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Mitigating the Urban Heat Island effect through building envelope modifications

Anurag Kandya[a,*], Manju Mohan[b]

[a] Pandit Deendayal Petroleum University, Gandhinagar, India
[b] Indian Institute of Technology Delhi, New Delhi, India

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ABSTRACT

Mitigation techniques aiming to counterbalance the Urban Heat Island (UHI) phenomenon deal with the intensive usage of green spaces, application of highly reflective materials, materials having high thermal resistivity, decrease of the anthropogenic heat, solar control of open spaces, use of environmental heat sinks and increase of the wind flow in the canopy layer. Though materials having high thermal resistivity do not directly mitigate the UHI effect however upon using them as constructional materials, the buildings become naturally cool which reduces the anthropogenic (waste) heat from the buildings thereby mitigating the UHI effect. In addition to this, the reduction in the power demand would eventually lead to the reduction in the burning of coal in the thermal power plants and consequently reduces the release of CO_2 (a green house gas). Moreover, if naturally grown materials (like bamboo in the present case) are used for construction applications, it would pave way for 'profitable greening' which would significantly reduce the UHI effect in two ways (1) by increasing the latent heat flux through evotranspiration (2) by sequestering CO_2. The embodied energy of local materials having high thermal resistivity like Rammed Earth is significantly less than that of the popularly used Cement and Bricks which makes it a greener option having relatively low carbon footprint. Cumulating these facts it can be stated that usage of 'natural materials' having adequate strength and high thermal resistance offers high potential for mitigating the UHI effect.

With this background, the present study of investigating the thermal performance (in terms of energy consumption for space cooling) of composite materials like *Bamcrete* (bamboo-concrete composite) and natural materials like *Rammed Earth* along with energy intensive materials like bricks and cement was undertaken. In addition to this, the thermal performance of building envelope modifications like (i) increasing the thickness of wall, (ii) construction of a cavity wall was also attempted. Of the 6 scenarios simulated, the use of 6″ bamcrete in walls depicts the highest cooling potential (around 7.5%) when compared to the popularly used 5″ brick thick wall. The present study is first of its kind to quantitatively report the performance of *'bamboo'*–a wonder grass of India, in reducing the cooling load of a building. The results should definitely help the green building community to take suitable actions at their ends for designing buildings having low carbon footprint and effectively mitigate the UHI effect.

1. Introduction

With the onset of development, the whole earth is getting urbanized and it is expected that by the year 2050, around 70% of the human population will be living in the urban areas [1]. Urban areas typically have high building density, reduced green cover and various anthropogenic sources of excess heat generation. These factors significantly alter the surface heat balance viz. radiant balance of the urban space, the convective heat exchange between the ground and the building, the wind flow and the evotranspiration process which affect the urban microclimate especially the air temperatures. Subsequently, the air temperature in the densely built-up areas is higher than the air temperature of the surrounding areas which is commonly referred to as the 'heat island effect' [2–8]. Urban Heat Island (UHI) effect is considered as one of the major problems in the 21st century posed to human beings and around three billion people living in the urban areas across the world are directly exposed to the problem, which will increase significantly in the near future [9]. It is the most documented phe-

* Corresponding author.
E-mail address: akandya@gmail.com (A. Kandya).

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nomenon of climatic change, and is associated with a very significant increase of the cooling energy demand of buildings and a global deterioration of the local environmental conditions [10–14]. Translating the anthropogenically altered meteorological conditions into the energy requirements for space cooling, various researchers across the globe have estimated that the effect of the heat island phenomenon inflates the energy requirements by around 20–100% [15–21]. According to Akbari et al., for US cities with population larger than 100,000 the peak electricity load will increase 1.5–2% for every 1°F increase in temperature [22]. In addition to the enhanced energy requirements, UHIs have the potential to have the potential to directly influence the health and welfare of urban residents. Within the United States alone, an average of 1000 people die each year due to extreme heat, more than due to all other weather events combined [23]. Moreover, higher level temperature increases the amount of ground level ozone and smog [24–26]. Looking to the rate of urbanization across the world and its impact on the ecological footprint of the city and on the overall environmental quality, there is an urgent need to evolve a robust framework of the mitigation strategies so that the development takes a sustainable route. Mitigation techniques aiming to counterbalance the heat island phenomenon deal with the intensive usage of green spaces, application of highly reflective materials, decrease of the anthropogenic heat, solar control of open spaces, use of environmental heat sinks and increase of the wind flow in the canopy layer [27–29].

Many experimental researches were specially undertaken for evolving a cool roof technology which reduces the cooling load thereby mitigating the heat island effect. Synnefa et al. studied the thermal performance of 14 reflective coatings for the urban environment and demonstrated that the use of reflective coatings can reduce a white concrete tile's surface temperature under hot summer conditions by 4 °C and during night time by 2 °C [30]. Karlessi et al. investigated the performance of various organic 'phase change materials' (PCM) when incorporated in coating for building and urban fabric and reported that coatings containing PCMs store heat in a latent form maintaining a constant surface temperature and discharge with time delay thereby maintaining a thermally comfortable indoor environment and reducing the cooling load [10]. By increasing the roof reflectance, Akbari et al. reported cooling energy savings of 46% and peak power savings of 20% [31] and in a separate study he documented energy savings of 31–39 Wh/m^2/day by coating roofs with a white elastomer with a reflectivity of 0.70 [32].

Various researchers simulated the impact greenery on ambient temperature and the subsequent effect on the building energy requirement. Ashie et al. used computer modeling and reported air temperature reduction of 0.4–1.3 °C with building cooling energy savings of as much as 25% through planting vegetation [33] while Tong et al. reported that temperature reduction of 1.6 °C was possible in the case of replacing urban development by grass and shrub land [34]. It was reported in a study conducted by Spronken–Smith et al. that parks could help control temperatures through an evaporation of more than 300% as compared to its surrounding [35]. Yu and Hien have used computer simulation to report that parks and green areas could achieve 10% reduction of cooling load [36] while Ca et al. reported that planting a 0.6 km^2 park could reduce temperatures by 1.5 °C and achieve potential savings of 4000 kWh in an hour of a summer day [37].

In lines with the global efforts for evolving techniques for reducing the power consumption for space cooling, the present study is undertaken to investigate the thermal performance of natural materials like Bamboo and Rammed Earth along with options like increasing the thickness of wall and construction of a cavity wall. It is worth mentioning that 58% of the world's bamboo grows in India; Mizoram, the major bamboo growing state of Northeast India, produces around 37 lakh tons of bamboo per year from the natural forest and is still able to consume only 1% of its produce in its current form of applications. Thus any breakthrough in utilizing bamboo as a main load bearing structural element or even for making walls in a framed structure would pave way for profitably greening the vast wastelands (160 million hectare of wasteland is in India alone). The building envelope modifications were considered for modifying the walls of 'Block V' building which is a 4-storied educational building located in the Indian Institute of Technology (IIT) Delhi campus and subsequently the cooling loads were numerically estimated using eQUEST for the years 2008 and 2009. The study quantifies the performance of these modifications in terms of reduction in power consumption for space cooling thereby mitigating the UHI effect. It would also help the green building community to take suitable actions at their ends for designing buildings having low carbon footprint.

2. Data used

2.1. Building data

The present building envelope modification study has been done for a 4-storied educational building i.e. 'Block V' of Indian Institute of Technology (IIT) Delhi located in the less-dense urban canopy of megacity Delhi. Fig. 1(a) shows the Google image of the respective less-dense urban canopy in Delhi along with the location of the study building 'Block V' of IIT Delhi marked with capital letter 'A' while Fig. 1(b) gives a closer view of the entire academic area of IIT Delhi i.e. Block I, II, III, IV, V and VI and the Main building. All the 6 blocks have almost a similar constructional pattern while the main building is different; however, the entire academic area has similar functional usage.

The Block V building has offices of the teaching faculty, computer labs, committee/seminar rooms, civil engineering labs, class rooms, electrical rooms, rest rooms and corridor. While the offices of the teaching faculty, computer labs and committee/seminar rooms are air-conditioned having space-cooling facility, the civil engineering labs, class rooms, electrical rooms and rest rooms are non air-conditioned having fans for artificial ventilation. Fig. 2 (a–h) shows the respective schematic floor plans along with the air-conditioned and the non air-conditioned areas of the Ground Floor, First Floor, Second Floor and Top Floor of the building. These building footprints were processed in eQUEST software for customized zoning i.e air-conditioned area, non air-conditioned area and open-to-sky area. The light blue shaded area represent the air-conditioned zones while the rest are the non air-conditioned areas. The area enclosed within the red boundary depicts the corridor while the white shaded area in the top floor is open-to-sky. The floor-wise details of the air-conditioned and the non air-conditioned areas of the building are described in Table 1 while Table 2 puts forward the floor-wise fenestration details in terms of number of doors and window as well as net opening area of the building. The doors were of size 2.13 m × 0.91 m having wood as the construction material while the windows were made of glass.

2.2. Meteorological data

The site specific hourly meteorological data was available through a weather station which was installed at the top of the Block VI building which was adjacent to Block V building. The hourly data for 5 meteorological parameters i.e. Dry Bulb Temperature, Wind Speed, Wind Direction, Relative Humidity and Occurrence of Rainfall for a period of two years (2008–2009) was used. Since hourly solar radiation data was not available for