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RECOMMENDATIONS FOR DESIGNING BUILDINGS WITH A PASSIVE APPROACH FOR WARM AND HUMID CLIMATE OF INDIA.

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Abstract: The study aims to identify the optimum and suitable passive design strategies for designing a building in warm and humid climate of India with the help of a broad literature study in order to bring down the indoor temperatures and reduce the overall energy consumption. The climate study is taken into consideration to find out the physiological objectives on which the techniques can be optimized. It is found that the major discomfort is caused by humidity which can be catered by strategies that enhance natural ventilation. Also, there are strategies that help cut off the solar radiation and glare like deep eaves and verandas. Courtyards have been proven to induce ventilation into the buildings thereby reducing the indoor temperature if surrounded by verandas. Similarly other passive strategies which are important in this climate are orientation, lightweight walls which do not store thermal mass, roof insulation, plan form, shading devices, and materials etc.

Key words **– Warm and humid climate, Passive techniques, natural ventilation, Orientation, roof insulation.**

I. INTRODUCTION

In the race of reshaping the world due to the forces of globalization, the present-day architecture has lost its pertinence with the local climate, neighborhood, and the surrounding environment. Since historical times, the traditional buildings have been a great example of how the primitive architects took advantage of the local climate to design the shelters which responded to the climate and culture of that region. Passive techniques present in the traditional buildings are what make them better than the modern buildings. Although these buildings were not designed considering energy efficiency, with time it has been proved that these buildings not only respond to the regional climate but also act as energy efficient structures. The traditional buildings used solar passive design passive features like courtyard, natural ventilation, insulated walls, and roofs, etc.

Climate plays a major role in any passive cooling or heating techniques. The Major discomfort is caused in the regions with high humidity which comes with a warm and humid climate type. In order to find out the physiological objectives, a thorough study of the climate type has been carried out by understanding the basic climate parameters like the minimum maximum temperature ranges and humidity levels which cause discomfort. The research investigates the passive strategies applicable for this type of climate in respect to building form, building envelope, siting, orientation, WWR, ventilation, shading, wall thickness, landscape etc.

II. AIM AND OBJECTIVES

The aim of the research paper is to give recommendations for designing a building with a passive design approach in a warm and humid climate of India. The objective of the paper is to study the characteristics of a warm and humid climate found in mostly southern regions of India. It also requires collecting the physiological objectives of this climate based on which the suitable techniques will be discussed. Another objective of the study involves the literature review of papers related to the passive techniques. The research is limited to the secondary data and includes only recommendations as researchers are still undergoing various experiments and studies to find out more data suitable for such a climate. These recommendations have been achieved by documenting various research papers for this matter.

III. UNDERSTANDING THE CLIMATE

In order to design any building which involves passive strategies, it becomes extremely important to understand the climate. It is crucial to define the climate of a place in order to understand how with the help of design buildings can respond to the climate of their region. A climate responsive design is the one which uses design strategies appropriate for the climate of the site. It utilises available resources like daylight for optimising energy consumption keeping minimum dependency on conventional energy.

3.1. *Warm and humid climate*

The warm and humid type of climate covers the coastal regions of India. This climate is characterised by high humidity, strong sun, glare from the sky and surroundings. This zone comes under the temperatures which are in the range of 30 to 35 degree Celsius for summer days and 25 to 30 degrees for summer night (table 1). The temperatures are not very high throughout the year. The diurnal variation in warm and humid climate is not very large. This happens for the sole reason that they are near the water body which is sea so they remain in the same temperature range. Unfortunately, the most problematic factor for warm and humid climates is the humidity which is very high throughout the year. Because of this extremely high humidity, evaporative cooling is not possible. Also, the annual precipitation is very high (more than 1200 mm/y) resulting in many days which receive rainfall. The sky conditions are mostly overcast, ranging between 40 to 80 percent of cloud cover causing extremely unpleasant glare and blocking the heat from the clouds.

Climate zone	Mean Temperature (°C)					Mean Relative Humidity	Annual Precipitation	Sky Condition
	Summer midday (high)	Summer night (low)	Winter midday (high)	Winter night (low)	Diurnal Variation			
Hot & Dry	40 – 45	20 – 30	5 – 25	0 – 10	15 – 20	Very Low 25-40%	Low < 500 mm/yr	Cloudless skies with high solar radiation, causing glare
Warm & Humid	30 – 35	25 – 30	25 – 30	20 – 25	5 – 8	High 70-90%	High > 1200 mm/yr	Overcast (cloud cover ranging between 40-80%) causing unpleasant glare
Temperate	30 – 34	17 – 24	27 – 33	16 – 18	8 – 13	High 60-85%	High > 1000 mm/yr	Mainly clear, occasionally overcast with dense low clouds in summer
Cold (Sunny/ Cloudy)	17 – 24 / 20 – 30	4 – 11 / 17 – 21	(-7) – 8 / 4 – 8	(-14) – 0 / 3 – 4	20 – 25 / 5 – 15	Low:10-50% High:70-80%	Low: < 200 mm/yr Moderate : 1000 mm/yr	Clean with cloud cover < 50% Overcast for most of the year
Composite	32 – 43	27 – 32	10 – 25	4 – 10	35 – 22	Variable Dry: 20-50% Wet: 50-95%	Variable 500-1300 mm/yr during monsoon reaching 250mm	Variable Overcast and dull in the monsoon

Figure 1 classification of climate under defined parameters, source: ECBC User guide, 2011

3.2. *Physiological objectives*

For the given climatic conditions of warm and humid climate, the physiological objectives can be easily identified. Some of them could be as follows:

- To slightly reduce the temperature by 5 to 8 degrees centigrade and not much.
- To bring down the humidity in order to bring the environmental conditions within the comfort range.
- The attempt should be made to facilitate ventilation.
- Due to the sky conditions which cause glare, the objective is to cut down the solar radiation on the top of the roof. Thus, walls and roof need to be shaded.

IV. PASSIVE TECHNIQUES IN WARM AND HUMID CLIMATE

While designing a school building with a passive design approach it is important to consider a few design parameters like orientation, form, layout, design elements, materials and techniques, fenestration, design of roof, landscape techniques etc. The paper discusses the suitable techniques applicable for all these parameters.

4.1. *Orientation*

The orientation of the building with respect to the relative movement of the sun is an important factor in controlling the heat gain (Attalage, 1999). The main purpose of orientation in warm and humid climates is to be oriented in a direction that reduces the exposure of sun from east and west. However, more than this the orientation should be such that it enhances the natural ventilation inside the building. In that case the building blocks must be oriented with the longer facade being perpendicular to the direction of the wind.

Figure 2 (left) Optimum orientation w.r.t to the sun direction and, (Right) Optimum Orientation as per wind direction

4.2. Settlement and Layout

Climates like hot and dry need to have a compact planning to achieve mutual shading and shaded pathways for that case. On the other hand, settlements for warm humid areas are laid out to make maximum use of the prevailing breeze. Therefore, buildings must be scattered and have an open layout. The buildings placed next to each other can be utilised to channelize wind inside the structures with the help of vegetation. (Paul Gut, 1993).

Figure 3 Typical layout and settlement of warm and humid climate

4.3. Plan form

The plan form not just affects the air flow around the building but also the heat loss and heat gain inside the building. Here, open, and outward oriented plan forms are the key to enhance ventilation. The building's P to A ratio is defined by its plan form. Forms with large surface area are preferred over compact buildings. This is since the more the perimeter, the more is the amount of heat transfer and larger is the surface area, larger is the heat and air movement. H is the best type of form for warm and humid climates. The east and west walls can be reduced and north south walls can be increased to form long thin buildings. This is done because the buildings require heat transfer instead of thermal mass and so the form needs to be open, elongated, and thin with many openings and lightweight construction.

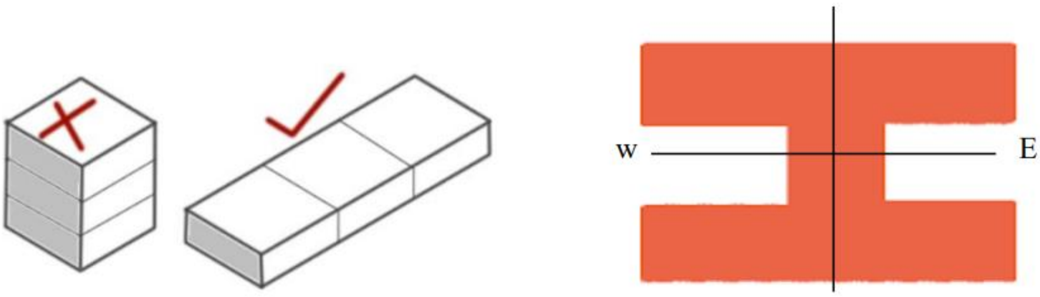

Figure 4 Plan forms with large surface area

Another method is to keep the building on Stilt floor to attract the flow of ventilation. Traditional houses were raised off the ground on stilts to avoid the damp ground, and to catch the breeze. The careful placing of external walls can be used to create high- and low-pressure zones to achieve cross ventilation „turning‟ the air movement through 900. The staggering of rooms can be used to achieve the same result, obtaining the benefit of cross ventilation and protection from solar radiation at the same time. (Evens, 1980).

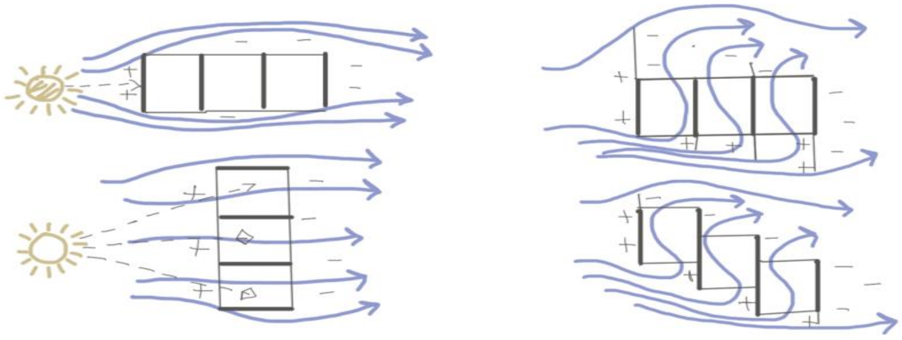

Figure 5 Alternative solutions when the sun and wind both are in the west direction

4.4. Roof

The highest thermal impacts of heat loss and heat gain happen on the roof. The roof is that part of the building which receives the maximum radiation and therefore it is gets important to shade it. The shape of the roof should be such that it covers precipitation, solar impact, and layout i.e., pitched, vaulted, flat etc. Pitched roofs with wide overhangs and verandas provide shade and protection from rain. To minimize thermal impact from solar radiation, multiple layers of materials may be required to make up a building envelope. In addition, a ventilation gap may be beneficially provided between the different layers of the envelope materials to vent excessive heat accumulated within. (Chenvidyakarn, 2007)

Thus, in a warm humid climate zone, focus should be made on providing a double roof with an air gap and some insulation. An example that can be utilized in buildings of this climate is to give a base roof which can be made of either RCC beams or bamboo beams covered with bamboo mats, coconut coir or thatch as a covering material. Another roof can be provided on top of this roof with the help of a truss system or through rafters and purlins. An air gap can be maintained in between the two roofs for flow of ventilation.

Various researches have been carried out to find the suitable roof construction for naturally ventilated buildings in warm and humid climates. In her research, (Rameshika Perera, 2004) A. Madhumati from Thiagarajar College of Architecture, Madurai, performed field experiments in the indoor of residential buildings with various roof materials like standard Reinforced concrete slab with lime concrete terracing, Madras Terrace roof, Thatch roof, Reinforced concrete slab with filler materials and Reinforced concrete slab with roof shading by clay pots and clay tiles. She then carried out a calculation for U values of these roofs and simulation through Ecotect software to find out the comfort level provided by each one of these roofs for which the outdoor air temperature, indoor air temperature, and indoor humidity were monitored during the experiment. The results showed that cooling inside buildings can be considerably improved by the application of passive roof design. It was also seen that the Air temperature and Relative Humidity of rooms with Madras Terrace roof and Sloped Reinforced Concrete roof with clay tile roof covering and air space in between remained stable and were close to the comfort limits.

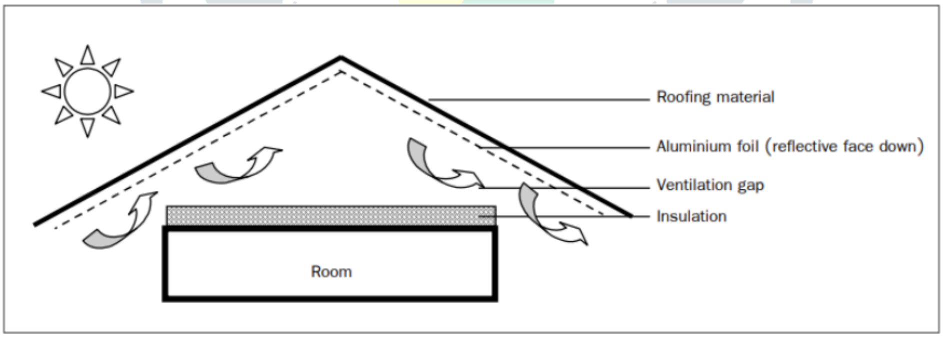

Figure 6 A schematic sketch of a roof section showing an example of a combined use of insulation and a ventilation space

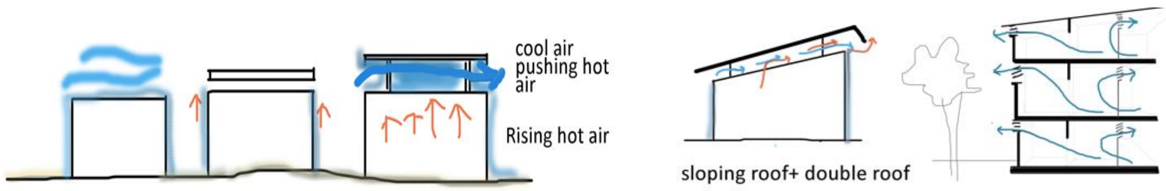

Figure 7 Different types of double roof techniques

A combination of double roof can be provided in the form of either a flat roof or sloping roof with air gaps in between. Other ways that improve the natural ventilation in the roof are to provide openings in the roof for the warm air to rise and leave the buildings from these openings

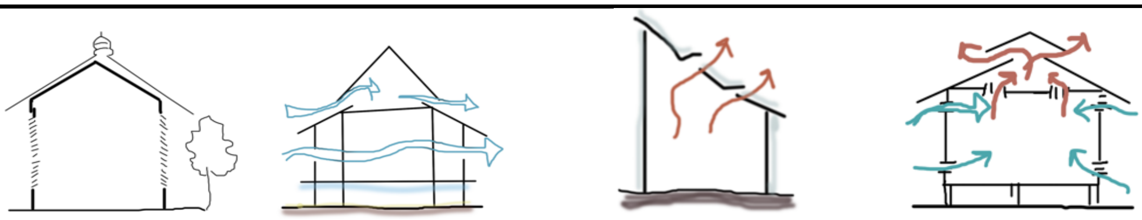

Figure 8 Effective roof shading techniques

4.5. Fenestration

Fenestration controls the air movement, effects the indoor temperature, allows ventilation and daylight. Large openings are the key to natural ventilation and arrangement should focus on enhancing air circulation. In warm humid areas openings are important elements for the regulation of the indoor climate. They should be large and fully openable, with inlets of a similar size on both sides of the room allowing a proper cross-ventilation. Windows are preferably equipped with flexible louvers allowing a regulation of ventilation. Door shutters may also incorporate louvers or grills. Windows with fixed glass panes are of no advantage and should be avoided.

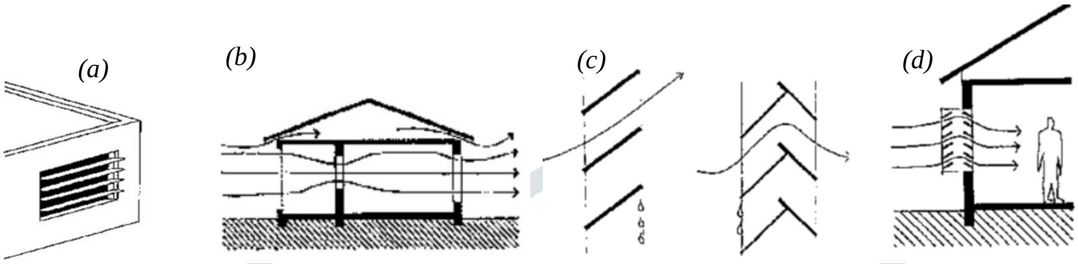

Figure 9 (a) Window with glass louvers, (b) Large openings and screened in porches, (c) Ordinary louvers, (centre) modified louvers, (d) Modified louvers in windward direction.

A difficult problem is the design of large openings which at the same time protect from driving rain. Ordinary louvers direct the wind upwards above body level. Furthermore, they are not safe against driving rain. Modified louvers keep the wind at lower level (living area) and provide protection from driving rain, but reduce the airflow to a certain extent. Another alternative is the use of a second set of louvers to direct the air down to the occupants. (Paul Gut, 1993). Openings need to be shaded by overhanging roofs, verandas, screens, lattices, grills etc. Openings should be placed according to the prevailing breezes, to permit a natural airflow through the internal space. This airflow is most effective if concentrated at body level. (Paul Gut, 1993). As per ECBC, the optimum WWR which is Window to wall ratio, should be 20 to 30 % for proper daylighting integration inside the classrooms.

4.6. Shading devices

The intensity of radiation is not as much as in hot and dry climates, but still in warm and humid climate due to moisture, there is a lot of glare which needs to be cut down to avoid radiation into the building. Furthermore, the openings should be far larger than in hot-dry climates. This is another reason why the shading devices should be much larger. (Chenvidyakarn, Passive Design for Thermal Comfort in Hot Humid Climates, 2007). Shading can be achieved through overhangs of pitched roof, deep eaves and verandas, screens and jails, vertical fins or through vegetation on the facade.

4.7. Natural Ventilation Strategies

There are many ventilation enhancement strategies that can be applied in the building to maintain proper air exchange into the building. The best type of ventilation for this climate is cross ventilation. In climates like this wind direction becomes the most critical aspect for natural ventilation. An article by Benny Kuriakose examines the scope of cross ventilation and techniques to enhance it further into the building.

4.7.1. Placement of Door and Windows.

Windows can be designed with a low height sill level to let the person embrace the wind till body level if one is lying down. Apart from this, incorporating adjustable louvres instead of glass, improves the ventilation flow inside the room. A small inlet and large outlet will result in a high maximum speed but with large areas of room experiencing low wind speeds resulting in poor distribution of air whereas if the room layout has large inlet and small outlet, it will eventually result in a lower maximum speed but a proper distribution of air in the entire room with only a small area having low speed. Figure below clearly demonstrates this.

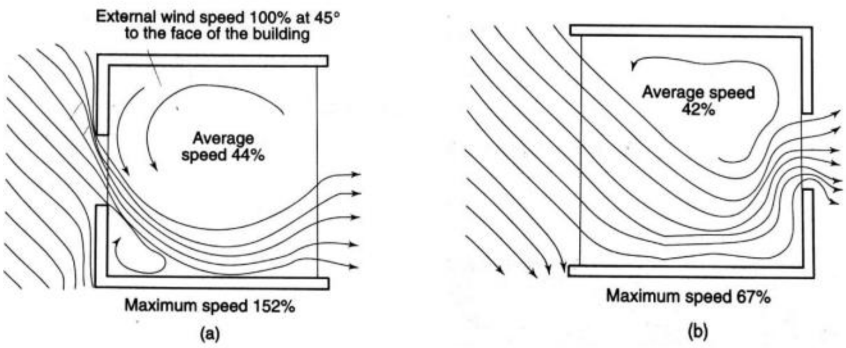

Figure 10 effect of window openings and size on the cross ventilation

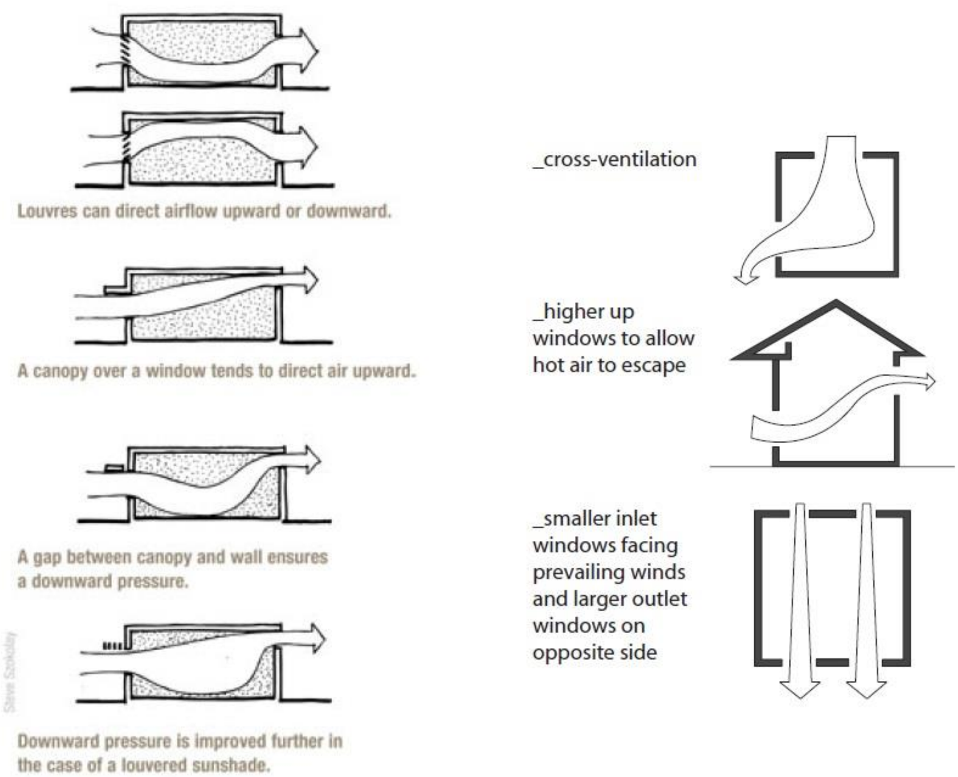

Figure 11 Effect of different type of openings, (YANIV, 2022)

4.7.2. Courtyards and verandas

Courtyards induce wind and cut off direct solar radiation into the building. Courtyards are one of the oldest architectural design elements that have been used in so many traditional buildings of warm and humid climate that respond well to their climate. Various studies have shown that courtyard can be a passive solution to reduce the level of humidity through ventilation. For better thermal performance of courtyards, the design should consider the shape, size, orientation, material, shading devices etc. Muhaisen says that when it comes to the size, deep courtyards work better in providing thermal comfort than shallow ones in warm climates. He also suggests the optimum height for courtyards which should be three stories. Sh. Abbas and Che Munaaim in their study evaluated U shaped courtyards for this climate in Malaysia using CFD analysis. Three types of shapes were studied, one with a cantilever U shape, other with a rectangular U shape of ratio 1:2 and last one with a square U shape of ratio 1:1. It was observed that the rectangular U-shaped semi open courtyard performed better than the latter. The use of cantilever provided shade and a drop in air temperature thereby enhancing the thermal comfort. (Esra'a Sh. Abbaas, 2019). Sadafi et. Al, 2011 investigated and found out that raised courtyard roofs with 500mm height can reduce the heat gain in the courtyard during peak hours (around 13:00) by 85%. Verandas near the courtyard can reduce the temperature by 1.5 0 C compared to outside temperature.

4.7.3. Courtyards and verandas

One of the reasons why old Kerala houses were cooler is because their timber roof had gables through which the hot air would escape and cool air would sweep in to take up the space, resulting in natural ventilation inside the room. The stack effect works on the same principle. Double roofs can also improve this effect. The stack effect happens when hot air travels from a low-pressure zone to a high-pressure zone, thus openings also should be designed accordingly. Another approach is that of a ventilated roof. (Ibrahim et al., 2014b) concluded that the indoor temperature could come down by 8°C after providing a ventilated roof. It happens so because the roof openings allow the trapped hot air to escape from them resulting in cooler wind flow.

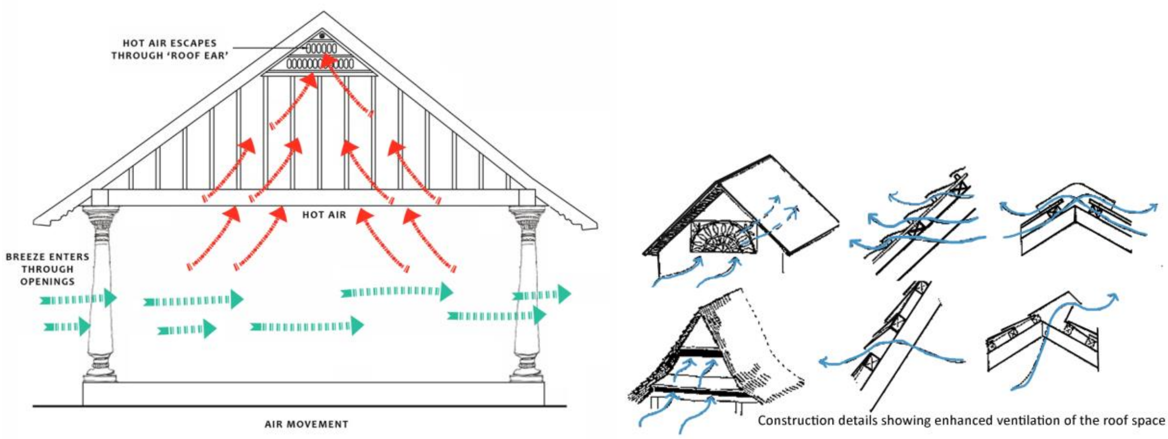

Figure 12 Roof gables and ventilation techniques

4.7.4. Landscape and layout

The buildings placed next to each other can be utilised to channelize wind inside the structures with the help of vegetation. A careful consideration that must be taken care of is that of wind shadows. These adjacent buildings can completely cut off the wind due to the formation of wind shadows especially in crowded and dense cities. So, their placement and layout are of utmost importance. Figure below illustrates the principle of wind shadowing which applies for the designing of either a building or tower). (Arvind krishan, 2001)

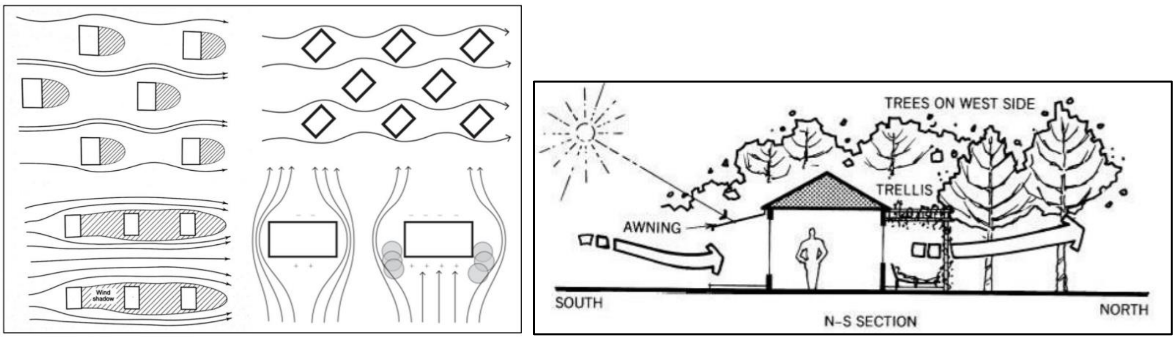

Figure 13 (left)Air flow and wind shadow patterns around a building and vegetation to attract wind inside or around a building Source: (Lechner & Norbert, 2001) (Right) Landscape for Naturally ventilated buildings in warm humid regions

V. MATERIALS

The main objective is that the building materials should not store thermal mass and therefore should be lightweight and airy. Thus, materials that are suitable for this climate type are wood, plastics or related alternative materials instead of concrete, brick or stones with high density and thermal storage capacity. In research carried out for a climate with heat and humidity, a reduction of 63% heat gain through the sun was achieved with the use of hollow clay tiles arranged in a manner that allowed air movement through it (K.C.K.Vijaykumar & P.S.S.Srinivasan, 2007)

Figure 14 Wall construction made of hollow concrete blocks Source: dezeen,2014

Deshmukh (2013) suggests a material which is a combination of cement mortar combined with a reinforcement of wire mesh known as ferrocement. While, timber is one of the best materials and widely used in this climate in traditional buildings because of its properties of high thermal resistance, and good regulation of moisture content and humidity.

Figure 15 Timber screens on the facades for allowing breeze and to cut off glare.

(Maklur Nisha, 2018) analyzed the properties about laterite as a building material and found out that it can be a suitable material for this climate type. It gains strength against exposure from Sun and rain when it is plastered with lime mortar and has been used in various traditional buildings of this climate. Another eco-friendly material is the construction from coconut coir. The Thai people have already used coconut coir in the development of a light weight cement board for construction of buildings. These boards are a balanced combination of cement, coconut coir mixed with the right proportion of water (Asasutjarit & Hirunlabh, 2007)

Figure 16 Coconut coir construction

In Auroville, most of the construction is focused on reducing steel and cement so they extensively use CSEBs (compressed earth blocks) for building construction. It is a local material produced on the site itself reducing the embodied energy.
For all those places in warm and humid climate that receive heavy rainfall throughout the year, Mangalore tiles work well for the construction of pitched roof. Made up of laterite clay, these tiles are used in sloping roofs, kitchens, and bathrooms and to cater the problem of seepage and moisture caused by typical RCC construction. These tiles have air gaps in between for warm air to escape. Bamboo can be an effective material for construction of trusses or framework for a double roof. Corrugated bamboo sheets can be used instead of steel or tin roofs. Mats made from bamboo thatch are effective for designing screens and jaalis. Recycled steel can also be used for window frames instead of wood or any other metal.

VI. CONCLUSIONS

The recommendations in the study if practised can actually bring down the indoor temperatures thereby reducing the energy consumption for buildings in a warm and humid climate zone. The major concern in this climate is to control humidity by amplifying natural ventilation. Therefore, cross ventilation strategies, courtyards, lightweight structures for walls, stack effect, shading devices like deep eaves and verandas, and roof insulation strategies become the most effective passive techniques as proven by various researchers. These recommendations can be applied in all the low rise and well as high rise building types in order to be designed with a passive approach.

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