NATURAL COOLING OF RESIDENTIAL BUILDINGS IN HOT-DRY CLIMATE

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ABSTRACT

Dwellings in rural areas of the developing countries do not have artificial systems of cooling or heating. These buildings, especially in hot-dry climate, are provided with natural cooling systems. Parameters which influence natural cooling of such buildings can be classified as (i) surrounding environmental factors and (ii) parameters associated with the buildings. Present paper describes influence of above parameters in providing natural cooling of residential buildings in general and in hot-dry climate in particular. These effects are supported by case studies of few residential buildings.

Keywords: hot-dry climate, natural cooling, residential buildings

1. INTRODUCTION

1.1 Economic conditions

In most of the developing countries like India, more than 50% of the population, stay in rural area where their houses do not have artificial systems of cooling or heating. Even more than 50% of the houses in urban area also do not enjoy these facilities. This is primarily due to poor economic conditions of the residents and secondly due to shortage of electric power to operate cooling and heating facilities. Thus, most of the residential buildings in urban and rural areas are provided with environment friendly designs to have the advantage of natural cooling during summer and heating during winter.

1.2 Influencing factors

In order to construct a building with the advantage of natural cooling, it is necessary to know the effect of various factors which influence natural cooling of buildings. These factors or parameters can be grouped as (i) surrounding environmental factors and (ii) parameters associated with the buildings.

Surrounding environmental factors which influence cooling of such buildings include landform and its orientation, vegetation pattern, water bodies, street width and orientation, open spaces and built form etc. Parameters associated with the buildings include roof form

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and its material, thickness and type of walls, window openings - its design and positioning, shading devices, overhangs and louvers, skylight openings etc.

A detailed analysis has been carried out in the present study for understanding the influence of above parameters in providing thermal comfort to the residents in hot-dry climate. Six residential buildings in Gulbarga city of Karanataka State in India have been taken as case studies for observing passive cooling systems used in these buildings.

2. SURROUNDING ENVIRONMENTAL FACTORS

2.1 Landform and its orientation
The land form or topography of a site and surroundings could either be flat, sloping or undulating. If the land is flat, similar conditions would prevail over the entire site. However, in case of undulating ground in hot-dry climates, constructing a building in a depression implies relatively lower air temperature. It is due to the fact that cool air being heavier than hot air, tends to settle down in depressions while hot air rises. Similarly while making a building on slopes, leeward side is preferable. Nevertheless, warm winds would be minimum on either slope [1].

Landform orientation has little meaning when the land is flat. However, the orientation of slopes would make a difference. In area of hot-dry climate, a north slope would be preferable as it would receive least direct radiation. It is true only if the slope is steep enough to shade the building [2,3].

2.2 Vegetation pattern
Vegetation and trees in particular effectively shade and reduce heat gain. They increase humidity level. They also cause pressure differences thereby increasing and decreasing air speed or directing air flow. They can, therefore, direct air into a building or deflect it away. Plants, shrubs and trees absorb radiation in the process of photosynthesis. As a result they actually cool the environment. In hot dry climates where heat gain is to be minimized, trees can be used to cut off the east-west sun as well as hot breezes.

2.3 Water bodies
Water absorbs relatively large amount of radiation. They also allow evaporative cooling. As a result, during day time area around water bodies are generally cooler. At night, however, water bodies release relatively large amount of heat to the surroundings. In hot-dry climates, water bodies can be used both for evaporative cooling as well as minimizing heat gain. Taking into account wind pattern and vegetation, cool breeze can be made to enter into the house. Similarly a roof pond minimizes heat gain through the roof [4-6].

2.4 Street width and orientation
The amount of direct radiation received on the street (and to some extent the lower floors) is determined by the street width. The orientation affects the time of the day when the radiation is received. Modulating the street width and orientation can very effectively minimize or maximize heat gain. Street width to building height ratio also affects the daylight received.
In hot-dry climates, the prime need is to minimize heat gain. This could be achieved by cutting off the sun. Small street width to building height ratio ensures narrow streets and thereby shading. In particular, streets running north-south should be narrow. This would enable mutual shading from morning and evening sun [7]. However, this aspect can be considered advantageously only when planning and designing new residential colonies.

2.5 Open spaces and built form
Open spaces have to be seen in conjunction with the built form. Together they can allow for free air movement and increased heat loss or gain. Open spaces in any complex are inevitable. The question is how should they be and how much should there be? After all, any built mass modifies the microclimate. An open area, especially a large one allows more of the natural climate of the place to prevail [8,9].

Open spaces gain heat during the day. If the ground is hard and building surfaces are dark in colour, then much of radiation is reflected and absorbed by the surrounding buildings. If however, the ground is soft and green, then less heat is reflected [10].

In hot-dry climates, compact planning with little or no open spaces would minimize both heat gain as well as heat loss. When the heat production of the buildings is low, compact planning minimizes heat gain and is desirable. This is how traditional settlements often are.

3. PARAMETERS ASSOCIATED WITH THE BUILDINGS

3.1 Building configuration
In hot-dry climate regions, it is desirable to lower the rate of temperature rise of the interior during day time in summer. To achieve this, the building should preferably be compact. The surface area of its external envelope should be as small as possible, to minimize the heat flow into the building. The ratio of the building envelope’s surface area to its volume or ratio of floor area to its volume determines the relative exposure of the building to solar radiation. The best layout is that of a patio or a courtyard surrounded by walls and thus partially isolated from the full impact of the outdoor air. This configuration is very common in hot-dry climate.

3.2 Building orientation
The main objective in deciding upon a given orientation in hot-dry climate regions is to minimize the impact of the sun on the building in summer [11]. Pattern of solar radiation on different walls results in a clear preference for north-south orientation of the main facades, and especially of the windows. Such orientation enables easy and inexpensive shading of the southern window in summer. The heating effect of solar radiation impinging on walls can further be minimized by choosing reflective colours of the walls.

3.3 Other parameters
Other parameters associated with buildings, proper planning of which can provide thermal comfort to occupants of such buildings in hot-dry climate, include roof form and its materials, thickness and type of walls, windows openings – its design and positioning,
shading devices, overhangs and louvers, skylight windows etc. [12-14]. Due to paucity of space, influence of these parameters is not being discussed here.

4. CASE STUDIES

4.1 Traditional aspects
In order to see the practical use of above listed parameters in providing natural cooling in hot-dry climate regions, six residential buildings in Gulbarga city of Karanataka State in India have been considered. Description of each of these houses is given below. Before going into case study, a brief description of the traditional residential architecture of Gulbarga needs be given.

The most prominent characteristic of any traditional building in Gulbarga is thick external wall having small openings, which reduce transfer of heat. The plan of the building is square or rectangular in shape with central courtyard. Rooms are arranged around the courtyard. All doors open towards the courtyard. Only main door is placed on the external wall. Roof is constructed with well-compacted mud supported by wooden joists and planks. Material of construction is stone, mud and wood.

4.2 House of Mr. Ram Chandra Patil
It is 80 years old two-storied building. Plan of the building is simple, square and symmetrical about East-West axis. The building is functionally convenient. The main entrance is from the Southern side. The first entry leads to front yard. Then it goes to main building. The plan of the building is compact. All rooms are arranged around central courtyard. Doors of all the rooms are opened to the central courtyard, Figure. 1.

All external and internal walls are constructed with stone, mud and lime mortar. The external wall thickness is 825 mm and the internal walls are 450 mm thick. The external walls being thick, it reduces the heat inside during day time. Small openings are provided to get required ventilation and to stop solar radiation, glare and dust. Two staircases lead to the upper floor on either side of entrance. Roof is flat in nature and constructed with compacted mud and lime mortar finish on the top. The court yard and roof top is used for sleeping at night in summer.

This house is provided with no artificial cooling system. Still occupants enjoy good thermal comfort.

4.3 House of Mr. Baswaraj Patil
It is believed that the building is around 200 years old, Figure. 2. It is a two-storied building. The plan is simple but more functional. It is almost square in shape and symmetrical about North-South axis.
The main entrance is towards North. It is 1.8 m wide and 3 m in height. The main entrance leads to the verandah. There are four staircases leading to upstairs, two in front and two in rear side. First floor is raised towards the south side. It creates shadow on the terrace in the afternoon. All the door openings lead to the central courtyard. The courtyard is measuring about 7.2 m × 7.2 m in size. It admits the light inside the building. The building is having only one external entry. The backyard is used for general utility purpose.

External walls are 900 mm thick and internal walls 450 mm. Materials used for the construction of walls are stone, mud and lime mortar. The time-lag factor of external walls is
more than 12 hours. So it absorbs the heat during day time and release at night. Thus it maintains daytime comfort, but at night hours some discomfort is felt during summer because of small ventilation. Roof is made with well-compacted mud.

But throughout the year the building is comfortable without using artificial systems of cooling.

4.4 House of Mr. Parvath Gouda

It is a two-storied building which is about 250 years old. The plan of the building is square in shape with attached back yard. The building is compactly planned with central courtyard measuring 9.9 m × 6.9 m, Figure 3. The main entrance is from East side. Entrance gate is 1.8 m wide and 3 m in height. On all sides, external wall of 900 mm thick are made. Internal walls are 450 mm thick. Small openings are provided on the external walls to get light and required ventilation. From the main entry there is separate entry for cattle shed. Only one external entry is provided in the building for security reasons.

![View of courtyard in Mr. Parvath Gouda’s house](image)

For the construction of wall, the material used is stone masonry. On roof, a layer of well-compacted mud is present which is in good condition till now. Rooms have been constructed on southern side of the first floor, and remaining portion is open terrace. The major light is admitted through central courtyard.

The buildings function according to seasonal changes. In summer, one feels cool and comfort inside during daytime. Courtyard and roof top is used for sleeping as the rooms remain hot at night due to small ventilation. During winter, the heat stored in walls during daytime radiate at nights in the rooms and provides the comfort without using mechanical system. The backyard of the building is used for general utility as well as to maintain privacy.
4.5 House of Mrs. Ratna B. Kalamdani
The building is two storied located near the main road on Gulbarga-Bangalore highway. The building faces towards South. While designing the building Architect has considered all the climatic factors.

The plan of building is almost square in shape with few offsets only. The main offset is provided near the main entrance in southwest direction where water pond is located, Figure 4. From water pond the water channel is provided below the flooring. Few openings are provided on the water channel in the floor. The direction of wind is from South-West to North-East. When hot wind is funneled from South-West direction, the pressure is created in the main offset and hot air pass through the water channel. The water pond cools the air by evaporation and gets into the building through openings provided in the flooring.

![Figure 4. View of water pond at Mrs. R.B. Kalamdani’s house](image)

The staircase is located in the centre of the building between hall and dinning room, Figure 5. The advantage of staircase is it gives double height to the roof. It gives free air circulation inside the building. Hot air passes through openings provided in the roof.

The material used for the construction of walls is brick. All the external walls are of one and half brick thick and all internal walls are one brick thick. Further whereas, internal walls are made solid, external walls are provided with openings in it by using rat-trap bond. The technique used for the construction of external wall is to minimize the heat transfer from outside to inside the building.

Architect has not used the plastering or any treatment to external surface of the wall. He exposed the brick with red oxide coat on it. It is because cement is a good conductor of heat. Material used for the construction of roof is R.C.C slab. But the slab is made in slopping form. The inclination is given to the roof considering sun path diagram so that maximum
reflection of solar radiation takes place. The holes are provided in the first floor slab to pass lighter air from ground floor to first floor and from first floor to dormer window, which is provided in the roof slab. Thus circulation of air occurs in the building.

![Figure 5. Ground floor plan of Mrs. R.B. Kalamdani’s house](image)

All the window and ventilator openings provided on external wall are of size 0.6m × 1.5m. Whereas ventilator is made of fixed glass, window is provided with wooden shutter. The purpose of providing wooden shutter is due to the fact that timber is a good insulator of heat.

Architect has also planned a good landscape, which is suitable for hot-dry climate. On west and south sides, trees of larger height have been planted. It creates shadows on the building as well as open spaces to keep it cool.

4.6 House of Mr. M.B. Patel

The building is two storied. The road is facing towards the south west of plot. Architect has considered the climatic factors in the design of building.

The building is planned in such a way that rooms are arranged around the central courtyard. The plan is fitted in to the site, which makes 45° to the main road. The main concept of this system is to generate required movement of air in different spaces of building by minimum use of mechanical or electrical energy. Four vertical towers are used to extract hot air from the building. Above the courtyard, the technique used is such that cool air
passes downward and circulates through all the rooms to achieve thermal comfort in the rooms.

All walls, internal and external, are constructed with brick masonry with one and half brick thickness. The roof is constructed with R.C.C slab with insulation materials covering laid by Madras hollow block and covered with terracotta tiles. The roof is made sloppy to create wind pressure and pass through fine openings provided above courtyard for evaporative cooling.

A ventilator duct is provided connecting to each room to remove hot air. On east and west sides, plastic barrels are placed very close to wall for rain water collection used for evaporative cooling. There are no windows towards east and west sides of the wall to avoid direct sunlight. Architect minimized the window openings. They are of 600 mm to 900 mm wide and 1.35 m in height. In windows the evaporative cooling system has been provided. The openings are provided in duct tower to extract hot air and convert it into down draft evaporative cooling system.

4. 7 House of Mr. S.V. Bakshi
It is a single storey building with total built up area of 76.5 sq. m. Building was completed in 1995. Plan of the building is rectangular in shape with one of the long walls being a common wall. Building is symmetrical about shorter axis. Main entrance of the house is from east side. All windows in the building are of same size i.e. 0.75 m × 1.35 m.

The central courtyard acts as a passage to flow hot air from the rooms. The courtyard can be operated according to the season to control the air flow. For the construction of walls, architect used rat-trap bond to reduce temperature by providing the cavities in the wall. No plastering has been done on either side. Material used for window is pre-cast blocks laid over one another, Figure 6. Design of the blocks is such that it maintains privacy and permits flow of air through it.

Figure 6. Front view of Mr. S.V. Bakshi’s house showing windows
Architect of the house tried to provide maximum comfort with the help of passive cooling technique with minimum energy and cost.

5. CONCLUDING REMARKS

Following conclusions are drawn from the study presented herein with respect to natural cooling of residential buildings in hot-dry climate:

(i) To minimize energy demand and provide better degree of natural conditioning, it is essential to give climatic considerations for designing of residential buildings.
(ii) For a building to function in co-ordination with the environment, there should be a relation between the interior and exterior environment, orientation, building form, materials etc.
(iii) Orientation of the overall built form should be in co-ordination with the orientation of the sun and prevailing wind direction.
(iv) Land-scaping is a passive energy saving technique. It controls wind, solar radiation and temperature extremes of climate.
(v) Rectangular form of the building should be elongated along east-west direction, i.e. the orientation of the building should be north-south.
(vi) When buffer spaces are provided between exterior and interior spaces, heat from outside dissipates before entering interiors. Non-habitable rooms such as toilets, stores and galleries can be provided as heat barriers in the worst orientations on the outer periphery of the building.
(vii) Heat removal can be affected by natural or induced ventilation, evaporation of water and the use of heat sinks.
(viii) Provision of a central courtyard is preferable which helps in achieving shaded spaces, natural light in most of the places and better circulation of air without providing much openings on the exteriors surfaces. However, provision of courtyard is effective only if it has a plan area and volume relationship proportional to built-up area and its volume.
(ix) Thick walls create thermal time-lag, thus creating comfortable conditions.
(x) As the position of a window goes higher, light penetration increases with lesser heat gain.
(xi) Size and location of ventilators be decided in such a way that it helps to take the hot air out and improves cross ventilation.

REFERENCES


