Hollow Roof Tiles : Passive Solar Heat Control in Tropical Climate

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Abstract

The present research work was conducted with two isolated and identical rooms having South facing roofs specially constructed for the purpose. It was made possible for the roofs to be tilted at different angles. The roof of one room was finished with hollow brick tiles and the other with bare concrete Thus the effect of hollow brick tiles as a means of passive solar heat control, could be compared with that of concrete roof under similar conditions. Experimental results show a substantial reduction of ceiling temperature for the room with hollow brick roof tiles and in some extreme conditions it was found to be around 12°C lower than that of the concrete roof ceiling.

Introduction

The primordial role of architecture was to act as an instrument for modifying extremities of nature even the most rudimentary shelters of the past and present were built to serve the very basic purpose of protection against the adversities of climatic environment. The physical environment, either man-made or natural, controls sun, wind, rain and light, acting as filter or amplifier. Environmental response of people in different cultures and climates thus found expression in their built-form producing a distinctive character in their architecture. Eskimos' Igloos, Bedouins' Black Tents and Arabs' Mashrabias are all indicative of the relative importance placed on the passive control of climate through the design of dwelling units.

As long as unselfconscious societies were preoccupied with their own cultural beliefs and attainments they maintained fairly consistent architectural development within a given geographic boundary. They shaped and organized their built-forms corresponding to prevailing climatic parameters in order to attain comfortable living conditions with the material, method and technology available.

Vernacular architecture therefore, developed with remarkable respect for solar geometry in its orientation and articulation. The traditional rural houses in Bangladesh centered around a courtyard can be explained as an oasis on an envelop of hot and humid climate. A house is never conceived in isolation from its trees and plants. This helped in exclusion of solar heat through shading and filtering hot summer wind and cold winter breeze. Walls could breathe through perforations and trapped hot air could escape through the slits between the roof and wall junction.

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In urban vernacular houses measures taken for passive climatic conditioning were also distinctly evident. The controlling elements were thick walls, high ceilings, clear story windows, double windows, a verandah running all around the outer periphery of the house in the form of canopy. The traditional building crafts developed by the Master masons were threatened by the new method, materials and means of construction developed during the industrial era.

The new technology was influenced by the spirit of building more with less time and material. The driving force was economy in all sectors of construction and management, leaving aside various important socio-cultural and human factors of habitation. Commercial success of rapid building technology was so overwhelming that it invaded entire formal construction sectors including dwelling house construction. The speed and economy of construction process gradually replaced all traditional elements of passive climatic control. Mechanical devices like ceiling fans, table fans, coolers, dehumidifiers, air conditioners, etc. were all introduced as an alternative means of environmental control.

This automatically placed high premium on energy consumption, not to speak about the associated installation and maintenance costs. Considering these factors, a long term return analysis may reveal that the traditional methods are still in many ways the more attractive alternatives. However, the purpose of the paper is in no way to advocate a return or revival to traditional practices, but to indentify alternative means and devices of passive control compatible with the contemporary building technology and discover new methods and systems to make the building itself an energy modifying instrument towards a conceptually coherent approach for a low energy, environment friendly and sustainable architecture for the developing world of the future.

Research Premise

Confronted with the energy crisis of the seventies, the developed countries turned to experiments in low energy architecture. Meanwhile, the developing countries were tempted to use the high energy models from the west. It is also evident that growing awareness about energy issues and the campaign for low energy consumption in the west, affected third world consciousness as a means for sustainable development.

The premise for research in climate responsive architecture is mutually opposing between developed and developing countries. The very global distribution have placed one in cold region and the other in hot region. One is trying to combat heat and the other is trying to combat cold.

Solar radiation is a major source of heat gain. The term 'Solar Passive' architecture is coined in cold countries and it applies to the use of solar radiation to the advantage of heating. On the contrary: the same terminology will apply in hot and humid countries to the exclusion of solar energies for comfortable living and working environments.

Thermal comfort is a product of diversified factors. The comfort response is also conditioned by cultural and psychological bias. Being confused by the complexity of the problem, architects are usually tempted to leave the matter to the mercy of mechanical devices. Contemporary studies on passive climatic control on the basis of different climatic regions are limited and not very well published. Designers therefore, are skeptical about their practical application and ultimate performance.

Hypothesis

In the contemporary world of information explosion we are flooded with climatic data, survey and analysis. However, they are yet to be processed in simplified forms for application by architects. Regualr practicing architects in the developing world seldom have time or resources or incentives to go through complex analysis or research to identify passive ways for climatic adaptation of buildings. Nevertheless, it is indeed possible to create an interest and incentive for applying climate adaptive architectural systems if a repertoire of passive control mechanisms, elements and materials are made available.

It is envisaged that techniques based on transformation of traditional methods, tested with the contemporary norms of architectural design and construction would definitely encourage their application. With this frame in mind an interdisciplinary research on passive climatic control has been undertaken at the Department of Architecture, BUET in collaboration with the Mechanical and Civil Engineering Departments. The very first endeavour of the research was to develop a mechanism of passive control of solar radiation through a device of thermal roof tiles. The research programme ventures into other areas of passive environmental control with a clear objective of developing easily applicable, economically viable and socially acceptable methods and devices, to augment natural incentive for popular architectural use. Application of double roof with a sandwich of air in between has been found in many examples of vernacular architecture, as well as in modern architecture, to offset heat gain by solar radiation. The system was considered more effective if air flow could be maintained in the space in between. The cost factor involved in making a double roof usually restrains such an undertaking of simple and straight forward solution. The hypothesis followed from this consideration was that if a cheaper means could be defaced that would perform the same insulating function with considerable efficiency, the acceptance of the system would grow automatically.

In vernacular architecture use of clay tile as a roofing material was all along very popular. Use of such tiles necessitated that the roofs be sloped. Popularity of tiled roofs subsided with the advent of R. C. C. flat roof construction system. The general practice is to apply a four inch or 100 mm thick lime terracing over the concrete roof that provides some degree of insulation. The flat roof remains exposed to solar radiation all day long and that becomes the major source of heat buildup inside the building. Moreover, the problem of rain water seepage is endemic in flat roof structures in the monsoon region.

Irrespective of the relative advantages and disadvantages between flat roofs and tiled sloped roofs, there is a market preference for tiled roof houses among the well-to-do class. This group is a trend-setter and stands as a reference group for the rest. So it is envisaged that the popularity of tiled roof may steadily grow if not for any technical reason but merely as a status symbol.

There is a distinct difference between the tile roof design of the past and present. The present one has a concrete roof underneath with tiles pasted over as facing material. The notion of passive solar control through the roof prompted the idea of developing thermal roof tiles that would perform with the same principle of double roofing. The central theme is that if the hollow tiles are designed and placed on a sloping roof in such a way that the hollows could form a continuous air tunnel through which the hot air may escape, then the solar heat transfer through the ceiling would be reduced substantially.

To simulate an average room size of a common dwelling house with the roof exposed to solar radiation, was considered most suitable for the proposed experiment. To obtain unobstructed solar radiation in Dhaka's setting, it was considered appropriate to conduct experimentation on the roof-level of a four-storey building, i.e. 40 ft. from ground level. An adjustable roof system designed to place the roof slope at varying angles, was deemed essential for evaluation of the impact of the slope and optimization of the effects. Orientation of the roof was in the north-south direction sloping down towards south, since north-south orientation of building is considered ideal in our climate. Effect of other orientations are to be studied at a later phase in the experiment.

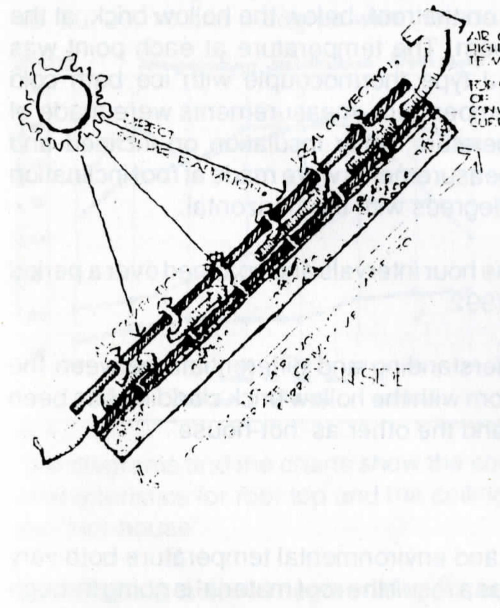
To compare the effectiveness of thermal tiles it was decided to build two identical experimental structures adjacent to each other both roofs were constructed of commonly used roofing materials, the exposed surface of one was convered with hollow bricks, while the other was left bare. This enabled the simultaneous comparison of their thermal performances, which were related to their cost effectiveness as well. Since hollow roof tiles are not available in the market, their closest alternative, light weight hollow bricks made for partition walls were used as tiles for the experimental purpose. It should be mentioned that prior to the experiment such hollow bricks have been used in sloping roofs of three residential houses as roof tiles with satisfactory technical and aesthetic results.

Experimental Set-up

The hollow brick is 230 mm in length, 170 mm in width and 115 mm in height, having two continuous holes along its length each measuring 75 mm in height and 55 mm in width.

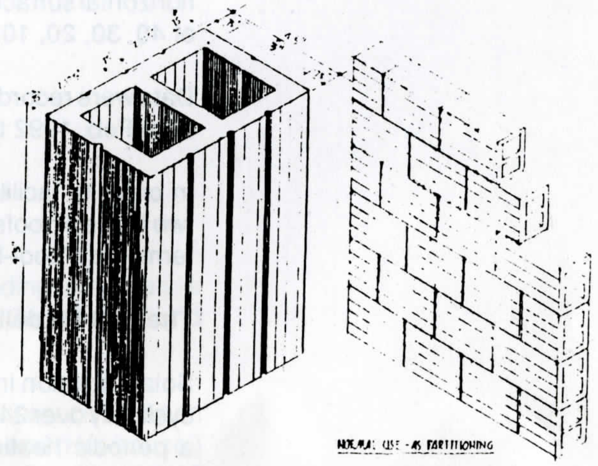
In order to study the effect of hollow brick in real situations, two identical rooms were constructed on the roof of the old academic building, having a height of 30 ft. from ground, at the Bangladesh University of engineering and Technology premises, Dhaka (Latitude 23.7° N, Longitude 90.38° E).

The roof was so designed that it could be tilted about its central axis, and thus inclination of the roof could be changed form horizontal position (Zero degree inclination) to around 40 degree with the horizontal. In inclined position the roofs face south. The roof of one of the rooms had hollow brick cladding, the brick was so laid that the hollow section aligned with the inclination, thus making a hollow air duct along the length of the roof. The other roof was bare concrete slab. Two identical rooms with different roof systems were placed under similar conditions and their thermal behaviour pattern could be analyzed and compared for information.



STUDY OF HEAT TRANSMISSION THROUGH CONCRETE SLOPPING ROOF SLAB DESIGNED WITH A TOPPING OF LOCALLY MANUFACTURED HOLLOW PARTITIONED BLOCKS

fig 1.



HOLLOW PARTITION BLOCK OF ... CERAMICS

fig 2.

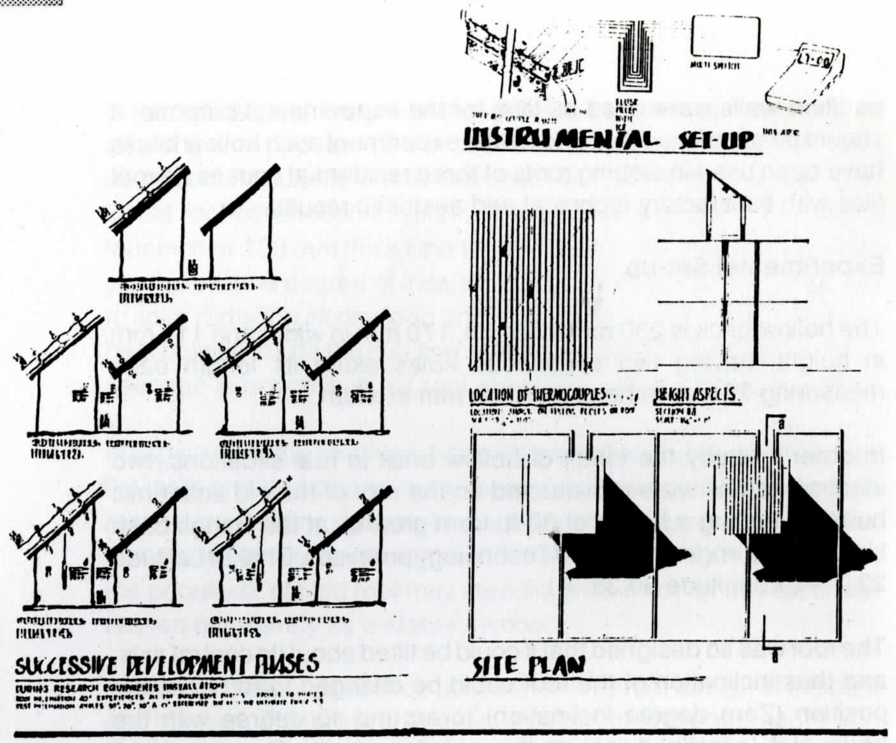


fig 3.

The schematic diagram of the set-up is shown in Figs. 1,2 and 3

Methodology and Instrumentation

The effect of hollow brick cladding was investigated by studying the variation of temperature on the roof, below the hollow brick, at the ceiling and inside the room. The temperature at each point was measured by installing J type thermocouple with ice bath cold junction. In addition to temperature, measurements were made of dry-bulb, wet-bulb temperature, solar insulation on inclined and horizontal surfaces, all measurements were made at roof inclination of 40, 30, 20, 10 and 0 degrees with the horizontal.

Data were recorded at one hour intervals and spanned over a period from Feb. 1992 to July 1992.

In order to facilitate understanding and differentiate between the two types of roofs, the room with the hollow brick cladding has been termed as 'cool-house' and the other as 'hot-house'.

Thermal Modeling

Solar radiation intensity and environmental temperature both vary cyclically over 24 hours, as a result the roof material is going through a periodic heating and cooling process. Thus the heat transfer problem is not a steady-state one. The heat balance for such situations may be written for the two situations as follows :

For hollow brick roof

Solar radiation incident on the roof-energy reflected back+Energy radiated out+Heat gain (loss) by the roof material+Heat taken away by the air in the duct+Heat conducted through the roof material+Heat convected inside the room.

For concrete roof

Solar radiation incident on the roof=Energy reflected back+Energy radiated out+Heat gain (loss) by the roof material+Heat conducted through the material+Heat convected inside the room.

Thermal analysis

It is important to note that the addition of brick cladding on the roof changes the thermal capacity of the roof and increases the resistance of heat transfer. In hollow brick since the top layer is being heated and the bottom remains cool, for negligible wind velocity either laminar or turbulent in the duct, hollow section the connective heat transfer from top to bottom layer will take place but this will be insignificant as it is a case of temperature-inversion.

Results and discussion

The temperature-time history (hourly temperature variation of the roof with time) for the varying roof treatments (i.e. roof with bellow-block cladding and roof with bare concrete) are shown in figs 4 to 9 both in line-diagram and bar- charts for different tilting positions of 40, 30, 20, 10 and 0 degree with the horizontal.

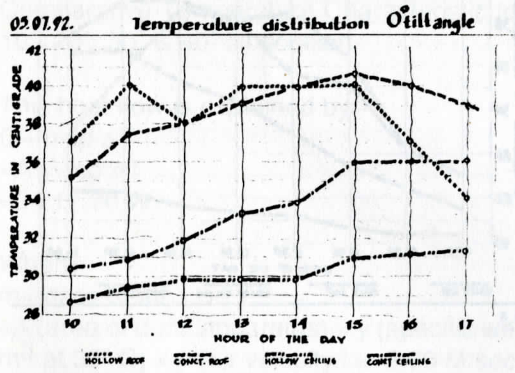


fig 4.

The diagrams and the charts show the corresponding temperature characteristics for roof top and the ceiling of the 'Cool-house' and the 'Hot-house'.

It was found that for 40 degree tilting position the difference between the two ceiling temperatures (i.e. of 'Cool-house' and 'Hot-house') was around 10 to 20 degree during the hottest part of the day (13:30 hr. to 16:30 hr).

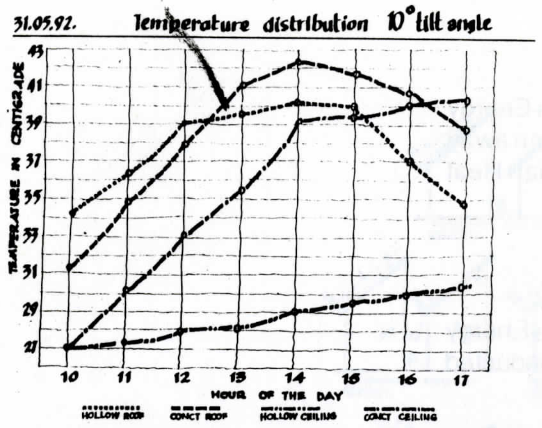


fig 5.

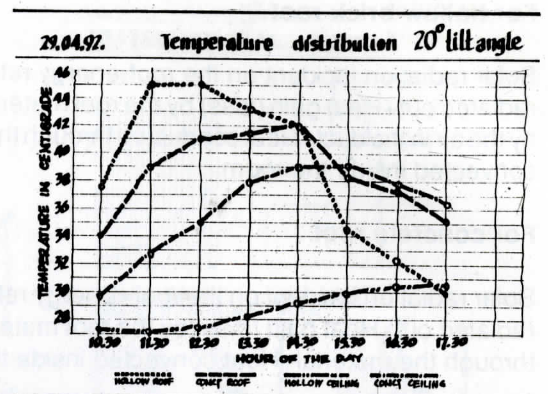


fig 6

This temperature difference remains fairly constant for different tilts between 10 to 40 degree with the horizontal and that indicates that the angle of roof tilts have little influence over the temperature change. However, a significantly lower temperature difference limited within 4-5 degrees was observed in horizontal position of roof. This result supports the hypothesis. In angular position (i. e. in 10, 20, 30, 40 degree) the air column within the ducts of hollow roof in cool house experience a temperature-gradient, which helps to generate a natural convective air current that takes away a considerable amount of heat.

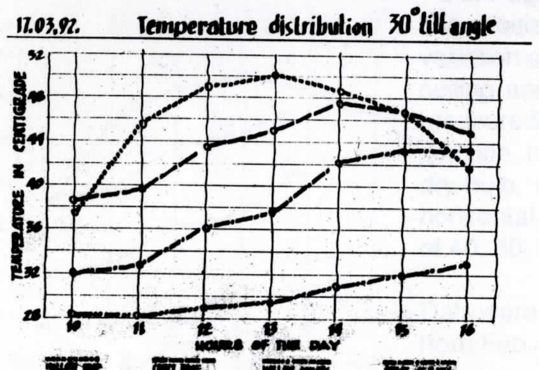


fig 7

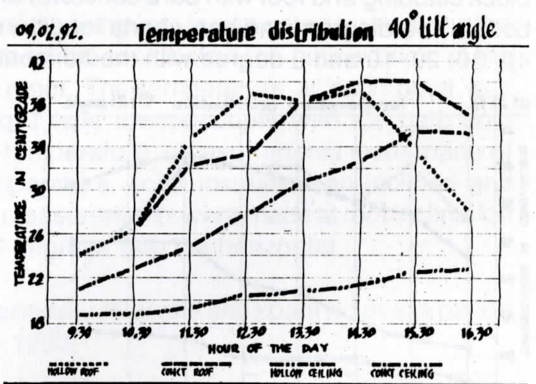


fig 8

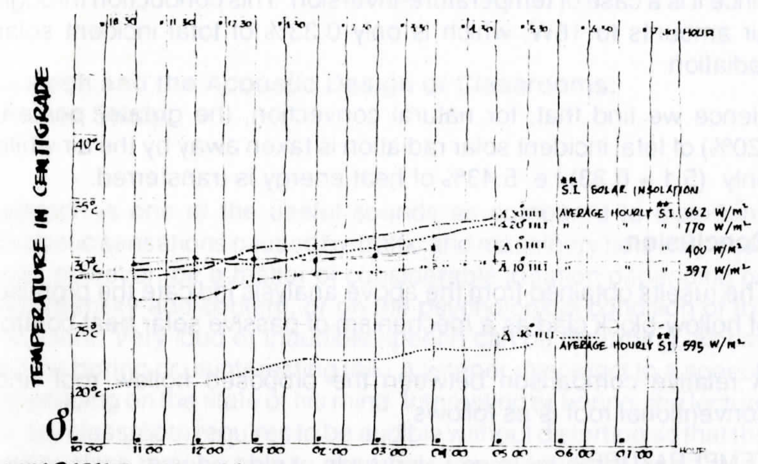
Another important observation is that, due to the relatively higher emissivity of concrete and absorptivity of brick, the roof temperature of hollow-brick i.e. 'Cool-house' shows faster rise and fall of temperature during the day compared to that of the 'Hot-house'.

Yet it is found that heat transfer by 'Cool-house' roof is significantly lower than that of 'Hot-house' through passive cooling by means of hollow-tiles (bricks). This keeps the ceiling temperature of 'Cool-house' constantly lower than that of 'Hot-house.'

The heat transfer of hollow roof can be explained by the following mechanism

- the heat taken away by the air (from the duct)
- heat transfer through the solid (brick fins)
- heat transfer by the air (within the duct)

Heat transfer analysis for heat taken away by the air through the duct is very much dependent on the prevailing wind velocity. The air velocity within the duct was considered equivalent to normal outside wind velocity i.e. 2.68 M/sec. or 6 miles/hr., measured at the site.



COMPARATIVE TEMPERATURE CHARACTERISTIC FOR HOLLOW CEILING at 0°, 10°, 20°, 30° & 40° TILT POSITION

fig 9

Comparative Temperature Characteristic for Hollow Ceiling at 0°, 10°, 20°, 30° & 40° tilt position.

This heat flow is explained by
Q=m cp ΔT
=A yv cp ΔT
=2.712.70 W

Where
m=mass of air
=Δ (area of duct, apparatus) × y (specific weight of air, i.e. 1.17 kg/m^3 at 32° C) × v (air velocity i.e. 2.68 M/sec.)
cp=specific heat of air, i.e. 1006.6 j/kg C
ΔT=rise in air temperature within the duct i.e. difference between inlet and outlet air temp i.e. 5C.
This calculation gives the amount of heat taken away by the air, which is 2,712.7j/sec. i.e. 2712.7 W

Since the incident solar radiation was 800 W/m for total roof area of 17 square meter the heat taken away amounts to 20% of this total incident radiation.

Again heat transferred from top of the hollow brick to the bottom of the brick is a case of parallel heat flow.
q= KAdt/dx
=715.176 W or 5.1% of total solar insulation.
Where:
K=conductivity of brick i.e. 1.32 W/m C
A=area of solid through which heat is transferred
dt=Temperature difference between upper layer and bottom layer of the brick i.e. 10° C.
dx= vertical height of brick or tile wall.

The heat transferred through the air layer is a very complicated one since it is a case of temperature-inversion. This conduction through air amounts to 16W, which is only 0.33% of total incident solar radiation.

Hence we find that, for natural convection, the greater percent (20%) of total incident solar radiation is taken away by the air while only (5.1 + 0.33) i.e. 5.43% of heat energy is transferred.

Conclusion

The ruselts obtained from the above analysis indicate the promise of hollow-block clad as a mechanism of passive solar heat control

A relative comparison between the proposed hollow roof and conventional roof is as follows:

TEMPERATURE :

	COOL HOUSE	HOT HOUSE
ROOF TOP :	39 C	33 C
CEILING:	19 C	27 C
ROOM :	22 C	24 C

For 40 degree tilt and hottest part of the day

The research work had to be done in non-ventilated situation because if ventilation is allowed the total impact of solar radiation within the room through the roof cover cannot be measured. This is the reason why the difference of room temperature between the two rooms is not very appreciable, as the cool house during the night period acts relatively more as a heat store than the hot house. Thus the heat stored contributes to the following day's starting room temperature, which remains higher in the 'Cool house.'

The comparison shows that when a conventional roof has lime-terracing the cost factor is very close to that of the proposed hollow brick cladded roof. For this research Mirpur Ceramic Partition Blocks were used, the ultimate shape of which has not yet been finalized for manufacturing purposes. When tiles will be designed and specifically manufactured for use, cost effectiveness will be made possible and it may prove to be more economically viable than the existing roof insulation facilities.

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