Comparison of Thermal Comfort of Old Indigenous Houses with New Residential Buildings of Kolkata, India

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Abstract

Earth has experienced a global warming of 1.09 degree C over the last two decades when compared to the previous century. This problem has become multifold in the urban areas, thus generating the new phenomenon of “urban warming” as quoted by the IPCC. According to the IPCC data sheet of 2018, the city of Kolkata remains at the top of this urban warming list (2.6 degree C). Majority of this urban warming is contributed by buildings. The residential buildings of Kolkata, which constitutes the lion’s share of the total built mass contributes considerably to this warming.

As the global warming phenomenon has been mostly observed from 1970 onwards, this research assumes that buildings designed and built after that year has larger contributions to it. Hence, this research examines the thermal performances of samples of old (100 years of age or older) and new (after 1970) residential buildings of Kolkata, and compares them to find out which group performs better than the other.

The research focuses on non-air-conditioned housing stocks and collects data on temperature, relative humidity, air velocity from the sample houses as well as does measured drawings of the same. It then uses the composite indexes of heat index, percentage comfort hour and comfort fraction to analyze the collected data and compare the two groups of residences.

Based on this analysis, it is concluded that the internal thermal performance of the old residential buildings are better than those of the new residential buildings.

Keywords: Thermal comfort parameters, Heat index, Percentage Comfort Hour, Comfort fraction, Residences of Kolkata, Comparison of old and new residences

Introduction

A building provides its inhabitants with a protective enclosure. Adapting to the local climatic requirements, houses built in each region differ in their material, design, orientation, and form. This function has been played by vernacular architecture at various places for ages by providing a comfortable indoor environment. As Pellegrino, Simonetti and Chie (2015) observes, the more mechanical air-conditioning devices have developed, buildings have become proportionately more dependent on HVAC devices to achieve artificial comfort levels. In conjunction to the previous observation Nayak and Prajapati (2006) classified building stocks broadly into two types based on their indoor thermal condition, viz. conditioned and non-conditioned.

As a result of too much reliance on mechanical HVAC devices in urban areas, the environment may be adversely affected in two ways as Mitra (2018) observes – firstly, by releasing ozone depleting CFC gases into the atmosphere, and secondly, by draining the internal heat of buildings, especially poorly designed and poorly heated buildings, into the outdoors, contributing to the development of urban heat islands.

Sustainable development and green building are among the primary goals of the Smart City Mission undertaken by the Ministry of Urban Development, Government of India in 2015. As mentioned in article 2.4, Sustainable Environment is the eighth of ten Core Infrastructure Elements (Ministry of Urban Development, GoI, 2018). Also, a number of smart solutions are proposed in article 2.5 of the document, among them "Energy Efficient and Green Building.". Architects and planners have a prerogative alike to contribute towards making the environment sustainable and create building stock that assures certain degree of thermal comfort to its occupants.

As per the Climate Change 2023 Synthesis Report published by IPCC (2023), an average global temperature rise of 1.09 degreeC has been observed in the decade 2011-2020 over the base period of 1850-1900. The report also observes that – "In urban settings, climate change has caused adverse impacts on human health, livelihoods and key infrastructure (high confidence). Hot extremes including heatwaves have intensified in cities (high confidence), where they have also worsened air pollution events (medium confidence) and limited functioning of key infrastructure (high confidence)." (IPCC, Climate Change 2023 Synthesis Report, 2023, Pp-50).

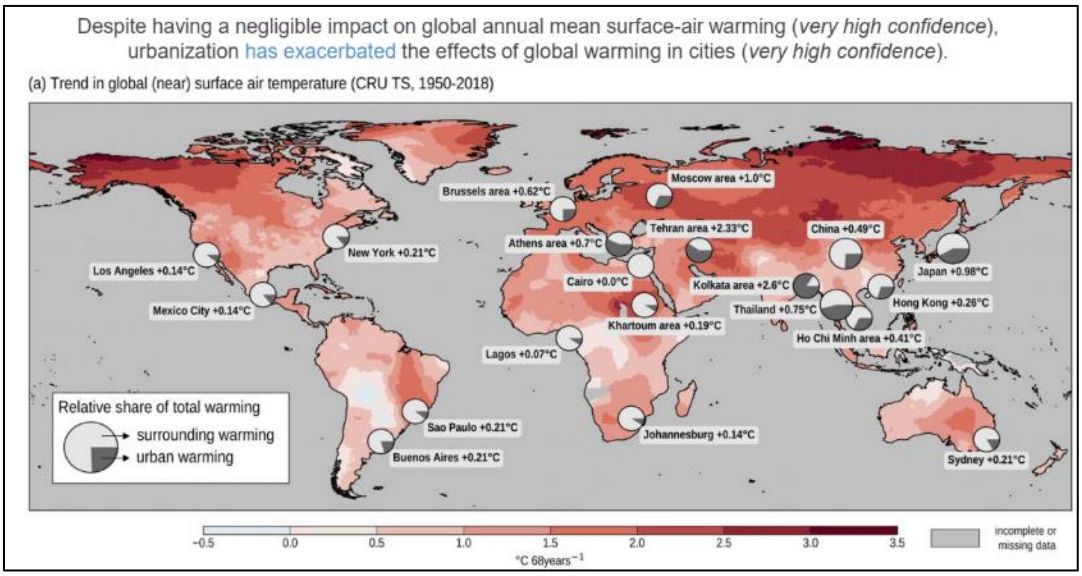

Fig. 1: Trend in Global Surface Temperature 1950-2018
Source: IPCC Intergovernmental Panel on Climate Change - Sixth Assessment Report - Regional Fact Sheet – Urban Areas

The map given in Fig. 1 is part of the – IPCC Sixth Assessment Report - Regional Fact Sheet – Urban Areas (2018) and shows that several urban centers around the globe are undergoing an annual rise in their average temperature. Among these urban centers the city of Kolkata is experiencing this phenomenon of "urban warming" at the highest level. The average temperature of the city has increased by 2.6 degree Celsius over the past sixty-eight years

(1950-2018). Of which, the urban area is responsible for an approximate 86% and the surrounding hinterland accounts for the rest 14% of heat contribution (Fig. 1).

Rizwan, et.al. (2008) concludes from their research that the large amount of re-radiated heat from the built-up structures of a city is primarily responsible for its warming and for creating of urban heat islands. Shalaby (2011) also observes that a large amount of re-radiated heat from the built-up area of a city is the main cause of creation of urban heat islands. The land use distribution for the city of Kolkata shows a total of 62% under residential use, which accounts for 73% of the total built up structures (Nath & Acharjee, 2013). This research therefore considers the residential buildings of Kolkata as its focus area. Further, IPCC (2023) in its report has observed that the phenomenon of global warming has increased particularly from the year 1970 onwards. This research therefore divides its sample study buildings into two parts – pre-1970, designated as 'old buildings' and post-1970, designated as 'new buildings'.

The aim of the research is to contribute to improving the design approach and methodology of the residential buildings of Kolkata by imbibing the traditional knowledge system of the old indigenous traditional building design and construction of the city. Its objectives are:

- To identify the old and the new buildings for the purpose of comparison of their thermal comfort.
- To identify suitable indices for the purpose of this comparison of thermal comfort.
- To compare the thermal comfort conditions of old and new residential buildings of Kolkata through the testing of various hypothesis. These hypotheses are stated in detail under the research methodology.

Theoretical Framework

Szokolay (2014) observes that the prerequisite of thermal comfort is the "condition of equilibrium" in the thermal balance of a human body. ANSI (2013) ASHRAE Standard 55-2013 defines thermal comfort as "the condition of mind that expresses satisfaction with the thermal environment". Hansen (1991) in his research defines it as "a state in which there are no driving impulses to correct the environment by behavior".

de Dear, et.al. (2013) point out that thermal comfort assessment is based on two models. The first of it was initiated by Fanger's (1970) work based on the indices of Predicted Mean Value (PMV) and Predicted Percent Dissatisfied (PDD). These indices were further taken up in the ISO standards of 1984 and 2005 and the ASHRAE Standard 55-2013. The second model is the Adaptive Comfort Model, first proposed in the work of Humphreys (1978) and Nicol (1996).

According to Szokolay (2014), the factors responsible for thermal comfort can be categorized under three sets – "Environmental", "Personal" and "Contributing Factors". Pioneering researchers like Fanger (1970), Humphrey (1978), Nicol (1996), Olgyay (1963), Koenigsberger, et.al. (1973) have endorsed these or other similar factors in their work. Djongyang, et.al. (2010) further underlines the fact that thermal comfort is essentially a subjective model that takes into consideration both the objective factors of environment as well as the subjective factors of human perception. Djongyang, et.al. (2010) and de Dear et.al. (2013) in their review of previous thermal comfort research discusses about this dependency of the models and indices on the human perception and reaction to the objective environmental conditions.

Literature Review

Studies have shown that a considerable amount of work has been undertaken in order to assess and compare the thermal comfort offered by the residential buildings of Kolkata – a city lying in the tropical wet and dry climatic zone. However, Pellegrino, et.al. (2015) raises a question whether enough research on the climate responsiveness of residential buildings of India has been conducted. They observe that until the beginning of the twenty-first century, majority of the work on this field has focused on non-residential building types. This is also corroborated by UNHABITAT (2014):

> "Sustainable architecture in tropical climates is a still an unexplored field, and it is an extraordinary challenge for architects, who should be willing to integrate basic information about building physics and aesthetics, and to abandon the approach, (now old and out-dated) which imitates the architecture of developed countries."
>
> UNHABITAT,2014:9

Bose (2010) has taken an extensive inventory of heritage residential buildings of Chitpore area of Kolkata, one of the oldest built districts within the city. Pellegrino, et.al. (2012) worked on the premise of comparing bioclimatic features and thermal comfort within heritage and modern buildings of Kolkata. Bose and Sarkar (2015) have explored the sustainable design solutions to make top floors of modern buildings more thermally comfortable, and their research has taken into consideration the design and construction approaches of old buildings to learn from them. Pellegrino, et.al. (2016) again have attempted to investigate and ensure better thermal comfort within Indian residences with particular focus on Kolkata

Similar works of comparison have been done in other parts of India but lying in the same climatic zone. Considerable amount of work has been done in the southern peninsular part of India. Radhakrishnan, et.al. (2010) have conducted a detailed study on the climate responsiveness of vernacular architecture of Tamil Nadu. Similarly, Madhumathi, et.al. (2014) have examined sustainability of the traditional rural houses of Tamil Nadu, where a part of the study has focused on the indoor thermal comfort of these houses. On the other hand, Shanti Priya, et.al. (2012) have conducted comparative research between the traditional and modern buildings of coastal area of Tamil Nadu on the basis of their thermal performance. Although it is found that the traditional buildings performed better, the number of samples are considerably less and the sampling areas are not necessarily urban in nature. Subramanian, et.al. (2017) have compared traditional buildings of more than hundred-year age with modern residential buildings of less than twenty years and have found that the indoor thermal comfort conditions are both subjectively (residents' feedback) and objectively (measurable indices) much better in the traditional houses.

Researches comparing traditional or heritage architecture with modern architecture in similar climatic zones but in other places of the globe have also revealed similar results. Tablada, et.al. (2005) have examined the naturally ventilated residences of warm-humid climate of Cuba and verified their performances against Fanger's PMV model to observe both their nature and degree of discordances with the prediction of the model. Mahar, et.al. (2018) examines the modern residential and in particular the unplanned or uncontrolled RCC frame structure buildings of Quetta, Pakistan to find out that majority of them fails to provide adequate thermal comfort for their inmates. Benkaci and Benabbas (2022 compares the thermal performance of vernacular vis-à-vis contemporary architecture of Algeria through the indices of thermal comfort as well as measurements of energy consumption.

Rai (2014) discusses the traditional as well as contemporary architecture of Kathmandu, Nepal and then use\s the traditional passive cooling building features in the simulation approach. However, he does not attempt to take up any conclusive comparative approach to compare the thermal comfort of these two types of buildings.

All this research has followed one or the other model observed by de Dear, et.al. (2013) – the PDD/PMF model or the ACT model. Either of these two models involve the objective or measurable data as well as the subjective or humane perception-based feedback. An initial reconnaissance of the old indigenous residential buildings of Kolkata revealed that a significant portion of these buildings are un-inhabited. Hence, collection of subjective data would not be possible from these buildings.

This research therefore took up two composite indices suggested by Nayak and Prajapati (2006) in the Handbook of Energy Conscious Building published by IIT Bombay and Ministry of Non-Conventional Energy Sources, Govt. of India – (a) Heat Index (HI) and (b) Percentage Comfort Hour (PCH) and Comfort Factor (CF) based on Adaptive Comfort Temperature.

Heat Index (HI)

As per the Rothfusz Regression equation prescribed by the Weather Prediction Centre of the National Oceanic and Atmospheric Administration, Govt of USA (NOAA, USA), the composite index of Heat Index (HI) can be calculated as

$$HI = -42.379 + 2.04901523t + 10.14333127r - 0.22475541tr - 0.00683783t^2 - 0.05481717r^2 + 0.00122874t^2r + 0.00085282tr^2 - 0.00000199t^2r^2 \quad \ldots\ldots \textit{Eqn. 1}$$

Where,

HI = Heat Index (in degree Fahrenheit)

t = Ambient Dry Bulb Temperature ((in degree Fahrenheit)

r = Relative Humidity (percentage value between 0 and 100)

with the following adjustments:

$HI_{rev} = HI + [(r-85)/10] * [(87-t)/5]$

When, $r > 85\%$

Hypothesis tested in this research using Heat Index:

Adaptive Comfort Temperature (ACT)

The premise of Adaptive Comfort Model rests on the concept of Neutral Temperature proposed forty years ago by Humphrey (1978). It differs from the assumption of static comfort model in the idea that Comfort Temperature cannot be a static value to be standardized across all climate zones in all weather. On the other hand, it takes into consideration the 'comfort votes' given by occupants of a built environment choosing a particular thermal condition as comfortable on a "right now right here" basis (Manu, et.al., 2016). Adaptive temperature therefore has the subtlety of considering the current ambient condition and sets the standard for the performance and acceptability of a built envelope on a dynamic scale.

Since then, various models that are actually linear regression developed on the basis of controlled thermal condition and user responses have been proposed. The following Table 1 showcases various Adaptive Thermal Comfort models proposed since the inception of the concept.

Table 1: Various ACT Models since inception
Source: Author

Name of the Proposer	Model of Adaptive Comfort Temperature or Neutral Temperature (Tn) based on average outdoor Temperature (To_{av})	Year proposed
Humphreys (Humphreys, 1978)	$Tn = 11.9 + 0.534 \times To_{av}$	1978
Auliciems (Aulicliems, 1981)	$Tn = 17.6 + 0.31 \times To_{av}$	1981
Griffith (Griffith, 1990)	$Tn = 12.1 + 0.534 \times To_{av}$	1990
Nicol and Rauf (Nicol & Rauf, 1996)	$Tn = 17 + 0.38 \times To_{av}$	1996
Szokolay (Szokolay, 2014)	$Tn = 17.8 + 0.31 \times To_{av}$	2016

In India, Adaptive Thermal Comfort studies have been conducted on different building typologies in different regions over the years. To unify all these into a pan-Indian code Manu et al (2014) proposed the Indian Model for Adaptive (Thermal) Comfort (IMAC) in 2014 that researched multiple types of buildings including mixed mode buildings over various climatic zones.

According to IMAC 2014, the Adaptive Comfort Temperature or Neutral Temperature is given as

Neutral temp. = 12.83 + 0.54*(30-day outdoor running mean air temp.)

However, IMAC 2014 has a comparative limitation of being more suitable for mixed use buildings or office buildings and for envelopes relying more on mixed mode than purely non-ventilated (NV) shells.

> *"The IMAC study models for neutral temperatures and acceptability limits for air-conditioned, naturally ventilated, and mixed mode buildings, as derived through an empirical field study specific to the Indian context, offer an energy efficient pathway for its commercial building sector without compromising occupant comfort."*
>
> \- Manu, et.al. (2016)

Another adaptive comfort model has been proposed by the "Handbook on Energy Conscious Buildings" prepared by Nayak and Prajapati (2006) under the interactive R & D project no 3/4(03)/99-SEC done by IIT Bombay for the Solar Energy Centre, Ministry of Nonconventional Energy Sources (Nayak & Prajapati, 2006). The Adaptive Comfort Temperature given by this standard is given by

$ACT = 16.2 + 0.41 \times T_m$ ……………………………………………………. *Eqn. 2*

where, T_m is the monthly mean ambient dry bulb temperature, and is equivalent to the parameter average outdoor temperature (To_{av}) as stated in table 3.

This standard has built its premise over all types of buildings and non-ventilated indoor environment. This research therefore builds its premises on the recommendations of this standard. In addition, the last model gives a steep slope (second steepest) as illustrated in Fig. 3 where the ACT values have been compared for the same To_{av} value of 25 degreeC.

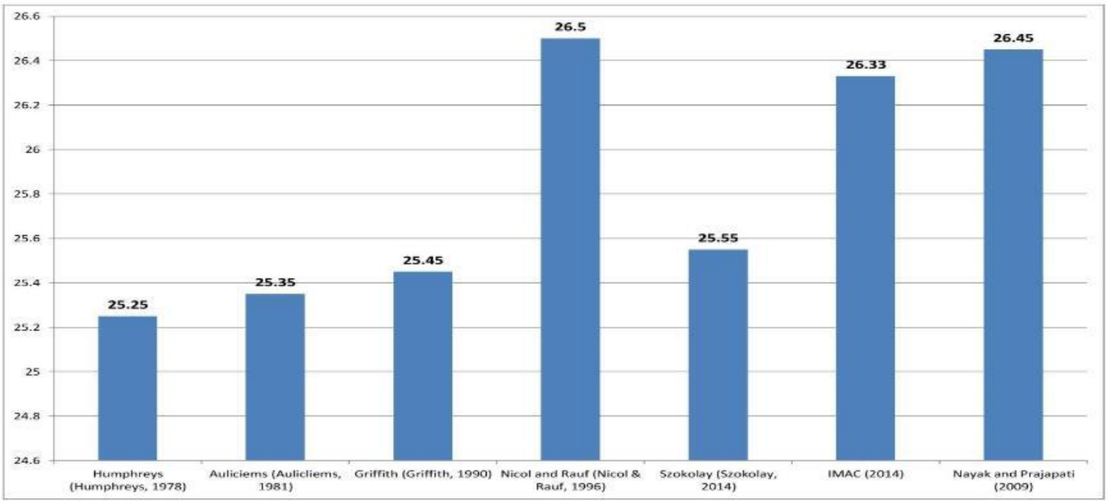

Fig 3: Comparative Steepness of ACT Models
Source: Author

Based on the Adaptive Comfort Temperature (ACT) value, Nayak and Prajapati (2006) suggests to parameters by which the thermal performance of a building can be assessed. These are:

1. **Percentage Comfort Hour** or PCH**:** Percentage of hours in a year that a building would remain within the comfortable temperature range. The comfortable temperature range proposed by the standard has a maximum value of ACT + 2.2 degreeC and a minimum value of ACT – 2.2 degreeC.

2. **Comfort Fraction** or CF, which is calculated using the following equation:
   CF = 1 – (Discomfort Degree Hours)/105.6 ……………………………….. Eqn. 3
   where, Discomfort Degree Hours = (100-PCH)

For the comparison between the old and new type of buildings, as well as absolute performance of each building against ambient temperature, these two indices have been considered in this research.

Research Methodology

The study involves residential buildings as it constitutes the majority of Kolkata's built-up area, and only the non-conditioned, that is naturally ventilated housing stocks have been considered in the study as they rely only on the natural and design factors for their interior thermal condition. Residences of Kolkata has been divided into two parts – pre-Independence houses built before 1947 CE (henceforth mentioned as "Old Building") and post-Independence houses built after 1947 CE (henceforth mentioned as "New Building"). Moreover, buildings from the period between 1905 and 1980s have not been considered as the design typology as well as construction materials and techniques have undergone a transition due to social, political and economic changes that the World, India and specifically Calcutta (or Kolkata as it is now called) have undergone. (Taylor & Lang, 2016;270-271).

Delineation of Study Region

Since the British empirical rulers have established Fort William and then settled in the immediate vicinity of Maidan (the large urban open ground that surrounds the Fort due to strategic requirement), the city of Kolkata has been divided into three distinct parts, viz, the North, Central and the South. The 'Great Houses', as Taylor and Lang (2016) call them, or the old indigenous residences belonging to the Indian citizens of Kolkata are mostly concentrated in North Kolkata.

For the purpose of delineating and limiting study regions for the research, following zones have been designated within the city of Kolkata (Fig. 2) –

- *The Northern City, or the Old Traditional City*, is the area between Mahatma Gandhi Road and Dumdum Road. To the east, Jessore Road follows CIT Road to Sealdah.
- *The Central or European Quarter* of the city is located between Mahatma Gandhi Road on the north and Acharya Jagadish Chandra Bose Road on the south. Acharya Prafulla Chandra Roy Road forms the eastern boundary of this area.
- *Southern or the Newer City* - AJC Bose Road, APC Roy Road, and Sealdah Station form the northern boundary of this area, while the South Suburban Railway track runs south of Ballygunge area and Rabindra Sarovar Lake forms the southern boundary.

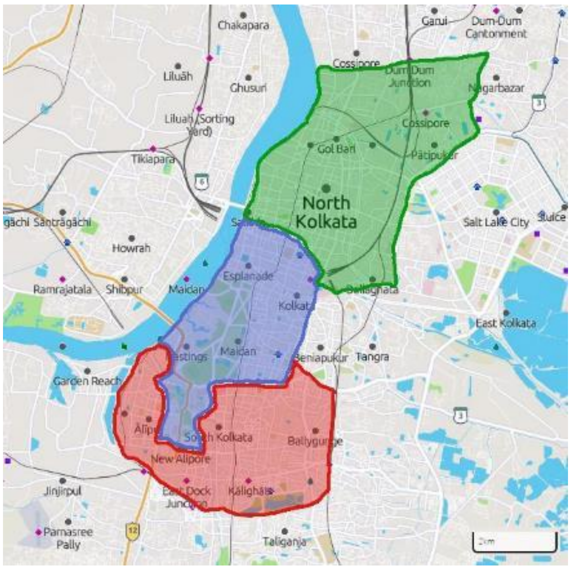

Fig. 2: Map of Kolkata with delineation of research zones
Source: Author

Inventory of Study Buildings

The study buildings have mostly been chosen from the northern part of the city. However, the southern part of the city has also been represented with two old and one new building studied there.

The study thus included ten numbers each of "Old" and "New" buildings. Table 2 and Table 3 enlists these buildings along with their locations within Kolkata and their year of construction. Actual identities of these buildings have been masked in order to ensure the privacy of the owners as per their consent.

Table 2: Old Buildings of Kolkata surveyed (arranged in chronological order)
Source: Author

Sl	Nomenclature	Area	Date
1	**Old Residence 1**	Pathuriaghata	1782
2	**Old Residence 2**	Pathuriaghata	1830
3	**Old Residence 3**	Khidirpur	1843
4	**Old Residence 4**	Shobhabazar	1860
5	**Old Residence 5**	Bagbazar	1876
6	**Old Residence 6**	Vivekananda Road	1895
7	**Old Residence 7**	Shobhabazar	1903
8	**Old Residence 8**	Gopal Neogi Lane	1906
9	**Old Residence 9**	Bagbazar	1920
10	**Old Residence 10**	Gariahat	1942

Table 3: List of New Buildings of Kolkata surveyed (arranged in chronological order)
Source: Author

Sl	Nomenclature	Area	Date
1	**New Residence 1**	Belgachhia Dutta Bagan	1984
2	**New Residence 2**	Lake Town	1992
3	**New Residence 3**	Lake Town	2000
4	**New Residence 4**	Lake Town	2000
5	**New Residence 5**	Dumdum	2000
6	**New Residence 6**	Khidirpur	2001
7	**New Residence 7**	Dumdum Motijheel	2007
8	**New Residence 8**	Lake Town	2013
9	**New Residence 9**	Bagbazar	2016
10	**New Residence 10**	Dumdum	2016

Following satellite image shows the locations of these houses studied within the city of Kolkata.

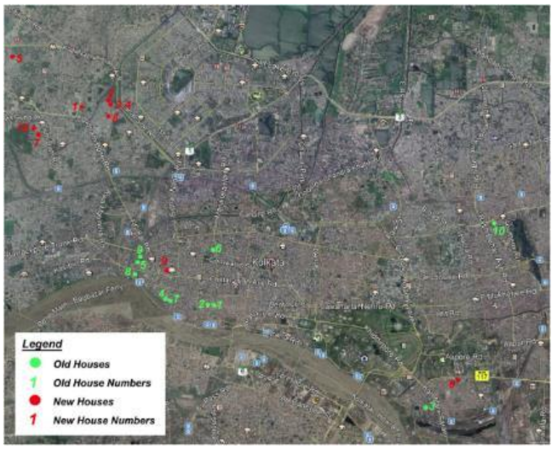

Fig 3: Locations of the Survey Buildings in the city of Kolkata
Source: Author (Satellite Image courtesy: Google Earth)

Building Study Techniques

The study of an individual building involved the following steps –

Step 1- Marking the location of the building: The location of the building is marked on a static satellite image of Kolkata, extracted from Google Earth website.

Step 2- Recording of the architecture of the building: In this stage, scaled measured drawings of the building is prepared. For measurements, HTC laser distance meter has been used. In addition, every portion of the building is also photo-documented in detail.

Step 3- *Recording of Indoor Climatic Data:* Temperature and relative humidity data are recorded with the help of HTC data logger for 48 hours in each building at an interval of 15 minutes – thus generating 192 temperature data for each building. The datalogger is kept in a room that has maximum or standard occupancy expectation throughout the day (with the exception of few un-inhabited old buildings). They are kept on a tableor stool or a horizontal non-magnetic, non-heating and un-enclosed surface maintaining a distance of 1 m. from the centre of nearest wall and at a height of 0.6 – 1 m. from the floor. Wherever the nearest wall has a window on external space, the machine is kept at a distance of at least 1 m. or more from the centre of the window. Wind velocity data is also manually recorded at a height of 1 m. from floor at an interval of 3 hours using HTC digital anemometer.

Step 4- *Recording of Ambient Climatic Data:* Ambient temperature and relative humidity data are recorded with the help of HTC data logger for 48 hours at an interval of 15 minutes – thus generating 192 temperature data. For every building a simultaneous set of ambient climatic dataset is also recorded using HTC datalogger. The datalogger is kept in a shaded and ventilated outdoor area. Outdoor wind velocity data is manually recorded at a height of 1 m. from floor at an interval of 3 hours using HTC digital anemometer.

Some of the Old Buildings shows significant difference in their thermal performance in different floors within the same building block. The thermal conditions for these floors are therefore considered separately in the study. Thus, the Old Buildings group is augmented to fifteen samples, whereas the New Buildings group comprises of ten samples only.

Comparison of Buildings on the Basis of Heat Index (HI) using "Testing of Hypothesis for Single-Tailed Testing"

The data surveyed are analyzed in two separate groups of Old buildings and New buildings. Each building has 192 sets of temperature and relative humidity data recorded. For each of these data, the Heat Index (HI) values are calculated using Eqn 1. The central tendency of these 192 HI values is calculated using arithmetic mean, i.e., average and is tabulated under two separate tables of old (Table 5) and new (Table 6) buildings.

These tables are then compared by testing the following hypotheses through a single-tailed test.

Null Hypothesis (H_0) - *the average heat indices of old buildings (H_O) equalls to the average heat indices of the new buildings (H_N) sampled, i.e.,* $H_O = H_N$.

Alternative Hypothesis (H_A) - *the average heat indices of old buildings (H_O) are lesser than the average heat indices of the new buildings (H_N) sampled. i.e.,* $H_O < H_N$.

The testing of hypothesis is conducted for a confidence level of 5%, i.e., $\alpha = 0.05$.

Comparison of Buildings with (a) Percentage Comfort Hours (PCH) Calculated Based on Adaptive Comfort Temperature (ACT) and (b) Comfort Fraction (CF)

In this stage of the data analysis, thermal performance of all study buildings are measured on two absolute scales of Adaptive Comfort Temperature (ACT) and Comfort

Fraction (CF). Based on the decadal data on the summer weather of Kolkata, the Adaptive Comfort Temperature (ACT) is calculated using the Eqn 2.

The two extreme acceptability limits (ANSI, 2013) are given to be 2.2 degrees higher and lower than the calculated ACT value. The average ambient dry bulb temperature during the summer months of April, May and June during 2016-2017 is calculated to be 30.56 degrees. Using equation 2, the ACT for this period is calculated as 28.73 degrees.

Similarly, the average heat index converted from the ambient temperature for this period is calculated as 37.08 degrees and the resultant ACT for HI is calculated as 31.4 degreeC.

Using these values, the upper limits of acceptable comfort condition are calculated to be 30.93 degree C for ambient DBT and 33.6 degree C for ambient HI.

Using these two benchmarks, thermal data for all survey buildings are analyzed and tabulated for two indices - Percentage Comfort Hour (PCH), and then using Eqn 3 Comfort Factor (CF) (Table 7, 8, 9 and 10).

The data in these four tables are then used for testing of the following hypotheses (Table 4) through single-tailed test.

Table 4: Formation of hypotheses for testing of indices PCH and CF
Source: Author

Sl. No.	*Indices*	*Null Hypotheses for Single-Tailed Test*	*Alternative Hypotheses*
1	**PCH on ACT (calculated on DBT)**	The average percentage comfort hour calculated on DBT (PCH_{ACT}^{DBT}) of old buildings (PCH_{ACT}^{DBT}OLD) equals to the average heat indices of the new buildings (PCH_{ACT}^{DBT}NEW) sampled, i.e., $\mathbf{PCH_{ACT}^{DBT}OLD = PCH_{ACT}^{DBT}NEW}$	$\mathbf{PCH_{ACT}^{DBT}OLD > PCH_{ACT}^{DBT}NEW}$
2	**PCH on ACT (calculated on HI)**	The average percentage comfort hour calculated on HI (PCH_{ACT}^{HI}) of old buildings (PCH_{ACT}^{HI}OLD) equals to the average heat indices of the new buildings (PCH_{ACT}^{HI}NEW) sampled, i.e., $\mathbf{PCH_{ACT}^{HI}OLD = PCH_{ACT}^{HI}NEW}$	$\mathbf{PCH_{ACT}^{HI}OLD > PCH_{ACT}^{HI}NEW}$
3	**CF for ACT (calculated on DBT)**	The average comfort fraction calculated on DBT (CF_{ACT}^{DBT}) of old buildings (CF_{ACT}^{DBT}OLD) equals to the average heat indices of the new buildings (CF_{ACT}^{DBT}NEW) sampled, i.e., $\mathbf{CF_{ACT}^{DBT}OLD = CF_{ACT}^{DBT}NEW}$	$\mathbf{CF_{ACT}^{DBT}OLD > CF_{ACT}^{DBT}NEW}$
4	**CF for ACT (calculated on HI)**	The average comfort fraction calculated on HI (CF_{ACT}^{HI}) of old buildings (CF_{ACT}^{HI}OLD) equals to the average heat indices of the new buildings (CF_{ACT}^{HI}NEW) sampled, i.e., $\mathbf{CF_{ACT}^{HI}OLD = CF_{ACT}^{HI}NEW}$	$\mathbf{CF_{ACT}^{HI}OLD > CF_{ACT}^{HI}NEW}$

The testing of hypothesis is conducted for a confidence level of 5%, i.e., $\alpha = 0.05$.

Data Analysis

The data analysis for average Heat Index (HI) values are presented in Table 5 for Old buildings, and in Table 6 for New buildings. These data are then further put into single-tailed hypothesis testing.

Table 5: Average heat index (HI) values for OLD buildings studied
Source: Author

Serial No.	House Nomenclature	Average HI
1	**Old Residence 1**	35.12
2	**Old Residence 2**	33.66
3	**Old Residence 3** – Gd Floor	38.07
4	**Old Residence 3** – First Floor	40.85
5	**Old Residence 4**	37.17
6	**Old Residence 5** – Ground Floor	34.25
7	**Old Residence 5** – First Floor	35.13
8	**Old Residence 6**	40.4
9	**Old Residence 7**	31.2
10	**Old Residence 8**	38.37
11	**Old Residence 9** – Ground Floor	36.98
12	**Old Residence 9** – First Floor	38.88
13	**Old Residence 9** – Second Floor	36.29
14	**Old Residence 10** – Ground Floor	34.23
15	**Old Residence 10** – First Floor	34.23
	Average HI of Old Buildings (Ō)	***36.12***

Table 6: Average heat index (HI) values for NEW buildings studied
Source: Author

Serial No.	House Nomenclature	Average HI
1	**New Residence 1**	34.32
2	**New Residence 2**	39.28
3	**New Residence 3**	40.15
4	**New Residence 4**	38.43
5	**New Residence 5**	32.88
6	**New Residence 6**	37.49
7	**New Residence 7**	41.47
8	**New Residence 8**	39.26
9	**New Residence 9**	42.03
10	**New Residence 10**	38.87
Average HI of New Buildings (Ń)		***38.42***

The data analysis for average Percentage Comfort Hour (PCH) values are presented in Table 7 for Old buildings and in Table 9 for New Buildings. Similarly, the data analysis for Comfort Fraction (CF) values are presented in Table 8 for Old buildings and in Table 10 in New buildings. These data are then put into single-tailed hypothesis testing in the next stage.

Table 7: Percentage Comfort Hour for OLD Buildings observed on basis of ACT calculated on DBT and HI values
Source: Author

Sl No	Bldg Name	Old Building Data	
		PCH on ACT (DBT)	PCH on ACT (HI)
1	**Old Residence 1** - 1st Floor	46.4	41.8
2	**Old Residence 2** - Gd Floor	100	45.8
3	**Old Residence 3** - 1st Floor	12.8	2.1
4	**Old Residence 4** - 2nd Floor	99	25.5
5	**Old Residence 5** - Gd Floor	73.7	51.5
6	**Old Residence 5** - 1st Floor	99.7	88.7
7	**Old Residence 6** - 1st Floor	38.1	0
8	**Old Residence 7** - 1st Floor	100	97.2
9	**Old Residence 8** - 1st Floor	13.3	2.1

10	**Old Residence 9** - Gd Floor	23.1	20
11	**Old Residence 9** - 1st Floor	28.2	14.4
12	**Old Residence 9** - 2nd Floor	31.3	25.1
13	**Old Residence 10** - 1st Floor	58.8	52
14	**Old Residence 10** - 2nd Floor	61.8	58.8
	AVERAGE	**56.15714286**	**37.5**

Table 8: Comfort Fraction (CF) for OLD Buildings using DBT and HI values
Source: Author

Sl No	Bldg Name	Old Building Data	
		CF for ACT (DBT)	CF for ACT (HI)
1	**Old Residence 1** - 1st Floor	0.786268939	-0.256273674
2	**Old Residence 2** - Gd Floor	1	0.667992424
3	**Old Residence 3** - 1st Floor	0.756628788	-1.092163826
4	**Old Residence 4** - 2nd Floor	0.873745265	-0.962973485
5	**Old Residence 5** - Gd Floor	0.954498106	0.640506629
6	**Old Residence 5** - 1st Floor	0.993347538	0.61077178
7	**Old Residence 6** - 1st Floor	0.857954545	-2.122537879
8	**Old Residence 7** - 1st Floor	0.977367424	0.911268939
9	**Old Residence 8** - 1st Floor	0.462050189	-1.202817235
10	**Old Residence 9** - Gd Floor	0.735795455	-0.721472538
11	**Old Residence 9** - 1st Floor	0.527462121	-0.347703598
12	**Old Residence 9** - 2nd Floor	0.436600379	-0.605421402
13	**Old Residence 10** - 1st Floor	0.882954545	0.569625947
14	**Old Residence 10** - 2nd Floor	0.913754735	0.714109848
	AVERAGE	**0.797030574**	**-0.228363433**

Table 9: Percentage Comfort Hour for NEW Buildings observed on basis of ACT calculated on DBT *and HI values*
Source: Author

Sl No	Bldg Name	New Building Data	
		PCH on ACT (DBT)	PCH on ACT (HI)
1	**New Residence 1**	59.8	35.1
2	**New Residence 2**	0.5	0
3	**New Residence 3**	1	0
4	**New Residence 4**	0	0
5	**New Residence 5**	75.8	65.7
6	**New Residence 6**	68.8	27.5
7	**New Residence 7**	32.8	0
8	**New Residence 8**	0	0
9	**New Residence 9**	33.9	0
10	**New Residence 10**	12.9	0
	AVERAGE	**28.55**	**12.83**

Table 10: Comfort Fraction (CF) for NEW Buildings using DBT and HI values
Source: Author

Sl No	Bldg Name	New Building Data	
		CF for ACT (DBT)	CF for ACT (HI)
1	**New Residence 1**	0.702035985	-0.386410985
2	**New Residence 2**	0.381344697	-1.635890152
3	**New Residence 3**	-0.027272727	-2.037997159
4	**New Residence 4**	0.753432765	-1.228219697
5	**New Residence 5**	0.921448864	0.371046402
6	**New Residence 6**	0.89670928	-0.908120265
7	**New Residence 7**	0.744720644	-2.299124053
8	**New Residence 8**	-0.047230114	-1.611055871
9	**New Residence 9**	0.475307765	-2.594105114
10	**New Residence 10**	0.380042614	-0.447395833
	AVERAGE	**0.518053977**	**-1.277727273**

Findings

Hypothesis calculations on the HI data as given in Table 5 revealed the standard deviation of H_O to be $\sigma_O = 2.5967$ and calculations on the HI data in Table 6 gives the standard deviation of H_N to be $\sigma_N = 2.8933$.

Using the values of σ_O and σ_N, the value of z_0 is computed as

$$Z_0 = \frac{\bar{O} - \acute{N} - \Delta}{\sqrt{\left(\frac{\sigma_O^2}{n_O} + \frac{\sigma_N^2}{n_N}\right)}}$$

$$= -6.8229$$

Where, Ō and Ń are average HI values of Table 5 (Old buildings) and Table 6 (New buildings) respectively.

For a confidence level of 5%, i.e., for $\alpha = 0.05$, the value of z_α is found to be 1.65788

Therefore, $|z_0| > z_\alpha$, which signifies that the null hypothesis is rejected and the alternative hypothesis, i.e., H_A is accepted.

Hence, the research concludes that *"the average heat indices of old buildings (H_O) are lesser than the average heat indices of the new buildings (H_N) sampled. i.e., $H_O < H_N$".*

Similarly, hypotheses as stated in Table 4 are tested based on the data tabulated under Tables numbered 7, 8, 9 and 10 through single-tailed tests. The findings of these tests are tabulated in the following Table 11.

Table 11: Results of Testing of Hypotheses Formed for Indices PCH and CF
(for confidence level 5%, i.e., α=0.05 and Z_α=1.658)
Source: Author

Sl. No.	Indices		Testing Variables			Z_0 calculated	Hypothesis proven True
			No of samples	*Average*	*Standard Deviation*		
1	**PCH on ACT (calculated on DBT)**	Old Buildings	14	56.16	33.46	2.104	$\mathbf{PCH_{ACT}^{DBT}OLD > PCH_{ACT}^{DBT}NEW}$
		New Buildings	10	28.55	30.36		
2	**PCH on ACT (calculated on HI)**	Old Buildings	14	37.5	30.61	2.264	$\mathbf{PCH_{ACT}^{HI}OLD > PCH_{ACT}^{HI}NEW}$
		New Buildings	10	12.83	22.75		

3	**CF for ACT (calculated on DBT)**	Old Buildings	14	0.797	0.194	2.282	$\mathbf{CF_{ACT}^{DBT}OLD} >$ $\mathbf{CF_{ACT}^{DBT}NEW}$
		New Buildings	10	0.518	0.35		
4	**CF for ACT (calculated on HI)**	Old Buildings	14	-0.228	0.933	2.707	$\mathbf{CF_{ACT}^{HI}OLD} >$ $\mathbf{CF_{ACT}^{HI}NEW}$
		New Buildings	10	-1.278	0.939		

Based on the results of the hypotheses formed for the two indices, viz, Percentage Comfort Hours (PCH) and Comfort Fraction (CF), calculated on both the variables DBT and HI, it can be conclusively remarked that the internal thermal conditions of the old residential buildings studied are more comfortable than the internal thermal conditions of the new residential buildings.

Conclusion

The objectives put forth at the beginning of this paper has been fulfilled. The research intended to examine whether the thermal performance of Old residential buildings are better than that of the New residential buildings in Kolkata. This has been put into assessment through formation of two sets of hypotheses, and the research has proven all the hypotheses to be true. Thus, the premise behind this study that 'Old Indigenous Architecture of Kolkata have better indoor thermal performance than the modern residential buildings' has been established conclusively for the sample buildings studied and analyzed in the research.

However, this research has certain challenges in terms of its scope. The actual population of the residential buildings in Kolkata being in multitude for both old and new genre, the sample size of ten buildings taken in each category has limited the validity of the data collected. However, this paves a way for future work in this field, for which this research contributes in form of a methodology to be considered.

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