CHAPTER 10:
DESIGN STRATEGIES FOR
HOT & DRY CLIMATIC ZONE
OF RAJASTHAN
10.1 INTRODUCTION

Rajasthan having mostly hot-dry climate zone & partly composite climate zone needs to have an integrated approach towards planning & designing of affordable, sustainable & eco-friendly buildings.

Broadly affordable, sustainable & energy efficient buildings should have the following properties:

1. Should use less water
2. Should be energy efficient
3. Should conserve natural resources
4. Should generate less waste
5. Should provide healthier spaces for occupants
6. Should be economically viable

Consequent upon studying of various literatures, energy rating codes, case studies related to affordable, sustainable eco homes, experimental studies for affordable materials, analysis through IT tool kit software of an important parameter in design i.e. orientation following design approaches & strategies have been formulated & drawn for hot & dry climate/composite of Rajasthan.
10.2 CLIMATE ZONE

INDIA can be broadly categorized into five regions with distinct climates. These climate zones, as shown in the adjoining map, require special provisions in the functional design of buildings with respect to human thermal comfort and energy efficiency.
### 10.3 GENERAL STRATEGY FOR HOT – DRY / COMPOSITE CLIMATE ZONE

The table below shows the general strategy for the hot-dry climate/composite zone particularly for Rajasthan, which is the focus of the research.

<table>
<thead>
<tr>
<th>Climatic features</th>
<th>Situation in Hot – Dry Climate</th>
<th>General corresponding strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>landscape &amp; vegetation</td>
<td>Sandy / rocky ground with little vegetation; Low water level</td>
<td>Preserve vegetation and conserve water</td>
</tr>
<tr>
<td>Solar radiation</td>
<td>Intense (800 - 950 W/m²)</td>
<td>Shade building especially openings as they admit maximum solar radiation Solar energy generation</td>
</tr>
<tr>
<td>Mean Temperature.</td>
<td></td>
<td>Prevent solar access in summer but allow in winters Insulate building to prevent conduction of heat indoors during the day time Passive measures to reduce heat gain and promote heat loss through vegetation &amp; water bodies.</td>
</tr>
<tr>
<td>Mean relative humidity</td>
<td>Very low (25 - 40 %)</td>
<td>Can use evaporative cooling where water is available</td>
</tr>
<tr>
<td>Annual rainfall</td>
<td>Low &lt; 500mm / yr</td>
<td>Harvest rainwater for use in dry spells</td>
</tr>
<tr>
<td>Winds</td>
<td>Dust laden local winds often developing into sandstorms</td>
<td>Prevent wind infiltration; Avoid wind-induced ventilation during overheated times</td>
</tr>
<tr>
<td>Sky conditions</td>
<td>Cloudless skies with high solar radiation causing glare</td>
<td>Prevent direct radiation ingress and glare into rooms</td>
</tr>
</tbody>
</table>
10.4 SUSTAINABLE DESIGN STRATEGIES FOR HOT & DRY/COMPOSITE CLIMATE OF RAJASTHAN

Sustainable housing design strategy should satisfy following five criteria:

- USE LESS WATER
- IS ENERGY EFFICIENT
- CONSERVES NATURAL RESOURCES
- GENERATES LESS WASTE
- PROVIDES HEALTHIER SPACES

STAGES OF PLANNING & DESIGN

**Sustainable Site Planning**
Utilizing existing infrastructure, laying out building blocks to benefit from existing landform, sun path and wind while minimizing damage to soil, flora, water and air quality.

**Appropriate Landscaping**
Planting the right way to conserve water and improve micro-climate.

**Building Design**
Building & fenestration design, construction details to promote shading, insulation and heat loss.

**Building Materials**
Choosing materials which are local, durable, utilize waste, have low embodied energy content, use less water for processing and help insulate the building.

**Building Energy Use**
Efficient electricity usage and usage of clean energy.

**Building Water Use**
Saving water through efficient fixtures and augmenting water through rain water harvesting & waste water treatment.
10.4.1 SUSTAINABLE SITE PLANNING

10.4.1.1 SITE SELECTION

Site selection is very important & is considered before its layout. Appropriate site for the proposed building should result in less damage of virgin land and less energy expenditure in ‘developing’ a site.

AVOID NATURAL DRAINAGE LINES
- Especially important in sloped sites.
Obstructing natural drainage lines would involve energy use to drain out storm water or risk site flooding.

READY ACCESS TO EXISTING INFRASTRUCTURE
- Electricity supply
- Water supply
- Public transport
Helps reduce need for new infrastructure

10.4.1.2 COMPACT CLUSTER PLANNING
Cluster based planning of the building blocks results in more compact utilities network, reduces damage to existing environment and promotes walk ability. Sharing spaces, services and creating a medium-rise, high density development complements this.

COMPACT ACCESS ROADS AND UTILITIES
- Improve efficiency of movement and feasibility of common maintenance on campuses
- Reduce paved areas on site and consequently reduce heat gain
- Connecting to adjacent structures for common services & access road would reduce servicing costs and improve walk ability

One block shades the other
Possibility of future expansion reduces need for encroaching on Greenfield sites
Shaded spaces
10.4.1.3 BUILDING ORIENTATION

BEST POSSIBLE ORIENTATION OF TYPICAL EXISTING PLANFORMS

ORIENT BUILDING LONG FACES ALONG N-S

N-S orientation can be used in creative ways to generate a variety of built and open spaces.

N-S orientation can also be used in case of unfavorable orientation of land.

ORIENT BUILDING LONG FACES ALONG N-S

High sun angle in summer on the south side. Hence easy to shade.

Low sun angle in winter allows welcome solar access.

Low sun angle on east and west. Difficult to shade in summer.

Minimum radiation on the north side allowing large windows for excellent day lighting.
10.4.1.4 PLANFORM

TYPICAL EXISTING PLANFORMS IN ASCENDING ORDER OF PERIMETER - TO - AREA (P/A) RATIO

In the hot-dry climate, a smaller perimeter-to-area ratio (P/A) would result in less area exposed to radiation and lesser conduction heat gains.

Greater the perimeter-to-area ratio, greater is the heat gain by the building.

Planforms with greater P/A ratio may be applied in certain cases to include features like water bodies & vegetation which can modify the micro-climate. The intermediate spaces can also be effective as interaction spaces.

Wind for night ventilation is welcome.
10.4.1.5 ACTIVITY ZONING

ACTIVITY ZONING FOR VARIOUS PLANFORMS

Most concepts in hot, dry climate focus on decreasing heat gain but adequate daylight is also important. Depending upon the building use, choosing an appropriate plan form and proper activity zoning at the initial design stages can ensure heat gain reduction and optimum day lighting.

This approach is useful in placing service spaces like toilets/storage areas/staircase at locations where they can act as thermal barriers.
10.4.1.6 BUILDING TYPES

Detached
- High exposure to radiation and wind
- Hence shading through various building elements is vital
- New buildings should be placed as close as possible to existing buildings for possibility of shading one another

Row
- Solar gains are reduced due to common walls
- Relevant for barracks and housing

Courtyard
- Courtyards are important for daylight & ventilation and has a cultural significance too
- Ventilation in hot dry climate is useful if the air is cool. Thus the courtyard should be proportioned to be mostly shaded, and/or contain cooling elements like trees, soft paving and water bodies if water is available.

Courtyard effect in traditional settlements
- Shaded street
- Partly shaded courtyard
- Variable sizes create temperature-pressure differential & can induce cross ventilation

LOW-RISE VS. HIGH RISE
- Higher footprint
- Foundation embodied energy is more as multiple floors are not sharing the foundation

- Lesser footprint
- Could be optimum in terms of total energy and shading

- Least footprint
- Higher service energy to move resources and people up and down

Typical modern courtyards
- Courtyard Height- Width (H/W) ratio almost 1:4. Hence courtyard not shaded and no courtyard effect

Possible strategies include:
- Cooling the courtyard by shading (H/W ratio nearing 1:1)
- Shading by verandahs / covered passages or by vegetation
10.4.1.7 PRACTICES AT CONSTRUCTION STAGE

Preserving existing trees with tree guards etc. and protecting their roots from excavation and material storage

Information board about safety and ‘green’ practices and emergency contact numbers

Waste bins for segregating Construction waste

Site roads paved with gravel or brickbats to prevent dust rising up

Appropriate workers’ facilities for resting/ toilets/ Crèche

Segregated material storage to reduce waste & for easier handling. Covered storage where necessary

Pre-planned movement path for materials & labour

Sedimentation tank to collect & reuse surface flow or rainwater. Explore possibility of using treated water for construction.

Strict delineation of excavated / affected area on site from the unaffected areas

Electrical lines separated/ elevated vis-a-vis human/ material movement

Roads/barriers to reduce air pollution and spread of waste materials, loose soil from site

Fire buckets / extinguishers at crucial locations including near electrical input points

CONSERVATION OF FERTILE TOP SOIL ON DELINEATED SPACE

Temporary plants to hold top soil for later use in landscaping

Max. 40 cm. Top soil
Geo textile / other sheet separating top soil from sub soil
Pre-existing sub- soil
10.4.2 APPROPRIATE LANDSCAPING

PLANNING PLANTATION

Less trees on the north to let in daylight. More trees to the NW and NE to cut off summer radiation.

Trees close to building on the east with moderate spacing help in shading.

Trees act as noise and dust barrier.

Trees prevent infiltration of dust laden hot summer winds.

Deciduous trees on the south side for shading in summer and solar access in winter.

Preserve existing vegetation as they are a ‘free’ micro-climate modifier. Promote native species needing less water.

REDUCING URBAN HEAT ISLAND EFFECT (UHIE) TO COOL BUILDINGS & SURROUNDINGS

Roof surfaces absorb the highest heat.

Paved surfaces absorb heat and the reflected heat is absorbed by surrounding building surfaces thus increasing heat gain.

Use roof finishes with high albedo.

Shade parking area & pavements through pergola, vegetation, photovoltaics etc.

Light colored wall surfaces will absorb less heat.

Increase soft paved area.

ALBEDO: refers to surface reflectivity of various materials.
Higher the albedo, more reflective the material.
Dark surfaces: 0.1 - 0.3
White-coloured (e.g. white-washed) surfaces: 0.7 - 0.8
High reflective paints: 0.8 - 0.9
White ceramic tiles: 0.7
Heat resistant terrace tiles: 0.7

PROMOTING GROUNDWATER RECHARGE
Reducing paved areas and using pervious paving reduces UHI effect and improves groundwater recharge. Such paving can be used in walkways, pavements, vehicular roads within the site, ramps, etc.

Concrete grid paver
Sand compact sub-base
Gravel
Compact sub-soil base
10.4.3 BUILDING DESIGN

10.4.3.1 SHADING STRATEGIES FOR BUILDING & OPENINGS

Shading is the most important building design strategy for comfort in the hot-dry climate. Shading of openings like windows is very important and in any case the Window-Wall-Ratio (WWR) should not be more than 60%. Effective day lighting is possible with a much lower WWR.

Shading of window and wall surface by small screens.

Shading of building surface by vegetation.

Shading of building surface by surface texture.

Shading of building surface by architectural projections.

Jharokhas are an architectural heritage of the region and provide effective shading. A Jharokha window on the south also cuts out the east-west sun.

Besides shading, utilizing Double Glazed Units (DGUs) help insulate the window panel and reduces large heat ingress which would otherwise enter the living space.

**ORIENTATION BASED SHADING STRATEGIES**

Larger windows could be placed on the north facade as direct solar radiation is least on this facade. Radiation from low sun during peak summers can be cut off by small vertical shades.

Light shades help in deeper penetration of daylight into the room & uniform distribution of daylight of light.

On the west closely spaced vertical shades cut out the low evening sun. As the heat built up during the day is already present, minimization of openings is desirable.

Windows must be small on the east and west sides and must be adequately shaded.

Larger windows can be placed on the south side but is relatively easier to shade the south side from the high summer sun with a horizontal sun-shade. This can also allow desirable winter sun.
10.4.3.2 SHADING FROM SUN PATH DIAGRAM

Shading from the sun and well designed shading devices are a primary need in the hot-dry climate. It is well established that a majority of the solar heat gain comes from radiation through openings. When designing shading devices for windows, the required horizontal and vertical shadow angles need to be established. They are dependent on both the orientation of the window plane and the sun path.

**Horizontal shadow angle (HSA: characterizes the vertical shading device)** This is the horizontal angle between the normal of the window pane or the wall surface and the current sun azimuth angle. It is relevant for designing vertical shading devices such as fins.

**Vertical shadow angle (VSA: characterizes the horizontal shading device)** This is the angle that a virtual plane containing the bottom two points of the wall/window and the centre of the Sun makes with the ground when measured normal to the window plane. It is required when designing horizontal shading devices such as overhangs.

**Calculating HSA & VSA from Sunpath Diagram**

E.g. Sunpath Diagram of Jodhpur, Rajasthan (26.29° N, 73.03° E). The following diagram is also called a stereographic projection which showcases the movement lines of the sun relative to a location on earth.

- **HSA** = solar azimuth - window orientation
- **VSA** = \( \tan^{-1}\left(\tan(\text{solar altitude}) / \cos(HSA)\right) \)

**Shading**

- Azimuth line (the sun's position vis-a-vis the north direction)
- Altitude lines (shows the sun's elevation over the horizon)
- Lines showing the sun's movement on a certain day of the year
- Lines showing the hour of the day on the day's sun path
10.4.3.4 FENESTRATION SHADING DEVICE DESIGN

Example of shading device design on south and west facades of building located in Jodhpur, Rajasthan (26.29° N, 73.03° E)

STEP 1
Determine the cut-off dates i.e. the over-heated period of the year when the window is to be completely shaded. During this period the date of longest and shortest sun-path is recorded, i.e. the two extremities of the sun-path.

In Jodhpur, for e.g., the cut-off dates are taken as 1st April to 31st August. Within this period, the longest sun path is recorded on 21st June and the shortest sun path on 1st April.

STEP 2
Determine the start and end times representing the times of day between which full shading is required for different facades. It should be kept in mind that the closer to sunrise and sunset these times are, the exponentially larger the required shade.

In Jodhpur, for e.g.,
West facade = 12 noon - 5pm
The shades for this face are designed for the longest sun path within the over-heated period i.e. 21st June.

South facade = 11am - 5pm
The shades for this face are designed for the shortest sun path (sun travels low in the sky) within the over-heated period i.e. 1st April. These two periods together avoid direct sun completely in the overheated period.

STEP 3
Look up the sun position using sun-path diagrams to obtain the azimuth and altitude of the sun at each time on the designated day for facades of different orientations.

In Jodhpur, for e.g., from the sun path diagram
Sun position 5pm, 21st June = -77.4° or 282.6° Azimuth / 31.5° Altitude (for designing shading device for the west facade) Sun position 1pm, 1st April = -165.7° or 194.3° Azimuth / 69.5° Altitude (for designing shading device for the south facade) Similarly, the sun positions are recorded for every half hour interval on the designated day for facades of different orientations.
10.4.3.4  FENESTRATION SHADING DEVICE DESIGN (CONT.)

**EFFECTIVE SHADING DEVICE DESIGN**

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Effective shading</th>
</tr>
</thead>
<tbody>
<tr>
<td>South</td>
<td>Fixed horizontal device or window recessing.</td>
</tr>
<tr>
<td>West and East</td>
<td>Vertical device/louvre (possibly moveable). East/West faces are difficult to shade with fixed shades as the sun is very low. Hence only small windows are recommended. External moveable shades/rollable blinds are more effective than fixed shades. These also help preserve the view from the windows.</td>
</tr>
<tr>
<td>North side</td>
<td>Generally not required except from low evening sun in peak summer when the sun path is long and hits the North from the side. Cutting this out can be achieved by vertical shades.</td>
</tr>
</tbody>
</table>

**STEP 4**

Calculate HSA and VSA at different times during designated period for each facade. We need to design a shading device for the lowest possible VSA (horizontal shade) and the lowest possible HSA (vertical shade).

**EXAMPLE**

In the west facade, one can design vertical shades for which the HSA is calculated. The lowest HSA is found to be at 2:30pm (0.5°). Designing for this HSA would result in very large shades. Hence the shading device is designed for an intermediate sun position. The HSA at 1:30 pm and 5 pm is about 12°. But at 5 pm, the altitude angle of the sun is less (31.5°) and the facade can be shaded by vegetation. Hence, in this case, the shades will be designed for the sun position at 1:30 pm.

Sun position 1:30 pm, 21st June = -101.3° or 258.7° Azimuth / 78.2° Altitude

HSA = solar azimuth - window orientation
     = 258.7 - 270 = -11.3°

In the south facade, we shall design horizontal shades for which the VSA is calculated. The lowest VSA is found to be at 1 pm (70.1°).

(These shades are designed for the lowest sun path within the overheated, summer period. The sun path is lower in winter but during this period solar ingress is preferable)

Sun position 1 pm, 1st April = -165.7° or 194.3° Azimuth / 69.5° Altitude

HSA = tan^-1(tan(solar altitude) / cos(HSA))
     = tan^-1(tan(69.5) / cos(14.3)) = 70.1°.

**FENESTRATION SHADING DEVICE DESIGN**

**Step 5** Calculate required depth of shade.

For west facade

Shading by single vertical shade is not feasible as the shade depth becomes prohibitive. Hence the width is subdivided and several louvers are designed. If 6 divisions are created, i.e. effective width to be shaded is 250mm

depth (d) = width / tan (HSA)
         = 250 / tan (11.3°)
         = 250mm

This depth can be reduced much further by designing the louvers at an angle. As mentioned earlier, on the west facade fixed shades will not shade the window at all times. Movable louvers or shading by trees could be better.

For south facade

If two horizontal louvers are used then,

Depth (d) = Height / tan (VSA)
         = 850 / tan (70.1°)
         = 300mm
10.4.3.5 **DAY LIGHT DISTRIBUTION**

An integrated design approach utilizes indirect radiation for day lighting and avoids the heat of direct radiation.

**Room & Opening dimensions for appropriate day lighting**

For spaces where regular windows are not required higher clerestory windows can be a suitable daylighting option.

**LIGHTSHELVES / SHADING DEVICES**

Since in the hot, dry climate a compact building approach would reduce the sky dome available for daylighting, daylight penetration can be enhanced by use of lightshelves.

**REFLECTANCE OF INTERNAL FINISHES**

For better daylight distribution, the reflectance of the internal surfaces should be higher. Secondly, full-height partitions to be minimized in favors of open office plans where more people can share the natural light & ventilation from a window.

<table>
<thead>
<tr>
<th>Typical finishes of surfaces</th>
<th>Reflectance</th>
</tr>
</thead>
<tbody>
<tr>
<td>White wash</td>
<td>0.7 - 0.8</td>
</tr>
<tr>
<td>Cream colour</td>
<td>0.6 - 0.7</td>
</tr>
<tr>
<td>Light green</td>
<td>0.5 - 0.6</td>
</tr>
<tr>
<td>Light blue</td>
<td>0.4 - 0.5</td>
</tr>
<tr>
<td>Light pink</td>
<td>0.6 - 0.7</td>
</tr>
<tr>
<td>Dark red</td>
<td>0.3 - 0.4</td>
</tr>
<tr>
<td>Medium grey</td>
<td>0.3</td>
</tr>
<tr>
<td>Cement terrazzo</td>
<td>0.25 - 0.35</td>
</tr>
<tr>
<td>Brick</td>
<td>0.4 - 0.5</td>
</tr>
<tr>
<td>Vegetation (mean value)</td>
<td>0.25</td>
</tr>
</tbody>
</table>

**DISTANCE BETWEEN BUILDINGS FOR DAYLIGHT INGRESS**

Ideally for daylight penetration, the lowest floor windows should subtend a maximum angle of 22.5° with the top of the adjacent building/object. But for regulating heat radiation, a closer fit would help.
10.4.3.6 PASSIVE COOLING STRATEGIES

Passive cooling strategies need to be incorporated at the design initiation stage based on the planned organization of spaces in the building. This will ensure minimum HVAC loads even if any active cooling systems are desired.

Evaporative cooling
Evaporative cooling works well in the hot-dry climate as humidity is low in this zone.

Wind catcher
Water bodies outside or in courtyard for cooling the air. Water bodies should be shaded to minimize evaporation losses.

Central Wind Tower
Central wind tower system with water spray on top. Useful for cooling double loaded corridors. Very acceptable method as humidity is welcome.

Earth Air Tunnel System
This system is viable if the ground below has good thermal capacity, for e.g. soil with adequate water content. The design

Night ventilation
Night ventilation works well in this climatic zone as diurnal variations are high. In this process, buildings are ventilated at night when ambient temperatures are lower to resist heat build-up.

Earth berming
Earth berming reduces outside air infiltration, keeps temperatures cool in summer and warm in winter as the earth's temperature at a depth of a few meters remains almost stable throughout the year. Berms may cover a part of the ground floor, sometimes entire buildings, provided daylight and ventilation requirements are taken care of. Needs adequate water-proofing measures. Basements are similarly cool and preferred spaces.

Thermal mass
A building envelope with higher thermal mass will retard heat transfer from the exterior to the interior during the day. When temperatures fall at night, the walls re-radiate the thermal energy back into the night sky. Extensively used in traditional buildings in the region.
10.4.4 BUILDING MATERIALS

10.4.4.1 SELECTION CRITERIA

- Stones from sustainable mines:
  Better mining practices, less air pollution, reuse of mine waste and mine land.

- Reuse of mine waste, like use of stone dust and chips to make concrete blocks, also helps reduce air & land pollution.

- Salvaged timber, reused wood, particle boards etc. reduce use of new wood & saves trees.

EEV of flyash blocks = 2.32 MJ/brick
EEV of stabilised earth block = 2.79 MJ/brick
Even though A flyash block has lesser EEV, it is more efficient only if it travels less than 50 km

EEV of Material 1 = 90 MJ/sq.m; Life = 80 yrs.
EEV of Material 2 = 72 MJ/sq.m; Life = 40 yrs.
2x durability of Material 2 means 1/2 energy for extraction, processing, installation & disposal

PPC has lower embodied energy due to fly ash content which is waste from thermal power plants. It can be used in both structural concrete and plaster mortar.

- Stabilised earth block has less embodied energy vis-a-vis bricks as bricks use higher energy for firing.
  EEV of CSEB = 138 MJ/sq.m of wall
  EEV of brick = 681 MJ/sq.m of wall

- Waste glass is used in the manufacture of glass. Used marble chips used in the manufacture of terrazzo reduce embodied energy.

- Ability to reuse with minimum processing.

- Use of low VOC paints, adhesives and sealants.

- Insulation, free of CFC and HFC which have ozone depleting properties.

- If material unavailable, skills do not help. But if material available, skills can be created by training programs.

- Stone is a local material in Rajasthan and the related expertise and craftsmanship is also available.

R value 2.12;
- High EE due to XPS
- Low EE
- Lowest EE

UPVC windows are more insulating than Aluminium windows.

Iron is superior to Aluminium in terms of ease with which it can be recast and reutilized.

Green material depends on the selection criteria applied. In utilizing these 8 selection criteria (from A to G), but the priority needs to be given for the upper one than the lower one if one needs to choose between the two. See example in boxes which illustrate the criterion in more detail.
10.4.4.2 MATERIAL PROPERTIES

Thermal mass:
Thermal mass: the ability of a material to absorb heat energy. This heat storing capacity of building materials helps achieve thermal comfort conditions by providing a time delay to the flow of heat. High density materials, like concrete, brick and stone have high thermal mass. Thermal mass is most appropriate for climates with a diurnal variation of more than 10°C.

Thermal insulation:
Thermal insulation: the reduction of heat transfer through a material. Heat flow is a consequence of contact between objects of differing temperatures. Insulation reduces thermal conduction thus reducing unwanted heat loss or gain.

The insulating capability of a material is measured with thermal conductivity (k). Low thermal conductivity is equivalent to high insulating capability (R-value).

Thermal mass & Thermal insulation in Hot-Dry Climate:
High thermal mass materials, without insulation, can radiate heat all night during a summer heatwave, or absorb all the heat produced on a winter night.

Use of insulation with low thermal mass materials will not be effective in keeping indoor temperatures comfortable. It can trap heat within the building envelope.

High mass construction with high insulation levels is the most effective strategy to reduce heat gains and should be used with proper shading. In the hot-dry climate, insulation should be on the external side with the high mass material on the inside, protecting it from the summer sun.

<table>
<thead>
<tr>
<th>EMBODIED ENERGY TABLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
</tr>
<tr>
<td>230mm thick. Red clay Brick wall</td>
</tr>
<tr>
<td>300mm thick. Stone wall</td>
</tr>
<tr>
<td>300mm thick. AAC wall</td>
</tr>
<tr>
<td>230mm thick. FAL G wall</td>
</tr>
<tr>
<td>50mm thick. XPS</td>
</tr>
<tr>
<td>50mm thick.PUF</td>
</tr>
<tr>
<td>50mm thick.EPS</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MATERIAL PROPERTIES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MATERIAL R VALUE TABLE</strong></td>
</tr>
<tr>
<td>Material</td>
</tr>
<tr>
<td>230mm thick. Brick wall</td>
</tr>
<tr>
<td>300mm thick. Stone wall</td>
</tr>
<tr>
<td>300mm thick. AAC wall</td>
</tr>
<tr>
<td>230mm thick. FAL G wall</td>
</tr>
<tr>
<td>75mm thick. Rockwool</td>
</tr>
<tr>
<td>50mm thick. XPS</td>
</tr>
<tr>
<td>50mm thick. EPS</td>
</tr>
<tr>
<td>50mm thick.PUF</td>
</tr>
<tr>
<td>75mm thick. Inverted kulhar in lime concrete</td>
</tr>
<tr>
<td>25 - 100mm air cavity</td>
</tr>
</tbody>
</table>

**Surface Air film resistances:** These are added to the material R value
- Outside surface (vertical) = 0.04 m².K/W
- Inside surface (vertical) = 0.13 m².K/W
- Outside surface (horizontal) = 0.06 m².K/W
- Inside surface (horizontal) = 0.16 m².K/W

**Note:** Values used are indicative & may vary slightly based on exact material property.

**Embodied energy (EE):**
It is the sum of all the energy required to produce a material, considered as if that energy was incorporated or "embodied" in the material itself. Units MJ / kg or MJ / m² (MJ= Megajoules)

(Note: Values used in this document do not include the energy of transporting materials to site which will vary based on location.)
10.4.4.3 HEAT INGRESS

REDUCING HEAT INGRESS THROUGH WALL

The choice of materials must optimize between the insulation provided & the embodied energy of the material based on its local availability.

R-value calculation example:
Wall assembly 5: 300mm thk. stone wall + 70mm air cavity + 115mm brick Wall + 12mm plaster one side

<table>
<thead>
<tr>
<th>Material</th>
<th>Resistance: R-value (m².K/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside air film</td>
<td>0.04</td>
</tr>
<tr>
<td>300mm thk. stone</td>
<td>0.08</td>
</tr>
<tr>
<td>70mm air cavity</td>
<td>0.18</td>
</tr>
<tr>
<td>115mm thk. brick wall</td>
<td>0.19</td>
</tr>
<tr>
<td>12mm plaster</td>
<td>0.02</td>
</tr>
<tr>
<td>Inside air film</td>
<td>0.13</td>
</tr>
</tbody>
</table>

R value of the wall assembly = Sum of the component R-values = 0.64 m².K/W

ECBC recommended R value for wall assembly = 2.27 m².K/W

Add-on insulation should be judiciously used especially in the case of non-conditioned buildings with cost constraints and need to keep embodied energy low.

WALL ASSEMBLY 1
300mm thk. stone wall + 12mm plaster one side
EE= 644 MJ / m²
R value= 0.27 m².K/W

WALL ASSEMBLY 2
300mm thk. brick wall + 12mm plaster both sides
EE= 711 MJ / m²
R value= 0.59 m².K/W

WALL ASSEMBLY 3
rat-trap bond + 12mm plaster both sides
EE= 365 MJ / m²
R value= 0.70 m².K/W

WALL ASSEMBLY 4
230mm brick wall + 70mm air cavity + 115mm brick Wall + 12mm plaster both sides
EE= 1052 MJ / m²
R value= 0.95 m².K/W

WALL ASSEMBLY 5
300mm stone wall + 70mm air cavity + 115mm brick Wall + 12mm plaster one side
EE= 986 MJ / m²
R value= 0.64 m².K/W

WALL ASSEMBLY 6
230mm FAL wall + 70mm air cavity + 115mm brick Wall + 12mm plaster
EE= 318 MJ / m²
R value= 1.80 m².K/W

WALL ASSEMBLY 7
20mm stone cladding + 300mm AAC + 12mm plaster
EE= 272 MJ / m²
R value= 2.27 m².K/W

WALL ASSEMBLY 8
230mm brick wall + 50mm XPS + 115mm brick Wall + 12mm plaster both sides
EE= 1194 MJ / m²
R value= 2.51 m².K/W

WALL ASSEMBLY 9
3D Eco wall: 50mm shotcrete + 100mm EPS + 50mm shotcrete (reinforced with wiremesh)
EE= 470 MJ / m²
R value= 3.00 m².K/W
REDUCING HEAT INGRESS THROUGH ROOF

(C) INSULATE

**ROOF ASSEMBLY 1** ([EE excluding that of 100mm RCC slab = 506.44 MJ/m²](#))

- RCC slab + 50mm (avg. thickness) brickbat coba + 20mm cement mortar finish
- \[ EE = 185 \text{ MJ/m}^2 \]
- \[ R \text{ value} = 0.39 \text{ m}^2\text{K/W} \]

**ROOF ASSEMBLY 2**

- RCC slab + 75mm mud phuska + 20mm cement mortar finish
- \[ EE = 36 \text{ MJ/m}^2 \]
- \[ R \text{ value} = 0.40 \text{ m}^2\text{K/W} \]

**ROOF ASSEMBLY 3**

- RCC slab + 75mm Inverted earthen pot in lime concrete + 20mm cement mortar finish
- \[ EE = 74 \text{ MJ/m}^2 \]
- \[ R \text{ value} = 0.60 \text{ m}^2\text{K/W} \]

**ROOF ASSEMBLY 4**

- RCC slab + 75mm brick laid at intervals of 230mm c/c + brick tile covering + 20mm cement mortar finish
- \[ EE = 300 \text{ MJ/m}^2 \]
- \[ R \text{ value} = 0.60 \text{ m}^2\text{K/W} \]

**ROOF ASSEMBLY 5**

- RCC slab + 100mm PUF + waterproofing + Marble crazy
- \[ EE = 419 \text{ MJ/m}^2 \]
- \[ R \text{ value} = 4.48 \text{ m}^2\text{K/W} \]
10.4.4.4 MATERIAL USAGE

MATERIAL USAGE: GOOD PRACTICES

- Possibility of thermal bridging
- Jalis in the roof parapet allows air movement over the hot roof surface comparatively cooling down in day-time and increase speed of heat loss in night-time
- Continuous cavity reduces possibility of thermal bridging
- 20mm stone jamb for windows. The reduced thickness minimizes thermal bridging
- 300mm thick stone wall
- 115mm thick brick wall
- Recessing windows affords shading and creates ancillary storage spaces on the side
- Storage space
- Storage space
- Continuous cavity overlapping with the beam would minimize thermal bridging
- Metal ties will act as thermal bridge. Plastic ties better
- Placing insulation outside the wall is better as it increases the time lag of the wall assembly & prevents heat ingress at source
- Avoid thermal bridging by taking insulation below parapet wall and meeting with wall insulation on the exterior of the walls
- Detail to overlap AAC wall on beam to minimize thermal bridging through beam
10.4.4.5 LOW ENERGY OPTIONS

FERROCEMENT
(EE= 111 MJ / m²)
A versatile form of RCC possessing unique properties of strength and durability. Made up of rich cement mortar and wire mesh reinforcement, it has a high ratio of strength to weight. A cost-effective material, it also enables faster construction and has lower embodied energy in comparison to conventional RCC due to its thin section & minimization of steel.

CLC (CELLULAR LIGHTWEIGHT CONCRETE) & AAC (AERATED AUTOCLAYED CONCRETE) BLOCKS
(EE= 215 MJ / m² for wall thickness 300mm)
CLC and AAC blocks are air-cured lightweight concrete with fly-ash as a major ingredient. The difference lies in the process of generation of air bubbles. In CLC the air bubbles are generated in the form of a foam while in AAC they are produced from a reaction that uses aluminum powder. These light-weight blocks reduce structural steel requirement and provides higher thermal insulation. As it uses fly-ash which is a waste material it leads to substantial material saving and has lower embodied energy.

PERFORATED BRICK MASONRY
These are high strength hollow bricks with 50-60 percent perforations. These perforations act as sound and heat insulators and saves materials.

ALTERNATIVE LOW ENERGY OPTIONS

PRE-STRESSED SLAB
This helps in reduction of section of slab. Pre-stressed slabs are up to 25% lighter than conventional RCC slabs due to a reduction in section size.

SANDSTONE ROOFING
(EE= 196 MJ / m²) An extensively used material, this consists of 25mm thick stone slabs on pre-cast RCC beams or iron sections.

3D ECO WALL
(EE= 470 MJ / m²)
This wall assembly consists of a 100mm EPS panel finished with 50mm shotcrete on both sides, reinforced by wiremesh. The 200mm thick panel saves space and provides excellent insulation. This may be used both for walling & roofing. The EPS can be reduced to 100mm for interior walling.

GEOPOLYMERS
Geopolymers are a class of synthetic aluminosilicate materials with potential use essentially as a replacement for Portland cement. Fly ash based geopolymer concrete has superior strength and mortar / plaster made from it does not require curing. GPC (Geo Polymer Cements) use a host of waste and virgin materials in feedstock. Besides Structural Concrete, GPC can be used also for Building Blocks and Paver Blocks.

CSEB (COMPRESSED STABILISED EARTH BLOCKS)
(EE< 138.6 MJ / m² for 230mm thick wall)
Blocks made of mud stabilised with 5% cement lime and compacted in block-making machines without firing. Compressive strength equal to red clay fired bricks.

FALG (FLY ASH-LIME GYPSUM) BLOCKS
(EE< 202 MJ / m² for 230 thick wall)
These blocks require less mortar, plastering can be avoided, are cost effective and environment-friendly as it avoids use of fertile top soil.

PRE-CAST STONE BLOCKS
Blocks manufactured using waste stone pieces of various sizes with lean cement concrete.

Please note: The embodied energy values taken here are indicative. They do not include transportation energy to deliver material on-site. Values will vary as per exact construction detail utilized.
10.4.5 BUILDING ENERGY

10.4.5.1 STRATEGIES FOR ENERGY EFFICIENCY

A. Control amount of heat reaching building:
- Building orientation, shading by projections, vegetation etc.

B. Minimize carriage of heat through building skin:
- Insulation
- Usage of fixtures and appliances with low equipment power density and efficient BEE rating.
- Keep outdoor equipment like window ACs in shade to improve efficiency.
- Use efficient artificial lighting

C. Reduce internal heat gain and improve daylight

D. Cooling the building through:
- Passive cooling strategies (for non-AC buildings)
- Low energy HVAC technologies (for AC buildings)

ARTIFICIAL LIGHTING EFFICIENCY

1) Use of optimum Lighting Power Density (LPD): It is the amount of electrical power used to illuminate a space. (Expressed in Watts per unit of area)

<table>
<thead>
<tr>
<th>Exterior building LPD (ECBC 2007)</th>
<th>Indoor LPD of common building types (BCBC 2007)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application Area</td>
<td>LPD</td>
</tr>
<tr>
<td>Building entrance with canopy</td>
<td>13 W/m² of canopied area</td>
</tr>
<tr>
<td>Building entrance without canopy</td>
<td>90 W/m² of door width</td>
</tr>
<tr>
<td>Building exit</td>
<td>60 W/m² of door width</td>
</tr>
<tr>
<td>Building facades</td>
<td>2 W/m² of vertical facade area</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2) Selection of efficient lighting fixture on the basis of efficacy (ratio of lumen output to energy input)

<table>
<thead>
<tr>
<th>Lumen efficacy of different lamps</th>
<th>Type</th>
<th>Lamp wattage (W)</th>
<th>Ballast power loss</th>
<th>Total Power (W)</th>
<th>Lamp flux (lumen)</th>
<th>Efficacy (lumen/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incandescent</td>
<td>100</td>
<td>1340</td>
<td>13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TL-D 36W</td>
<td>36</td>
<td>4</td>
<td>40</td>
<td>3250</td>
<td>81</td>
<td></td>
</tr>
<tr>
<td>TL5 HE 14W</td>
<td>14</td>
<td>2</td>
<td>16</td>
<td>1350</td>
<td>84</td>
<td></td>
</tr>
<tr>
<td>TL5 HE 28W</td>
<td>28</td>
<td>2</td>
<td>30</td>
<td>2900</td>
<td>97</td>
<td></td>
</tr>
<tr>
<td>CFL 18W</td>
<td>18</td>
<td>4</td>
<td>22</td>
<td>1200</td>
<td>54</td>
<td></td>
</tr>
</tbody>
</table>

3) Use of controls where possible like master switches, timers, occupancy sensors etc.
10.4.5.2 RENEWABLE ENERGY

RENEWABLE ENERGY FOR ELECTRICITY GENERATION
With the high solar radiation available in the hot, dry climate zone, it is highly recommended to use solar energy to meet at least some part of the building’s electricity demand. The simplest way to generate solar energy is by using stand-alone photo-voltaic (PV) systems with or without storage battery.

SOLAR PHOTO-VOLTAICS INSTALLATION
The ideal orientation for optimal performance of a solar cell is at an angle equivalent to the latitude of the place of installation. Area required for generation of 1 kWp electricity is on an average 12 m² for 15% efficiency panels.

POSSIBILITIES OF PV PANEL PLACEMENT

ENERGY EFFICIENCY & RENEWABLE ENERGY

SOLAR WATER HEATER
Use of solar energy for water heating is one of the most commercialized and easily available options.

| Typical hot water consumption in different buildings (varies as per local criterion) |
|---------------------------------|-----------------|
| Residential                     | 100 litres/day  |
| Office                          | 4 litres/person/day |
| Hostel                          | 30 litres/person/day |
| Dispensary                      | 30 litres/bed/day |

FLAT PLATE COLLECTOR (FPC) VS. EVACUATED TUBE COLLECTOR (ETC)
ETC, though more expensive, is generally more efficient due to better heat absorption and less heat losses. The circular tubes also allows better sun tracking and are better suited for hard water.

Commonly, units are available for 200 litres per day, 500, 1000 and more.
10.4.6 BUILDING WATER

10.4.6.1 RAINWATER HARVESTING (RWH)

Water conservation and reuse is of utmost priority in the hot-dry climate.

**STRATEGIES FOR WATER EFFICIENCY**

- Water efficient landscaping
- Reduce water demand
- Rainwater harvesting and recharge to augment local water resource
- Treatment and reuse of wastewater reduces need for extra municipal water / ground water
- Reduce potable water use

**RAINWATER HARVESTING AND RECHARGE SYSTEM**

- Catchment area on ground
- Jaali on roof to prevent pollutants into water
- First flush device
- Filtration tank
- Recharge system or pervious pavings
- Storage tank for direct use if rainfall frequent and the ground water table is high

**CASCADE SYSTEM RWH FOR RAINWATER REUSE**

- Rainwater from 2nd terrace collected & used on the lower flr.
- Rainwater from 1st terrace collected and used for irrigation etc.

**COMPARISON BETWEEN DIRECT RAINWATER USE & RECHARGE INTO GROUNDWATER**

<table>
<thead>
<tr>
<th></th>
<th>Direct use</th>
<th>Recharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Used if rainfall</td>
<td>Recharge</td>
<td></td>
</tr>
<tr>
<td>frequent</td>
<td>Used if rainfall infrequent</td>
<td></td>
</tr>
<tr>
<td>Used if groundwater</td>
<td>Used if groundwater table is high</td>
<td></td>
</tr>
<tr>
<td>table is high</td>
<td>Used if groundwater table is low</td>
<td></td>
</tr>
<tr>
<td>low to augment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>groundwater resource</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**PRECAUTIONS TO BE TAKEN WHILE HARVESTING RAINWATER**

- Filtration and first flush system essential to prevent entry of contaminants
- Cleaning of tank at the beginning of summer and winter rainfalls

**RAINWATER HARVESTING FOR MULTIPLE BLOCKS**

- Multiple buildings within a cluster can have a common rainwater harvesting system

**RUN-OFF CO-EFFICIENTS FOR VARIOUS SURFACES**

<table>
<thead>
<tr>
<th>Surface type</th>
<th>Run-off co-efficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roofs conventional concrete</td>
<td>0.95</td>
</tr>
<tr>
<td>Concrete / Kota paving</td>
<td>0.95</td>
</tr>
<tr>
<td>Gravel</td>
<td>0.75</td>
</tr>
<tr>
<td>Brick paving</td>
<td>0.85</td>
</tr>
<tr>
<td>Vegetation</td>
<td>0.2 - 0.3 (depending on slope)</td>
</tr>
<tr>
<td>Turf slopes (Lawn)</td>
<td>0.25 - 0.45 (depending on slope)</td>
</tr>
</tbody>
</table>

**RAINWATER HARVESTING POTENTIAL**

- Catchment area (m²) x Annual rainfall (m) x Surface run-off co-efficient

A thumb rule for estimating tank size is to store 15 minutes of peak rainfall. So, if peak rainfall = 90mm/hr, then in 15 minutes rainfall = 22.5mm

Hence, (22.5mm x collection area x run-off co-efficient) would be the optimum tank size for storage.
10.4.6.2 WASTE WATER

**WASTE WATER USE STRATEGY**

- Building water use
- Waste water treatment
- Reuse options

**TOILET FLUSHING**
- Horticulture
- Floor washing
- AC cooling tower make-up

**LOCATION**

The treatment systems can be located within the setbacks around the building depending upon the space availability.

**DEWATS SYSTEM**

If more space is available, further treatment can be incorporated like polishing ponds.

**MULTIPLE BUILDINGS**

Multiple buildings can combine their water treatment systems. In a campus, this is all the more feasible.

**(C) DECENTRALIZED WASTEWATER TREATMENT SYSTEM (DEWATS)**

**PRIMARY TREATMENT (Septic tank)**

**SECONDARY TREATMENT (Anaerobic baffled tank reactor)**

**TERTIARY TREATMENT (Reed bed system / Planted gravel filter)**

**WASTE WATER USAGE**

**Zero discharge is possible by creative treatment and reuse of water, thus reducing load on municipal drains.**

**TECHNOLOGIES FOR SMALL STAND-ALONE PROJECTS:**

**(A) IMPROVED SEPTIC TANK**

Area required (sq.m.): 6 - 8 m² / m²
Capital investment: Rs. 35000 - 50000 / m²
Operation cost: Rs.1000 / year for sludge removal

**(B) EFFECTIVE MICRO-ORGANISMS**

Effective micro-organisms (EM) system has anaerobic organisms introduced to waste water after primary treatment to remove organic content. Using EM reduces sludge in the secondary treatment.

Area required (sq.m.): 3 m² / m²
Capital investment (EM + baffled tank): Rs. 6700 / m²
Operation cost: Rs.12/m² (cost of EM solution)
10.4.7 EXISTING BUILDINGS

STRATEGIES FOR MODIFYING SMALL SCALE EXISTING BUILDINGS

(A) ADD-ON INSULATION ON WALL AND ROOF
Insulation can be added on to the wall and roof, as shown in the examples, to reduce heat ingress into the building.

Insulation added on existing roof
RCC slab + 50mm sloping screed + 75mm XPS + china mosaic
R value = 2.97 m².K/W

(B) ENERGY AUDITS for replacing existing electrical fixtures with efficient ones. This includes...
- Lighting fixtures with higher lumen output and lower heat output
- Lighting fixtures with electronic ballasts
- Other efficient appliances as per the ECBC 2007

(C) WINDOW RETROFITTING involves
- Cleaning out blocked openings which afford natural light
- Shading the window glazing to prevent heat ingress by add-on projections on East, West and South sides
- Adding light shelves, in the interior or exterior, for better daylight distribution

(D) SHADING
- Using spaces like courtyards for add-on shading features. For e.g. adding a shaded porch into the courtyard helps shade the building surface and openings.
- Shading the window ACs also helps provide better performance.

(E) ADD-ON COOLING DEVICES
Passive cooling devices, which consume less energy as compared to air-conditioners, can be incorporated into the building even at a later date. For e.g. Desert coolers / Evaporative coolers

Use of desert coolers is another way of evaporative cooling. Adequately placed coolers can affect the temperatures of large contiguously ventilated spaces.