Integrated approach in building design for passive cooling in hot and dry climates of India

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Abstract - *The energy consumption in building sector is quite high and is expected to further increase because of improving standards of living and growing world population. Artificial cooling of buildings requires huge power consumption. To overcome this situation without compromising human comfort is challenging task for developing countries like India. The Integrated approach in building design deals with the building as a system and with the means to achieve passive cooling and thereby energy conservation. In integrated approach for buildings, building components should be so designed to reduce the heat gain, to modify heat transfer, and certain cooling techniques should be adopted to remove the heat gained by the building. In this paper various methods and techniques have been discussed, which can be implemented for passive cooling in hot and dry climate zone of India to achieve objective of energy conservation.*

Key Words: Integrated approach, Thermal mass, Phase change materials, Wind tower, Ventilative cooling, evaporative cooling, Direct evaporative cooling, Indirect evaporative cooling, Passive downdraft evaporative cooling.

1. INTRODUCTION

India has fifth largest user of electricity & fourth largest user of overall energy as per energy information administration Nov 2014 report. Electricity consumption in domestic & commercial building is 23.53 % & 8.77%. As per CPWD 2004 report space conditioning &refrigeration has consumed 32 % and 8% of energy respectively. There is 8 % rise in annual demandof electricity consumption in residential and commercial buildings in India as per "India statistics data 2010". In India hot and dry climatic zones lies in central and western part of the country which includes some part of Rajasthan, Maharashtra Gujrat and Madhya Pradesh state. In this climatic zone maximum ambient air temperatures are as high as 40–45 ºC and relative humidity 25-30% in summer days. As we are well aware about the problems associated with use of conventional air conditioning technology which increase the peak electricity load, ozone layer depletion, global warming, high operating and maintenance cost, we should explore the alternatives for cooling needs. There are many traditional cooling techniques which have been used at many places in the world. But very less focus have been given on integrating these various cooling techniques during the design of the building. Integrated approach in building design means integrating various passive cooling techniques and building service expertise from the design stage of the building project. Our aim is to implement integrated approach in building design for energy conservation in hot and dry climates of India.

J.K. Nayak, J.A. Prajapati in their book have mentioned that design criteria for buildings should aim at resisting heat gain by providing shading, reducing exposed area, controlling and scheduling ventilation, and use of passive cooling techniques to achieve energy conservation goal [1]. Pablo La Roche in his research paper mentioned that one can build passive cooling system with materials and components which are locally available as long as physics of the system don't get affected [2]. In India, Old Havelis and Mahals had built most appropriately to local climate in terms of material selection, construction techniques and spatial orientation of the building [3]. According to Barozzi et al. (1992) there is greatest need of passive cooling strategies in developing countries due to limited financial resources and poor building technologies [4]. Researchers throughout the world are working on various passive cooling technologies appropriate to their climates with help of various materials and experimentation methods. Sudaporn Chunglo et al (2006) in their experiment cell observed that spraying water on the roof together with solar chimney can reduce indoor temperature by 2.0–6.2 °C compared with ambient air [5]. TRC building in India built by architects Abhikram with Brian Ford is a large demonstration of the evaporative cooling strategy [6]. Botha, DW, Dobson, RT, identified that solar chimney augmented passive downdraught evaporative cooling system as a promising approach to achieve thermal comfort in buildings [7]. Pearlmutter et al have done investigation on effect of droplet size with or without fan on cooling process [8]. Ana Claudia et al. (2005) in their paper says that PDEC can be an excellent technique to provide efficient cooling and ventilation in hot and dry regions with little or even zero consumption of energy where domestic water can be re-used [9].

2. PARAMETERS FOR BUILDING DESIGN

2.1 Site Conditions

Site-specific conditions such as land form, vegetation, water bodies, open spaces, etc. play an important role in building design.

A. Landform:

In undulating terrain slopes and depression causes variation in air movements and air temperature at various points of site. Cooler air gets collected in depressions. Air speed goes on increasing along the height and it is maximum on crest and minimum on leeward side.

B. Vegetation:

Vegetation lowers the wind speed and surrounding temperature and increases humidity of air. Trees can be used to cut off solar radiation hot breezes.

C. Water bodies:

Surface of water bodies reduces ambient air temperature either by evaporation or by contact of hot air with cooler water surface. Ponds, streams, waterfalls, fountains or mist sprays may be used as air cooling sources.

D. Location and Orientation of street:

The planning of building, shape, size, area of opening, shading depends upon the location and orientation of road.

2.2 Building envelope

A. Building Orientation:

The orientation of building should be such that building should receive minimum solar radiation in summer and maximum in winter. Optimum orientation can be decided by using sun path diagram of that zone.

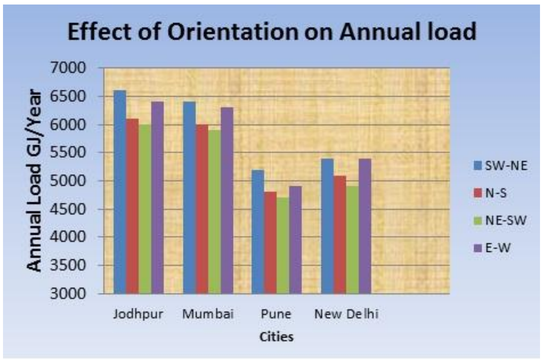

Chart 1: Effect of orientation on the annual load of a conditioned building in various Cities [1]

B. Wind circulation inside building:

Meteorological data of site should be studied for last few years and wind roses are drawn to finalise wind direction and speed. Opening in the building is to be designed for the requirements based on this wind analysis.

C. Building physical configuration:

a) Surface area to volume ratio (S/V ratio): Magnitude of the heat transfer in and out of the building can be determined by S/V ratio. The S/V ratio is directly proportional to the heat gain or loss for a given volume of space.

b) Shape of the building:

When wind obstruct the building a pressure difference is created around it causing positive pressure on wind ward side and negative pressure on leeward side. Thus appropriate wind speed inside the building can be achieved by giving proper shape to the building.

c) Buffer spaces:

Buffer spaces such as courtyards, atria, balconies and verandas should be provided to the building as they provide shading and catch the wind.

d) Arrangement of openings:

Appropriate openings should be provided in such a way that they should connect high and low pressure areas providing effective ventilation inside the building.

e) Shading:

Building should be constructed in such a way that it should self-shade the surfaces e.g. H-type or L-type construction instead of just simple cube. Walls can be shaded by using projections, balconies, fins, textured paints and vegetation. Appropriately sized chajjas, fins, Operable shutters and movable covers like curtains and venetian blinds can be used to shade the openings.

2.3 Building components

A. Roof

a) Roofs flooding or spraying lower down temperature of roof.

b) White washing of the roof can reduce temperature up to 10^{0}C.

c) Insulating materials applied externally or internally to the roofs.

d) Movable covers of suitable heat insulating material, if practicable.

e) Shining and reflecting material (e.g. glazed china mosaic) may be laid on top of the roof.

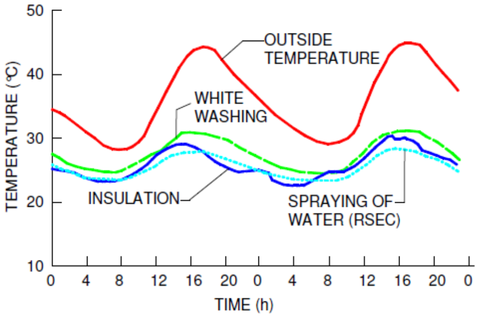

Chart 2: Relative performance of different techniques on a flat roof [1].

f) The roof ventilation and day lighting can be improved by incorporating vents and skylights.

g) A false ceiling of insulation material below the roofs with air gaps in between roof & ceiling.

h) The roof covered by inverted earthen pots with a layer of earth over them can reduce temperature.

B. Walls

The resistance to heat flow the exposed walls may be increased in the following ways:

a) Increase in thickness of wall.

b) Light coloured whitewash or white colour may reduce large amount of heat act as reflecting surface.

c) The use of suitable heat insulating material without compromising the structural & water proofing needs.

d) Cavity wall construction, the rat trap bond for external walls save material upto 25% and faced on external walls reduce large amount of incoming heat & sound proof.

C. Fenestration (openings)

Fenestration is major source of day lighting, heat gain and ventilation. Light of proper lumen is welcome in each of building space but amount of glare that enters needs to be controlled. This can be controlled by shutters and movable covers like curtains or venetian blinds. Tinted glazing or glazing with surface coatings can be used to control solar transmission, absorption and reflection.

Window size should be kept minimum in the hot and dry regions. As the general tendency of hot air is to raise, exhaust window at higher levels should be provided. The size, shape and orientation of the opening affect the speed and flow of air inside the building which plays important role in deciding ventilation system of building. Small inlet and large outlet increases the velocity and distribution of airflow through the room.

a) Spectrally selective glazing

Spectrally selective glazing permits non thermal portions of the solar spectrum to enter through it while blocking others which reduces heat gain inside the building.

b) Angular selective solar control

Angular selective facades have high transmittance at lower angle of incidence and much lower transmittance at higher angle of incidence. Hence during day time when radiations are high at higher angle of incidence, most of the radiations are blocked or reflected admitting only diffused light which avoid excessive heat gain inside the building during summer.

c) Smart windows

Smart windows have the ability to vary the visible light as well as solar radiation. This is achieved by incorporating a film of chromogenic material in the window. These films may be photochromic, thermochromics electrochromic in nature.

D. External colour and texture

The nature of the external surface finish means its smoothness and colour. It determines the amount of heat absorbed or reflected by it. A smooth and light-coloured surface reflects more light and heat; a rough textured surface causes self-shading and increases the area for re-radiation.

3. HEAT MODULATION TECHNIQUES

Heat modulation means modifying the heat gain inside the building. It can be achieved by two methods. In one method thermal mass or Phase change materials are used to manage the heat gain. These materials absorb the heat during the day time preventing its entry inside the building. In second method unoccupied building portion is pre-cooled by night ventilation and this coolness is used on sub sequent morning to delay the heating of building.

3.1 Thermal mass in the construction material

Thermal mass contained in walls, floors etc. effectively reduces the wide outdoor temperature fluctuations and keeps the indoor temperature within a narrow comfortable range [10]. For selecting thermal mass two important thermal properties of the materials should be considered, i.e. the heat capacity by volume and the heat-absorption rate.

3.2 Thermal mass using PCM based systems

To enhance the thermal storage of the building fabric, phase change materials (PCMs) should to be used as these materials have high thermal inertia. PCM, having melting temperature between 20 and 36°C, have been used for thermal storage in conjunction with both passive storage and active solar storage for cooling in buildings [11].

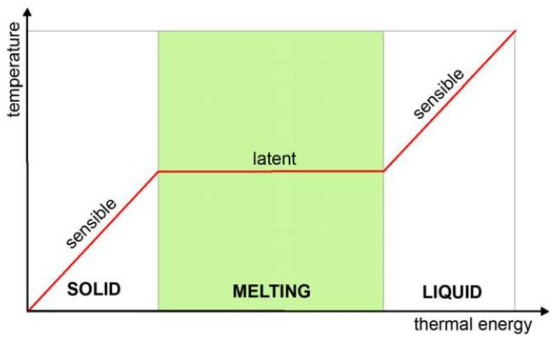

Fig 1: Temperature-energy diagram of one typical PCM material [11].

3.3 Nocturnal Cooling

Nocturnal cooling is cooling the building by ventilation during the night when ambient air temperature is lower than room temperature. Due to this interior mass of the building is cooled which in turns reduces the rate of temperature rise inside the building on following day.

4. HEAT DISSIPATION TECHNIQUES

In many cases, the avoidance and modulation of heat gains cannot maintain indoor temperatures at a control level. Heat dissipation techniques are based on the transfer of a buildings' excess heat to a low temperature environmental sink.

4.1 Ventilation Cooling

The replacement of stale air by fresh air is called as ventilation. Cooling is also done by moving air. A faulty ventilation design & use of glasses will increase the heat absorbed by building. The ventilation requirements of different seasons, for different types of occupancies should be determined & then ventilation system should be suitably designed to meet the required performance standards.

A. Cross ventilation

In cross ventilation during the day, the indoor air temperature closely follows the ambient temperature. Hence during daytime cross ventilation should be considered only when indoor comfort can be experienced at the outdoor air temperature.

B. Induced Ventilation

In this method air is heated in a particular area by solar radiation, which creates temperature difference leading air movements. Hot air has low density, rises and escapes to the ambient air which draws in cooler air inside causing cooling.

4.2 Wind Tower

It works on the principle of differential air pressure and temperature which induce the ventilation. This system has been used for centuries in Arabian countries for natural ventilation and passive cooling. It operates in many ways according to the presence or absence of wind and time of day.

4.3 Earth-Air pipe system

Seasonal variations of the soil temperature get reduced rapidly at depths of 4 to 5 m with increasing depth from the earth's surface. Energy and peak load requirements for space cooling of a building can be significantly reduced by using an earth-air pipe system. It can be used for heating purpose during winter season. To get desired effect pipe of adequate length should be used.

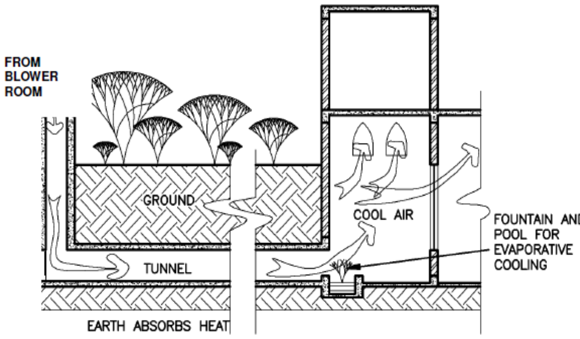

Fig 2: Earth-air pipe system [1]

4.4 Evaporative cooling

Evaporative cooling is a well-known system which was extensively used in the vernacular architecture of Egypt, Iran, and Turkey. Wind catchers capture wind and direct it to porous water pots where heat is absorbed by water from air making the air cool. Desert cooler is the mostly used evaporative cooling system in north India which consists of evaporative pads, a fan and a pump. Evaporating cooling system has basically two type's viz. direct and indirect evaporating cooling system.

A. Direct Evaporative cooling:

This is simplest system in which water come in direct contact with the air absorbing the heat of vaporization from hot air and making it cool and moist. Cooled stream of air is introduced directly into internal space. In this method humidity within cooling zone is increased. The air temperature is thus reduced by about 70-80% of the difference between the dry bulb temperature (DBT) and the wet bulb temperature (WBT). The major disadvantage of this system is in the increased moisture content of the ventilation air supplied to the indoor spaces. This may result in discomfort due to high humidity. The passive downdraft evaporative cooling system is an example of this process.

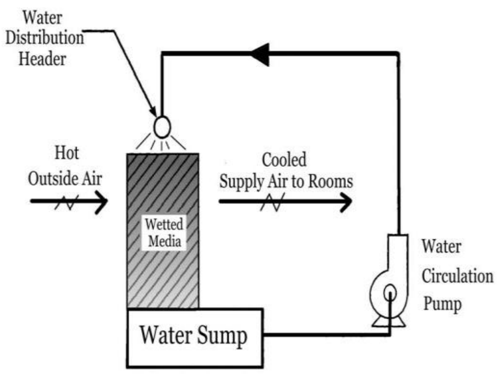

Fig 3: Schematic of Direct Evaporative Cooling System [12]

B. Indirect Evaporative cooling:

In this system cooling is produced to the internal space without adding moisture to the supply air. This is alternative method to direct system to cool supply air indirectly via a heat exchanger avoiding the problem of increased humidity and any health concerns regarding droplet contamination.

4.5 Passive Downdraft Evaporative Cooling

PDEC system consists of modified wind tower which guides outside breezes over a raw of water filled pots, mist spray or waterfall. They are designed to capture wind at top and cool outside air using water evaporation before delivering it to space. Application incorporating cooling technology can be categorised into two types according to evaporative devices: 1) PDEC tower with Pad 2) PDEC tower with spray.

A. PDEC tower with pad:

The PDEC towers consists vertical wetted pads. Water is distributed on the top of the pads, collected at the bottom into a sump and recirculated by a pump. Air when move through this tower it comes in contact with water where water absorbs heat from air making it cool and moist. This air as being cool become denser and move downward in tower which is then directed to the internal space for cooling.

B. PDEC tower with spray:

PDEC tower with spray system has same working principle as that of PDEC tower with pad. But has the difference that instead of using pads water is directly sprayed in fine droplets to increase the contact surface between the air and water particles. So that maximum heat from the air will be absorbed in minimum time. This system was first introduced in EXPO 92 in Seville, Spain by Baruch Givoni. It was intended to cool outdoor rest area at site. Here largest temperature drop of 12° C appeared within 1st m and 2nd m from top when smaller particles were sprayed, whereas temperature gradually decreased with bigger drops [13].

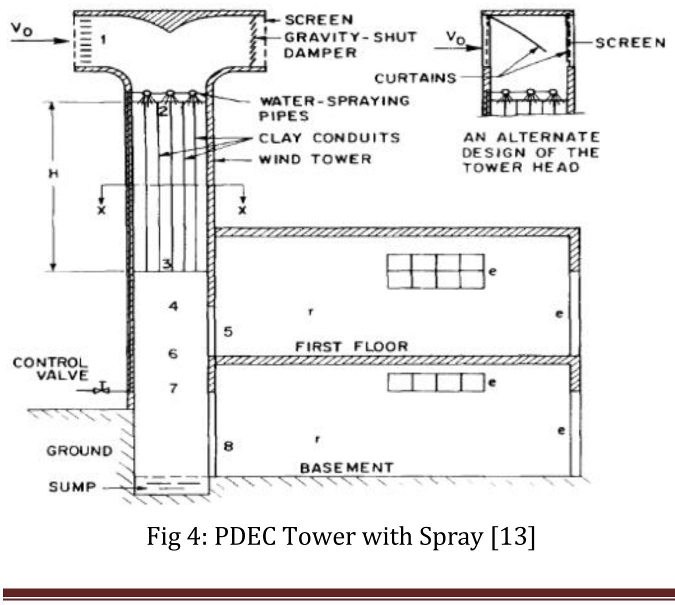

Fig 4: PDEC Tower with Spray [13]

Water is made to drip or sprayed using nozzles or micronisers instead of pads. Misting tower systems are very efficient; nozzles are fitted at the top of the tower and the sizes of the water droplets sprayed are reduced and this significantly enhances the evaporation process. TRC building in Ahmadabad, India has installed this technology for evaporative cooling research laboratories & its results are comparable to conventional air conditioning.

5. CONCLUSIONS

Conventional air conditioning in building consumes more energy& increases power bills. It is estimated that during lifetime of building a consumer pays energy bills which are 10 times cost of construction of building. Experts in this field should rethink on process of building design with reference to energy consumption. Building, planners should have to cut down this energy costs so as to conserve the nature. It is need of time to build the energy efficient buildings. Integrated approach in building design using various techniques will help to conserve precious natural resources. Also this will help to control problems of global warming & ozone layer depletion which are linked with energy consumption. Passive cooling systems mentioned in this paper will create healthy indoor conditions with meagre amount of energy consumption. The detailed site specific studies for various parameters are needed to apply integrated approach & various technologies of passive cooling in context of hot and dry climate of India. A methodology should be devised to undertake the design of building components and to check feasibility and adaptability of these techniques.

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