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REVIEW

Review of Works on Comparison of Old Indigenous Residences with Modern Houses in India on Non-Subjective Indices of Thermal Comfort

Sanmarga Mitra [1,2*], ***Shailendra Kr. Mandal*** [1]

[1] *Department of Architecture and Planning, National Institute of Technology, Patna, Bihar 800005, India*

[2] *Department of Architecture, School of Planning and Architecture, Bhopal, Madhya Pradesh 462030, India*

ABSTRACT

During the past few decades, we have witnessed the phenomenon of constant warming occurring everywhere on the globe. Cities have suffered from urban warming to a greater extent than any other part of the world, and Kolkata has one of the highest levels of urban warming of any city around the world. In Kolkata, 73% of the buildings are residential, and it is this type of building that contributes to a significant amount of this warming. With the city of Kolkata as the case study, this paper aims at understanding the multiple domains of urban heat islands and thermal comfort within the context of the city, from a macro perspective of an urban heat island down to a micro perspective of a building level, with the ultimate aim of mitigating global warming through this study. Various research works have been undertaken in India and abroad to understand the individual as well as composite effect of various building components on the indoor thermal comfort. Researches have also been undertaken to compare and comprehend the differential thermal comfort of old indigenous residences with that of the new residential buildings. Hence, this paper discusses methods that have been applied in past works to evaluate the thermal comfort of old and new residential buildings in a non-subjective manner, without having recourse to user feedback, in the final segment that views the process of learning from comparing old and new residential buildings.

Keywords: Review of Works; Global Warming; Urban Heat Island; Thermal Comfort

*CORRESPONDING AUTHOR:

Sanmarga Mitra, Department of Architecture and Planning, National Institute of Technology, Patna, Bihar 800005, India; Department of Architecture, School of Planning and Architecture, Bhopal, Madhya Pradesh 462030, India; Email: smitra@spabhopal.ac.in

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1. Introduction

Since the last few decades the phenomenon of constant warming has been observed all over the globe. The magnitude of this global warming has been observed to be as much as 1.09 degrees centigrade over the last forty years [1]. In cities and urban areas, heat is being concentrated in smaller areas of cities, giving rise to the Urban Warming effect, a term that was coined by the Intergovernmental Panel on Climate Change. According to the data sheet of 2018 published by IPCC [2], Kolkata has been observed to have the highest urban warming of any city in the world at 2.6 degrees centigrade. The buildings of a city are responsible for a large portion of this warming, and for Kolkata, 73% of these buildings are residential [3].

This paper aims at the study of the multiple domains from the macro or urban level understanding of Urban Heat Island to the micro or building level understanding of Thermal Comfort with the city of Kolkata as the case study, with the final aim of mitigating global warming. An inventory has found that many of Kolkata's old indigenous buildings that provide good indoor thermal comfort are uninhabited [4]. Hence, the conventional method of user or occupant survey for assessing indoor thermal comfort cannot be applied in these buildings. In the final segment this paper has thus reviewed the process of learning from the comparison of old and new residential buildings, and has also discussed past works that have laid out methods of assessing thermal comfort in a non-subjective manner without using user feedback.

The literature review of this research is therefore stratified in two stages as follows:

- Study on Urban Heat Island
- Study on Thermal Comfort, its Indices and its Factors
- Study on the city of Kolkata and the evolution of its indigenous residences

2. Urban Heat Island

Urban Heat Islands (UHIs) are characterized by a higher temperature in urban areas than in undeveloped or rural areas [5–9]. In cities with one million or more residents, the mean air temperature can be one to three degrees Celsius higher than its surroundings. Furthermore, on a clear, calm night this difference can increase up to 12 degrees Celsius [5] (**Figures 1** and **2**). For at least the last century, the urban heat island phenomenon has been a topic of research in Europe due to its role as a trap for atmospheric pollutants, damage to quality of life, and socioeconomic impact [10–13].

During the summer, urban heat islands can affect a community's environment and quality of life by increasing temperatures. According to Shalaby [14], these impacts include:

- A higher consumption of energy
- An increase in greenhouse gas emissions and air pollution
- Human comfort and health compromised
- Elevated water demand and water quality impairment
- Effect on meteorology and climate
- Relation to global warming

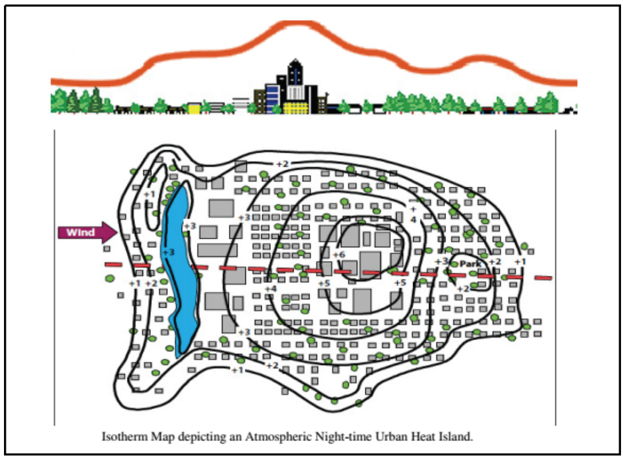

Figure 1. Isotherm Map depicting night-time UHI.
Source: https://thebritishgeographer.weebly.com/uploads/1/1/8/1/11812015/949911_orig.png.

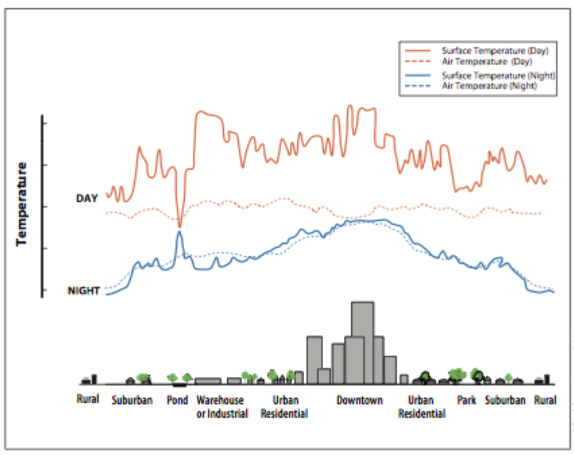

Figure 2. Urban Heat Island formation during day and night time.
Source: https://thebritishgeographer.weebly.com/uploads/1/1/8/1/11812015/4097836_orig.png.

According to studies, Urban Heat Island can be classified in two manners as stated in **Table 1**, where both Surface UHI from classification type I as well as Canopy Layer UHI from type II are directly affected by the nature and density of the built environment.

Some studies [7, 14–19] indicate that urban heat islands have the following characteristics:

- There can be urban heat islands at any time of the year.
- In summer, they tend to be higher than in winter.
- As sunset approaches, they are usually at their highest and at their lowest, sometimes even negative, overnight. The intensity of these phenomena peaks after sunset, usually a few hours later.
- Cloudless skies and calm air are highly conducive to the development of UHIs.
- In highly developed areas, they have the greatest impact.
- They develop rapidly with urbanization and their effect often increases in proportion to the size of the city.
- Urban centers tend to be most affected by these factors, with urban peripheries being less affected.

The variation in UHI in urban areas is caused by a variety of natural and manmade factors, including land use, building materials and heights, street geometry, and building spacing. These factors are influenced by how much sun-warmed urban surface is exposed to cold night skies.

Table 1. Classification of urban heat islands.

Classification Types	Types of UHI	Brief Description
Type I As per Shallaby (2011) [14], USEPA (2009 b) [5] and USEPA (2009 d) [5]	Surface UHI	• Surface UHI is the result of higher surface temperatures in urban areas compared to nearby rural areas. • During the day, when the sun is shining, surface UHI tends to be strongest.
	Atmospheric UHI	• A temperature differential between urban areas and nearby rural areas defines atmospheric UHI. • After sunset, the atmospheric urban heat island becomes more pronounced as heat from urban surfaces and structures slowly escapes to the atmosphere.
Type II As per Shallaby (2011) [14], Golden (2004) [16], USEPA (2009 b) [5] and USEPA (2009 d) [5]	Canopy Layer UHI	• A canopy layer (UHI) can be found in the air below trees and rooftops, in the air layer where people live.
	Boundary Layer UHI	• Atmospheric boundary layer UHI extends from rooftops and treetops to the point where urban landscapes are no longer influencing the atmosphere.

Santamouris [10] found in an analysis of 101 Asian and Australian cities that the magnitude of UHI has varied from 0.5 to 11 degrees centigrade with a central tendency of 4 degree centigrade. Mohan, Bhati and Sati [20] report that in dense and compact urban areas, UHI can reach magnitudes of 4 to 8 degrees centigrade. Rizwan et al. [8] conclude that urban heat islands are primarily caused by the re-radiated heat from built-up structures that characterize a city. Shalaby [14] observes that urban heat islands are created primarily by re-radiated heat from the built-up areas of cities.

3. Indoor Thermal Environment—Concepts

3.1. Definitions of Thermal Comfort

On a general understanding, thermal comfort is the condition in which a person feels most comfortable psychologically in a thermal environment.

A subjective evaluation of thermal comfort is defined by ASHRAE 55-2013 as a state of mind that expresses satisfaction with a thermal environment [21].

According to Nayak and Prajapati, thermal comfort defines a range of climatic conditions within which the majority of people don't feel uncomfortable either because of heat or cold [22].

As Szokolay describes thermal comfort in detail, equilibrium is when the summation of metabolic heat production, exchange of radiation, convection, conduction, and evaporation including respiratory heat equal to zero, and such an equilibrium is necessary to achieve thermal comfort [23].

In his groundbreaking work, Olgyay defined thermal comfort as maintaining a minimum level of energy expenditure to adjust to the environment. Those conditions, where a human is most productive, can be described as the "comfort zone" [24].

As Gulati and Pandya explain in their article, psychological comfort can be defined as a condition of satisfaction with a thermal environment within a built form [25].

3.2. Factors of Thermal Comfort

Szokolay categorizes the factors that affect thermal comfort under two categories, viz, Environmental and Personal [23]. The factors are further listed as

Environmental Factors:

- Temperature of Air
- Movement of Air
- Humidity in Air
- Radiation of Heat

Personal Factors:

- Post-Activity Metabolic Rate
- Cloth (Insulation) or the Clo-Value
- Condition of Health
- Adaptation to a new climate or acclimatization

ASHRAE 55 includes six factors that contribute to thermal comfort, which are as follows [21]:

- Metabolic Rate
- Cloth (Insulation) or the Clo-Value
- Temperature of Air
- Radiant Temperature
- Speed of Air
- Humidity in Air

As the research excludes personal factors from its scope, the factors explored are the environmental ones irrespective of any personal opinion of any occupier.

3.3. Thermal Comfort Standards in India

Simha in his work divides thermal comfort assessment approaches into two types, viz, Static and Dynamic [26]. The former adopts a more classical approach of a prescribed static range of thermal conditions on the bioclimatic chart and does not take into consideration the location or the climate of the place of survey [24]. The other is a flexible model and considers an Acceptable Thermal Condition that is based on the average outdoor temperature [21].

Pellegrino, M et al observes that the two standards that monitor and prescribe thermal comfort in India are the National Building Code (NBC) and the Energy Conservation Building Code (ECBC). However, the lacuna lies in the fact that both of these base their standard of thermal comfort on the static model and do not take into consideration the vast regional variation in climate conditions in India [27]. These standards are mostly suggested for non-residential (office etc.) buildings and hence do not take into consideration the large proportion of India's buildings which are residential [28].

However, since 2000 more research into the adaptive ways of thermal comfort has been taken up all around the world, of which India is no exception [28].

However, the GRIHA manual, although published in 2007, follows the same static benchmark of thermal comfort as NBC and ECBC [29].

4. Works on Study and Comparison of Buildings Based on Thermal Comfort

According to Szokolay, thermal comfort is dependent upon the "condition of equilibrium" in the body's thermal balance [23]. According to the ANSI ASHRAE Standard 55-2013, thermal comfort is the state of mind that expresses satisfaction with how a building's thermal environment feels [21]. A state of thermal comfort, according to Hansen, occurs when there are no driving impulses to correct the environment through behaviour [30].

There were two models that were used to assess thermal comfort as observed by de Dear et al. [31]. It was first established by Fanger (1970) using the Predicted Mean Value (PMV) and Predicted Percent Dissatisfied (PDD) indices [9]. ISO 1984 and 2005 standards and ASHRAE Standard 55-2013 both adopted these indices. The Adaptive Comfort Model, originated by Humphreys in 1978 [32] and Nicol and Rauf in 1996 [33], is the second model.

It has been suggested by Szokolay that the factors determining thermal comfort are stratified into three types:

- Environmental Factors
- Personal Factors
- Contributing Factors [23].

Several pioneering researchers [9, 24, 32–34] concurred with these factors and/or similar ones. Djongyang, Tchinda and Njomo emphasize the subjective nature of thermal comfort and how it involves both objective factors of the environment and subjective factors of human perception [35]. A review of previous research on thermal comfort by Djongyang, Tchinda and Njomo and de Dear et al. [31] stresses the dependence of models and indices on human perception and response to objective environmental factors.

Researchers have undertaken a substantial amount of work to evaluate and compare the thermal comfort conditions prevailing inside the residential buildings in the city of Kolkata that is within the tropical wet and dry climate. However, Pellegrino, Simonetti and Chie [36] questioned how much research has been conducted on the climate sensitivity of residences in India. According to their research, until the early 21st century, building types other than residential have been the focus of most works in this field.

As UNHABITAT stated in 2014, sustainable architecture in tropical climates remains an underexplored field, and it presents an extraordinary challenge to architects. The approach (now old and outdated) of attempting to imitate the architecture of developed countries needs to be abandoned and basic information about building physics and aesthetics should be integrated [37].

4.1. Researches on the Thermal Comfort Conditions of Residential Buildings of Kolkata

A survey conducted by Bose examined old residences of Chitpore, one of Kolkata's oldest districts [38]. Pellegrino, Simonetti and Fournier conducted a study of bioclimatic features and thermal comfort compared between heritage buildings and modern buildings in Kolkata [28]. By studying old buildings' construction and design approaches, Bose and Sarkar explored a sustainable design solution for making top floors of modern buildings more thermally comfortable [39]. Pellegrino, Simonetti and Chiesa investigated thermal comfort in the residential buildings of Indian cities, particularly Kolkata [27].

4.2. Researches on the Thermal Comfort Conditions in Other Parts of India

Comparative studies have been conducted in other parts of India with similar climatic conditions. In the southern peninsular region of India, a substantial amount of work has been conducted. Radhakrishnan, Shanthi Priya and Sundarraja examined the climate responsiveness of Tamil Nadu's vernacular architecture in a detailed study in 2010 [40]. Similarly, Madhumathi, Vishnupriya and Vignesh conducted a study on the thermal comfort of homes in Tamil Nadu in 2014 to evaluate their sustainability [41]. The research of Shanti Priya, Sundarraja and Radhakrishnan examined and compared the thermal performance of traditional buildings versus modern structures in Tamil Nadu's coastal areas [42]. The results of this study show that traditional buildings performed better than other types, but there were substantially fewer samples and the sampling areas weren't necessarily urban. Subramanian, Ramachandran and Senthamil Kumar examined traditional buildings that were aged hundred years or more against modern residential buildings that had an age less than or equal to twenty years, and found that traditional houses provide better thermal comfort both subjectively (reports from residents) and objectively (measurable indices) [43].

4.3. Researches on the Thermal Comfort Conditions in Other Parts of the World

Similar results have also been found in research comparing traditional and heritage architecture in similar climate zones around the world. A review of the naturally ventilated residences of Cuba's warm-humid climate was conducted by Tablada, Troyer and Pena to determine if their predictions conflicted with Fanger's PMV model [44]. Mahar, Amer and Attia analyze the modern residential buildings in Quetta, Pakistan, examining their unmonitored reinforced concrete residential structures to determine that almost all of them fail to provide the required thermal comfort to their tenants [45]. In Algeria, thermal comfort inside vernacular architecture was compared with that of contemporary architecture by measuring consumption of energy and by monitoring comfort indices in the research of Benkaci and Benabbas, who found out that the vernacular building performed better in terms of thermal comfort and resultant requirement of energy [46].

In Rai's post-graduate dissertation, traditional and contemporary architecture of Kathmandu, Nepal, are discussed, and passive cooling features are applied to the simulation of buildings [47]. Although the study does not attempt to make any definitive comparison between these two types of buildings in terms of thermal comfort, it has incorporated certain design features of the traditional house into the design of contemporary houses through simulation software (Design-build) and has noted positive changes in terms of thermal comfort.

4.4. Thermal Comfort Indices Used

It should be noted that all of these studies have followed one or the other of the models described by de Dear, etal. – the PDD/PMF model or the ACT model [31]. A combination of objective, measurable data and subjective feedback based on human perception is incorporated in both of these indices. A preliminary survey of Kolkata's indigenous residential buildings revealed a large number of vacant homes. Therefore, it will not be feasible to collect subjective occupant response data from these residences. Thus, the research used two composite indices developed by Nayak and Prajapati in the Handbook of Energy Conscious Building of IIT Bombay and the Ministry of Non-Conventional Energy Sources of the Government of India [22] – (a) Heat Index (HI) and (b) Percentage Comfort Hour (PCH) and Comfort Factor (CF) based on Adaptive Comfort Temperature.

4.5. Non-Subjective Thermal Comfort Index 1—Heat Index (HI)

In order to calculate the composite index of Heat Index (HI), one needs to apply the Rothfusz Regression equation.

This equation has been prescribed by the Weather Prediction Centre of the National Oceanic and Atmospheric Administration, Govt of USA [48–50] and is stated as follows:

$$\begin{gathered} HI = -42.379 + 2.04901523t + \\ 10.14333127r - 0.22475541tr - 0.00683783t^2 \\ -0.05481717r^2 + 0.00122874t^2r \\ 0.00085282tr^2 - 0.00000199t2^2r^2 \end{gathered} \quad (1)$$

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, $r > 85\%$.

4.6. Non-Subjective Thermal Comfort Index 2—Adaptive Thermal Comfort (ACT)

Adaptive Comfort Model operates on a concept Humphrey proposed forty years ago called Neutral Temperature. The dynamic comfort model assumes that Comfort Temperature cannot be standardized across climate zones and weather conditions. Additionally, it takes into account the "comfort votes" that occupants give when determining whether a particular thermal condition is comfortable "right now right here" (manufactured environment), as proposed by Manu et al. in 2016 [51]. Therefore, adaptive temperature provides a dynamic standard for building envelope performance and acceptability that is sensitive to changing ambient conditions.

There have been various models proposed since then, which are linear regression models based on controlled thermal conditions and user responses. Based on Szokolay's discussion of the concept, **Table 2** depicts various Adaptive Thermal Comfort models [23].

Table 2. Various ACT Models since inception.

Name of the Proposer	Model of Adaptive Comfort Temperature or Neutral Temperature (Tn) *(To_{av} Is the Monthly Average Outdoor Temperature)*	Year Proposed
Humphreys, 1978 [32]	$T_n = 11.9 + 0.534 \times To_{av}$	1978
Griffith, 1990 [52]	$T_n = 12.1 + 0.534 \times To_{av}$	1990
Nicol and Rauf, 1996 [33]	$T_n = 17 + 0.38 \times To_{av}$	1996
Szokolay, 2014 [23]	$T_n = 17.8 + 0.31 \times To_{av}$	2014

Over the past few decades, Indian researchers have examined Adaptive Thermal Comfort on different building typologies in a variety of regions. The Indian Model for Adaptive (Thermal) Comfort (IMAC) was proposed by Sanyogita Manu and colleagues in 2014 to unify all these codes into a pan-Indian code that assessed multiple types of buildings, including mixed mode buildings, in various climate zones.

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

$$\text{Neutral temp.} = 12.83 + 0.54 * (30 - \text{day outdoor running mean air temp.})$$

According to Manu, Shukla and Rawal, IMAC study models for neutral temperatures and acceptability limits in air-conditioned, naturally ventilated, and mixed-mode buildings have been derived from an empirical field study tailored to the Indian context and offer an energy efficient pathway for its commercial building sector without compromising occupant comfort [53]. Though this is true, IMAC 2014 still has the disadvantage of being best suited to mixed-use or office-oriented buildings and envelopes with more mixed modes than pure non-ventilated envelopes.

The "Handbook on Energy Conscious Buildings," prepared by Nayak and Prajapati [22] in 2009 under IIT Bombay's interactive research & development project no 3/4(03)/99-SEC for the Solar Energy Centre, Ministry of Nonconventional Energy Sources, offers another adaptive comfort model [22].

Adaptive Comfort Temperatures are given by this standard as follows:

$$\text{ACT} = 16.2 + 0.41 \times \text{T}_\text{m} \quad (2)$$

where, T_m is the monthly mean ambient dry bulb temperature.

There are no exceptions to this standard. It applies to all types of buildings and non-ventilated indoor environments. A comparison of various ACT models has been conducted for an uniform To_{av} value of 25 degrees Celsius and a steep forecast of adaptive comfort temperature is predicted by the last model (Nayak and Prajapati [22]) – thus preparing any building design for a higher thermal condition for the same design parameters. Hence, this study suggestively took up the ACT model suggested by Nayak and Prajapati, and discusses it in the following section.

4.7. Performance of Building Based on ACT

The parameters that Nayak and Prajapati suggest to assess the thermal performance of a building are based on adaptive thermal comfort values [22]. These are:

1. Comfort Degree Hours = The percentage of hours during which a building remains within a comfortable temperature range. The standard proposes a maximum temperature range for a comfortable environment that is ACT + 2.2 degree C and a minimum value of ACT – 2.2 degree C.
2. Discomfort Degree Hours = Total no of Hours in the Study Period – Comfort Degree Hours
3. Comfort Fraction, CF given by

$$\text{CF} = 1 – (\text{Discomfort Degree Hours})/105.6 \quad (3)$$

These two indices thus may be used to compare old and new buildings, and to evaluate the performance of each building against ambient temperature.

5. Thermal Performance and Building Physical Factors

The contributing factors of thermal performance have been more or less similarly proposed by Nayak and Prajapati in 2006 [22], Abed in 2012 [54], Shanthi Priya, Sundarraja and Radhakrishnan in 2012 [42], Szokolay in 2014 [23], Madhumathi, Vishnupriya and Vignesh in 2014 [41], Gulati and-Pandya in 2014 [25] and Fang in 2015 [55], and these are listed as:

- Orientation of Building
- Velocity of Air
- Shading Devices
- Ratio of Surface versus Volume
- The Thermal Conductivity of the Envelope
- Opening versus Wall-Area Ratio

6. Discussion on the Architecture of Residences of Kolkata

The city of Kolkata was already a small settlement in the form of a conglomerate of villages and hamletsinhabited mostly by the weaver community and wealthy traders dealing with them. It was in 1690 that Job Charnock arrived in

Kolkata and the British historians marked this date as the inception of the city [56]. Within a century, the city became the capital of British India, and its rise in power started after the Battle of Plassey in 1757. In the 19th century, it flourished in leaps and bounds to become the second largest city of the Empire. The flourish of the city as a whole has a history of a little over a century, starting from the introduction of Permanent Settlement in 1793. The decline of the city initiated with the shifting of the capital to Lutyen's Delhi in 1911 and the final decline started with the Independence of India and the partition of Bengal into West Bengal and East Pakistan (now Bangladesh) [57].

The sudden growth into prominent urbanization after the Permanent Settlement Act of 1794 initially created two distinct architectural prototypes – European architecture and Indian architecture. The former strictly followed the European styles following its architectural treatises [58]. However, the latter followed its own heritage of rural Bengal, nawabi Murshidabad and badshahi Delhi in its form and architectonics. As per Bose, the three distinct types of buildings that shaped this architecture included the adobe huts with their small-scale modular design, the extrovert stone palaces of the Mughals and the courtyard-centric introvert design of the Havelis [59].

6.1. Typical Components

Irrespective of outer appearance, these indigenous houses had designs befitting their Indian cultural fabric and religious needs. Like North Indian havelis housing the elites, these mansions also had courtyards for their socio-religious life. Often, there was more than one courtyard, and they had a hierarchy suitable to their function [58]. With the passage of time, they also developed a unique built form of their own. There were several typical components introduced in their design that differentiated them from their precedents. These elements, identified concurrently by Bose [59] and Taylor and Lang [58], are as follows:

- Ornamental entrance to the premise, such as a lion door
- Portico or porch to shelter the vehicle and mark the formal entry to the house
- Colonnades and or arcades (around courtyards, along passages)
- Sweeping ornamental staircases
- Decorative sculpture, stucco mouldings, wall motifs etc
- Stained and tinted glass windows
- Wrought iron decorative and/or utilitarian elements

6.2. Building Materials and Construction System

The choice of building material prior to the introduction of railways in India in the year 1853 was vernacular. It was influenced by the availability of material in the locality as well as the climatic trend. Although Kolkata is a hot and humid region having a large amount of annual rainfall, impervious material like stone was not used in its architecture due to unavailability. Rather, terracotta bricks and tiles were preferred as good quality clay was abundant in the hinterland. Two more elements that were popular were good timber for structural members and glass for windows.

Kamalika Bose has enlisted the building materials used in old indigenous buildings as follows [59]:

- Bricks – the presence of abundant good clay initiated the use of burnt brick in this area even before the Islamic era. The basic component remaining the same, brick sizes have varied. During the colonial period, standard bricks of 250 × 125 × 75 mm were introduced in construction. Lofty walls as thick as 800–1000 mm were also built to improve the structural system as well as thermal insulation in these mansions.
- Lime Stucco – lime was used both as a component of mortar as well as for plastering. In the great mansions of the city lime was used for creating beautiful stuccowork. Lime was also used to prepare lime terracing by mixing it with surkhi or powdered brick, brick bat and gur or jaggery.
- Cast Iron – since the British brought this fruit of the Industrial Revolution to India, it became a status symbol both in Europe and India. Just as architect John Nash designed the Royal Pavilion at Brighton with its wrought iron indoor decors, the rich houses of Kolkata also employed this material for making decorative elements like balusters, gas lamp posts, arches, etc. The huge requirement of iron elements, structural as well as ornamental, initiated an iron-based industrial belt in Howrah so large that the city got the nickname of Sheffield of the East by the turn of the 20th century.

- Bamboo and Cuscus – to ward off the unwanted sun from the public and semi-public areas of verandahs, sunshades made of split bamboo and cuscus were widespread. These have however been replaced by static wooden louvers.
- Terracotta – terracotta tiles had two structural uses at this time – roof tiles as well as tiles for arches.
- Stained Glass – stained as well as tinted glass was imported into the city from Europe, especially Belgium. They were commonly used in windows as well as for making partition screens.
- Dutch Wall Tiles – these were glazed tiles and were used to make dados in all sorts of places like drawing rooms, bedrooms, corridors and other prestigious spaces. These tiles were polychrome and patterned to make attractive visual compositions wherever they were installed.

6.3. Contemporary Small Residences of Old Kolkata

Like their large counterparts, small residences also reaped the fruit of new materials and design innovations of the time. Although they did not enjoy such lavish sites to sprawl in, they could innovatively incorporate many of these indigenous concepts in their design. This is why we observe small scaled-down courtyards or rather "court-wells", as they may be called, being incorporated in these small residences.

These residences continued the practices of thick walls, although the common thickness has reduced to 400–500 mm, which was commensurate to the scale of the building. On the other hand, other construction features such as metal joist roofs, IPS stone tiles, lime terracing or stained glass continued to be used en masse.

The latter houses of the early 20th century started going up as sites were constricted but families remained large. Thus we have 3–4 storied houses frequenting the streets and alleys of North Kolkata during this time. However, they started abandoning decorative motifs, glazed tiles and other "redundant" elements from their houses due to two reasons – the shifting of the capital from Kolkata to Delhi in 1911 gave the city a huge economic jolt where unnecessary expenditure in construction was done away with, and secondly, the "flat surfacing" architectural philosophy of America started trickling into the Indian society. Thus by the turn of Independence, the architectural form and language took a new shape that ultimately gave form to modern architecture in Kolkata.

7. Conclusions

The study shows that the architecture of residences in Kolkata has evolved drastically over the last three centuries, and the same has affected the indoor thermal comfort of the city as well as resulted in overall urban heating. The study further looks into the cause of this urban heating as well as creation of urban heat islands, and then reviews research done to mitigate the phenomenon of urban heating by learning from the old indigenous architecture from different parts of the world.

The study thus finds that although such comparisons of old indigenous residences with contemporary residential structures have been taken up in different parts of India as well as other parts of the world, such work of comparison has not been taken up for the city of Kolkata, and hence, there is a potential domain to work on the same.

For the creation of anything new, one must rely on the work of others before them to some extent. A close examination of any significant achievement will reveal a sequence of discoveries that led up to that achievement in the first place. In order to make any meaningful creative endeavor a reality, it takes a great deal of time, energy, and day-to-day effort. This review of preceding research and publications thus serves the said purpose, despite its lacunae in terms of scope and scale of study.

Author Contributions

S.M.: Research concept development, measurement drawing, data collection and analysis, interpretation of data, conclusion drawing, and writing of the rough and final drafts of the paper; S.K.M.: Conceptualizing the research, interpreting data, drawing conclusions, reviewing and scrutinizing first drafts, and writing the final version.

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Conflicts of Interest

No conflict of interest was observed by the authors while conducting the research.

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