International Journal of Advanced Research in Engineering and Technology (IJARET)
Volume 10, Issue 2, March-April 2019, pp. 403-413. Article ID: IJARET_10_02_039
Available online at http://iaeme.com/Home/issue/IJARET?Volume=10&Issue=2
ISSN Print: 0976-6480 and ISSN Online: 0976-6499

EXAMINING THE THERMAL PERFORMANCE OF OLD INDIGENOUS ARCHITECTURE OF KOLKATA TO ATTAIN SUSTAINABLE DEVELOPMENT

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ABSTRACT

Urbanization is a global phenomenon that needs to take up serious sustainable approaches in this time when rapid global warming is looming large on the earth. Like other science and technology domains, architecture is also taking up various sustainable approaches so that the urban built environment harms nature the least. Building design has become energy conscious and various rating systems have come to the forefront. However, another domain has remained largely unexplored in the aging urban centres of India where the old indigenous architecture of these cities has not been examined for their climate responsiveness. These indigenous architectures have evolved from the local vernacular building traditions, and thus synthesizes two aspects in them – they are climate responsive as well as functionally suited to their urban requirements. This paper examines the old indigenous residential architecture of Kolkata, the third largest urban centre in India after Delhi and Mumbai, by comparing them with the new residential buildings of the city and thus tries to find out to what extent they are better performing in the warm and humid climate of the city.

Keywords: Indigenous architecture, Thermal performance, Kolkata, Sustainable architecture

Cite this Article: Sanmarga Mitra, Examining the Thermal Performance of Old Indigenous Architecture of Kolkata to Attain Sustainable Development, *International Journal of Advanced Research in Engineering and Technology*, 10(2), 2019, pp. 403-413.
http://iaeme.com/Home/issue/IJARET?Volume=10&Issue=2

1. INTRODUCTION: KOLKATA

Kolkata, erstwhile Calcutta, is a city where major urbanisation and building activities have started with the inception of British occupancy of India (Taylor & Lang, The Great Houses of Calcutta: their Antecedents, Precedents, Splendour and Portents, 2016, p. 23). After over three hundred years of its busy and prosperous flourish, the city now aches under the tremendous urban conglomerate it has become by the turn of the millennium. Like other urban centres of India, Kolkata also suffers from the problem of urban heat islands (Padmanabhamurty, 1990).

As per a survey, the heat island intensity of Kolkata is 4 ▸▸C (Nayak & Prajapati, 2006, p. 35). The city needs immediate intervention to make its built environment bearable to its citizens. For this, its buildings need to perform better thermally so that their reliance on artificial indoor conditioning can be reduced.

The pre-Independence architecture of Kolkata can be grossly divided into two parts (Bose, 2008, p. 1), viz, buildings belonging to the European quarter of the city, and buildings belonging to the Non-European (Indian) quarter of the city. With time, the architectonics of the European designs infused into this Indian tradition to introduce the new Indo-Occidental Colonial style of Calcutta that was its own.

The city of Kolkata, since its inception from the three villages of Sutanuti, Kolikata and Gobindapur, has grown drastically and became the second largest city of the British empire (Nair, 1990, p. 12). Although population expansion in Kolkata has slowed down over the last two decades (1991-2011) than was ever envisaged since Independence (1947) (Stevens, 2017), the building activity of the city is fast flourishing under the tremendous need of housing stock that is still required. The city now thrives with new built developments of commercial, public and residential nature. Recent architectural practice in Kolkata has created a trend of designing public and commercial buildings in glass facade, while the residential condominiums are relying more and more on the RCC frame with indiscriminately placed glazed openings in them.

2. CLIMATE OF KOLKATA

The climatic zoning map of India as proposed in the "Handbook on Energy Conscious Building" (Fig. 1.1) reveals most of the country falling under hot regions having extreme summer conditions. These zones are subjected to the extreme heat conditions during summer and the condition of high humidity level further aggravates it. As per the climate map in Fig. 1, Kolkata comes under the warm humid zone. The city and its hinterland not only suffer from very high temperature (above 43 degree C), but is also subjected to high level of relative humidity (within a range of 60 – 85%) (Fig. 2 – highlighted cells). The resulting effect of these two factors combined together becomes extremely uncomfortable for the population of the city.

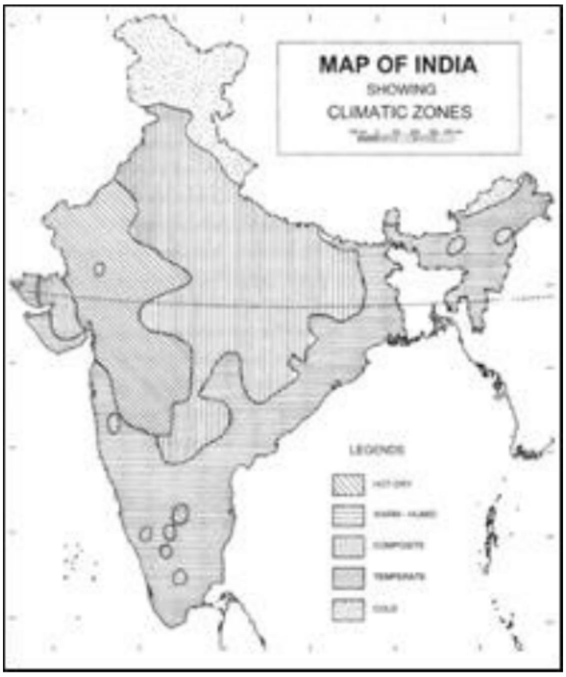


Figure 1 Climatic Zone Map of India

(Source: (Nayak & Prajapati, 2006)

Climate data for Kolkata (Alipore) 1971–1990													
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C (°F)	32.8 (91.0)	38.4 (101.1)	41.1 (106.0)	43.3 (109.9)	43.7 (110.7)	43.9 (111.0)	39.9 (103.8)	38.4 (101.1)	38.9 (102.0)	39.0 (102.2)	34.9 (94.8)	32.5 (90.5)	43.9 (111.0)
Average high °C (°F)	26.4 (79.5)	29.1 (84.4)	33.5 (92.3)	[illegible] (95.5)	[illegible] (95.7)	[illegible] (93.2)	32.3 (90.1)	32.1 (89.8)	32.4 (90.3)	32.3 (90.1)	30.3 (86.5)	27.0 (80.6)	31.7 (89.1)
Daily mean °C (°F)	20.1 (68.2)	23.0 (73.4)	27.6 (81.7)	30.2 (86.4)	30.7 (87.3)	30.3 (86.5)	29.2 (84.6)	29.1 (84.4)	29.1 (84.4)	28.2 (82.8)	24.9 (76.8)	20.8 (69.4)	26.9 (80.4)
Average low °C (°F)	13.8 (56.8)	16.9 (62.4)	21.7 (71.1)	25.1 (77.2)	26.0 (78.8)	26.5 (79.7)	26.1 (79.0)	26.1 (79.0)	25.8 (78.4)	23.9 (75.0)	19.6 (67.3)	14.5 (58.1)	22.2 (72.0)
Record low °C (°F)	6.7 (44.1)	7.2 (45.0)	10.0 (50.0)	16.1 (61.0)	17.9 (64.2)	20.4 (68.7)	20.6 (69.1)	22.6 (72.7)	20.6 (69.1)	17.2 (63.0)	10.6 (51.1)	7.2 (45.0)	6.7 (44.1)
Average rainfall mm (inches)	11 (0.4)	30 (1.2)	35 (1.4)	60 (2.4)	142 (5.6)	288 (11.3)	411 (16.2)	349 (13.7)	288 (11.3)	143 (5.6)	26 (1.0)	17 (0.7)	1,800 (70.9)
Average rainy days (≥ 1.0 mm)	1.2	2.2	3.0	4.8	8.7	14.7	20.5	20.2	15.7	8.1	1.5	0.9	101.5
Average relative humidity (%)	66	58	58	66	70	77	83	83	81	73	67	68	71
Mean monthly sunshine hours	203.9	201.2	225.8	235.4	227.1	123.1	93.1	104.9	116.2	182.6	190.8	203.4	2,107.5

Figure 2 Climate Condition of Kolkata

(Source: https://en.wikipedia.org/wiki/Climate_of_Kolkata#cite_note-NOAA-8)

Although common weather conditions of the city do not remain so extreme as is seen in Fig. 2, the average outdoor temperature in the city has always remained high and above 34 degree C throughout the months of April to June during the years 2005-2015 (Fig. 3). The level of relative humidity over these years have also fluctuated, with few exceptional values (e.g. 55% in April, 2014), most of the months show RH level above 60% (Fig. 3). The average maximum temperature during the period of 2005-2015 is observed to be between 35- and 36-degree C, whereas the average RH level over this period lies between 65 - 70%. The maximum tolerance of temperature for relative humidity level of 65% is given to be below 30 degree C (approx 25 degree C) (Fig. 4). If a considerable air movement and a very low clo value is considered in this comfort condition (Chenvidyakarn, 2007), the adjusted Standard Effective Temperature (SET) comfort conditions give us a maximum tolerance of temperature to be 32 degree C approximately for a RH level of 65%, whereas for higher RH level of 70% this tolerance comes to around 31 degree C. The observed average temperature of the city of Kolkata is thus found to be well above both the un-adjusted as well as adjusted values given by the bioclimatic chart. This needs to explore the thermal comfort capabilities of buildings in order to reduce their reliance on mechanical conditioning.

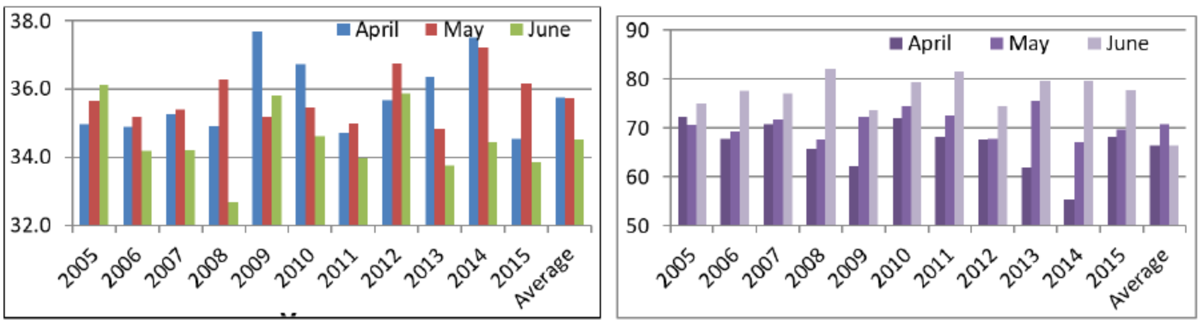


Figure 2 Average Maximum Outdoor Temperature and Relative Humidity of Kolkata during 2005-2015

(Data Source: Alipore Station (42807), Regional Meteorological Centre, India Meteorological Department)

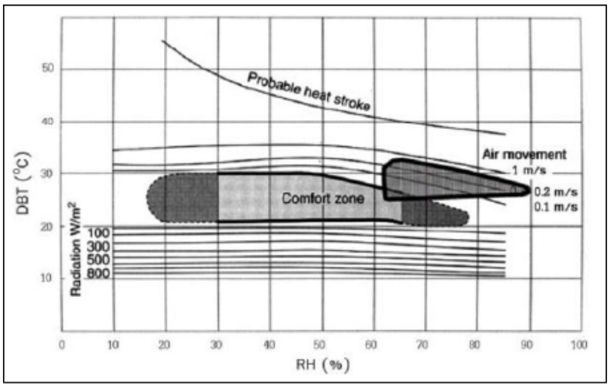


Figure 4 Bioclimatic chart after V. Olgyay modified for SET (Chenvidyakarn, 2007)

3. CONDITIONING OF BUILDING – BOON OR BANE

Buildings provide a protective enclosure for its inhabitants. As each region has its own climate, the houses built therein also varies in their form, material, orientation and design to adapt to the local climatic requirements. For ages, vernacular architecture designed at different places has played this role extremely effectively by providing an insulated indoor environment for its inhabitants. However, since the development of mechanical air-conditioning devices, buildings have relied more and more on HVAC devices to induce an artificial comfort conditions within the built environment (Pellegrino, Simonetti, & Chie, 2015). Buildings under study for their indoor thermal condition are thus divided into two types – conditioned and non-conditioned (Nayak & Prajapati, 2006).

It is envisaged that too much reliance on mechanical HVAC devices in urban areas may harm the environment in two ways – firstly, by the release of ozone layer depleting gases into air, and secondly, by draining the internal heat of the building, especially poorly designed and heated up buildings, into the outdoor environment and thus contributing in the built-up of urban heat islands (Mitra, 2018).

Smart City Mission undertaken by Ministry of Urban Development in 2015 takes up aspects of sustainable development and green building as one of its prime goals. Article 2.4 of the documents talks about ten Core Infrastructure Elements, where Sustainable Environment is the eighth one (Ministry of Urban Development, GoI, 2018). Moreover, "Energy Efficient and Green Building" is included as one of the twenty-one Smart Solutions proposed in article 2.5 of the said document. It becomes a responsibility for architects and planners alike to take all steps possible to make the built environment sustainable.

Figure 5 UNDP Sustainable Development Goal #11

United Nations Development Program (UNDP) took up 17 Sustainable Development Goals in its Rio-de-Janeiro conference of 2012. The target date for achieving these goals was set as the year 2030. Of these, goal number 11 (Fig. 5) was to achieve "Sustainable Cities and Communities: Make cities and human settlements inclusive, safe, resilient and sustainable" (UNDP, 2012). Under this goal, UNDP has set forth ten targets that call for an increased awareness on energy usage vis-à-vis thermal performance of built environment.

The above discussion clearly points at the requirement for promoting non-conditioned buildings in the city, especially its residential sector as it accounts for majority of the built environment. This would thus take care of the following benefits:

- Occupants in non-conditioned buildings become more adaptive to climatic changes than those in conditioned buildings. The former group may not get into poor condition of health even in extreme conditions, whereas the latter group may vary easily fall prey to slightest changes in their indoor thermal condition (Manu, Shukla, & Rawal, 2014). This is more so because the conditioned building mostly take into account the static model of comfort proposed by comfort standards proposed by ASHRAE 55 or similar codes (Rawal, 2018).
- Buildings occupy more than 40% of the primary energy consumption of the world (Manu, Shukla, & Rawal, 2014). India is no exception to this and conditioning of building accounts for 8% of the total expense on power consumption (Rawal, 2018). The income disparities of Indian population has grown drastically, where the top 1% of the population (in terms of their wealth) has seen a steady increase of over 5% since the turn of the millennium, whereas the bottom 50% in the income table has seen a sharp fall of almost the same 5% during the same tenure (Income Distribution:India, 2019). The constant rise in thermal discomfort of the urban centres affects this lower 50% of the population, who can afford no better than the minimum comfort of basic housing – circumstances that deny the indoor comfort of conditioned houses.
- It would also help achieve the goals of Smart City Mission of Govt of India.

4. INDIGENOUS BUILDINGS OF KOLKATA

Indigenous buildings, by virtue of being developed over prolonged period of time and thus respecting the local climate to a larger extent, are frequently found to be more climate responsive and thermally comfortable (Nayak & Prajapati, 2006). According to Lehmann, vernacular and indigenous buildings using traditional passive design principles perform better than the modern building stocks because of their *"heat avoidance, the appropriate use of local materials, the use of natural cross ventilation and the harnessing of natural energies offered by the location"* (Lehmann, 2011).

This indigenous architecture that took shape in late 17th and early 18th century Kolkata had some typical components, especially in the houses of the reach traders, landlords and administrative assistants of the British administrators. The entire plan got divided into two broad parts – (a) *Bahir Mahal* or the Outer House and (b) *Andar Mahal* or the Inner House (Fig. 6). Both these portions of the house would be typically designed around a courtyard that would be the centre of life for the built spaces around.

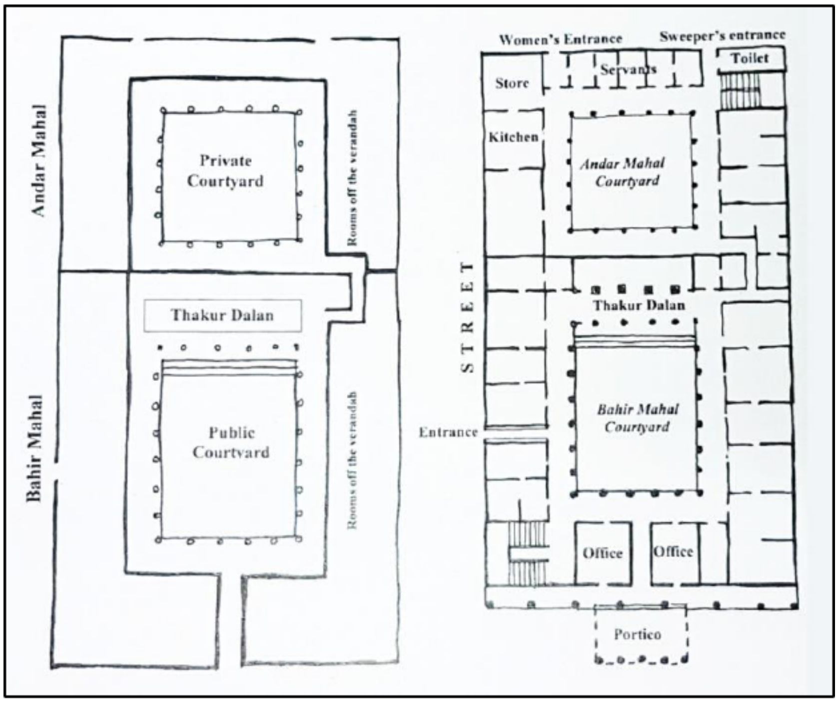


Figure 6 Generic plan and sample generated plan of indigenous house in old Kolkata

(Taylor & Lang, The Great Houses of Calcutta: their Antecedents, Precedents, Splendour and Portents, 2016)

Smaller building components and features that are characteristic of these houses are

- Ornamental entrance to the premise, such as lion door that were typical feature of many houses,
- Portico or porch to shelter the vehicle an mark the formal entry to the house
- Colonnades and or arcades (around courtyards, along passages)
- Sweeping ornamental
- Decorative elements – such as sculpture, stucco mouldings, wall motifs etc

Thus, this research intends to explore these indigenous houses of Kolkata and assesses their thermal performance against their modern counterpart to seek solution to counter-balance the growing thermal discomfort condition of Kolkata and other similar Indian cities.

5. OBJECTIVE

The objective of this study is to find out whether old indigenous residential buildings of Kolkata show better thermal performance than the new residential buildings of the city.

6. DELINEATION OF STUDY REGION

For the purpose of delineating and limiting study regions for the research, three zones have been designated within the city of Kolkata (Fig. 7)–

- <u>Northern or Old Traditional City</u> – the area between Mahatma Gandhi Road and Dumdum Road in present day city. The eastern boundary is delineated by Jessore Roadvand then CIT Road up to Sealdah.
- <u>Central or European Quarter of the city</u> – the area between Mahatma Gandhi Road on north and Acharya Jagadish Chandra Bose Road on south. The eastern boundary of this area is Acharya Prafulla Chandra Roy Road.

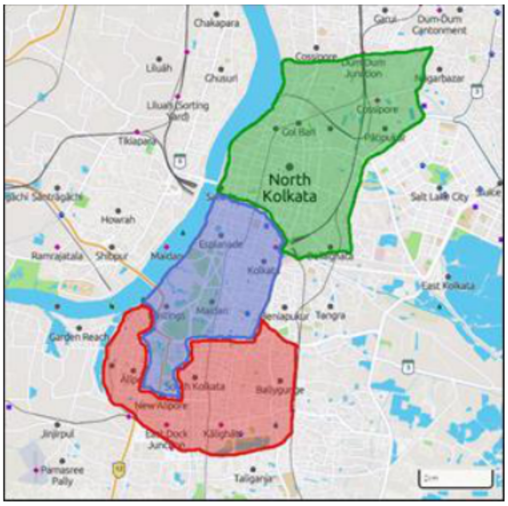


Figure 7 Map of Kolkata with delineation of zones

(Base map: https://mapcarta.com/Kolkata/North_Kolkata)

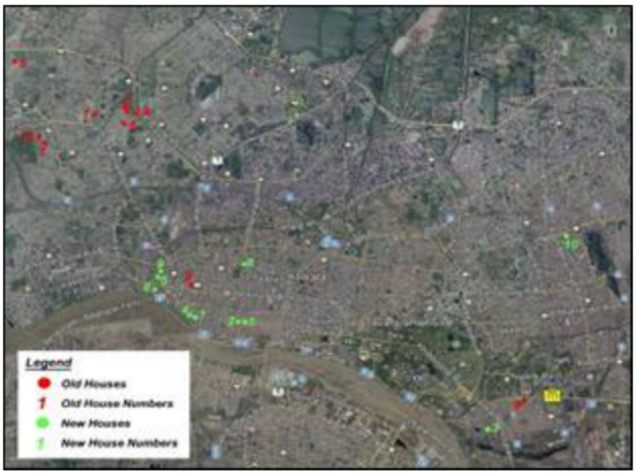


Figure 8 Satellite image of Kolkata showing Locations of the Survey Buildings

(Satellite Image courtesy: Google Earth)

- <u>Southern or the Newer City</u> – northern boundary of this area is AJC Bose Road, APC Roy Road and Sealdah Station, whereas southern boundary is the South Suburban Railway track running south of the Ballygunge area and Rabindra Sarovar lake.

From these zones, twenty buildings have been identified to be studied. Figure 8 shows a satellite image of the city, showing the location of these study buildings.

7. HERMAL CONDITION DATA

Thermal data of three types has been collected during this research:

- Data on Temperature and Relative Humidity on Kolkata for a decade (Secondary Data)
- Dry bulb temperature and dew point temperature on the days of survey (Secondary Data)
- Survey data on temperature and relative humidity from houses under study (Primary Data)

8. COMPARISON OF BUILDINGS WITH AMBIENT OUTDOOR CONDITION

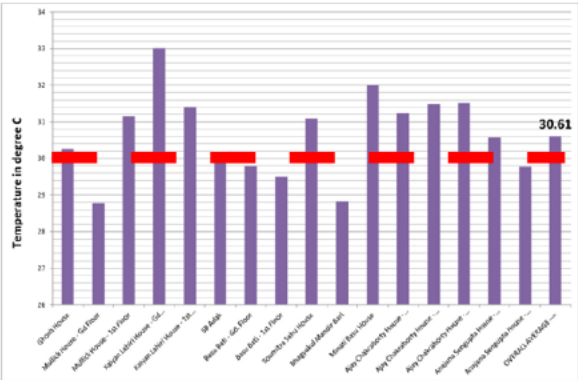
Average indoor temperature, relative humidity and heat index for old and new buildings are separately compared in two groups. The comparison is done in two ways. Firstly, these values are compared with the ambient air measurements, and then they are compared between each other. The whole study being divided between the summers of 2016 and 2017, the ambient air measurement data has been considered for these two years simultaneously. The average values of these two phases are given in Table 1.

Table 1 Average Ambient Outdoor Thermal Measurements in Kolkata during Study Period

	2016	**2017**	**Average**
Temperature	30.4□C	30.71□C	30.56□C
Relative Humidity	76.95%	71.44%	74.20%
Heat Index	37.38□C	36.78□C	37.08□C

In the first step of comparison, these average measurements are superimposed on the temperature comparisons of Old and New type of buildings. In the first comparison (Fig. 9), it is seen that the average temperature of 10 old buildings (30.61 ⏩C) is almost similar to that of the outdoor ambient temperature (30.56 ⏩C). On the other hand, the average temperature of the new buildings (31.28 ⏩C) is considerably higher than that of outdoor temperature (Fig. 10). Another trend observed is that irrespective of old or new building group, older buildings show better performance than later ones.

Comparison of relative humidity data show that both old and new buildings show efficiency of enclosure to keep the indoor humidity condition within control, despite few exceptions as is visible (Fig. 11, 12).



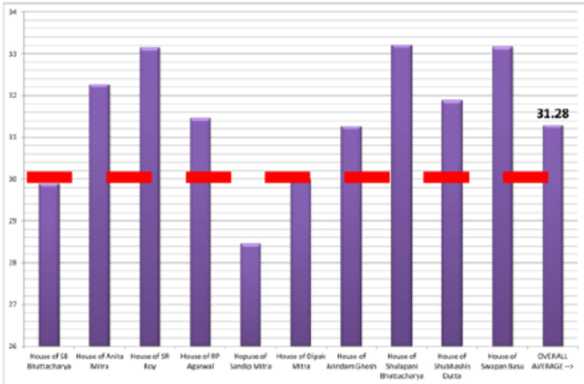
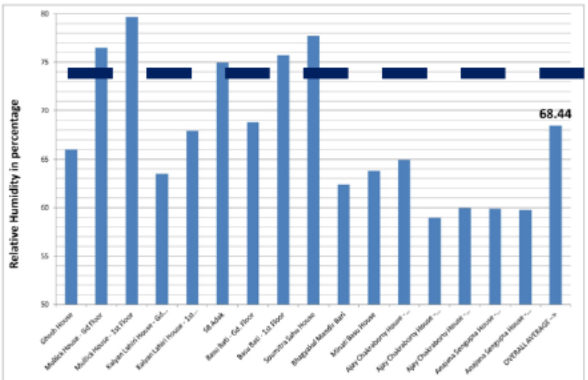


Figure 9 Figure 10

Figure 9 Average Temperature of Old Study Buildings against Average Outdoor Temperature

Figure 10 Average Temperature of New Study Buildings against Average Outdoor Temperature



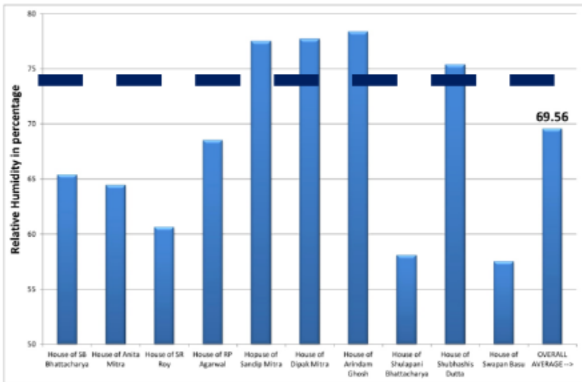
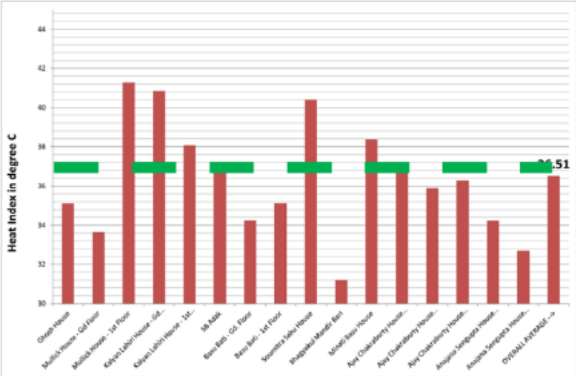


Figure 11 Figure 12

Figure 11 Average Relative Humidity of Old Buildings against Average RH

Figure 12 Average Relative Humidity of New Buildings against Average RH



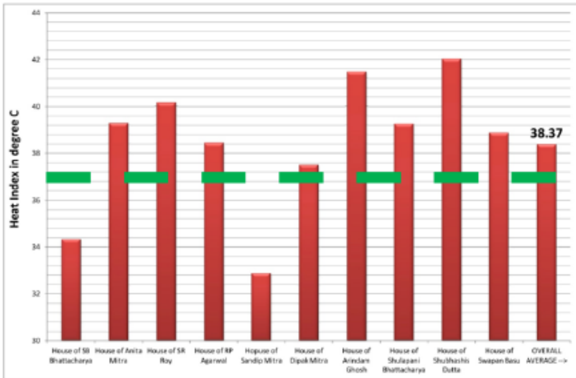


Figure 13

Figure 14

Figure 13 Average Heat Index of Old Buildings against Average HI

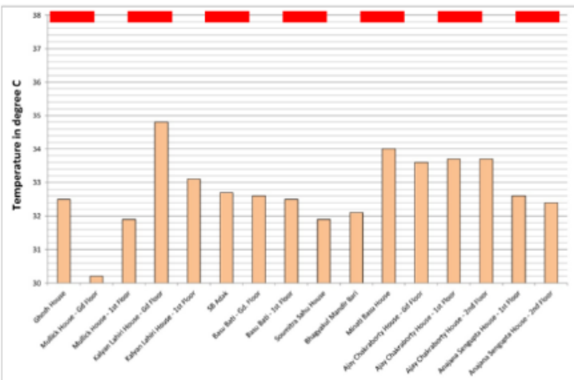
Figure 14 Average Heat Index of New Buildings against Average HI

On the other hand, the heat index graphs reveal where the difference between indoor thermal conditions old and new type of buildings can actually be observed. On one hand, the average HI value (36.51 °C) of old buildings is quite less than the average outdoor HI value (37.08 °C) (Fig. 13). On the other hand, the average HI value (38.37 °C) of the new buildings is quite high than the average outdoor value (Fig. 14).

This comparison is further extended to the maximum values observed during the study period. The maximum temperature and Heat Index observed during the two years of studies, viz, 2016 and 2017 have been retrieved from the ambient condition dataset (Table 2). These data have then been used as datum against maximum temperatures observed in various old and new buildings.

Table 2 Maximum Outdoor Temperature and HI recorded during Study Period

	Maximum Temperature	Maximum HI
2016	38°C	50°C
2017	37°C	47.16°C



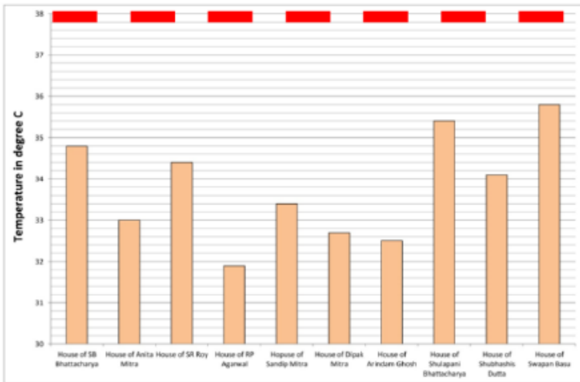


Figure 15

Figure 16

Figure 15 Maximum Temperature Recorded in Old Buildings against Maximum Outdoor Temp

Figure 16 Maximum Temperature Recorded in New Buildings against Maximum Outdoor Temp

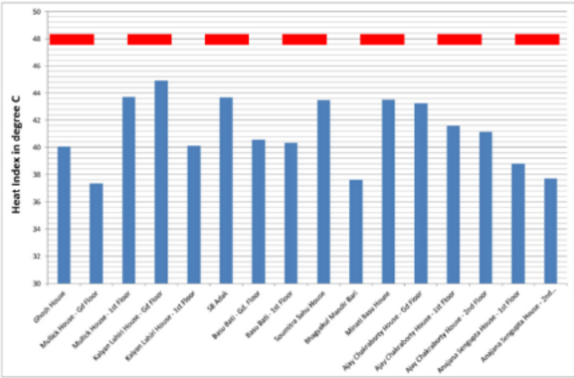


Figure 17

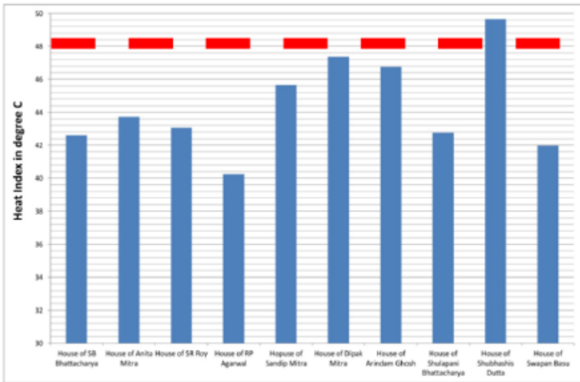


Figure 18

Figure 17 Maximum HI Recorded in Old Buildings against Maximum Outdoor HI

Figure 18 Maximum HI Recorded in New Buildings against Maximum Outdoor HI

On comparison of maximum temperature of old buildings, it was found that the maximum temperature observed in each of these buildings fall much below the maximum outdoor temperature observed (Fig. 15). Similar condition is also found for the new buildings, but in this case the difference between some of the buildings with their outdoor condition is comparatively much less (Fig. 16). A comparison with average data of temperature (Fig. 9, 10) explains the phenomenon. While the outdoor temperature condition fluctuates too much between the maximum and minimum values, the fluctuation is not so drastic within the buildings, especially the old buildings. In other words, the indoor conditions of old buildings have less fluctuation and are more stable than the new buildings.

Similarly, maximum heat Index data for old and new buildings were also compared with the maximum outdoor HI. In this also old building have much less HI values than the outdoor HI (Fig. 17). However, the condition of new buildings in terms of HI is not as good, with one building (house of Mr. Shubhasis Dutta) have more HI value than the outdoor condition (Fig. 18).

9. CONCLUSION

The study concludes that the old indigenous buildings of Kolkata indeed perform better than the new residential buildings. This leads to a further question as to what are the reasons for this superior performance. Further research can point out to this reason being explored further and the relationship of better thermal condition and the dependent factors to be established in a conclusive way.

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