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Solar Passive Features of the Heritage Building: the Case of the Gohar Mahal, Bhopal

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Abstract
The heritage buildings are examples of a sensitive approach to energy consciousness for indoor comfort conditions, by using solar passive techniques in the building. The study case taken in to account is the Gohar Mahal-a Heritage building of Bhopal, Madhya Pradesh. The building was built in 1820 by Gohar Begum the first women ruler of Bhopal .The inbuilt passive concepts applied by our ancestors to this Gohar Mahal, a palace besides Bhopal upper lake are analyse by taking all the solar passive elements. This study demonstrated that the thermal mass and building envelope of this structure mainly affect the indoor microclimate, stabilizing the inside temperatures and thus give the thermal comfort. The results of the measurements taken in summer and winter confirmed that the seasonal thermal storage of these structures allows comfortable temperatures. during the summer season, with values below 26°C, and stabilizes the indoor temperatures during the winter season.
Keywords: thermal comfort, solar passive techniques, indoor temperature, heritage building, microclimate.

1. Introduction:

The knowledge of architectural designs to create the comfort conditions in the building may be understand well by analyzing the concepts used in the old monuments or heritage buildings. These existing buildings were designed, developed and constructed to use the natural energy sources or sinks for the particular climatic zone. India lies in its Buildings as these buildings are the mirror of History of India. These buildings have been maintained and some restored to keep the glory India intact as in the past and also provide many lessons in designing for specific climates. The concept of energy conservation in buildings is not new but can be seen in our historical monuments. This can be clearly seen in old buildings of Nawabs like Gohar Mahal in Bhopal. It is built by Gohar begum, who was the first woman ruler of Bhopal. Constructed in the year 1820, Gohar Mahal is an architectural marvel, which presents a perfect blend of Hindu and Mughal. Earlier this beautiful palace was neglected by government and the structural condition became worst during late 20th century. In 2003 on an invitation from the Ministry of Textiles and Madhya Pradesh Handloom and Handicrafts Vikas Nigam (MPHHVN), INTACH has worked out a restoration and reuse proposal for the complex. To convert it into an Urban Haat, the palace will be restored maintaining the original fabric and construction details of the buildings and finally inserts new functions.

In reviewing the literature concerned with the heritage buildings many examples indicate that sensitivity to the climate and ingenuity in
gaining a reasonable level of human comfort were attributes of the building arts and the skills of these designers from around the world . Even though a great deal of literature has been published on the above subjects but there is no study is carried out for the composite region like
Bhopal (India). solar passive cooling techniques has been given in fGivoni[1].Energy Efficiency in Old Houses is give by Martin Godfrey Cook[2], architecture of Islamic bath houses has been given by Fodil Fadli Ma , Magda Sibley[3],a vernacular building of Jordan is compare with modern building to test the effect of heating and cooling,Saviana Badarneh ,Hussain Al Zoubi, Dr. Hikmat H. Ali[4], Effect of the thermal mass of the structures made of sandstones in Sassi and Trullli,mainly affect the indoor microclimate and give thermal comfort. By Nicola Cardinale1, Gianluca Rospi1, Pietro Stefanizzi, Valentina Augenti[5]. The comparison of passive cooling techniques of modern and heritage buildings is being discussed, Sanjay and Prabha Chand[6],comfort conditions find in traditional Diyarbakir Houses is given by Akin, Can Tuncay[7].
In this paper major guidelines for solar passive building has taken from, Environmental Building Guidelines for Greater Hyderabad — Ver. 1.1(2008) Solar Passive Design for new buildings (ENE BG1)[8] This research describes the passive feature used for energy efficiency and ecological appropriation in the old traditional buildings by taking example of Gohar Mahal at Bhopal in the composite climatic region like central regions of India. All the solar passive features e.g. site conditions, orientation, material building envelope, open spaces provide in this building to make the building thermally comfortable is being discussed . The main measurements taken to analyse the building are temperature, wind movements and humidity. Thermal performances of these heritage dwellings were evaluated for winter, pre-summer, summer months of the year

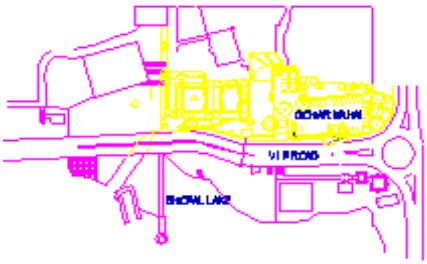
2010. This study also tried to find out the range of comfort temperature in this heritage building for different season of the year.

Fig.3 Rear view of Gohar Mahal

2. Climate of Site[9]:

Bhopal is a city in central India, a hilly but hot area, located on the Malwa plateau. 23.27° N, 77.4° E .Altitude is 499m above sea level. The summers are hot and dry and the temperatures soar as high as 40°-48°C. Winters are moderately cold with temperature not going below 8°C. It rains moderately during the rainy season.

Fig.2 location of Gohar Mahal in key plan



3. Building description[10] :

The Gohar Mahal was built in 1818, is a three-story building with an uninsulated full basement. A two-storey wing at the rear was added later. Major renovations were carried out in 1922. The total floor area is about 650 m^2 (not including the basement). The first- and second-story exterior walls are load-bearing solid brick walls (1000-330 mm thick), the third story is enclosed by a wood-frame mansard roof with the sides covered with slate tiles. The roof is insulated to approximately RSI-4.4 (R-25). All walls are finished with lath and plaster on the interior. Windows are either single-glazed, double-hung wood-frame windows with single-glazed wood-frame storm windows on the exterior; or leaded, single-glazed metal-casement windows with single-glazed wood-frame storm windows on the interior.

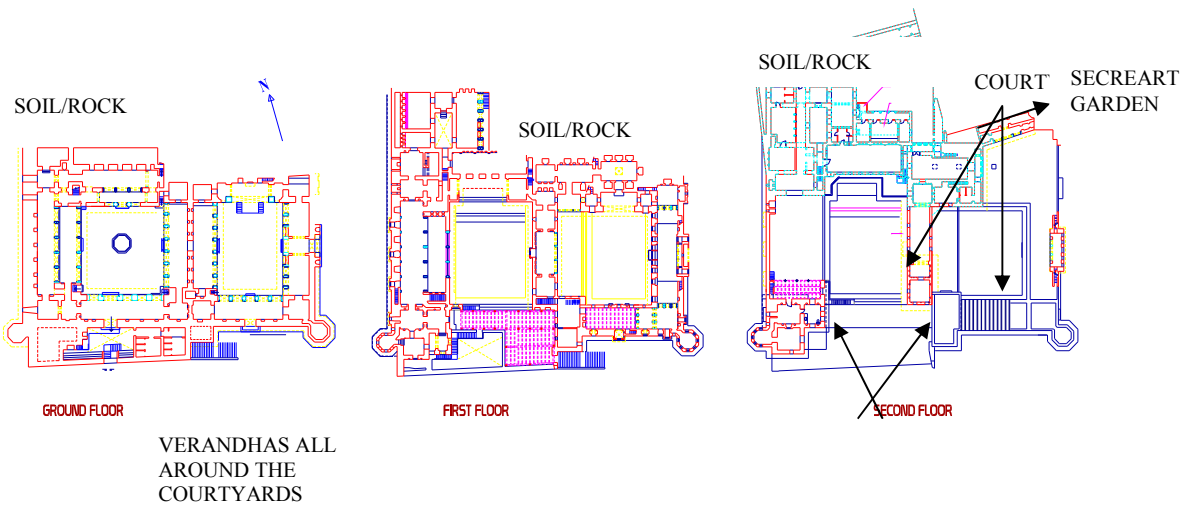


Fig.1Sectional plan of all the three floors Gohar Mahal [11]

Location of Gohar Mahal is at the lakeside, the main entrance is south-east facing. The two courtyards divide the building in three parts in longitudinal direction and two parts in transverse .The building is constructed on the slope of a hill,hence there is a road level entry at each floor also one of its part is attached with hill. Therefore the built up area is less at ground floor than first and second floor. The main entry is towards the lake side in the eastern corner at ground level.

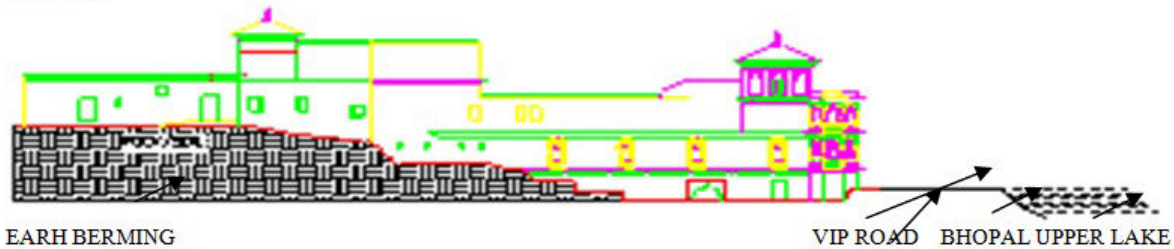
4. **Passive Solar Design of Buildings**:
The energy efficiency in the buildings can be achieved by studying the macro and micro climate of the site, applying solar passive and bio climatic design features and take advantage of natural resources on site. A few common architecture solar passive design elements are listed below [11:]

- Landscaping·
- Water bodies·
- Orientation
- Site And Site Conditions
- Open spaces and built form
- Building envelope

Assessment of many of our vernacular buildings like Gohar Mahal shows an understanding of PSD and demonstrates how simple it is to incorporate in modern building design.

4.1 Landscaping:
Landscaping by vegetation is one of the most effective ways of altering micro climate for better conditions. Trees provide buffer to sun, heat, noise, air pollution. As Gohar mahal is built towards lake side ,there is a dense vegetation around it. These trees ,plants and water body near by help the building to keep cool in summer by evaporation cooling. Water bodies like ponds, lake or fountains in the landscape help reduce micro climate air temperature around the buildings. The building consists of multi-level planning, as the building is built on a small hill with the different levels gradually increasing in height towards the north -east direction. Hence Ground cooling by earth berming keep the inside temperature much down in summer and moderate in winter .the principle behind this is the earth's temperature is practically constant after a depth of 2.5m and remains close to the average annual temperature, thus offering a vital sink for buildings to dissipate their heat hence the Gohar Mahal part, which is in contact with earth benefits from huge thermal mass of adjacent ground and is thus not affected by hot and cold climate, shown below the rear view of Gohar Mahal. the maximum openings are towards the lake side i.e. .in south west direction, to get the cool air in and let the hot air out. This makes building much cool in summer.

Fig .4 REAR VIEW OF GOHAR MAHAL



4.2Orientation:
In solar passive buildings, orientation is a major design consideration, mainly with regard to solar radiation, daylight and wind.. Gohar Mahal in respect to its orientation is perfect. Main entrance of Gohar Mahal is east facing.The long wall is at south side and maximum openings are given at wall that is lake side to capture the prevailing wind in summer. All the main rooms are towards north side with small openings but attached with large verandahs and courtyards.

4.3Site location and site conditions:
Gohar mahal is located besides Bhopal upper lake. Water has a moderating effect on the air temperature of the micro climate. It possesses very high thermal storage capacity much higher than the building materials like Brick, concrete, stone. A large body of water in the form of lake, river, and fountain has the ability to moderate the air temperatures in the micro climate. Water evaporation has a cooling effect in the surroundings. It takes up heat from the air through evaporation and causes significant cooling especially in hot & dry climate zone. This is observed in at the site also.

4.4 Openings, Semi Openings and Built Form
Openings and semi openings: Openings play main part in solar passive buildings. Main openings are in the form of courtyards and terraces whereas semi openings are in the form of verandahs in Gohar Mahal. There are four courtyards; two of them divide the building longitudinally in three parts and transversely in two parts. The central courtyard of a typical traditional house was a very common passive solar device and was often considered the lung of the house. The success of the cooling principle of courtyards depends on a combination of climate, building shape and wall materials and varied across the region depending on location, size and affluence.

One of the openings is a garden called as secret garden which is at back side of the second floor.
They are performing following functions:

Fig 5 Courtyard effect during night time

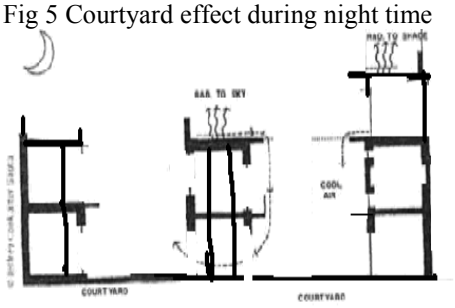
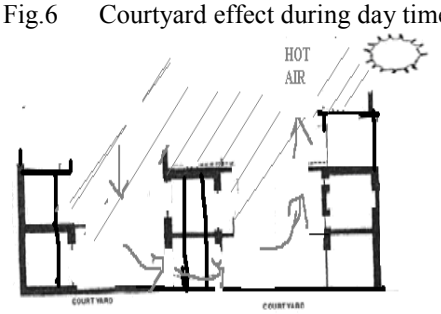


Fig.6 Courtyard effect during day time



- The division of buildings into thermal zones with buffer areas such as verandas, courtyards avoids providing barriers to cross flow ventilation where this is required; hence using courtyard as a space is to act as a thermal buffer. The courtyard was the main source of air exchange from inside the built space to the outer free space.

Fig.7 Low Height Parapets &water

- In Gohar Mahal more space is around the building, this provide prevalent and effected cross-ventilation through a series of openings from the rear/entrance door, through the central courtyards and out of an opening at the entrance/rear. This was the 'air funnel' of the house. The entrance lobby acted as a wind funnel focusing the incident wind into the courtyard that lay on this air funnel, which in turn ventilated the living areas grouped around it.

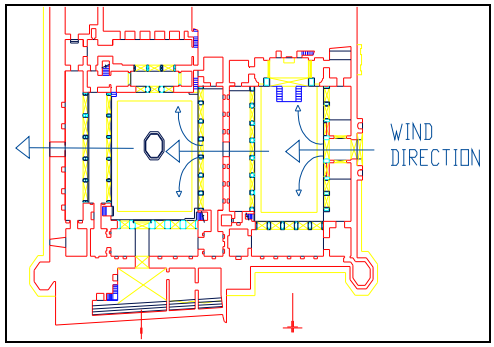


Fig.8 Air funnel formed by cross ventilation

- To facilitate the moment of cool air into the house, parapets are built at very low height and also slopes are towards the courtyard. A water sprinkler was placed in the courtyards to cool and humidify the incoming air.

- The principle of using central courtyards in Gohar Mahal as a means for keeping adjacent rooms cool was based on the pressure difference between cool air and warm air. Cool night time air from high above the courtyard, heavier than warm air, sank into the courtyard and replaced the slightly warmer air that had accumulated there during the day and which was unable to escape because the ambient daytime air temperature above the courtyard was warmer.

- The main function of verandahs found in Gohar Mahal was to prevent the direct heat and glare of the sun from entering the house. They are all the four sides of courtyards. This is analysing that all these verandahs are comparatively cool in summer while hotter in winters.

4.5 Building envelope:

Building envelope components are the key determinants of the amount of heat gain or loss and wind that enters inside the building. The primary components of building envelope which affect the performance of the building are:

- Walls
- Roof
- Windows
- Floor
- Surface finishes

Most of the walls are made of adobe bricks. Bricks are made up of local soil of size 10cm x 5cm x 5cm.Walls are of varying thickness i.e. from 5'3" to 2'2".All the walls are thick massive walls as to increase the time lag. Few walls are also made up of stone. The plaster provided is lime plaster with surkhi.

Fig 9: Doors and Tapered wall, Stone ceiling at Gohar Mahal ,Window at floor level

Few rooms (lake side) have double roof (false ceiling) .Building that has few roof /ceilings with a air gap in between is a good concept of passive cooling[10]. Two types of construction are used for roofs and floors. The traditional method is to lay closely spaced timber beams and cover them with flag stones and then layers of lime, jute and surkhi.

Fig.10 Windows and ventilators in Gohar Mahal:

Windows, Doors, Ventilators and other openings:

All the window shutters and frames are of timber. Most of the openings are towards windward direction in Gohar Mahal. Windows at the windward side are mostly placed at floor level; their sizes are 4'2"x2'8".

Wind catchers are provided in the form of hexagonal shaped. In verandahs also windows are provided which aerated the verandah and keep the temperature down even in hot summer afternoons.

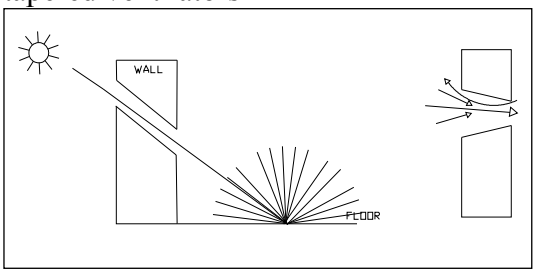
Doors: Timber doors are usually rectangular in shape and the dimensions of the doors are varied place to place. The entrance doors are quite huge. But most of the internal door height is about 5'3"-5'6''only. Tapered walls are here for easy movement of air from low pressure to high pressure. The latches provided are of iron commonly known as 'kari'

Ventilation and other openings:

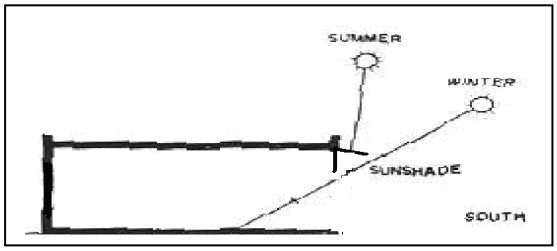
Ventilation is the exchange of air between the inside of a building and the outside. In Gohar Mahal traditional ways of ventilation to achieve passive cooling was adopted, briefly described below:

- For natural ventilation, the flow of air is caused by the pressure of the wind (cross ventilation) or by the buoyancy effect of temperature differences between inside and outside (Stack effect).
- Almost all the ventilators are inclined i.e. highly elevated at outside and low at inside.
- The arch shaped ventilators are highly tapered these are for spot light i.e. lightning the whole room naturally .
- Highly elevated small openings keep the room cool.
- Numbers of jharokhas are also given for free flow of wind.

Fig.11 Effect of Slanting (Spot light) and tapered ventilators



Sun Shades and chajjas : Shades play important role for protecting the building from direct sunlight. In Gohar Mahal shades of flag stone are provided all the four sides of the building. Generally they are slightly inclined and 900mm wide. They are supported on stone cornice. They are perfect to gain direct solar radiation in winter and shades in summer.



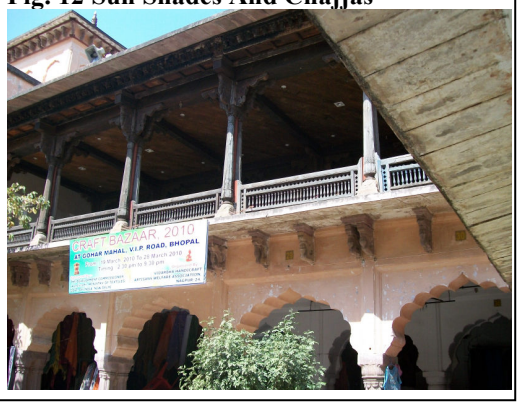
4.6 BUILDING STRUCTURE:

All the exterior walls are load bearing walls. Arches are provided to bear load uniformly. No steel is used for structural work. Huge massive Columns are of stone, Few columns are of timber also (mainly at the verandahs).Brick masonry columns and Stone masonry columns for less small structural support. Beams are of timber, spacing 25cm c/c.Roof is of stone coated with lime, supported on timber beams. Lintels are of timber mainly, otherwise arches are given to support the structure.

4.7 BUILDING MATERIAL:

Choice of building material for the envelope is important to reduce the energy content of the building, this means selection of building materials which use low energy in their manufacturing. The choice of building material is also important to achieve indoor comfort. The natural building materials available for construction in Bhopal are stones, timber, and clay and lime stone. Choice and positioning of appropriate building materials within internal and external fabric, particularly where thermal mass effects are used in Gohar Mahal.

Fig. 12 Sun Shades And Chajjas



In Gohar Mahal the building materials used are;

- Bricks
- Stone
- Timber
- Lime
- Sand stone
- Jute fabric

Table 1 : Table1 In Gohar Mahal the building materials used with their thermal properties
(Source www.bath.ac.uk/~absmaw/BEnv1/properties.pdf)

	Material Conductivity (KJ/Kg. K)	Specific Heat Capacity (Kg/m3)	Density (W/m K)
Brick	0.811	0.88	1820
Mud	` 0.750	0.88	1731
Stone	1.5	0 .84	2200
Timber	0.072	1.68	480
Limestone	1.80	0.84	2420
Timber	0.144	1.68	720

4.8 Load Distribution in Building:

In Gohar Mahal no steel bars are used in structure. The structural elements are as follows:

1. Foundation; foundation is made of stone, no major settlement is seen. .
2. Columns: columns are of stone, timber and brick, they are massive structure, and their sizes are varied.
3. Beams: Beams are made of timber only, all floor joist are 100mm wide and spaced 25cm c/c.
4. Slabs are made of stone resting on timber beams .lime coating is applied on the stone for finishing.
5. Lintels are made up of timber.
6. Arches: There are a large number of masonry arches in Gohar Mahal. They are either single or multiple. They have been built either with brick or stone masonry along with lime mortar.

5. Methodology -Field measurements

Method adopted for study of thermal behaviors of the building:
For study of thermal behavior of the building we observe following parameters by fixing some sampling points.

- Room temperatures at various sampling points
- Humidity at various sampling points
- And also wind speed at the various points at wind direction.

The two courtyards divide the building in three parts longitudinally and in two parts laterally. Observations are take at each part, various sampling points selected. The three parts are divided longitudinally as A, B and C and in 4 parts laterally.

5.1 Temperature and Relative Humidity:

Several sampling points were taken at each floor and at each part of the Mahal. Graph is shown for three points. Drawing showing sampling point and the temperature difference in summer i.e $\Delta T=T_M-T_P$, here T_M is metrological temperature and T_P = temperature of the point on same date

◆ SAMPLING POINT

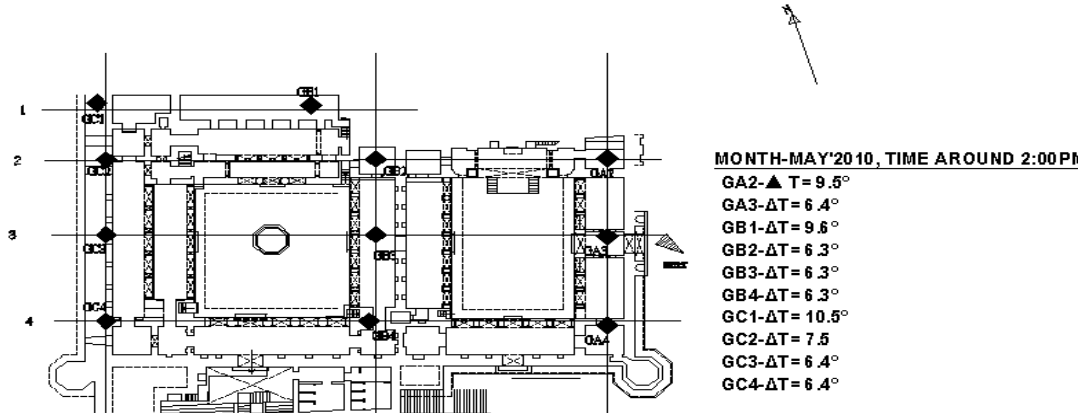


Fig 13 Difference of metrological and inside Temperatures of sampling points at Ground floor

Fig. 14 TEMPERATURE AT SAMPLING POINT **GA1**
X-AXIS-TIME, Y-AXIS-TEMPERATURE IN DEGREE CENTRIGRADE

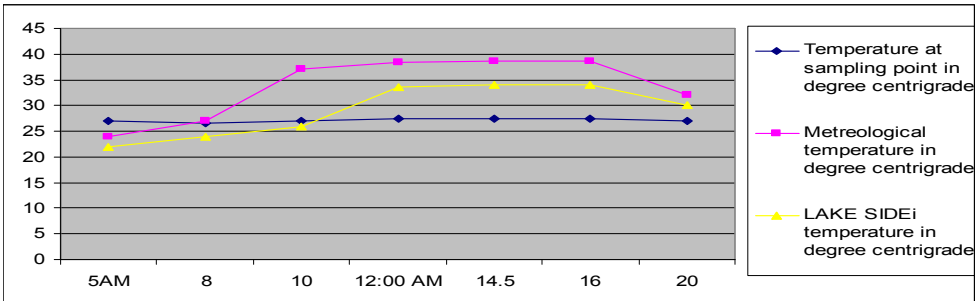
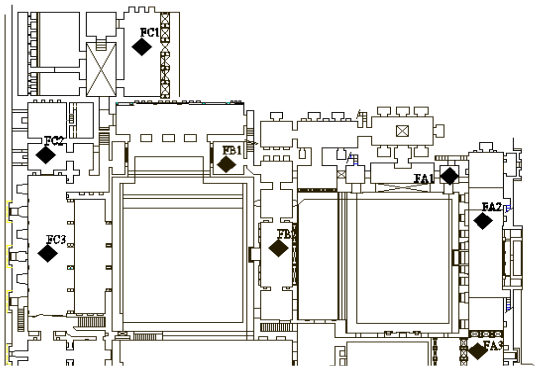


Fig 15 Difference of metrological and inside Temperatures of sampling points at first floor



TEMPERATURE DIFFERENCE AND HUMINITY
MONTH-MAY'2010, TIME AROUND 2:00PM

FA1-T= 9.5°	RH=39
FA2-T= 6.4°	RH=40
FA3 1-T= 9.6°	RH=40
FB1-T= 6.3°	RH=41
FB2-T= 6.3°	RH=41
FB3-T= 10.5°	RH=43
FC1-T= 6.4°	RH=41
FC2-T= 6.4°	RH=40
FC3-T= 6.4	RH=41
FB4-T= 6.3°	RH=42

Fig. 16 TEMPERATURE AT SAMPLING POINT **FC2**
X-AXIS-TIME, Y-AXIS-TEMPERATURE IN DEGREE CENTRIGRADE

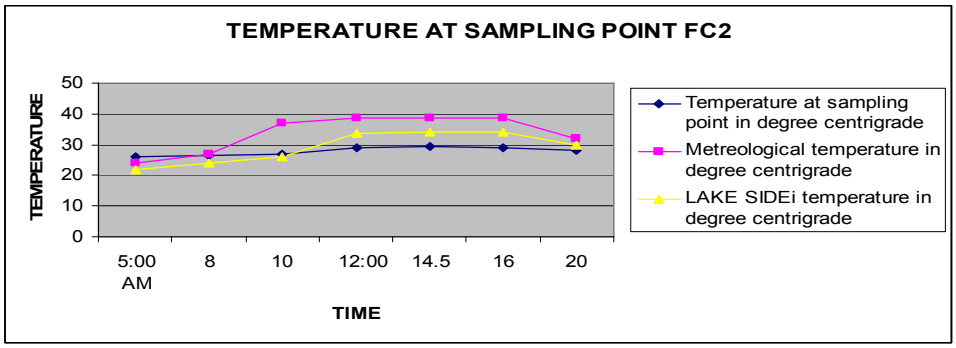
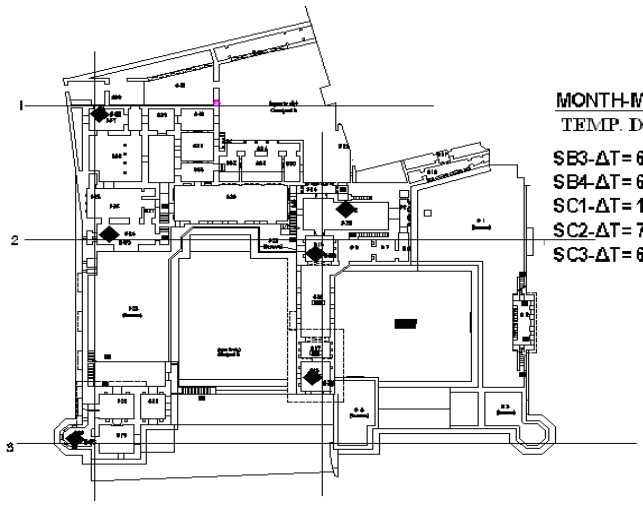


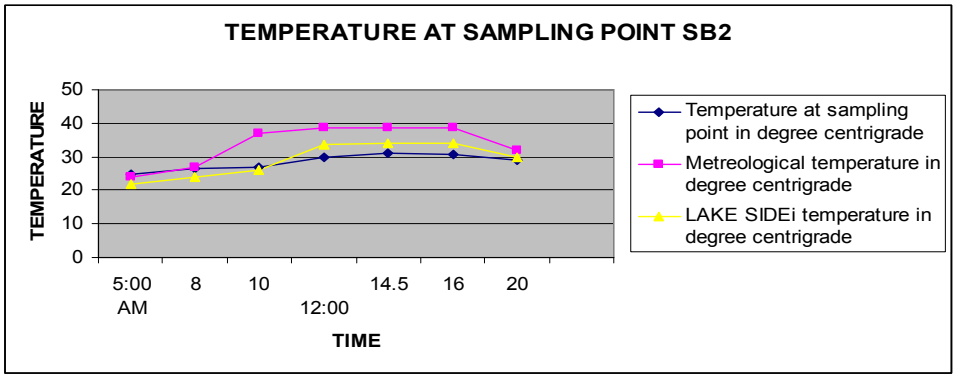
Fig 17 Difference of metrological and inside Temperatures of sampling points at second floor



MONTH-MAY'2010, TIME AROUND 2:00PM

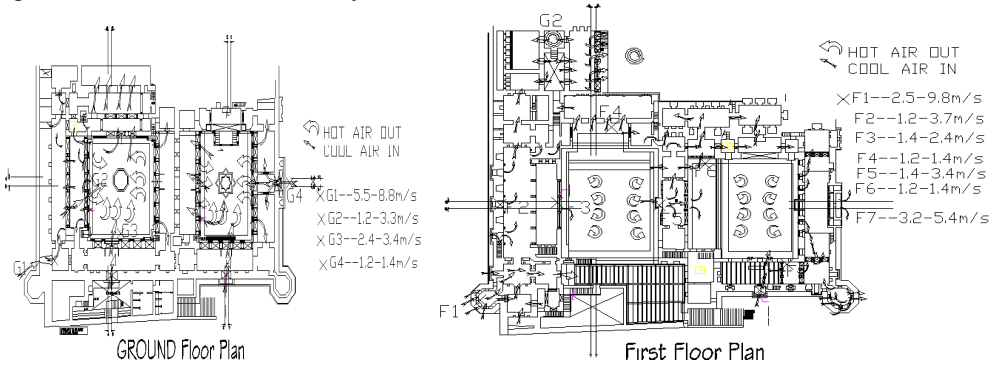
TEMP. DIFF	HUMIDITY
SB3-ΔT= 6.0°	RH= 39
SB4-ΔT= 6.0°	RH= 39
SC1-ΔT= 10.8°	RH= 38
SC2-ΔT= 7.5°	RH= 40
SC3-ΔT= 6.4°	RH= 41
	RH= 45

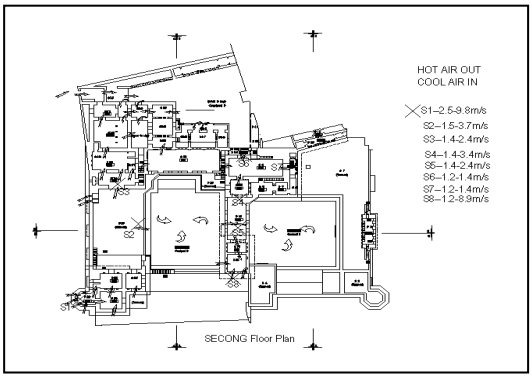
Fig. 18 TEMPERATURE AT SAMPLING POINT **SB2**
X-AXIS-TIME, Y-AXIS-TEMPERATURE IN DEGREE CENTRIGRADE



5.2 Observations for wind:
Wind directions and wind velocity:
Wind velocity (taken with anemometer) and wind direction shown in the following drawings:

Fig 18 Wind direction and velocity at all the three floors





6. **Result and discussion:**
The climatic parameters which effect the structure and comfort are shown below, describe the effect of these parameters on the building and the resident of the building:

Temperature: In summer during day time the temperature of all the rooms are much lesser than outside:
Min temp difference: 4 degree (south facing rooms)
Max temp difference: 9 degree (north facing rooms)

Early morning the temperatures are as follows :(higher than outer)
Min temp difference: -1 degree (north facing rooms)
Max temp difference:-4 degree (south facing rooms)
Humidity: Humidity is around 40-50% in all the rooms that makes more comfortable living
Wind velocity and Wind direction:: During summer the prevailing wind blows towards west and the velocity is quite high. In windward direction it varies from 3.2-13.6 km/hr.
Maximum openings are towards western side (lake side). In Bhopal during summer the prevailing wind blows towards west, as due to evaporative cooling from lake the temperature of this wind is also low. This gives cool breeze throughout the day and night time.
Diffused radiation and direct radiation:
Due to clear sky conditions the solar radiations are direct during summer in Bhopal. At Gohar Mahal the shades are placed in such a way that in covered verandahs the direct solar radiations are seen in morning time only in

summer rest of the day only diffused sunlight is there. Also windows are properly shaded not receiving direct sunlight.
But in winters there are direct solar radiations at most part of the day. Ventilators are shaped such that they provide direct solar radiation but avoiding heat.

7. Conclusion

From above observations and analysis this is prove that this building is solar passive and does not require any conventional method for cooling. That is use of natural energy (sun, wind, etc.) to conserve conventional energy for achieving thermal comfort refers to comfortable indoor conditions (temperature, humidity, air movement) is observed and analyzed in this building. The result from above analysis shows that the Gohar Mahal is an example for making solar passive modern building for climate of Bhopal.

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