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Passive cooling concepts of a building structure

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Abstract
Step by step human solace is raising its criticalness. Human solace is that state of psyche, which communicates fulfillment with the warm condition according to the American Society of Heating, Refrigeration and Air Conditioning Engineers. The traditional methods for accomplishing warm solace is the vitality devouring mechanical forced air systems framework and the refrigerant utilized is destructive to the natural framework. The vitality is a significant issue. Remembering this factor, the current work has been tried to lessen the cooling heap of a current structure by utilizing latent cooling ideas as opposed to utilizing the mechanical cooling framework to disperse heat for warm solace. Among the latent cooling, interior and outer concealing ideas have been actualized for the fenestrations and a practical course of action of earthen pots have been considered for the rooftop cooling. It has been seen that the cooling heap of the structure has been decreased about 47% because of concealing and up to 56% because of use of earthen pots when utilized independently.
Keywords:*passive cooling; shading; earthen pots, cooling load, building*

I. INTRODUCTION

Energy is one of the most important building blocks in human development, and, as such acts as a key factor in determining the economic development in all countries. As the world becoming more advance in technology, more energy is being used to keep up with the changing requirements. At the current rate at which energy is being used, the world is shortly come to an end of fossil fuel which is the world’s primary energy resource. Fossil fuels provide around 95% of the world’s total energy demands (including heating, transport, electricity generation and other use). Many research works had been conducted for different alternative fuel which could replace the fossil fuels [1-4]. Energy consumption of buildings is about 48% of all energy consumed, with 40% for the operation of buildings and 8% for the construction of buildings in the World. Most of the energy is for the provision of lighting, heating, cooling and air-conditioning. This energy is mostly derived from fossil sources that produce the global warming and also buildings are involved in producing about 40% of the sulfur dioxide and nitrogen oxides that cause the acid rain and smog formation. Building energy use also produces 33% of all annual carbon dioxide emissions, significantly contributing to the climate changes brought about by the accumulation of this heat-trapping gas [5].

Hence, the major focus of researchers, policy makers, environmentalists and building architects has been on the conservation of energy and its utilization in buildings. It is further established that alternative energy sources, techniques and systems can be used to satisfy a major portion of cooling needs in buildings.

A number of research works have been carried out with passive cooling in naturally ventilated buildings. The techniques of passive solar building design were practiced for thousands of years, before the advent of mechanical heating and cooling. it has remained a traditional part of vernacular architecture in many countries. Fully developed solar architecture and urban planning methods were first employed by the Greeks and Chinese who oriented their buildings toward the south to provide light and warmth. Nearly two and a half millennia ago, the ancient Greek philosopher Aeschylus wrote: “Only primitives and barbarians lack knowledge of houses turned to face the winter sun” [6]. Although earlier experimental solar houses were constructed using a mixture of active and passive solar techniques. The concept of passive houses was first introduced by Professor Bo Adamson from Lund University in Sweden. He developed this concept through an energy efficient houses project he had for Chinese Government in late 80s [7]. After that, passive houses spread rapidly all over the world. The passive house has a standard for minimum energy consumption and a high level of comfort. Therefore, a passive house should have very good insulation and air tightness of building envelope, in which only a very small amount of heating energy is needed for heating up the building. The concept of passive house is not focus on energy performance but also concern about a comfortable level of indoor climate of tenants who are living in the house [8].

The total heat required to be removed from the space in order to bring it at the desired temp by the cooling equipment is termed as the cooling load. The sensible heat gain occurred due to many sources of heat transfer. Those are the heat transfer into the building by conduction through exterior walls, floors, ceilings, the heat received from solar radiation etc. When there is an addition of water vapor to the air of enclosed a gain in latent heat is said to be occur. These heats can be removed by the air-conditioning equipment which is known as active cooling system. The active cooling system is a major energy consuming device. Passive cooling systems are energy-efficient and eco-friendly techniques. Passive cooling covers all natural process and techniques of heat decapitation and modulation without the use of energy. For a building passive cooling approach focuses on heat gain control and heat dissipation in a building in order to improve the thermal comfort with low or nil energy consumption [9-10]. This approach works either by heat gain prevention or natural cooling. There are several passive cooling concepts that vary widely in working principle and performance. The practicability of these techniques depends greatly on the local climate.

The techniques for passive cooling can be grouped in two main categories. One is preventative techniques that aim to provide protection and/or prevention of external and internal heat gains. The second is the modulation and heat dissipation techniques which allow the building to store and dissipate heat gain through the transfer of heat from heat sinks to the climate. The techniques can be result of thermal mass or natural cooling.
Considering the interference drawn by various researchers, the present work has been endeavored to reduce the cooling load of an existing building by using the following passive cooling concepts:

- External Shading
- Internal Shading
- Roof Treatment

In order to achieve this aim, the objective of this study is to overall reduction in cooling load using the passive cooling concepts.

II. Methodology

2.1 Passive Cooling concept

Passive design regards the particular way to construct a building using the natural movement of heat and air, passive solar gain and cooling in order to maintain a good internal comfort. It is a building design approach that focuses on heat gain control and heat dissipation in a building in order to improve the indoor thermal comfort with low or nil energy consumption. The flow of energy in passive design is by natural means: radiation, conduction or convection without using any electrical device. To prevent heat from entering into the building or to remove once it has entered is the underlying principle for accomplishing cooling in passive cooling concepts. This depends on two conditions: the availability of heat sink which is at a lower temperature than indoor air, and the promotion of heat transfer towards the sink. Environmental heat sinks are: outdoor air, water, the sky, ground. Passive cooling techniques can reduce the peak cooling load in buildings, thus reducing the size of the air conditioning equipment and the period for which it is generally required..

2.2 System Description

It gives the orientation and description of an existing building, the procedure adopted to calculate the required cooling load of the building and the economic part in order to achieve the aim of the present work.

2.2.1. Building Description

For the application of various passive techniques an existing building is taken into the consideration in the campus of NIT Silchar, Assam. It is a building made in 2011 in mechanical department of NIT Silchar for the sake of laboratory work and named as production building. It spreads over an area of 20,000 square feet. The three stored building is a rectangular building faces south on its small lot. North façade of the building is an open area consists of a lake and small trees. Those are not obstructing the flow of air into the building. West side is also faced towards a lake which comes from the middle of the campus. Since the trees in east façade are not closer to the building, they are not causing any shading effect. There is only one entrance to the building in the south façade. Thus from all side, the building is open to the sun’s irradiation which ultimately require to cut down in order to reduce the heat gain of the building. The central entrance has two concrete steps leading to the recessed huge rectangular opening with a glass double door. The entrance door heads towards a courtyard in the middle of the building which connects to each room of each floor and open to the sky. Top of the courtyard is covered by transparent plastic sheets which provide the necessary visible light to the building in day time. Each floor comprises of four big rooms each of size ’23.96 X 12’ square meter. Layout of one floor is shown in Figure 1. Dimensions of fenestrations is shown in Figure 2.

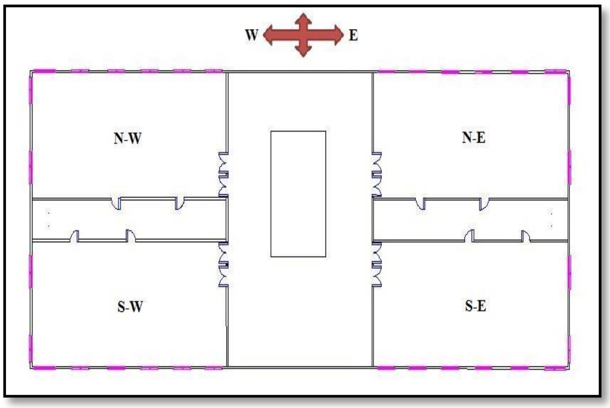

Fig. 1 Layout of one floor

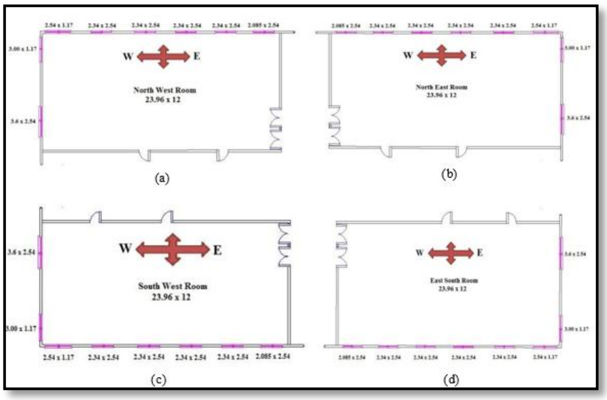

Fig. 2 Dimensions of fenestrations (a) north west room (b) north east room (c) south west room (d)south east room

2.2.2. Weather Description

Silchar is the headquarters of Cachar district in the state of Assam in India. It is located in the southern part of Assam situated in the banks of Bark River. The climate here is tropical by nature. The weather remains predominantly dry from October to March, while the rainy season starts near about the end of March or the beginning of April and that lasts up to the end of September. The winter in this place spans predominantly from November to the end of February and the summer is prevalent during the course of the rainy season. Summer is hot, humid and interspersed with heavy rainfall and thunderstorms. Silchar has a latitude of $24^0$49’ 0N, longitude of 92^0 47’ 60E and elevation of 21 meters and approximately an area of 7 km of radius from this point. In summer the temperature lies between 22^0 C to 36^0 C and the winter season the temperature lies between 12^0C to 25^0 C. Fig shows the monthly average of dry bulb temperature (DBT) against the each month of year calculated from the data of 5 year (2007-2011) of Silchar taken from NREL [11].The average temperature for the year in Silchar is around 25^0C.

2.2.3. Description of Adaptive Passive cooling techniques

The fenestration of the proposed building has 6 mm single pane type glass windows. Whole building consists of three floor, eight room and total of 715.14 m^2 of fenestration area. Each room is having fenestration area of 44.7 m^2. It has a wall of window ratio of 41.43 %. Total window area in south or north side is 192.2 m^2 and that in east or west side is 75.9 m^2. Window frame is made up of vinyl which is less expensive and energy efficient. The study focused on the passive techniques such as external and internal shading to minimize the heat gain from the fenestration area. A local available curtain has proposed for the internal shading. White color curtain having a thickness of 6-8 mm gas been suggested. It has a transmissibility, absorptivity and reflectivity of 0.15, 0.51 and 0.34 respectively.

The material of the supporting structure of the roof is made up of 150 mm high density concrete and the upper layer inner layer are of 20 mm cement plaster. The present study applied the passive concept of using earthen pot to produce shading on some part of roof so as to reduce the direct heat gain and the corresponding cooling load. Pots are arranged in a manner such that the space in the roof is well accessible from all side and make approximately about 60% of shading.

2.3. System Modelling

2.3.1 Solar geometry

The position of any point on the earth's surface, in relation to the sun's ray, is described at any instant by the latitude of the place '1', hour angle 'h' and sun's declination 'd'. These angles are illustrated in Figure3 for a point P in northern hemisphere of the earth, whose center is at point O [12].

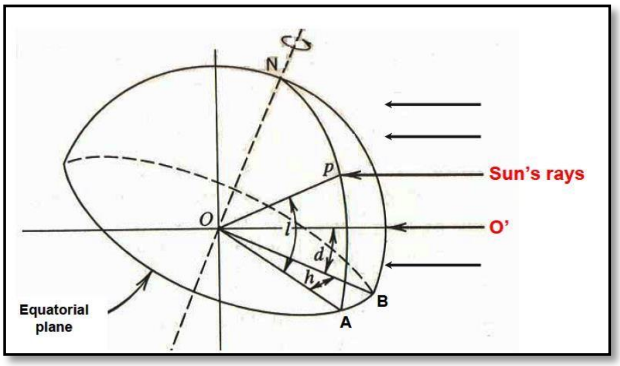

Fig. 3 Latitude angle (I), hour angle (h), declination (d) [12]

Declination, d is the angle between the center to center line and its projection OB. It is thus the angle between the sun's ray and the equatorial plane. For northern hemisphere, the declination varies from about +23.65^0 on June 21st to -23.5^0 on December 21st at equinoxes. The declination can be calculated approximately using the Equation (1)

$$d = 23.47 \sin\left(\frac{360(284+N)}{365}\right)(1)$$

2.3.2. Derived solar angles

Altitude angle β: It is the angle between the sun's rays and the projection of sun's ray onto a horizontal plane as shown in Figure 4[12]. The expression for altitude angle is given by Equation (2)

$$\sin\beta = (\cos l . \cos h . \cos d) + (\sin l . \sin d) \quad (2)$$

The altitude angle β is maximum at solar noon. Since the hour angle h is zero at solar noon, the maximum altitude angle β_{max} (solar noon) on any particular day for any particular location is given by substituting the value of h=0^0 in the expression for β in Equation (2)

Solar azimuth angle, γ, is the angle in the horizontal plane measured from north to the horizontal projection of the sun's rays. It can be shown that the solar azimuth angle is given by:

$$\tan\gamma = \frac{\sin h}{(\sin l.\cos h)-(\cos l.\tan d)}(3)$$

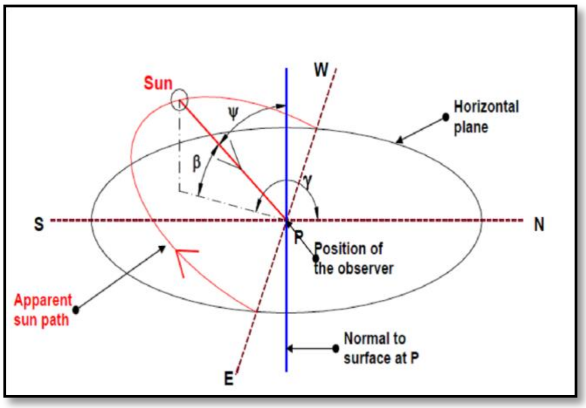

Fig. 4 Derived Solar angle

2.3.3. Direct radiation from sun (I_D)

Several solar radiation models are available for calculation of direct radiation from sun. One of the commonly used models for air conditioning calculations is the one suggested by ASHRAE. According to this model, the direct radiation ID is given by:

$$I_n = 1082e^{-0.182L}(4)$$

$$and I_d = I_n \cos\theta (5)$$

According to the ASHRAE model, the diffuse radiation from a cloudless sky is given by [13]

$$I_d = CI_n F_{ss} \qquad (6)$$

Where,

$$F_{ss} = 1 - \left[\frac{1}{2}(1 - \sin\emptyset)\right](7)$$

2.3.4 Fenestration

Fenestration refers to any glazed (transparent) apertures in a building, such as glass doors, windows, sky lights etc. Solar radiation incident upon a glass surface is transmitted, reflected and absorbed shown in Figure 5[14]. The heat gain of a space through glass then comprises:

- All the transmitted radiation
- A part of the absorbed radiation
- The heat transmitted due to the difference between the outside and inside temperature.

So the heat gain of glass due to transmitted radiation is given by:

$$Q_1 = A_{sun}\tau_D I_D + A_{tot}\tau_d I_d (8)$$

And due to absorption, radiation is given by Equation (9)

$$Q_2 = \frac{A_{sun}\tau_D I_D + A_{tot}\tau_d I_d}{1+\frac{f_0}{f_i}}(9)$$

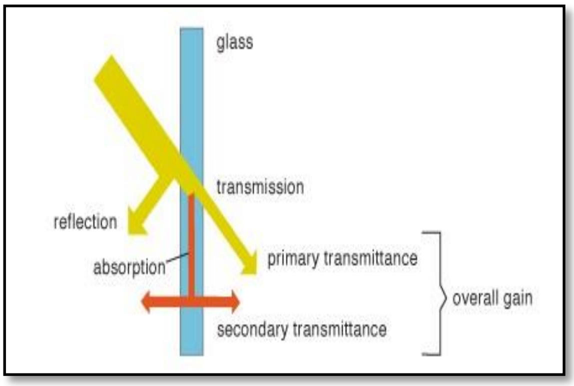

Fig. 5 Heat transfer through glass

Then the heat gain due to the inside and outside temperature difference is given by Equation (10)

$$Q_3 = UA\,(t_0 - t_i) \quad (10)$$

Thus we get for the heat gain of space is:

$$Q = Q_1 + Q_2 + Q_3 (11)$$

2.3.5. Internal shading

Consider a radiation I incident on an ordinary glass surface. A part of this radiation will be reflected, a part will be transmitted and a small part, of the order of 5 to 6 percent will be absorbed. Assuming about 40 percent of the absorbed radiation enters the space, the radiation heat gain through a 6 mm thick regular plate glass is given by Equation (12)

$$Q_g = \tau_g I + 0.4\, a_g I (12)$$

Now if an inside shading device is used, then the heat gain of the space to first approximation is given by Equation (13)

$$Q_{sd} = \left[0.4a_g + \tau_g\left(a_{sd} + \tau_{sd} + r_{sd} r_g + 0.4a_g r_{sd}\right)\right] I \qquad (13)$$

Figure 6 shows an inset window of height ***H***, width ***W*** and depth of the inset ***d***[12].Without overhang, the area exposed to solar radiation is H X W, however, with overhang the area exposed is only X x Y. The hatched portion in the figure shows the area that is under shade, and hence is not experiencing any direct solar radiation. It can be shown that x and y are given byEquation (14) and Equation (15):

$$X = W - d_x(\tan\alpha)(14)$$

$$Y = H - d_y\left(\frac{\tan\beta}{\cos\alpha}\right)(15)$$

Where β is the altitude angle and α is the wall solar azimuth angle

Then the sunlit area is given by Equation (16)

$$A_{sun} = X.Y(16)$$

The required heat gain of the fenestration now can be calculated by using Equation (8) to Equation (11) and Equation (16).

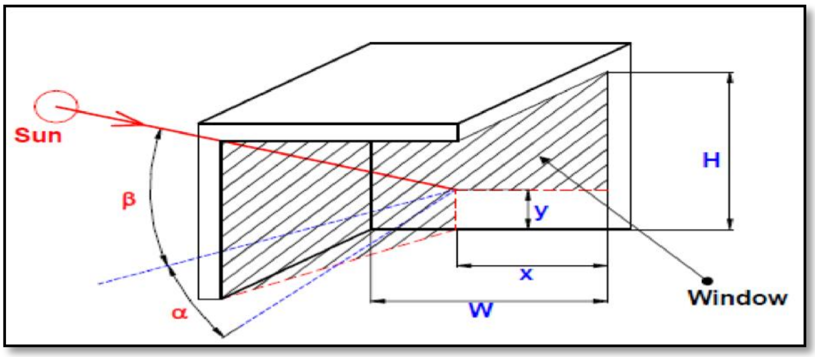

Fig.6 Shading of glass due to horizontal and vertical overhang

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