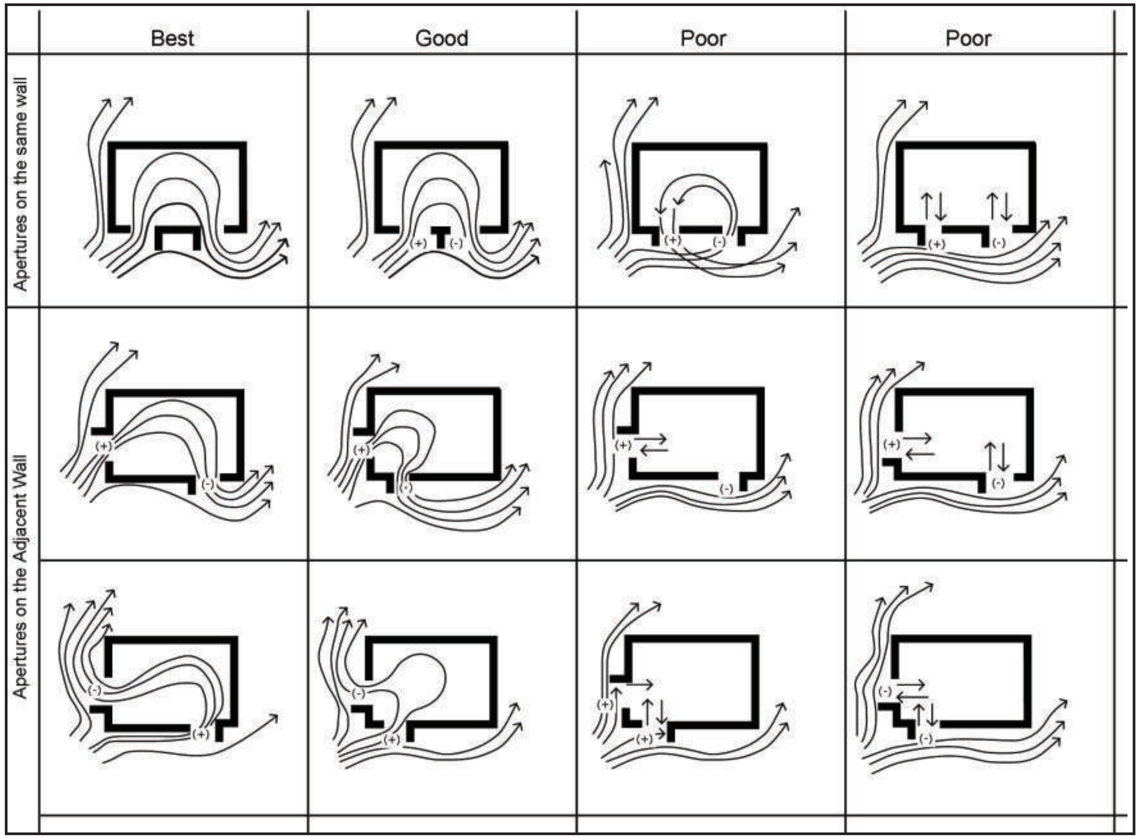


Fig | 26: Shape & Orient Building Shell and Openings to "catch" Maximum Wind

The matrix of options demonstrate the effect of varying placement of apertures (openings) and features such as vertical fins on the wind penetration into the interior space. In all options the wind direction and the interior space remain the same.

b. Use open plan interior to promote air flow

The position of partitions and openings are crucial in order to ensure a natural air flow within your house. (see the Fig. 27). Consideration of both the plan (horizontal layout) and the section (vertical layout) of the interior is essential.

i. Create an unobstructed air flow path

Choose placing of partitions to cause minimum hindrance to the air flow

Use perforated partitions

Use Partitions / walls that are low in height than the ceiling

Use openings in separations (partitions, walls) that can be opened or closed when desired

ii. Direct incoming Air Flow – zone critical areas of the space, split in-coming air Flow and redirect to desired areas.

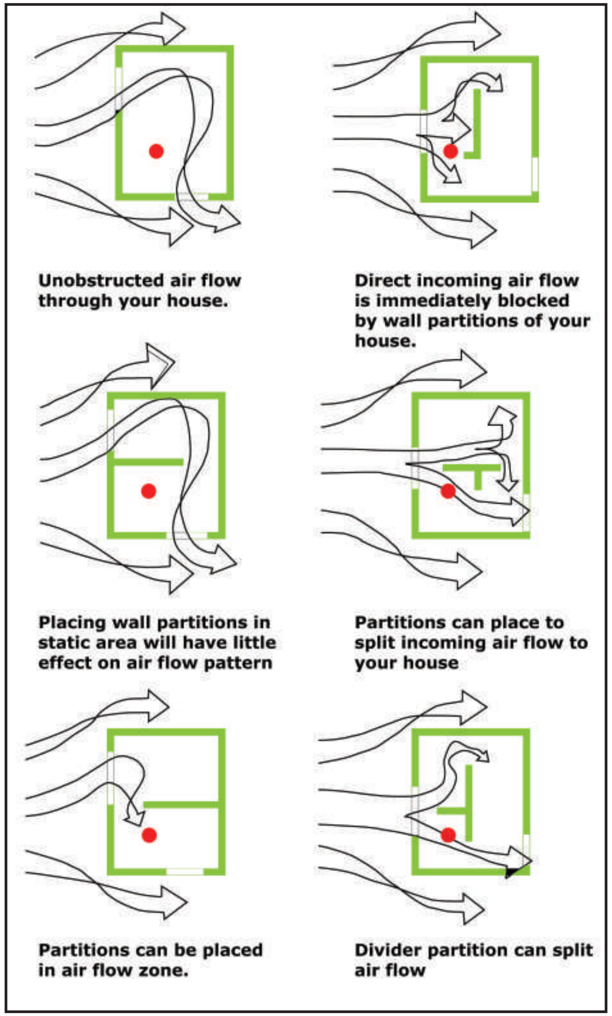


Fig | 27: Use Open Plan Interior to Promote Air Flow.

Demonstrates the effect of the partition on air flow. The marker denotes the crucial zone where ventilation is most needed.

c. Provide vertical air shafts to promote air flow

Cool air is sucked in through low inlet openings at the lower part of the house or the façade and hotter exhaust air escapes through high outlet openings from the roof or slab level. You can introduce mechanical air outlet too. (see Fig. 28)

The ventilation rate can be proportional to the air pressure variation and the area of the openings. The correct placement and the wind direction has an impact on encouraging air flow through your building. In addition the size of the openings at the top (outlet) and bottom (inlet) should be sized to encourage even air flow through your house.

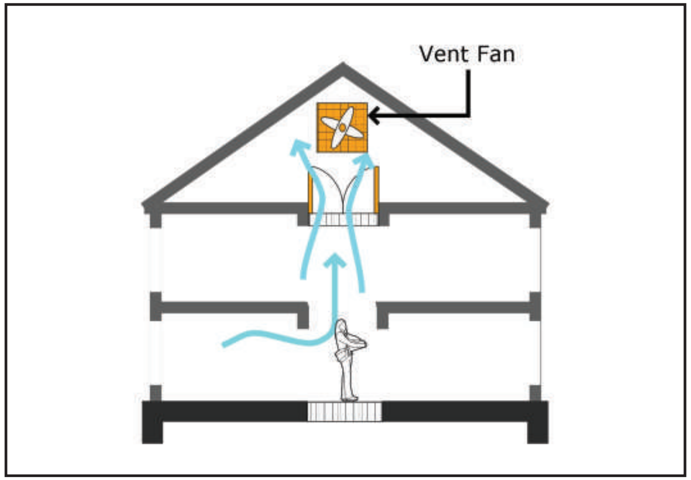


Fig | 28: Provide Vertical Air Shafts and Promote Air Flow

d. Use monitor roofs for stack effect ventilation

Monitor roofs are vent openings fixed to roof in order to remove hot air from your house. Monitor roofs can be fixed to the ridge of the roof or the roof planes.(see Fig. 29)

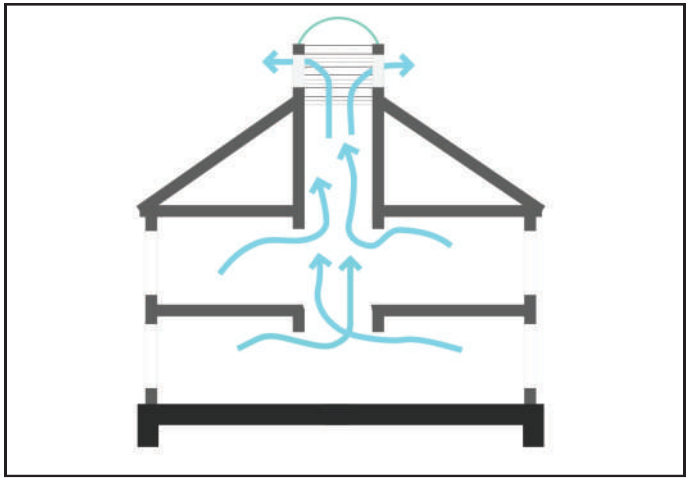


Fig | 29: Provide Vertical Air Shaft with Intermediate Openings and Roof Vent

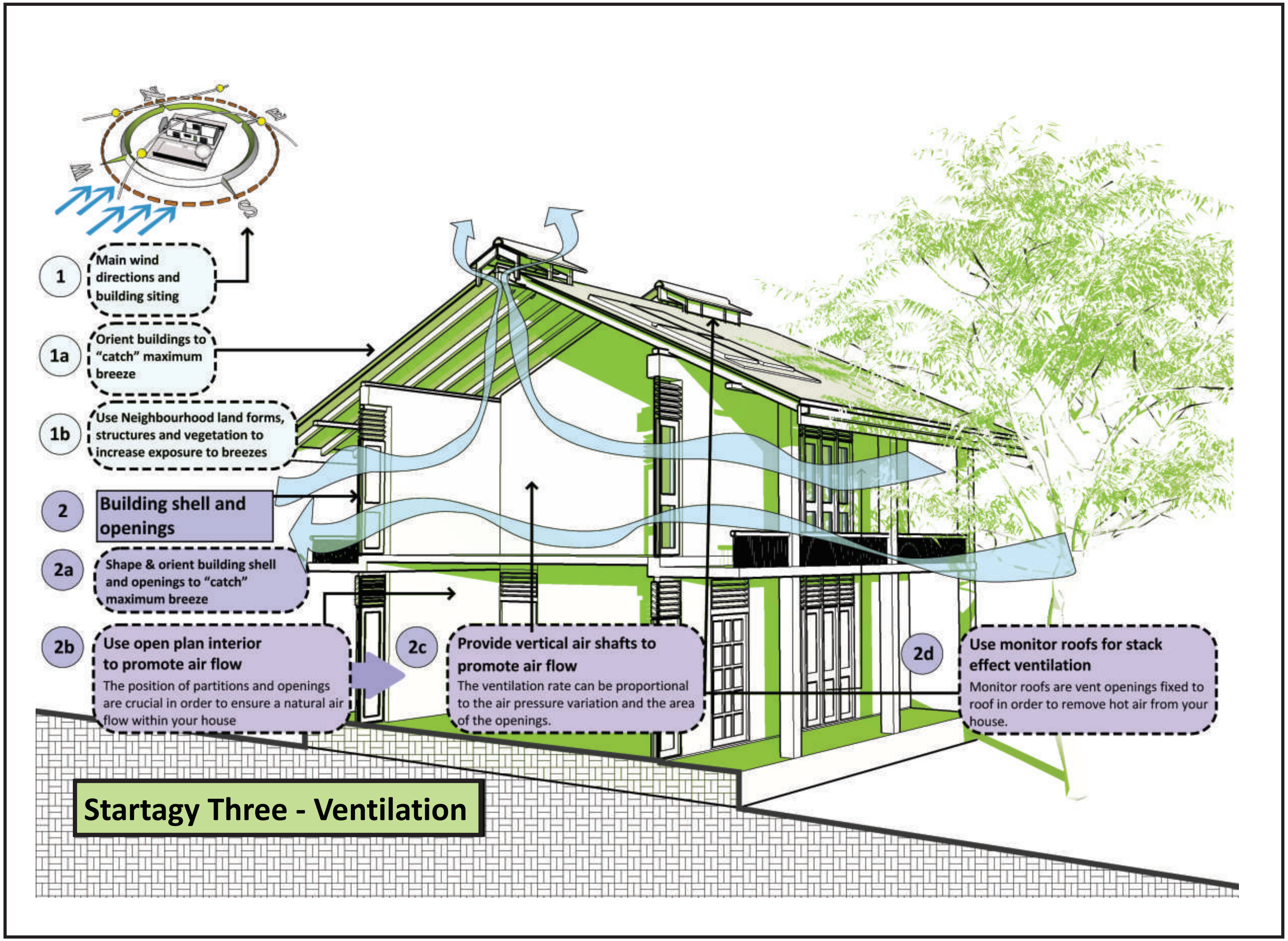


Fig | 30: Startagy Three - Ventilation

Example - Impact of Wind Direction

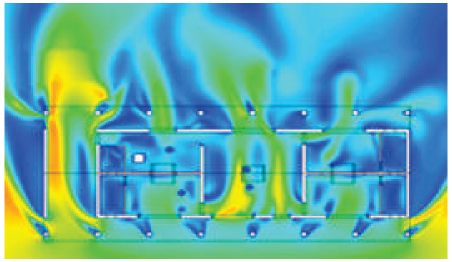
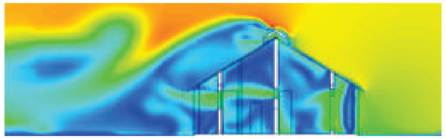


Fig |31: Plan View of Wind from South - Single Storey House



Fig|33: Elevation View of Wind from South-West - Single Storey House

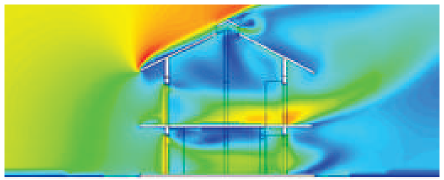


Fig | 35: Elevation View of Wind from South-West - Two Storey House

Wind direction has a significant impact on the velocity of air movement inside the building. Therefore, it is important to assess the wind direction based on local climatic conditions, barriers and landscape in and around your property before deciding on the plan form.

The following images shows air velocity around some of the generic house designs presented as examples in this document. These are the results of air-flow simulations of the single storey (Fig. 53 and Fig. 54) and the two storey house (Fig. 55 and Fig. 56) generic models described at the end of this guideline. However these images show that wind coming at an angle to the door/window openings create lower air velocities, also creating areas within the rooms where there is not much air movement. When the air is coming directly at the openings, higher air velocities are possible, thus reaching more areas within the rooms.

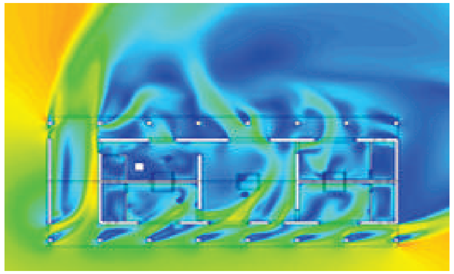


Fig | 32: Plan View of wind from South-West - Single Storey House

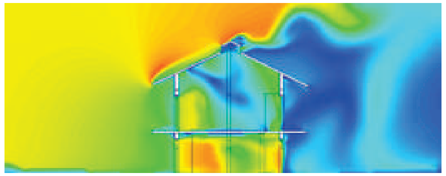


Fig | 34: Elevation View of Wind from South - Two Storey House

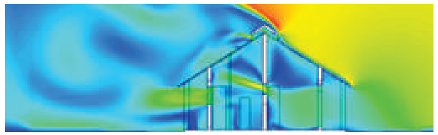
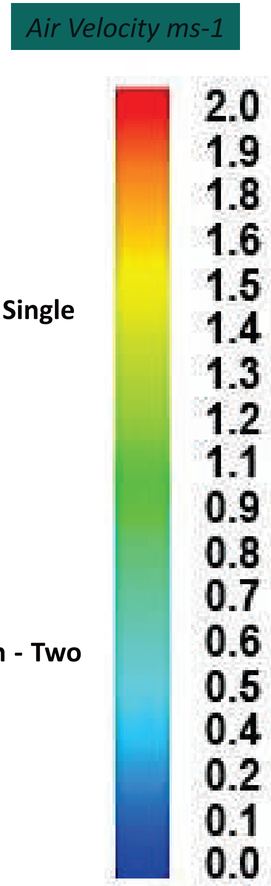


Fig | 36: Elevation View of Wind from South - Single Storey House



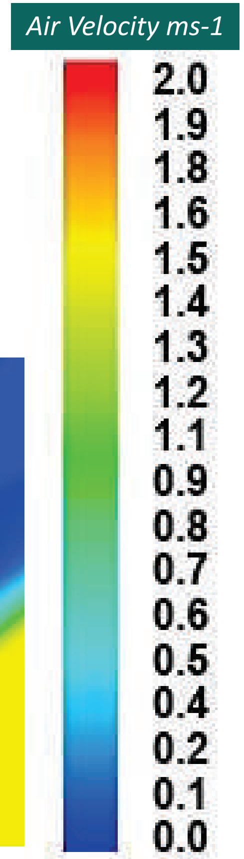


Fig. 37 to Fig. 39 illustrate results of air-flow simulations of the middle floor of the generic model apartment block presented in Fig 57 and Fig 58 described at the end of this guideline. As noted earlier, changes to wind direction can result in significant changes to airflow within the building. You can witness that wind coming at an angle to the door/window openings creates lower air velocities, creating areas within the rooms where there is not much air movement. When the air is coming directly at the openings, higher air velocities are present reaching more areas within the rooms.

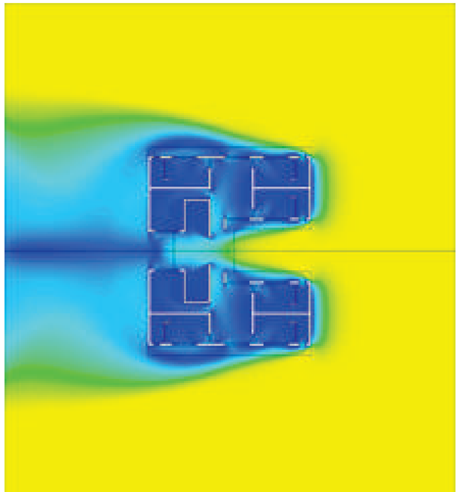


Fig | 37: Plan View of Wind from East
Least effective option for wind penetration into habitable spaces within units

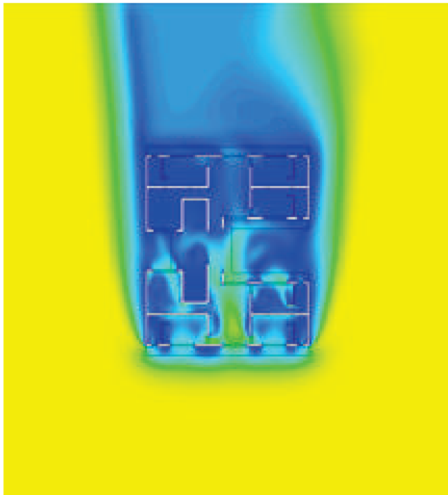


Fig | 38: Plan View of Wind from South
better option for wind penetration into habitable spaces in windward unit

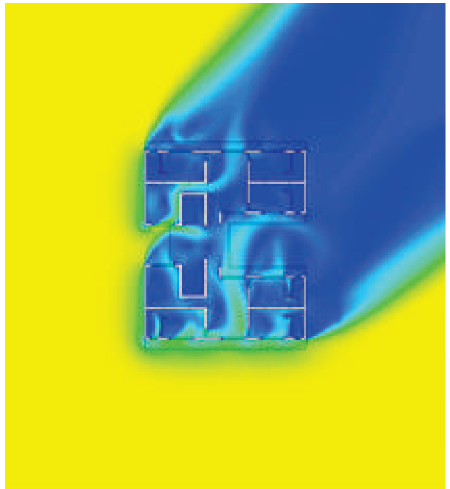


Fig | 39: Plan View of Wind from South-West
better option for wind penetration into habitable spaces within both units

1.3.4 Strategy Four – Select Materials Wisely

1.3.4.1 Insulation

Thermal insulation is a barrier to heat flow through material and helps reduce heat gain to interiors. Thus Insulation will also help to prevent cooled air from warming up.

Insulation can reduce the cooling load on a building by preventing heat gain. Because less heat passes into the living space, less energy is required to provide thermal comfort for occupants. Insulation can be installed in the roof, ceiling and walls, and can be either bulk insulation with or without reflective aspect

1. Reflective insulation is typically installed under roof sheets, where it reduces the amount of radiative heat that subsequently enters the building.
2. Bulk insulation slows conductive heat transfer and resulting convection and is generally used to keep air within the building cool.Bulk insulation of walls is probably most useful where buildings are air conditioned – in this case, insulation helps keep interior air cool and reduces the demand for cooling energy but needs to evaluate the true economic benefits. However, insulation will have adverse effects when certain zones need to get its heat released to the surrounding.

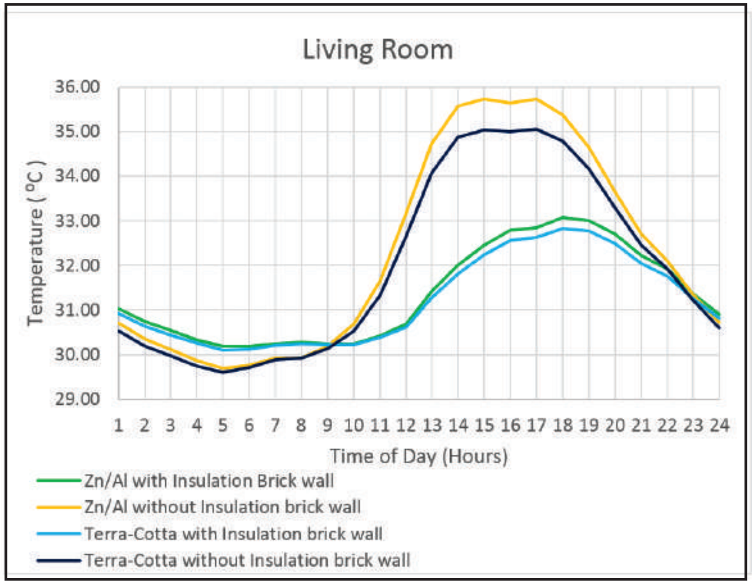


Fig | 40: Temperature Variation across a Typical Day for Different Roofing Materials in the Living Room of the Single Storey (Model) House.

As an example - The variation in the living room air temperature, in a typical day is shown - along with variations in roof construction and insulation (see Fig. 40). The graph shows the temperature variation due to insulation and roof material in a space under the roof for the single storey model house presented in this Guideline. One inch thick foam insulation with reflective barriers on both sides is assumed.

1.3.4.2 Thermal Mass (Roof and Walls)

Thermal mass is the capacity to store thermal energy thus influences the change in temperature of a material.

A lot of heat energy is required to change the temperature of high density/capacity materials like concrete, brick and tiles – they are high thermal mass materials. Lightweight materials like timber have low thermal mass. Thus buildings get classified as those with light, medium & heavy structures

Thermal mass is not a substitute for insulation, rather a contributor to the thermal inertia. Thermal mass stores and re-releases heat; insulation reduces heat flowing into or out of the building. A high thermal mass material may not generally a good thermal insulator.

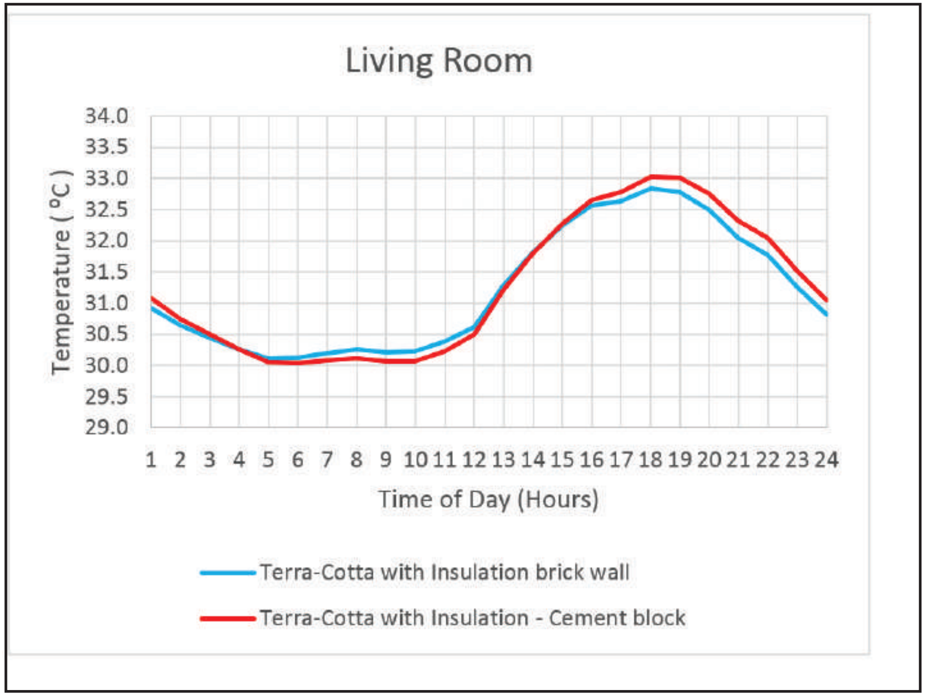


Fig | 41: Temperature Variation Across a Typical Day for Different Wall Materials in the Living room of the Single Storey House.

For passive cooling, thermal mass must be protected from summer sun and exposed to cooling night winds.

Add shading to protect thermal mass from the sun both internally and externally, particularly outside windows and in uninsulated double brick walls. Thermal mass's ability to absorb and re-radiate heat over many hours means that in hot climates it can be a source of unwelcome heat long after the sun has set.

Thus thermal mass could be intelligently used to control the indoor temperature variations in response to outdoor variations to suit indoor occupancy in different zones of the building.

1.3.4.3 Colour of Surfaces

Due to low wind speeds that can effect densely built in tropical cities, the effect of facade materials and their colours assume greater significance. Materials that can reflect solar heat and emit absorbed radiation reduce the amount of solar heat gain coming into the building. Thus, can significantly enhance the effect of thermal comfort and reduce energy use.

a Use light colours on walls and roofs

The solar heat reflectance is measured by Solar Reflectance Index (SRI value). The SRI is an estimation based on the solar reflectivity and emissivity values, and provides a value for how well a given material (or paint color in this case) rejects the sun's heat and also its subsequently absorbed heat. The higher the SRI value, the cooler the roofs, walls and therefore the interior spaces stays cool upon exposure to the sun. Light colour surfaces can reflect radiation and avoid direct solar heat gain while darker colours can absorb and subsequently transfit in the into the house interior.

b. Use reflective and low emissive materials for glazing exposed to sun

Direct radiation coming through the glazing in your fenestration form a significant portion of overall heat gain. Glazing is essential for the habitability of the spaces together with daylight integration, therefore difficult to be avoided.

Use low-emissive (low-e) glass or coatings / films to minimize heat gain through glazing used in the building.

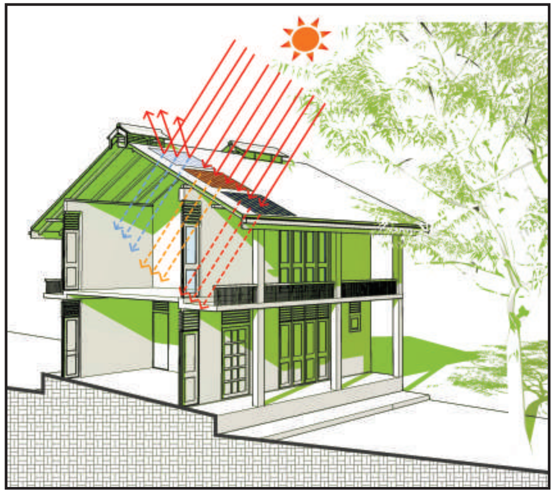


Fig | 42: Thermal Absorption of Colours

Table | 1: Common Solar Reflectance Indexes

Source – Lawrence Berkeley Cool Roof Lab. Not to be used as manufacturer data

RI of typical roof materials and colours			
Selected Materials	Solar	Infraed	SRI
Unpainted cement tile	0.25	0.9	25
Red clay tile	0.33	0.9	36
Light gravel on build up roof	0.34	0.9	37
Aluminum coating	0.61	0.25	50
White-coating gravel on built up roof	0.65	0.9	79
White-coating on metal roof	0.67	0.85	82
White cement tile	0.73	0.9	90
White coating, 1coat, 8mils	0.8	0.91	100
White coating, 2 coats, 20mils	0.85	0.91	107

Note: 1 mil = 00254 mm

Example - Thermal Comfort Observations

The environmental factors such as thermal comfort is directly affected by outdoor air conditions (temperature, humidity and wind velocity) and how that moderates the building interior conditions (heat transmission, thermal mass and air velocity), which are related to building design and materials. (see Table 1)

In a naturally ventilated building, the indoor air velocity would have the highest impact for thermal comfort, working to remove the hot air from the building and also providing comfort. Based on the model single storey building described at the end of this guideline, how these choices affect thermal comfort in different rooms is shown in Table 2. The model assumes 1.5 ms-1 wind as the environmental parameter.

Table | 1: Thermal Comfort Comparison with Roof Material

Location	Thermal Comfort			
	Roofing Materials with Insulation			
	Terra Cotta		Zn/Al	
	1:00 PM	6:00 PM	1:00 PM	6:00 PM
Bathroom 1	Average	Poor	Good	Worst
Bedroom 1	Average	Poor	Poor	Poor
Living Room	Average	Average	Worst	Poor
Bed Room 2	Poor	Poor	Poor	Poor
Bathroom 2	Good	Average	Poor	Worst
Bedroom 3	Poor	Poor	Poor	Poor
Bathroom 3	Worst	Poor	Poor	Worst
Kitchen	Good	Average	Average	Poor

Table | 2: Thermal Comfort Comparison with Wind Direction

Location	Thermal Comfort at 1 pm	
	Wind Direction	
	From South West	From South
Bathroom 1	Average	Average
Bedroom 1	Average	Average
Living Room	Average	Average
Bed Room 2	Poor	Average
Bathroom 2	Good	Good
Bedroom 3	Poor	Average
Bathroom 3	Worst	Worst
Kitchen	Good	Good

As the model indicates, thermal comfort is highly dependent on the wind, and changes in wind direction will have an impact into the interior thermal performances. Whilst, evening conditions can show adverse conditions, this also changes rapidly after sunset with the reduction of radiation and ambient temperature. Be that as it may, conditions are related to the locations too, where the rooms in North and South (bedrooms in this particular design) having better comfort compared to those in the East and West (bathrooms in this particular design) .

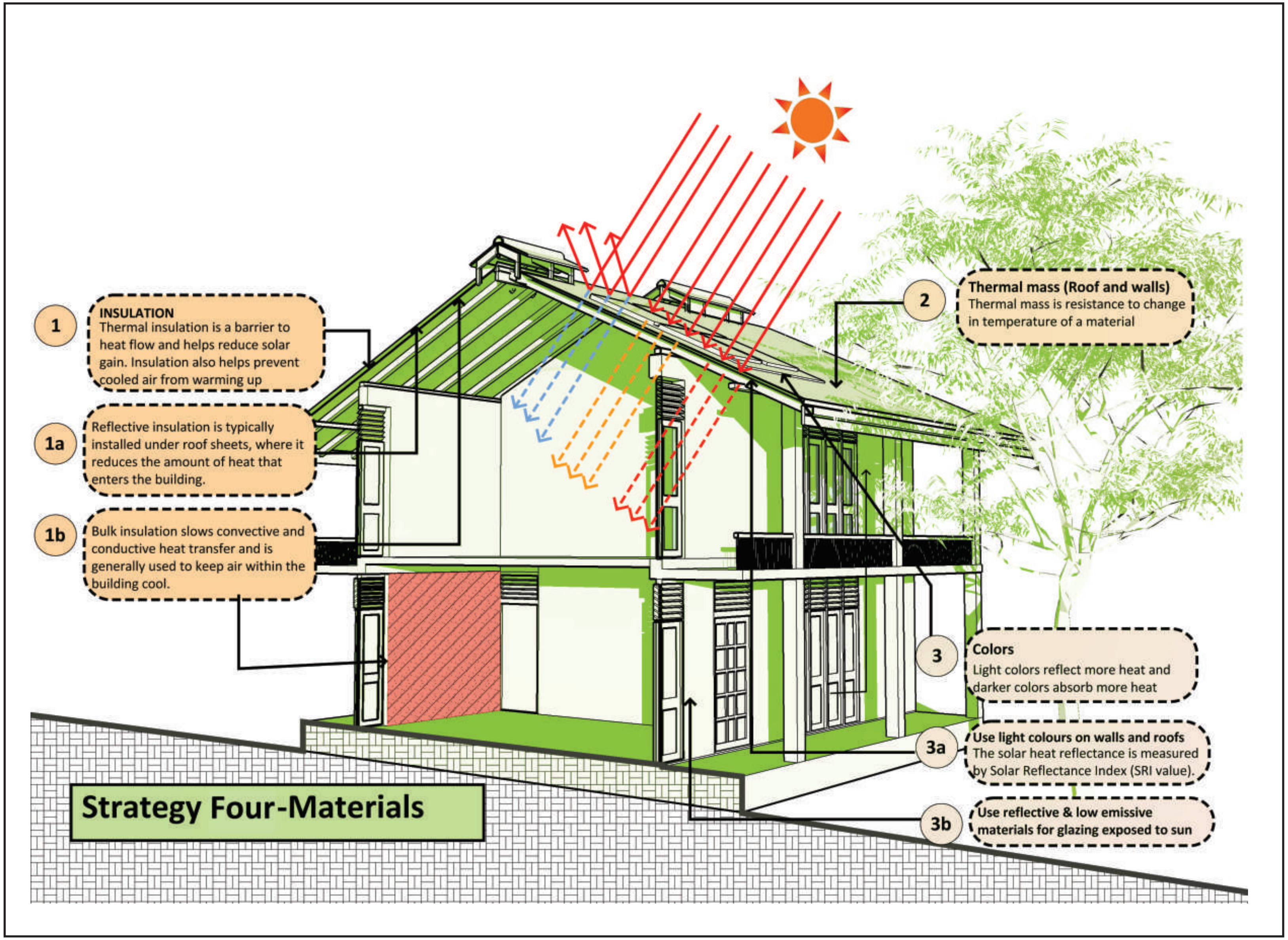


Fig | 43: Strategy Four - Materials

2. Lighting and Daylight Integration

Proper lighting is a critical element of a well-designed house. Availability of natural lighting during the daytime adds to the ambience as well as pleasantness of the house, in addition to reduced energy usage. Properties of daylight are better suited to human eyes than artificial lighting.

Good lighting serves to illuminate an area so that a task may be carried out safely, but good lighting can also improve productivity, improve mental efficiency and reduce errors.

What to look for in daylighting strategy

a. **Siting and massing the building**
b. **Choosing fenestration**

2.1 Siting and Massing the Building

As seen in the approaches to avoiding sun and ventilation (Section One) the primary consideration is the manner in which you place and shape your residence to receive optimum daylight during the day. (**Optimum** - the right amount of light, keeping in mind that you exclude excessive solar heat gain and ventilate thoroughly. Thus, it is important that a design considers all aspects) see figure 45.

2.1.1 Building Orientation for Optimum Daylight Gain

Recognise the context of the residence to integrate daylight into interior spaces. Zone habitable, more frequently used spaces considering the time of day they are used to benefit from daylight.

2.1.2 Sky and Reflected Light as Light Sources

Primary sources of natural daylight are the 'sky dome' and those that are reflected from the ground and adjacent buildings (structures). These sources give you diffused light. Although, direct sunlight is the obvious source, it brings with it radiation that has negative effects.

A good approach to daylight integration will encompass all three sources in its design.

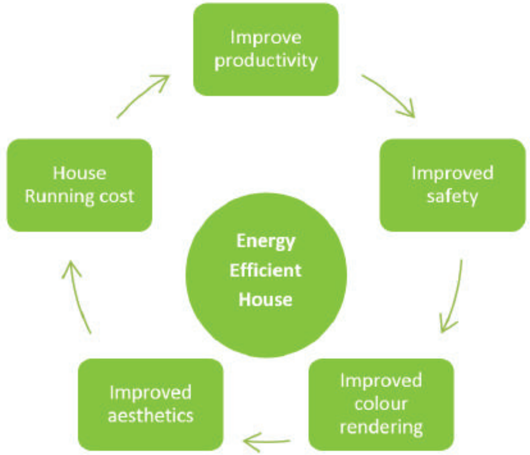


Fig | 44: Daylighting Benefits

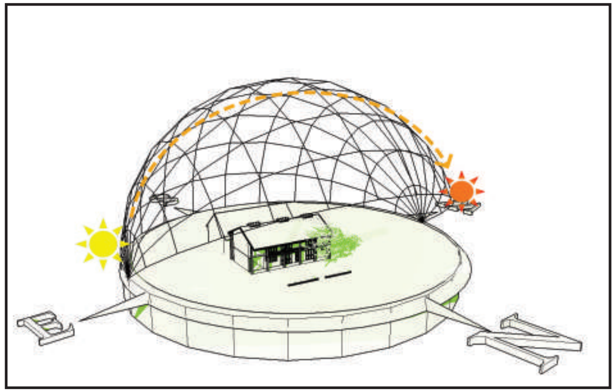


Fig | 45: Sun Path Diagrams

2.2 Choosing Fenestration

Choosing the right fenestration is important to permit the proper amount of light into the building, taking into account seasons, weather, and daily solar cycles. The primary objective should be to integrate an optimum amount of daylight that is uniform, diffused, and appropriate for tasks performed in the space, while ensuring ventilation and low solar heat gain.

2.2.1 Types of Fenestration

Fenestration can generally categorised as Side Lighting and Top lighting. As depicted in Fig. 46 is graphic representation the two strategies, highlights the advantage of top lighting in providing diffused, reflected daylight. It offers the opportunity to avoid direct light that brings in radiation and the ability to integrate light deeper into a space. Side lighting fenestration has the obvious advantage of providing a 'view' for the occupants.

Top lighting

- Clerestory lighting
- Sky lights
- Monitor roofs

Side lighting (see Fig. 47)

- Light shelves
- Window configurations

2.2.2 Factors to be considered for Effective Day Lighting

The higher the window area is on the wall; the more effective it is for day lighting

High ceilings for higher windows

Windows below desk height contribute little to the work plane

Horizontal windows are more effective than vertical windows

Balanced illumination is desirable

Windows on more than one wall

Spread windows apart if not specifying window wall

Place windows adjacent to other walls for reflection and diffusion effect

Use light coloured walls, ceilings and floors for maximum reflection of incoming daylight

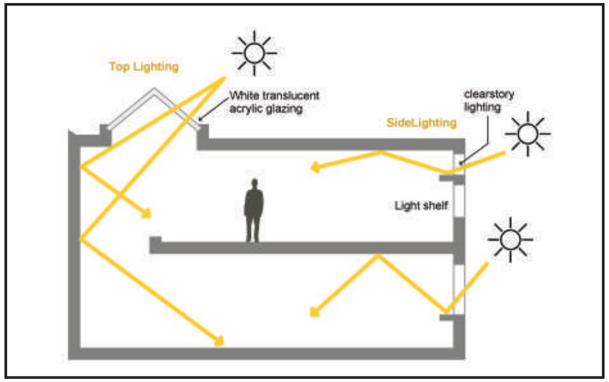


Fig | 46: Daylight Integration to Your House

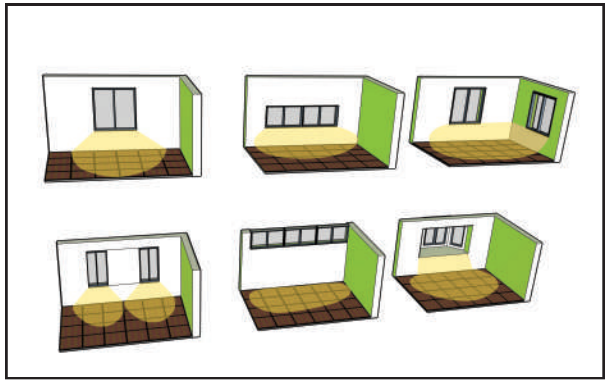


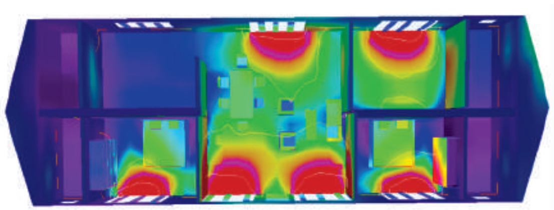
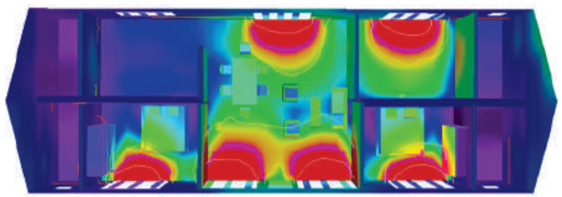
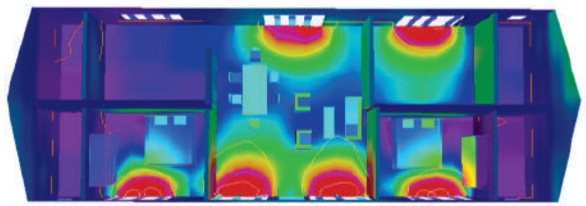
Fig | 47: Side Lighting - Daylight Distributions Produced by Different Window Configurations and Positions

Example - Daylight Simulation

The level of lighting achieved through daylighting will differ during the daytime based on the sky conditions. Lighting simulations can provide a good indication light levels at varying conditions. The following images are from a daylight simulation of the model single storey building described in this guideline.

Clear Sky | Mixed Sky (Partially Cloudy) | Overcast Sky

Illuminance with light colours applied to interior wall surfaces

lluminance with dark colours applied to interior wall surfaces

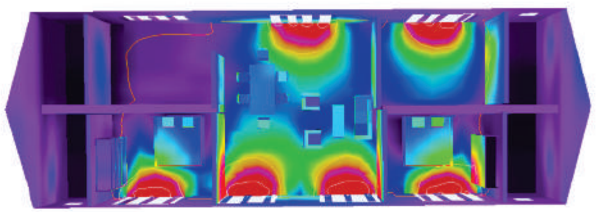
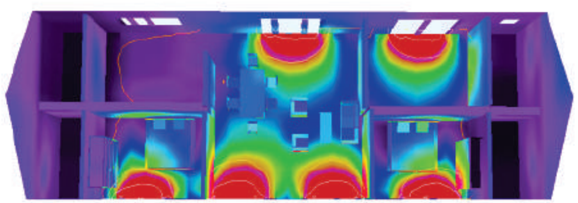
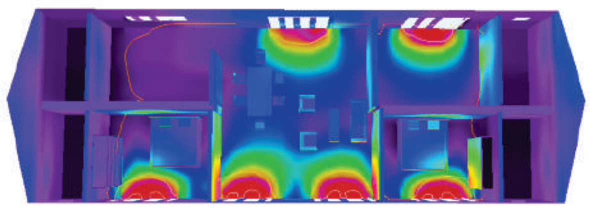
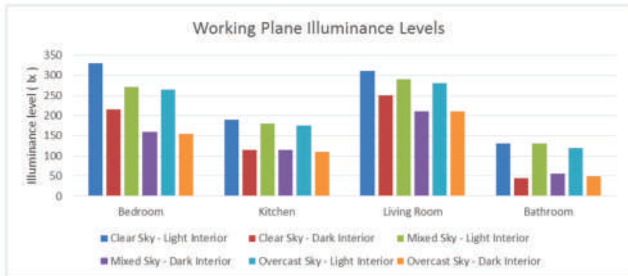




Fig | 48: Average luminance Levels in Each Room under varying conditions

Illuminance Levels (lx)
600 525 450 375 300 225 150 75 0

The lux contours show the comparative levels within spaces. Areas closest to the opening demonstrate higher lighting levels. Light colours on wall and floor surfaces better distribute the daylight within the spaces.



3. Solar Energy Integration

3.1 Solar Photovoltaic Based On-Site Power Generation

Solar PV is a renewable technology that generates electricity directly from sunlight that could be conveniently integrated to a building to generate building's own electricity while being connected to the grid with the possibility of exporting the excess or to import from the grid when necessary as a grid connected facility. There is also a scheme to export excess electricity to the grid and earn money, it the home has a larger than necessary roof area to provide its own electricity demand. This scheme, known as Net - Accounting ensures that the utility (CEB or LECO) will pay LKR 22.00 for a unit of electricity (1kWh) thus exported. This rate will apply for the first 7 years and will apply at a lower rate (LKR 15.50/kWh) during the balance 13 years. Alternatively, the home owner can separate the user account and export the total generation to the grid under another scheme named Net+Plus. The payment terms are similar to Net-Accounting scheme. Among renewable technologies that could be integrated to the building, solar PV is the most popular choice due to its simplicity, robustness, low maintenance, environmental and legislation aspects.

This technology brings significant cost savings to building users by generating electricity on site. In this grid connected configuration, under normal circumstances, the grid could be considered operating as an electricity storage device.

Photovoltaic technology could also provide a cost effective solution in areas where connection to the grid is more expensive or less practicable, such as remote locations. These solutions are known as off-grid solutions and involve an appropriately sized energy storage system(ESS).

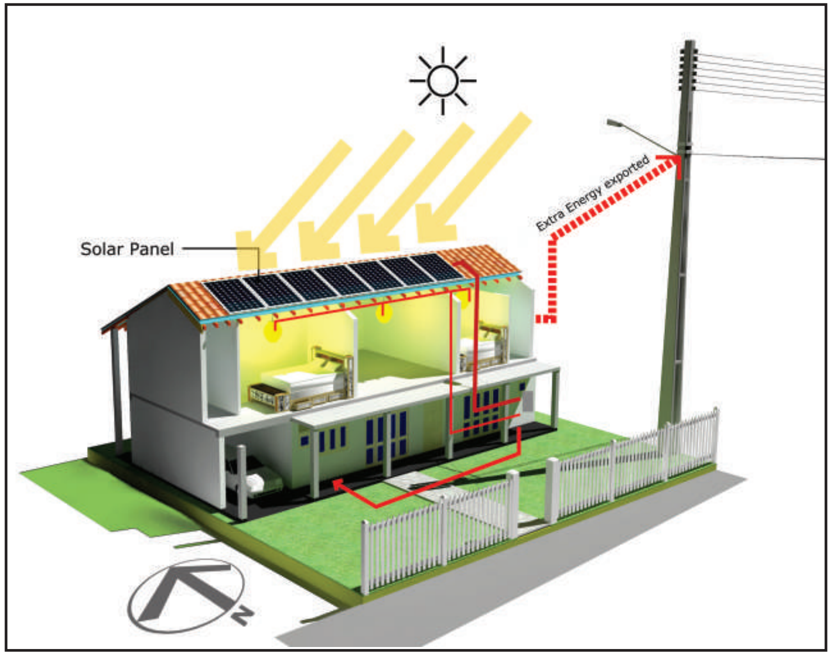


Fig |49: Solar PV Installation

The benefits of solar PV based electricity;

Reduce building's electricity bills: once the initial installation investment is made, for a properly sized system, the electricity costs will correspond only to what was imported from the grid when the building's own generation was not adequate to cater the building's need. This will be case over the life time of the installation which is in the order of 20 years or more.

Reduce the building's carbon footprint: Solar PV electricity is proven as a green technology and thus could lead the building to move towards net zero carbon emission targets.

3.1.1 Collecting Maximum Energy

In view of collecting the maximum amount of energy over the year, the local installation should be South facing with the angle of tilt of PV panels being equal to approximately 7 degrees. However, due to the practical limitations of installation for roof mounted systems the amount of generation would thus be reduced as shown in Table 3. However, steeper angles (than 7 degrees) facilitate self cleaning of panels and reduce the maintenance burden of the user.

The installation should be equipped with suitable surge protection, Not only for the protection purpose but also for the maintenance of the grid if in case

Table | 3: Solar Energy Generation Variation with Roof Angle and Orientation

Tilt angle of Panels (degrees)	Orientation Description	% Change in Energy Generation from base case (kWh/y)
7	South	Base Case
15	South	-1%
25	South	-3.50%
15	West	-2.20%
25	West	-5.40%
15	North	-4.80%
25	North	-9.90%

3.1.2 Sizing Solar PV Systems

To size the required solar PV system, you need to first estimate the monthly anticipated electricity use. In a non-shaded, south facing installation at 7 degrees, using current technology, a 1kWp system is expected to generate approximately 120 units (kWh) per month. location specific solar energy yields can be obtained from the Solar Resource Atlas of Sri Lanka published by SEA in 2014.

3.2 Solar Thermal System based Hot Water Generation

Solar Water Heating (SWH) systems convert radiant energy of the sun into thermal energy and store the thermal energy in water. Building users may have a hot water requirement for washing and cooking where this hot water can be used directly and also in certain areas in high altitudes in the country for space heating. In view of facing the challenge of the random nature of solar radiation and also the variations in the end use hot water requirement, a suitable storage integrated to the collector sub-system becomes essential. The fraction of energy that cannot be supplied by the sun in meeting the building hot water requirement can be topped by suitable auxiliary heating such as electrical resistance heating.

Among the commercially available solar water heating systems, there are several types of collector sub-systems which are dominantly used in buildings namely Glazed flat plate collectors and evacuated tube integrated flat plate collectors. Both these collectors have the option of using selective absorber surface where the absorber surface is specially treated to enhance the collection performance thereby improving the overall system performance.

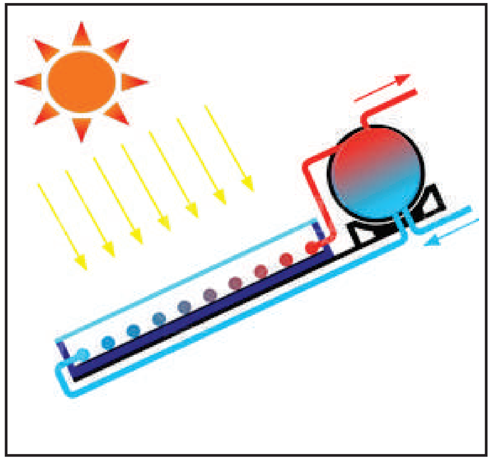


Fig | 50: Solar Thermal Collector

Table | 4: Solar Thermal Variation with Roof Angle and Orientation

Tilt angle of Collector Panels (degrees)	Orientation Description	% Change in fraction of energy collection by the sun
7	South	Base Case
15	South	+1%
25	South	0%
15	West	-5%
25	West	-9%
15	North	-11.5%
25	North	-22%

3.2.1 The Benefits of Solar Hot Water System based Heating

By employing this renewable energy technology, the building user can reduce the use of the commercial energy (electricity, oil, gas, etc.) consumption.

Reduce the building's carbon footprint and endeavour in moving towards Net Zero Energy Building.

Easy to handle in tropical countries like Sri Lanka, where the sun light is available during the whole day.

As in the case of solar PV, for collecting the maximum amount of energy over the year in terms of solar fraction, the local installation shall be South facing. However, due to the practical limitations of installation for roof mounted systems the amount of solar fraction in meeting the end user demand would thus be changed as shown in Table 4, relative to a typical sizing of a residential building (Glazed flat plate collector with storage, using electrical auxiliary heating):

4 - Optimization of Water Usage

Water is essential to our everyday lives: Perhaps water is the most important resource for human beings.

As our population grow, more and more people are using up this limited resource. Therefore, it is important that we use our water wisely and not waste it.

We use it for drinking, cooking and washing – the most basic human needs.

By reducing our water use, every individual can contribute to saving water, so that future generations can thrive as we do today.

Steps to improve water efficiency in your home;

Don't leave the tap running needlessly. There are simple ways you can reuse water for different purposes. For an example water used to wash food such as vegetables can be used for gardening.

Choose and use your appliances wisely. Use efficient water appliances in order to improve your water consumption.

Use low-flow fixtures for faucets and showers. Fixtures with aerators reduce the flow of the water, while maintaining the volume by mixing air into the water stream. Low-flow fixtures can reduce the flow rates by over 50% over non-aerated fixtures.

Convert your toilet to a dual flush, and don't flush it more than necessary. Low flush systems with dual flushing can reduce water use for flush systems by over 35%.

Stop leaks. Even a small water leak can contribute to wastage of large amounts of water.

Never throw water away. If you pour too much out or have some left in your glass, use it. Pour the surplus into your dog's water dish, water a plant, or add it to your water kettle

4.1 Irrigation Efficiency in Your Home

Efficient irrigation systems can significantly reduce water use. Following steps help reduce water used for irrigation.

Your landscaping should be based on climate appropriate plant species, that can survive without significant water input once established.

Design your storm water drainage system so that at least one inch of rainwater is retained on site before discharging into outdoor drainage.

Reduce the use of turfs/green yards landscapes as they require heavy water use.

Protect the soil through use of mulch by reducing evapotranspiration. You can shade the soil by plants and structures and reduce evapotranspiration rate, reducing the water demand of plants .

Irrigation should be done either early morning or at sunset (less evapotranspiration)

Design drip and micro irrigation systems that feed water directly to the roots of the plants. This can improve the irrigation efficiency by over 90% compared to using hosepipes.

For lawn areas, sprinkler systems are more effective than hosepipes.

Through careful observation, determine the appropriate irrigation requirements. Do not over-irrigate.

4.2 Rainwater Harvesting

Rainwater harvesting is a simple and effective way to reduce the potable water use in your house. Rainwater collection also reduces the stress into the city drainage systems and helps reduce the risk of flood. Rainwater can be collected from the roof drains and diverted to tanks for future use. (See Fig 51)

4.2.1 Guidance to Install a Rainwater Tank

i. Think of your water consumption

The main purposes that you should use rainwater is for flushing toilets and garden irrigation.

ii. What is the size of tank will you need?

The size of the tank depends on the following four factors:

How do you plan to use your harvested water
The size of your roof catchment area
The annual rainfall of your area
Your household water consumption

Once you have this information, you can work out how big your tank will need to match your household requirements.

iii. Where will you put your tank?

Considerations for the appropriate siting of the tank are outlined below;

Select a suitable shape and size water tank that fits your perfect location

Is it near the existing down pipes?

Consider your neighbours, ensure your tank does not block their natural light, ventilation or outlook or detract from the streetscape;

If you want to install a pump, make sure it is located in a place that will have low noise for your family or neighbours;

Consider access to the tank and your home for maintenance purposes;

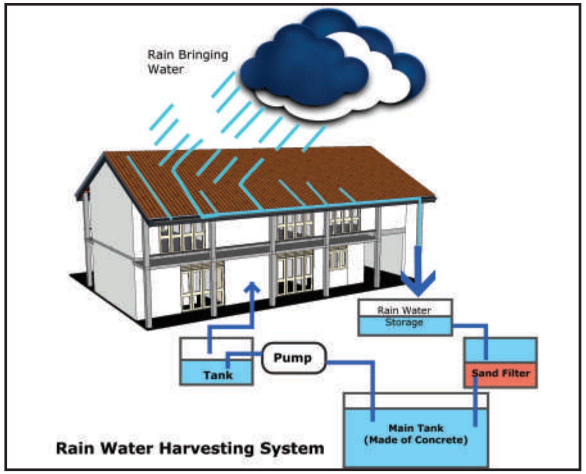


Fig | 51: Rainwater Harvesting Tank

Building regulations may also limit where you can locate a rainwater tank on your property in relation to the front, side and rear boundaries;

Be aware of the stresses placed on retaining walls, from a rainwater tank placed above or near any structure on your property or an adjoining property.

Using a sand filter will remove contaminants from your system. You should use the collected rainwater frequently without letting it stagnate as this may promote microbial growth in the tank. Regular cleaning and flushing of the water is also advisable.

5. Benefits of Sustainable Energy Residences

The primary benefit of a sustainable energy residence is its low energy use. While the actual demand for electricity may differ based on personal choices and lifestyles, a sustainable energy residence will reduce the energy use quite significantly due to its minimal requirement of energy for lighting, cooling and ventilation.

The lower electricity use also enables to get to net-zero energy with solar PV with a smaller system sizing and installation, with an appropriately reduced cost. Table 5 depicts a comparison for the single storey house and the apartment block when compared with an air-conditioned alternative of similar design, showing the typical savings.

Table | 5: Energy Consumption Variations of Sustainable Energy Residences and Air Conditioned Residences

	Electricity Use (kWh) per Month			
Load	Sustainable Energy Residence - Single Storey	Air-Conditioned Residence - Single Storey	Sustainable Energy Residence - Apartment Block	Air-Conditioned Residence - Apartment Block
Cooling and Ventilation	24	255	48	279
Lighting	18	29	22	33
Electrical Appliances	108	123	163	193
Total	**150**	**408**	**233**	**505**
Electricity cost, LKR	3,044	14,324	6,449	18,689
PV system size for net zero, kWp (@115kWh/month/kWp)	1.5	3.5	2	4.5

6. Demonstration Models

This sections outlines three generic models signifying typical house types in an urban context. The objective of the exercise is to give a very broad idea of how the strategies discussed at length throughout this document can be applied to achieve Energy Efficiency in your home. The models presented are in no means prescriptive and thus should not be applied as seen. Rather, they generate food-for-thought, a catalyst for a home owner or a designer to consider in constructing their home for long term energy efficiency.

The context both the physical and the climatic play a significant role in the decision making process. The design for energy efficient residences cannot be completed successfully without consideration of the context. Each building plot and therefore the residence built upon it becomes a unique set of circumstances, thus, generating a unique set of decisions for living and energy efficiency that cannot be generalised in the typical models demonstrated here.

6.1. Single Storey Residence

Objective

To represent a Single Storey Residence on a larger plot of land. A typical sub-urban scenario in the Sri Lankan context.

Design rationale

A typical rectangular form minimizing East and West façade exposure.

Land / Plot Area

400 m^2 (15 to 16 perch)

Footprint area of the residence

135 m^2

6.2. Two Storey Residence

Objective

To represent a Two Storey Residence on a typical urban plot of land.

Design rationale

A typical rectangular form minimizing East and West façade exposure.

Land / Plot Area

250 m^2 (9 to 10 perch)

Footprint area of the residence

150 m^2

6.3. Ground Plus Three Storey Residential Block

Objective

To represent a Four Storey (walk-up) Residence on a typical urban plot of land. An increasingly common scenario in fast developing Colombo. A typical rectangular form minimizing East and West façade exposure.

Design rationale

A typical rectangular form minimizing East and West façade exposure, in two distinct blocks, representing a typical courtyard form.

Land / Plot Area

400 m^2 (15 to 16 perch)

Area of an individual residence

115 m^2

Total area of the residential block

1,000 m^2

Area of an individual residence

150 m^2

Generic Model - Single Storey Residence

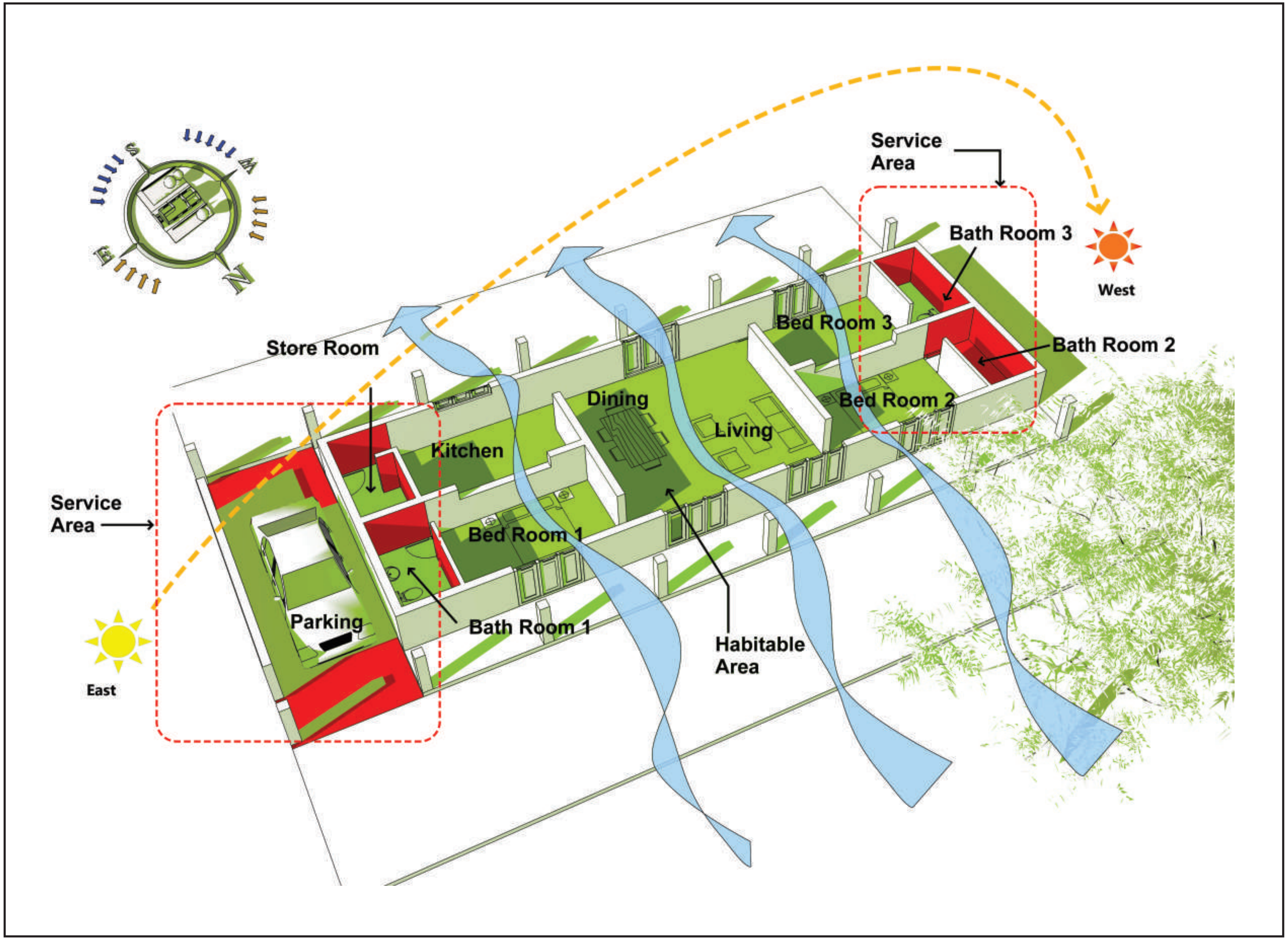


Fig | 52: Plan Form - Single Storey Residence

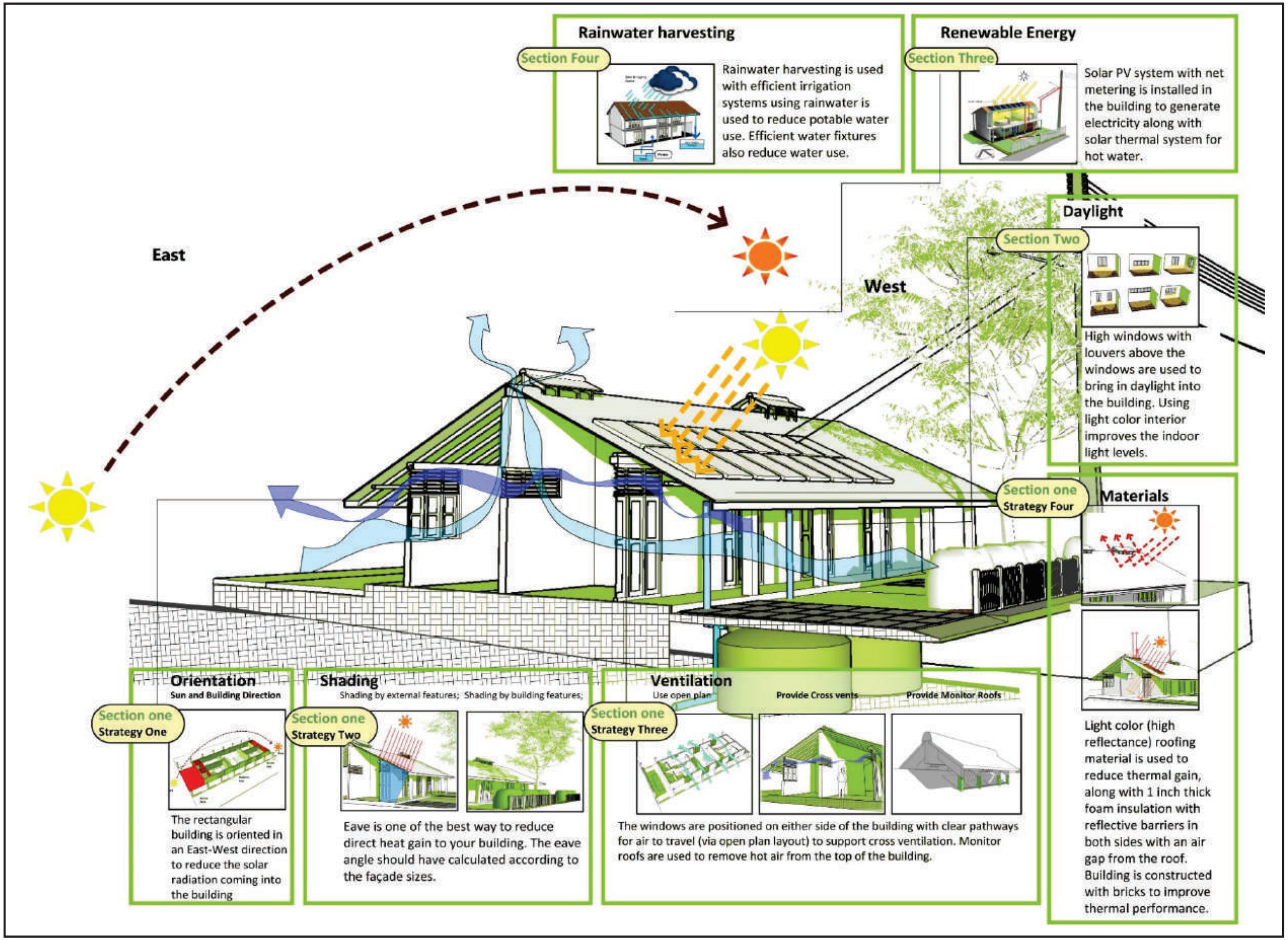


Fig | 53: Common Passive Design Strategies illustrated for Single Storey Residence

Generic Model - Two Storey Residence

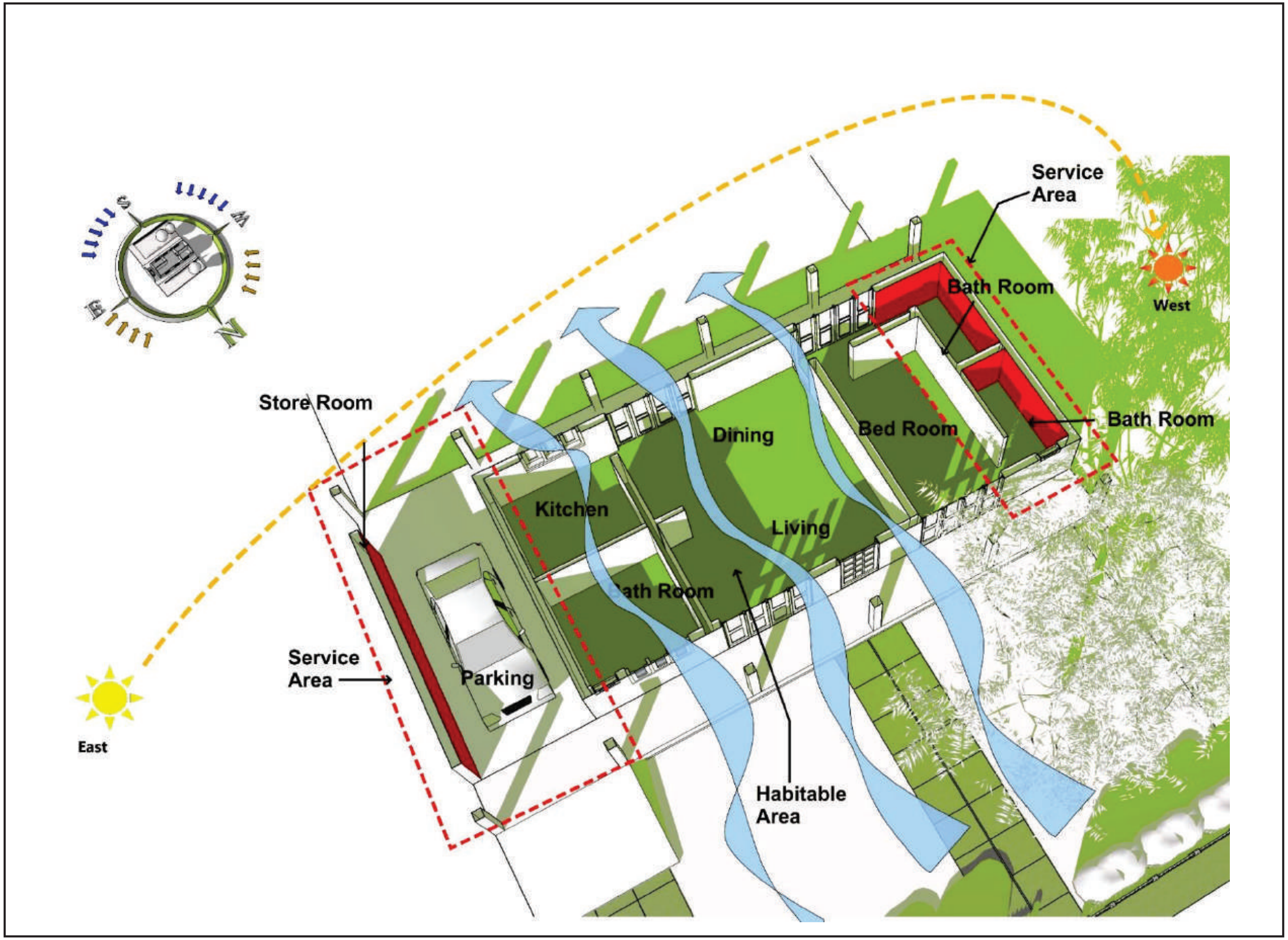


Fig | 54: Plan Form - Ground Floor Two Storey Residence

Fig | 55: Plan Form - First Floor Two Storey Residence

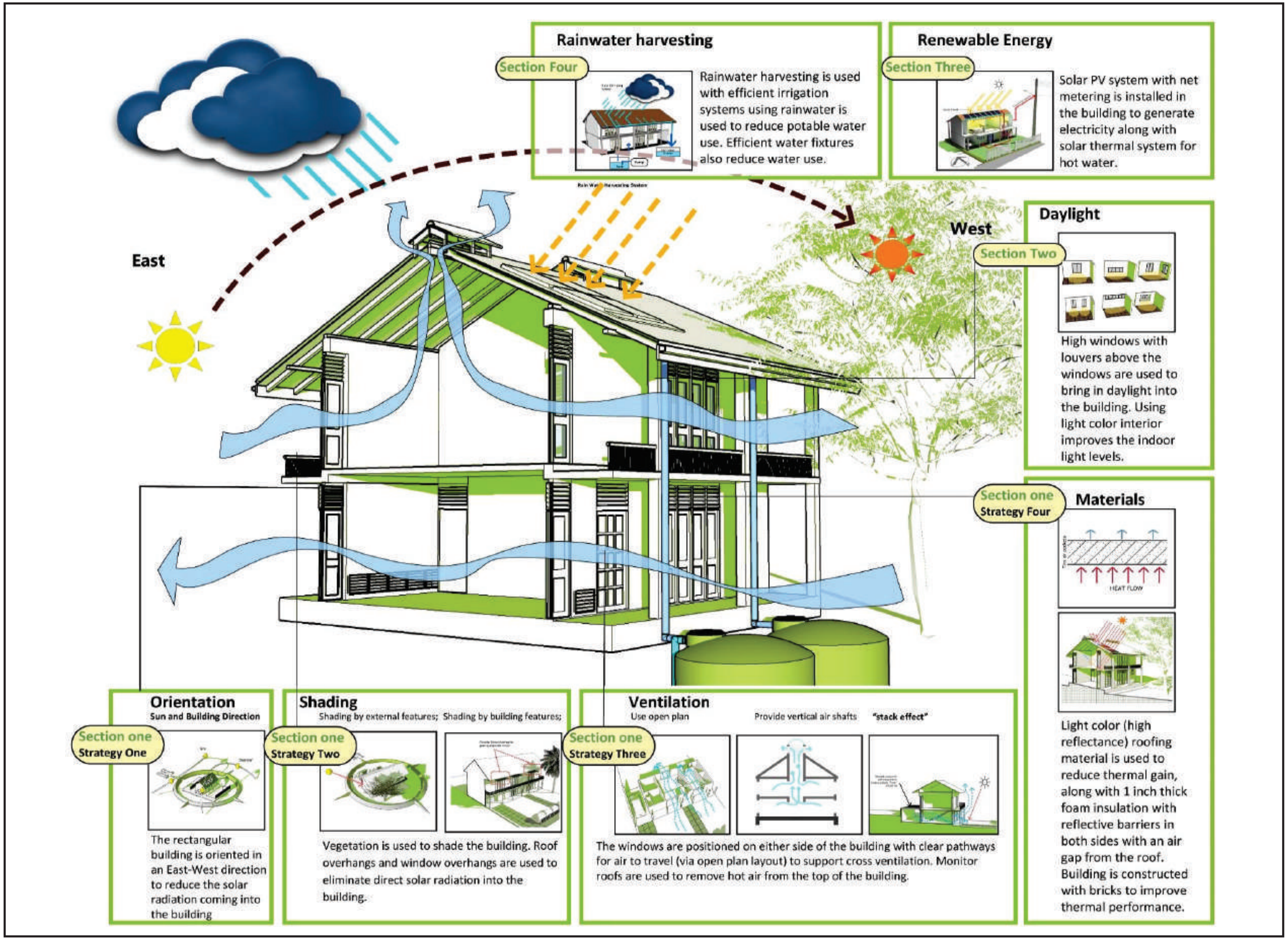


Fig | 56: Common Passive Design Strategies illustrated for Two Storey Residence

Generic Model - Ground Plus Three Storey Apartment Building

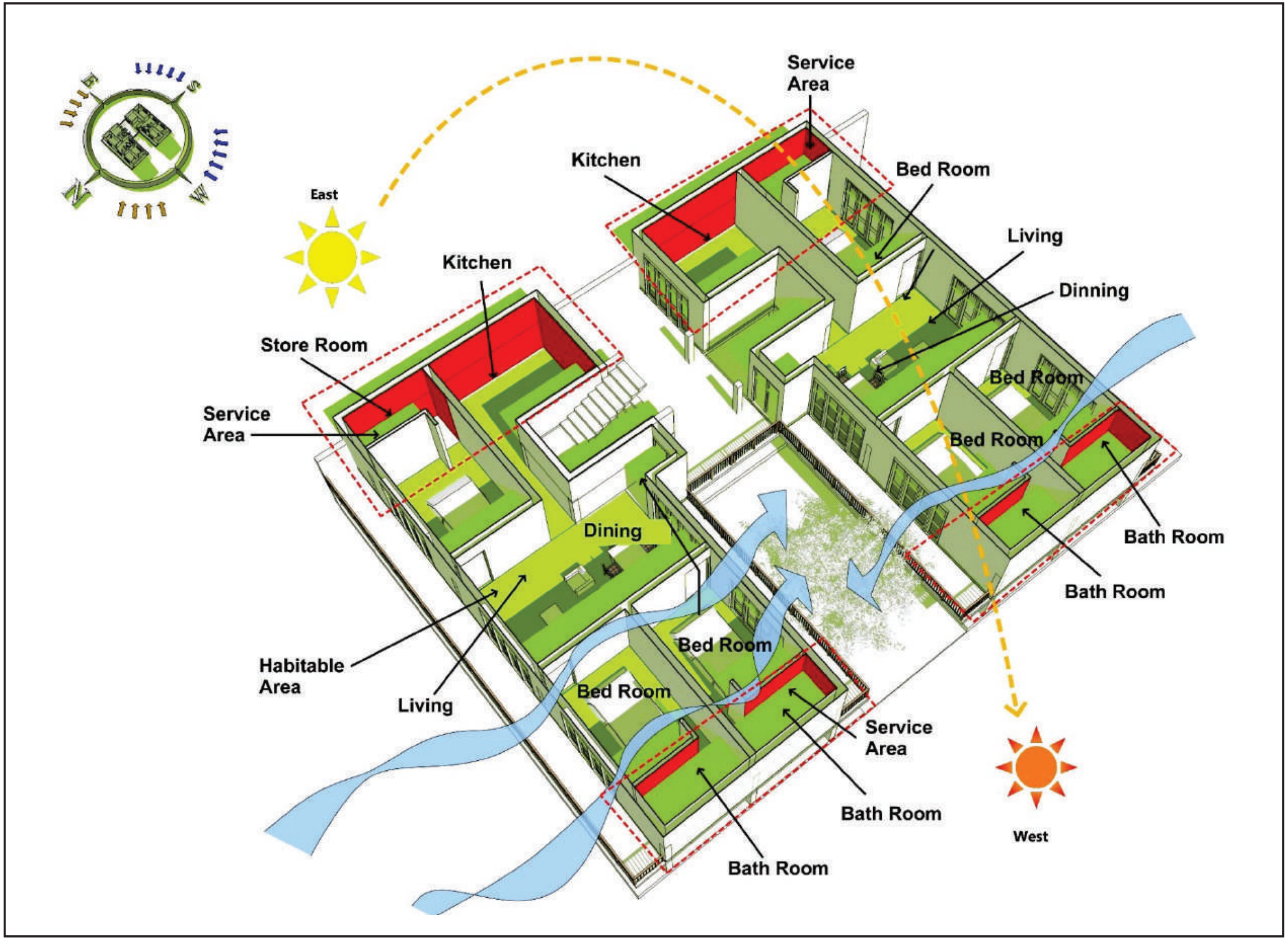


Fig | 57: Plan Form Typical Apartment

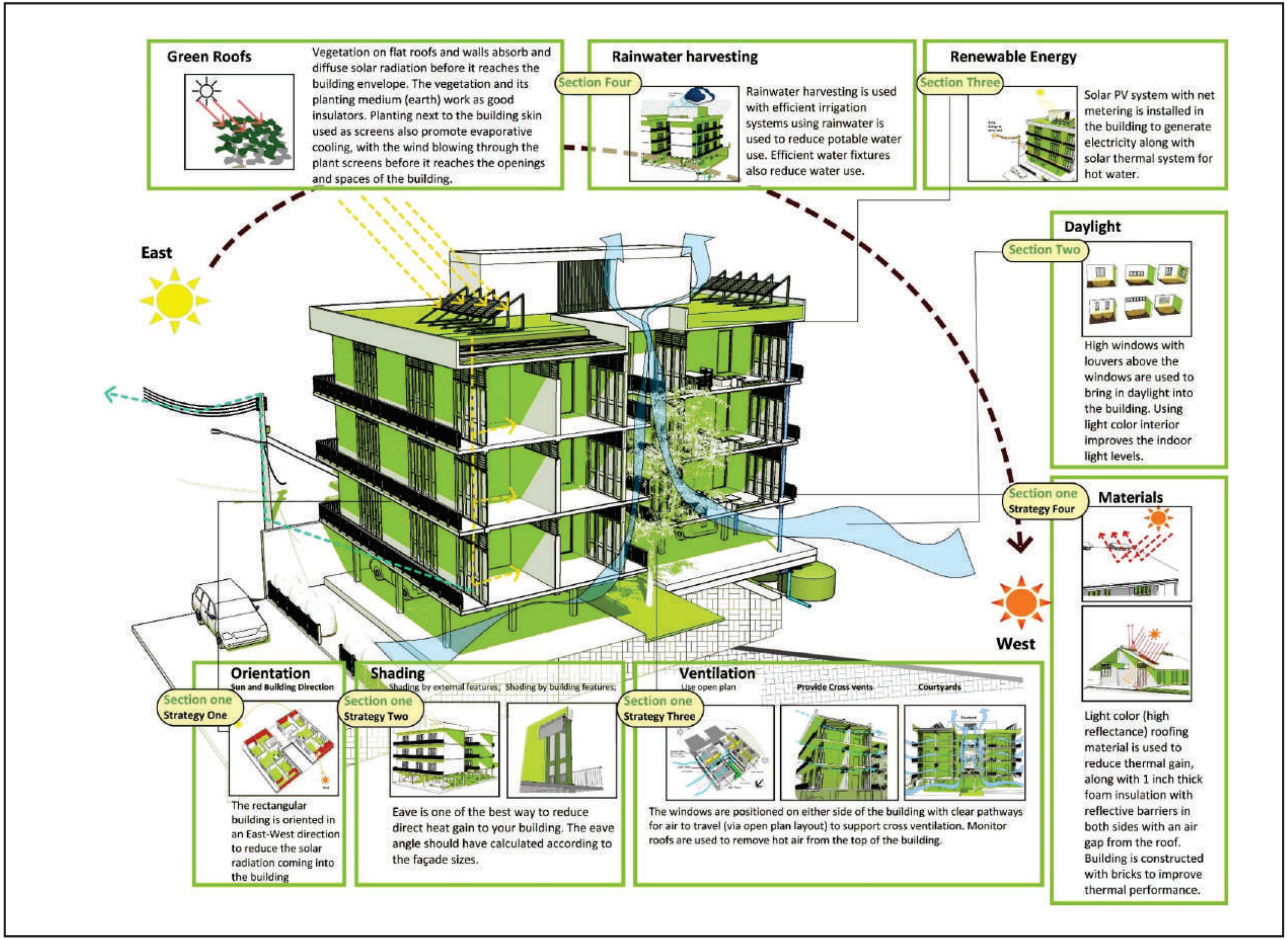


Fig | 58: Common Passive Design Strategies illustrated for Apartment Building

Glossary

Azimuth	–	azimuth is the angle on the horizontal plane that the projection of the suns position makes with the north or south direction of the location
Altitude	–	angle on the vertical plane that the sun makes with the horizontal plane of the location
Brise soleil	–	an external architectural feature that blocks the sun from the building. This acts as a projection from the surface that needs to be blocked from the sun. Can take various shapes including patterns or geometric shapes
Clerestory	–	windows that are located above eye level with the intention of bringing natural light into the building
Cross ventilation	–	a form of ventilation that allows the air to pass through the building with openings for entry and exit of air
Eave	–	a projecting overhang at the lower edge of a roof
Evacuated Tube	–	type of a solar thermal collector that uses evacuated heat pipe tubes as absorbing surface
Evaporative cooling	–	cooling induced by evaporation of water. This occurs naturally next to a water body.
Fenestration	–	window
Illuminance	–	a measure of rate of light quantity on a surface area
Solar PV	–	Solar cells and arrays, (solar panels) that convert sunlight into dc electrical energy
Solar surface	–	the surface which mostly affected by the direct sunlight
Stack effect	–	movement of air inside a building due to air buoyancy primarily driven by temperature differences
Sun path diagram	–	representation of principal parameters enabling identification of the location of the sun for a given time and day of a calendar year
Thermal comfort	–	state of mind which expresses satisfaction of occupants with the thermal environment
Thermal mass	–	thermal inertia or capacity effect of material to heat flow

References

Watson, D. and Labs, K. (1983) Climate Design: Energy Efficient Building Principles and Practices. McGraw-Hill, New York, 37

Brown, G. Z. (1985). Sun, wind, and light: Architectural design strategies. New York: Wiley.