Effects of Roof Treatment on Thermal Performance of Residential Buildings in Dhaka

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ABSTRACT: Energy consumption in buildings has tremendously increased in Bangladesh due to high population growth along with rapid Urbanization. Sustainable design of building elements can have great impact on reducing energy consumption of Bangladesh. Extensive field work has been done on several buildings with roofs of different compositions (flat concrete, water proofing-lime terracing, roof with water body, double roof of corrugated sheet, roof with plants on bamboo structure and using pot plants) of residential areas in Dhaka. The combined effect on Air Temperature in overheated period (April) has been investigated, under the assumption that the temperature of interior space of the floor below the roof being studied, is an indicator of Space Performance. These data have been correlated, to find out the effects of different treatments of roof on indoor temperature of buildings. This result was observed with the highest values of solar radiation for the period. An average gradient of around 2.7ºC between double roof and flat concrete slab, most commonly used, has been observed on clear sky days. This study provides recommendations, on the basis of the investigation, about sustainable roof design, aiming to reduce the pressure on energy needs, thereby helping to create more sustainable residential environments in Dhaka.

Keywords: thermal performance, roof treatment, energy, Air temperature, double roof

PROLOGUE

To ensure environmental comfort in indoor spaces, passive techniques have become an increasingly important issue. Thermal Performance of interior spaces, which is an extremely important issue in the context of sustainability in cities [1], is seen to have a significant role for efficient living. In residential areas humans need thermally comfortable environments to rest and revive after the day's work. Where energy or power supply is scarce, like in Dhaka [2], passive climatic control should be applied, for achieving thermal comfort. Over 15-25% of all savings, in both developed and developing countries, is invested in dwelling construction for shelter, security and comfortable living conditions [3]. Overheating is a growing environmental concern for tropical cities like Dhaka [4], though rules and controls, to achieve thermal comfort in residential environments, are non-existent [2]. This paper is based on a scientific investigation on thermal performance of various roofs, a key building design element, as this horizontal surface receives the highest solar radiation throughout the year in Dhaka [5]. The positive thermal effects of roofs are usually described by the reduction of the thermal transmittance into the interior space of the building [6], which forms the basis of 'Thermal Performance Ranking' of residential roofs, adopted in this paper.

PROBLEM STATEMENT

The Intergovernmental Panel on Climate Change (IPCC) predicts a rise of the mean annual temperature of about 3.3°C per century in the world. The effect of climate change is being felt in the tropics, and Bangladesh is one of the most vulnerable countries [8, 9]. Temperature trends during the last 60 years (1950-2010) shows a tendency of increase in the average day temperature [10, 11] (Fig. 1). Fig. 2 shows the temperature rise in Bangladesh using historical data of some selected meteorological stations [10]. The mean annual temperature here has increased during the period of 1895-1980 by 0.31°C over the past two decades [12].

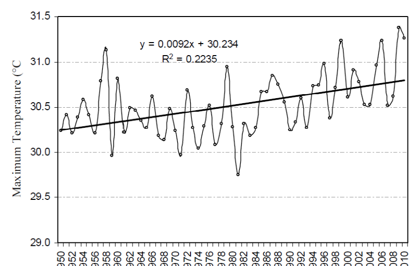


Figure 1: Temporal variation of annual maximum temperature of Bangladesh during1950-2010. (Source: Climate division, Bangladesh Meteorological Department, Agargaon, 2011.)

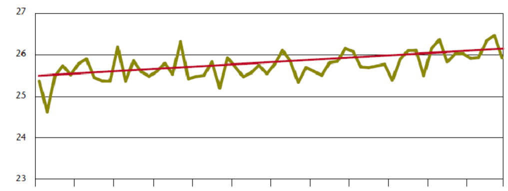


Figure 2: Observed trend in surface air temperatures for Bangladesh. (Source: Bangladesh Met Department, 2010)

Dhaka lies just north of the Tropic of Cancer, displaying characteristics of "Composite" climate, with approximately one-third of the year being hot-dry (mean max 33.6 ºC), two thirds warm-humid (mean max 31.3 ºC), while there is a cool-dry season [9]. Urban Dhaka is also subject to an urban heat island effect [13]. Dhaka has a high rate of residential development, to cater to the huge influx of rural to urban migration [1]. Residential areas form almost 27% (highest) of built areas [14]. There is a gap between power generation (4.5MW) and demand (6.5MW), resulting in frequent power-cuts [15], and situation deteriorate further during summer. Fig. 3 shows the variation of electricity consumption throughout a year, which peaks in the summer [14].

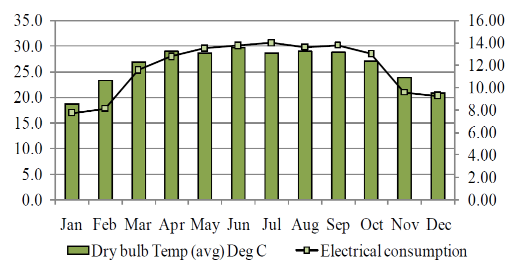


Figure 3: Relationship between Met data and energy consumption data, Year 2005. (Source: Met Data and PDB)

A Building Roof is the horizontal skin through which a man-made indoor space and outdoor space interacts, and it receives the highest amount of solar radiation in the tropics (5329Wh/m^2) [4, 5]. It is the building component most exposed to the climatic elements [4, 16]. Solar radiation particularly on clear days affects the thermal behaviour of roof more than any other part of the structure [4]. Under warm ambient conditions in the tropics, the roof significantly affects the indoor air temperature in adjacent interiors [4, 16]. Air temperature is the most important environmental factor and main criterion of human comfort [4]. Passive means of achieving thermal comfort inside the building is the best solution to provide a healthy and energy efficient indoor environment [17, 18, 19]. Dhaka's Energy consumption Data (Fig. 4) shows, domestic consumption is the highest, making it imperative to initiate passive measures for sustainability [14].

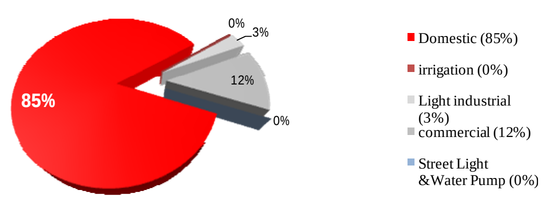


Figure 4: Energy consumption pattern of year 2005 of Dhaka city. (Source: Data from Power Distribution board)

Most of the buildings in the urban areas of Bangladesh (specially in Dhaka) usually have flat concrete roofs [4]. Some roofs have 75mm layer of lime terracing which provides some degree of insulation. There are a few examples of double roofs, rooftop swimming pools and roof gardening. As there are no standards of sustainable roof design, this paper aims to evaluate the performance of various roof treatments and identify the most efficient residential roofs of the city.

OBJECTIVE OF THE RESEARCH

This research investigates the effectiveness of various roof treatments, and their potential to achieve passive climatic control, by reducing the indoor air temperature, for residential buildings in warm-humid season in Bangladesh.

METHODOLOGY OF THE RESEARCH

To frame the knowledge base, previous thermal condition researches, relevant to climatic condition of Dhaka have been studied. Six residences with six types of roofing have been selected for the study. At each spot, measurements of air temperature (average value of five readings) were recorded at three different positions (at outdoor , roof surface and indoor space) at around 2 P.M. on the three days of survey (April, 2011) by Pocket Weather Meter (kestrel 3000). These days were characterised by clear skies, dry weather, high solar altitude angle, high solar intensity and high duration of sun-shine. The study was primarily based on, field data measurement, observations, discussions with inhabitants, comparison and analysis of data. The air temperature difference between the exterior (roof surface) and interior spaces was considered a significant indicator of the performance of the roof. Within the limited period of time for the study, residential areas of similar physical features were chosen, to minimize the impact of surroundings on the temperature variations.

FIELD INVESTIGATION

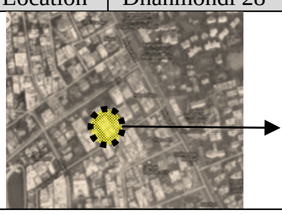
The six survey spots with six different types of treatments are based on the flat concrete roof (except Spot 4). The survey spots are as below:

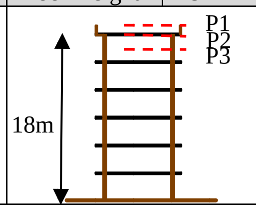
- Spot 1: the basic flat concrete roof,
- Spot 2: the flat concrete roof with water proofing-lime terracing
- Spot 3: the flat concrete roof with water body,
- Spot 4: double roof with corrugated sheet and thin bamboo layer (locally known as 'Chatai'),
- Spot 5: the flat concrete roof with plants on bamboo structure (locally known as "Macha") and
- Spot 6: the flat concrete roof with pot plants.

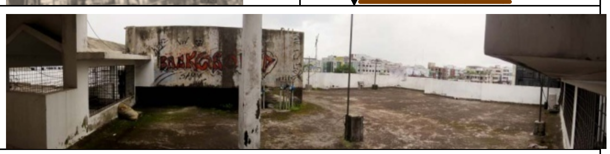
At each spot, the air temperatures for both indoor spaces (immediately below the roof surface) and outdoor spaces (1m above the roof and at roof surface) were recorded. Figures inset in Table 1 show the positions from which the temperatures were recorded for each of the six cases, along with their locations in Dhaka and their general surroundings. Outdoor air temperature was recorded from Position 1 (P1), 1m above the roof level; air temperature at roof surface was recorded from Position 2 (P2), while the indoor air temperature was recorded from Position 3 (P3), 1m above the floor level of the interior of topmost floor. It was observed that the relative humidity (62%) of air was nearly constant in the three days of recording. Only the wind speed was variable during this period. Solar radiation, relative humidity, Wind speed and air temperature were also collected from meteorological station.

Table 1: Collected Air Temperature in °C at different spots

Spot 1:	**Flat concrete roof**		
Location	Dhanmondi 28	Roof Height	18m

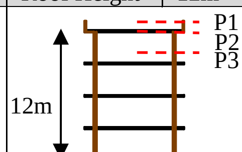


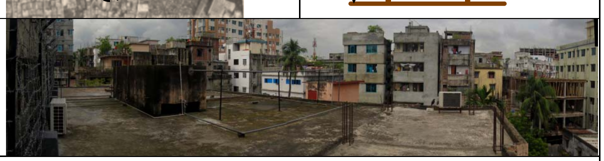




Positions	Day 1	Day 2	Day 3
P1	30.8	30.4	30.9
P2	31.4	31.4	30.9
P3	31.2	30.8	30.8

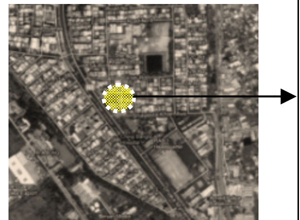
Spot 2:	**Roof with water proofing lime-terracing**		
Location	East Rajabazar	Roof Height	12m

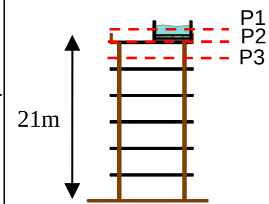




Positions	Day 1	Day 2	Day 3
P1	33.8	33.3	32.7
P2	34.2	33.8	33.2
P3	33	32.1	31.8

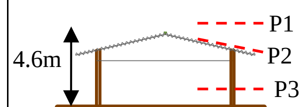
Spot 3:	**Roof with Water body**		
Location	Uttara	Roof Height	21m





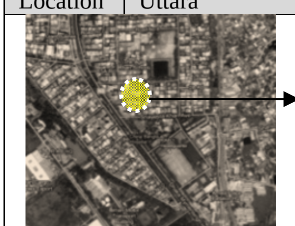
Positions	Day 1	Day 2	Day 3
P1	36.2	36	36.5
P2	37	36.9	37
P3	34.8	34.7	35

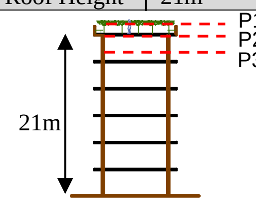
Spot 4:	**Double roof with Corrugated sheet**		
Location	East Rajabazar	Roof Height	4.6m



Positions	Day 1	Day 2	Day 3
P1	34.5	34.3	33.8
P2	37.6	36	36.4
P3	32.6	32.8	32.7

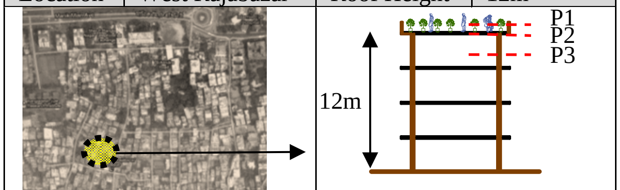
Spot 5:	**Roof with plant on bamboo structure**		
Location	Uttara	Roof Height	21m

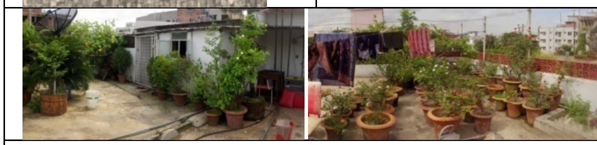




Positions	Day 1	Day 2	Day 3
P1	35.2	35.8	36.3
P2	35.2	35.1	36.1
P3	34.3	34.2	34.2

Spot 6:	**Roof with pot plants**		
Location	West Rajabazar	Roof Height	12m



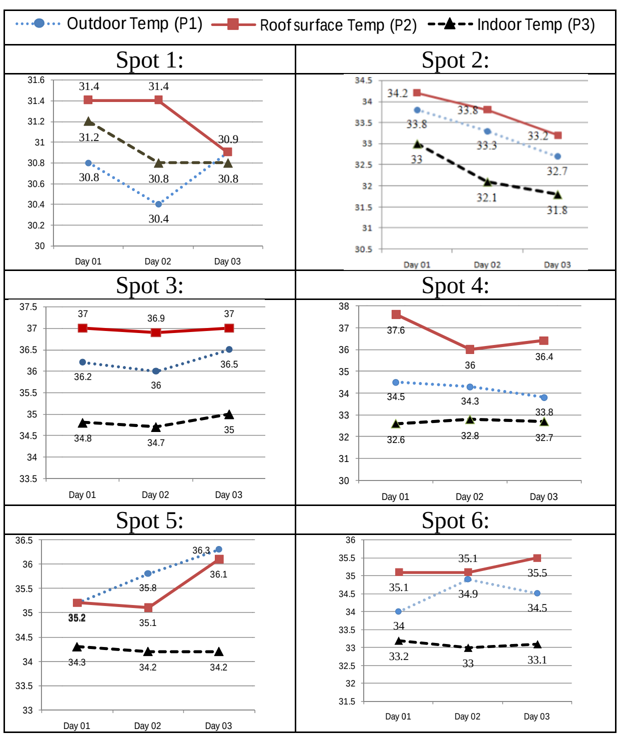


Positions	Day 1	Day 2	Day 3
P1	34	34.9	34.5
P2	35.1	35.1	35.5
P3	33.2	33	33.1

TEMPERATURE DATA ANALYSIS

Table 2 shows the changes of temperature of outdoor, roof surface and indoor for the period for the six cases.

Table 2: Changing Pattern of Temperature



The results show that indoor temperature is always below the outdoor temperature and roof surface temperature, except in Spot 1 (the basic flat concrete roof). Roof surface temperature for all the cases were higher than, either the outdoor or indoor temperature values, except in Spot 5 (plant on bamboo structure), where outdoor temperature was seen to be higher than the other values.

COMPARATIVE ANALYSIS

As there were variations in the temperatures of the different survey days, exact temperature values were not used for the analysis. In such a situation, the differences between the indoor, outdoor and the roof surface temperatures were examined. The effectiveness of the different roof treatments (Fig. 5) was, therefore, judged by the differences between the temperature of roof surface and indoor, as an indicator of its insulation value.

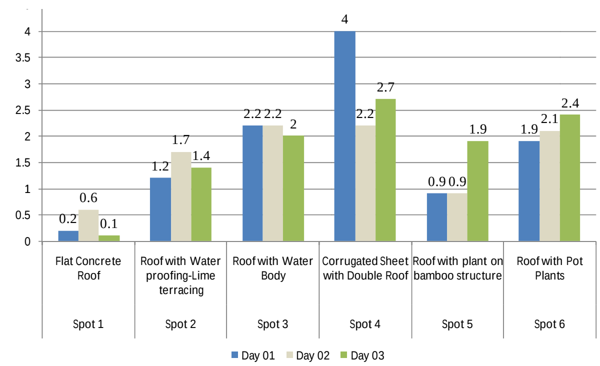


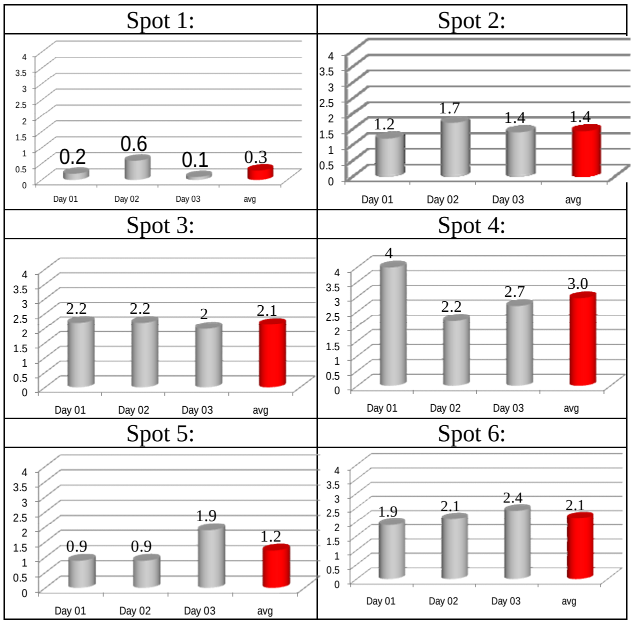
Figure 5: Temp. Differences between roof surface and indoor

This comparison shows that Spot 4 (double roof with corrugated sheet and thin bamboo layer) displayed the highest temperature difference in general with the highest difference of 4 degC on day 01. Spot 3 (roof with water body) and Spot 6 (roof with pot plants) also displayed significant temperature differences. The results on the other two days were consistent with the above. So these three treatments at Spots 3, 4 and 6 perform more efficiently in Dhaka's climate.

This comparison also shows, lowest difference was at Spot 2 (roof with water-proofing lime terracing), Spot 5 (roof with plant on bamboo structure), and Spot 1 (flat concrete roof) respectively. Thus, these three treatments are considered less efficient as insulation in the Dhaka context. As the flat concrete roof, happens to be the most common roof type in Dhaka [4], and is deemed the most incompetent in lowering indoor temperature according to this study, the result is alarming.

Undoubtedly, significant energy consumption can be reduced, if attention is paid to proper roofing, as passive means to allow cooler interiors. The average temperature differences between surface and interior temperature have been presented in Table 3.

Table 3: Average Temperature difference between surface and interior spaces



REMARKS

The ranking of thermal performance of roofs (Fig. 6) has been suggested on the basis of average temperature difference identified in this investigation.

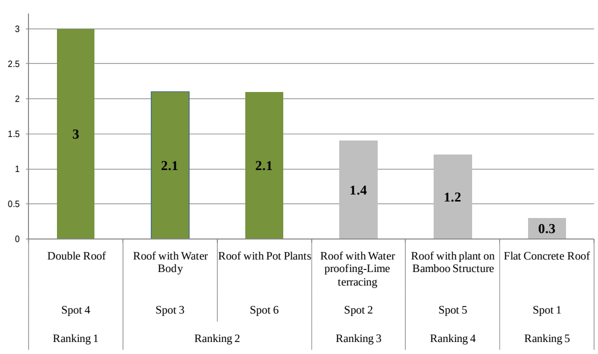


Figure 6: Ranking of Roof Treatments on Thermal performance

Double Roof (Ranking 1) displayed highest efficiency at reducing internal heat gain. It lowered the interior temperature from the exterior value by about 3 degC, generating temperatures 2.7 ^{0}C lower than the most commonly used flat concrete roof. The roof with water body (Ranking 2), reduced the internal temperature by about 2.1 degC, producing interiors with temperatures 1.8 ºC lower than with the flat-concrete roof. The Water content has a positive impact on heat transfer reduction. Roof having pot plants, sharing the same ranking (Ranking 2), also decreased temperatures by about 2.1ºC. The soil content of the pots, increases the thermal capacity insulation value, and thus helps to a great extent to reduce the interior temperature. Roof with water proof lime terracing (Ranking 3), is much less effective as a passive control tool. The roof with plant on bamboo structure (Ranking 4), while creating a cooler microclimate on the roof, was not found effective as a passive cooling tool to reduce internal heat gain. Ranked at 5, the flat concrete roof was found to be the most inefficient at reducing internal heat gain, decreasing the temperature by only about 0.3ºC on average.

Of the types examined, two of them, the one with pot plants (Ranked 2) and the other with bamboo structure (Ranked 5), are non-structural solutions and can be instituted on demand. It is obvious that the additional capacity insulation of the pot plants is more effective in controlling temperature, than the resistance insulation of the bamboo structure with plants.

Double roof with corrugated sheeting and bamboo layer (Ranked 1), is not a common practice in urban Dhaka, and has potential only if redesigned to suit the context. The Roof with water body (Ranked 2) was found very effective in contributing to cooling of spaces, again by virtue of increased thermal capacity insulation. But a water body container requires a substantial initial budget, while also increasing the structural load on buildings. Therefore, this cannot be suggested as a viable strategy to adopt in general. Placing pot plants (Ranked 2) on the roof top, works effectively to reduce the internal air temperature and also creates cooler microclimate on the roof. But it occupies the flat roof top, which is used as a social space, and therefore not encouraged by the inhabitants.

DOUBLE ROOF FOR URBAN RESIDENCES

Given the above discussion, for the Dhaka context, it is recommended that double roof with a local material named "Chatai" (made of woven bamboo) may be installed under the ceilings of the top floors of residential buildings. The "Chatai" is a very low-cost material and adds negligible load to the structure. A similar scheme was conceptualized by Givoni in a previous study, for houses with metallic sloped roofs in developing countries [4, 20].

The suggestion here is for retrofitting the large amount of multistoried residences with flat roofs, with a layer of "Chatai", forming a sort of false ceiling at the top floors of residences. If operable, the efficiency can be further increased. During the daytime, the space above it contains the heat, while during the night, when the concrete roof has cooled down, the ceiling can be adjusted.

For new constructions (Fig. 7), the upper floor can be made higher than the other floors and the layer of "Chatai" can be installed below the roof (Type 01). Its efficiency can also be improved by installing an operable roof [4] at the roof level, which can further decrease heat transfer (Type 02). Cooling the roofs has potential benefits on energy demand and power peaks [21]. The additional double roof while providing some passive cooling, would also create a social space for the inmates to gather.

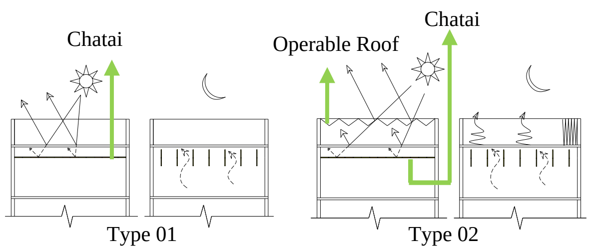


Figure 7: Installation of "Chatai" (Type 01) and both "Chatai" and "operable roof" (Type 02) for new construction. (Source: By Authors)

CONCLUSION

The selection of an adequate roof configuration influences the thermal condition of the space. But we do not have proper research-based building by-laws, to ensure desirable thermal conditions in urban residential environment [5]. The authors have monitored the thermal performance of roofs by observing the passive cooling capacity of various roof types. The outcome of this study may be implemented in roofs of residential buildings for achieving better thermal performance, thus, helping to reduce energy consumption of Dhaka city. The study can form baseline data, that can be used as a guideline for the formulation of Building Laws to ensure sustainable comfort conditions in residential buildings of Bangladesh. Appropriate computer simulation studies would help cross-checking with actual performance, for further authenticity and validity.

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