Sustainable Design Through Harmonizing Tradition and Innovation: Achieving Thermal Comfort in Mumbai's Residential Units.

Sub-theme: Goal 11- Sustainable Cities and Communities

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Abstract

Sustainability is a critical issue in urban development, as creating a favorable environment that balances development and housing with the environment is crucial to ensuring a high quality of life and productivity. Traditional architecture has successfully achieved this balance, but modern urban development has led to a deterioration in physical and psychological health, impacting the quality of life and productivity. It is essential to design buildings that provide comfortable indoor environments to address this issue. This research focuses on improving thermal comfort in Mumbai's residential units, which face warm and humid weather conditions. Considering contemporary challenges in achieving thermal comfort, the research aims to adapt traditional architectural principles to modern building design. This research develops a framework for designing interior spaces that promote thermal comfort, starting with identifying the interior elements that influence thermal comfort conditions. It analyzes these elements in the interior spaces of a conventional residential building and traditionally treated interior spaces of a contemporary structure. By examining the elements that contribute to thermal comfort in both, the researchers identify effective strategies for adapting traditional design principles to modern building design.

The scope is limited to the interiors of residential flats in apartment buildings in Mumbai. The framework developed in this research can be applied to achieve sustainable and comfortable indoor environments in new as well as existing residential units. The study's field survey collects observations and feedback from occupants. It provides valuable insights into how occupants perceive and experience thermal comfort in their living spaces, helping to identify effective strategies for improving indoor environmental quality. This framework for designing interior spaces to promote thermal comfort provides valuable insights for architects, designers, and developers seeking to create sustainable and comfortable indoor environments in contemporary residential units.

Keywords: Thermal Comfort; Traditional architecture; Sustainability; Sustainable interiors;

1. Introduction

1.1 - Background:

Urban development is propelled by the influx of populations into cities, seeking economic opportunities and enhanced living conditions. This surge necessitates a delicate equilibrium between developmental pursuits and environmental preservation. The core of this equilibrium lies in sustainability, emphasizing economic growth while concurrently ensuring a high quality of life and minimizing environmental impact. Central to the concept of sustainability is the creation of comfortable living environments, acknowledged as pivotal for the well-being and productivity of urban residents.

Mumbai, a metropolis synonymous with dynamism and growth, exemplifies the intricate challenges entailed in harmonizing economic progress with environmental considerations. The city, with its tropical climate, faces pronounced hurdles in achieving thermal comfort. Inadequacies in thermal comfort not only lead to immediate discomfort but can also give rise to health issues and diminished productivity, thereby impacting the overall quality of life.

This research is dedicated to unraveling and addressing the specific challenge of attaining thermal comfort within the residential landscape of Mumbai, with a specific focus on existing apartments. The objective is to explore the seamless integration of traditional architectural principles into contemporary design, fostering comfort within the micro-climate of individual living spaces. This integration is designed to align with the broader objectives of the United Nations' Sustainable Development Goals, adding a layer of social and environmental responsibility to the pursuit of comfort.

Rooted in practical wisdom, traditional architecture in Mumbai has historically harnessed natural ventilation, shading techniques, and specific materials to combat climatic challenges. The intent of this research is to refine and contemporize these proven principles, applying them judiciously to existing residential structures.

The study's objectives are clearly delineated, spanning the reevaluation of traditional finishing materials, the formulation of a comprehensive Thermal Comfort Framework, and the detailed analysis of interior elements influencing thermal well-being. Geographically, the research centers on the urban and suburban context of Mumbai, characterized by its warm and humid climate. The exclusive focus on existing residential structures within this geographical scope underscores the research's commitment to analyzing the pivotal factors influencing thermal comfort in the built environment.

While acknowledging the multifaceted nature of individual adaptability and demographic characteristics such as gender, age, health conditions, and race in influencing thermal comfort, this research consciously relies on general, quantifiable technical data. The emphasis is on broader technical and architectural aspects, with a deliberate omission of an exhaustive analysis of demographic characteristics. The study acknowledges its limitations while serving as a foundational step towards exploring sustainable solutions in the realms of urban development and thermal comfort..

2. Literature review

Urban areas, especially rapidly urbanizing ones with diverse climates, face a growing need for intervention to enhance thermal comfort in existing residential structures. Retrofitting and renovating buildings to improve energy efficiency and indoor environmental quality are critical for sustainable urban development (United Nations, 2021). The global surge in residential construction, including in cities like Mumbai, underscores the importance of addressing thermal comfort in existing building stock due to their significant population occupancy (United Nations, 2021). Many urban environments, including Mumbai, are focusing on renovating and retrofitting existing residential structures to meet contemporary standards for energy efficiency, thermal comfort, and sustainability (Napau, 2017).

Studies highlight that a considerable percentage of existing urban residential structures, especially those constructed in recent decades, may not meet current energy efficiency and thermal comfort standards (Napau, 2017). Retrofitting existing structures not only has economic implications but also significant environmental consequences. Enhancing energy efficiency contributes to sustainability goals and reduces carbon footprints in cities (Rao & Pachauri, 2017). Governments worldwide are responding to the need for retrofitting by introducing policies, incentives, and regulations to encourage energy-efficient interventions in existing residential buildings (Delen, 2020). This aligns with the global emphasis on sustainable urban development, aiming to balance economic growth, environmental conservation, and human well-being.

Thermal comfort in urban residential settings is crucial for the well-being of inhabitants, aligning with the United Nations' Sustainable Development Goals (WHO, 2021). Mumbai, as a densely populated and rapidly developing city, faces unique challenges due to its tropical climate (UNDP, 2019). Achieving thermal comfort is not merely a matter of preference but directly impacts health, productivity, and overall quality of life for the diverse population in Mumbai. Traditional architecture in Mumbai, developed over centuries, demonstrates effective strategies for mitigating the challenges posed by the city's climate. Elements like deep eaves, courtyards, and latticed screens facilitate natural ventilation and shading, contributing to historical thermal comfort (Santamouris, 2007). However, modern urban development in Mumbai has often deviated from these traditional principles, prioritizing aesthetics over thermal comfort and relying on energy-intensive mechanical systems (Bansal & Minke, 2014). Harmonizing traditional architectural wisdom with modern design is crucial for addressing the thermal comfort challenge sustainably (Kwak & Kim, 2012).

In summary, the literature underscores the global importance of retrofitting existing residential structures for thermal comfort, with Mumbai serving as a poignant case study. It highlights the significance of balancing traditional architectural principles with modern design considerations for sustainable and comfortable urban living.

3. Research methodology

The objectives of this research are to bridge the gap between traditional architectural principles and modern building design in Mumbai's residential units. By examining the elements contributing to thermal comfort in both traditional and contemporary buildings and identifying effective strategies for integration, this research aims to provide practical insights for architects, designers, and developers. The goal is to enable them to create residential units that are not only sustainable in terms of energy consumption but also conducive to the well-being and productivity of their occupants.

3.1 - Research Design:

Per the reviewed literature, this study employs a threefold approach to achieve its objectives:

1. **Understanding Traditional Architecture Principles and Modern Building Design Challenges:** Conducting a comprehensive literature review to identify key elements of interior space influencing thermal comfort, with a focus on understanding traditional architecture principles and contemporary building design challenges.
2. **Qualitative and Quantitative Exploration of Factors Influencing Thermal Comfort:** Implementing a mixed-methods research design to qualitatively and quantitatively explore factors influencing thermal comfort in existing

residential apartments in Mumbai. Two distinct case studies from the metropolitan city, designed and treated differently, serve as the basis for this exploration.

3. **Creating a Comprehensive Framework for Designing Interior Spaces:** Synthesizing the insights gained from the above steps to develop a comprehensive framework for designing interior spaces that prioritizes thermal comfort. This framework is informed by market surveys to ensure practical applicability.

This study utilizes a mixed-methods research design, combining qualitative methods like interviews and observations with quantitative data collection. By analyzing case studies and conducting field surveys, the research contributes to the understanding of sustainable urban development. Focusing on the interplay between tradition and innovation in thermal comfort, the study aims to provide insights applicable to residential units in Mumbai, enhancing the overall quality of living.

3.2 - Data Collection

Residential apartment residents were interviewed to gather insights into their satisfaction with thermal conditions and comfort perceptions. The interviews delved into preferences, challenges, and perceptions related to indoor thermal conditions. On-site observations assessed apartment characteristics and identified architectural features influencing thermal comfort. Quantitative data collection involved measuring temperature, humidity, and daylight using appropriate instruments. Technical data were graphically analyzed with Microsoft Office 2007. Aesthetic surveys and Likert scale responses were tabulated to create an analysis matrix. This mixed-methods approach provides a holistic understanding of the complex relationship between traditional architectural principles, thermal comfort, and well-being in residential apartments. Qualitative data offer rich insights into residents' experiences, while quantitative data support findings with objective measurements and statistical analysis, deepening our understanding of thermal comfort and the impact of integrating traditional architectural principles.

3.3 - Selection of Case Studies:

To thoroughly investigate the feasibility of attaining thermal comfort in existing residential structures within the urban context of Mumbai, two distinct case studies were meticulously chosen for in-depth analysis. The selected cases include:

1. **A residential flat in a building with contemporary interiors.**
2. **A residential flat in a building with traditional interiors**

These choices aim to represent diverse approaches to design and treatment within the Mumbai urban landscape. The residential flat in a building with contemporary interiors serves as a representation of contemporary urban development, characterized by modern design principles and potentially relying on mechanical systems for thermal regulation. On the other hand, the residential flat in a building with traditional interiors embodies the architectural practices rooted in local wisdom, incorporating elements designed to naturally address thermal challenges prevalent in Mumbai's warm and humid climate. The selection of these contrasting case studies allows for a nuanced exploration of the interplay between traditional and modern approaches to achieving thermal comfort.

4. Traditional Architecture Principles & Modern Building Design Challenges:

4.1 - Traditional Architecture Principles:

Shaped by centuries of practical wisdom, traditional architecture in Mumbai champions principles that have historically mitigated thermal challenges. From the strategic use of locally sourced materials for insulation to the meticulous planning of open spaces that facilitate cross-ventilation, these principles offer a blueprint for sustainable thermal comfort.

1. **Insulation: Principle - Strategic Use of Materials -** Traditional architecture prioritizes the use of locally sourced, natural materials with insulating properties (Givoni, 1994). Materials such as stone, brick, or mud are chosen for their thermal mass, providing effective insulation against external heat (Tregenza & Wilson, 1994).
2. **Ventilation: Principle: Cross-Ventilation and Courtyards -** Ventilation is a fundamental aspect of traditional architecture (Gupta, 2005). Designing for cross-ventilation allows the natural movement of air through spaces (Tregenza & Wilson, 1994). Courtyards, integral to Indian architecture (Gupta, 2005), act as vents, facilitating air circulation for natural cooling.
3. **Windows and Glazing: Principle: Jalis (Lattice Screens) and Ventilation Openings -** Traditional architecture incorporates jalis (lattice screens) and strategically placed ventilation openings in windows (Gupta, 2005). These features allow controlled ventilation, preventing excessive heat gain (Tregenza & Wilson, 1994).
4. **Building Orientation: Principle: Maximizing Shade and Minimizing Heat Gain -** The orientation of buildings is carefully considered to optimize shade and minimize heat gain (Gupta, 2005). Shading elements like balconies and overhangs shield the building from the sun (Tregenza & Wilson, 1994).
5. **Thermal Mass: Principle: Use of High Thermal Mass Materials -** Traditional buildings incorporate materials with high thermal mass, such as stone or adobe (Gupta, 2005). These materials absorb and store heat during the day, stabilizing indoor temperatures (Tregenza & Wilson, 1994).
6. **Color and Reflectivity: Principle: Light-Colored and Reflective Surfaces -** The choice of color for exterior surfaces is guided by the principle of reflection (Gupta, 2005). Light-colored and reflective finishes minimize heat absorption, contributing to a cooler interior environment (Tregenza & Wilson, 1994)

While these principles are rooted in the broader understanding of architectural strategies for thermal comfort, their application in Mumbai's traditional architecture draws from a rich history of practical adaptation to the local climate (Gupta, 2005).

4.2 - Modern Building Design Challenges: Achieving thermal comfort in modern residential units in Mumbai poses several challenges and exhibits certain shortcomings, reflecting the complexities of urban development and contemporary design practices. The challenges outlined below were identified through interviews with occupants and on-site observations.

1. **Over-Reliance on Mechanical Systems:**
   a. **Challenge:** Modern residential units often heavily depend on air conditioning and heating systems, leading to high energy consumption and increased strain on resources.
   b. **Shortcoming:** This approach may not be sustainable in the long term, contributing to energy inefficiency and exacerbating environmental impacts.
2. **Aesthetic Prioritization Over Functionality:**
   a. **Challenge:** Contemporary design in Mumbai often prioritizes aesthetics over functional considerations, leading to choices that compromise thermal performance.
   b. **Shortcoming:** While visually appealing, such designs may neglect crucial aspects like natural ventilation, shading, and material selection, hindering effective thermal comfort.

3. **Inadequate Building Orientation:**
    a. **Challenge:** Modern buildings may not be adequately oriented to maximize natural shade and minimize heat gain, leading to increased reliance on cooling systems.
    b. **Shortcoming:** Poor orientation contributes to higher energy consumption and compromises the innate potential for passive cooling through strategic design.
4. **Limited Access to Natural Light:**
    a. **Challenge:** High-rise buildings and dense urban layouts can obstruct natural light penetration into indoor spaces.
    b. **Shortcoming:** Insufficient natural light negatively affects mood, productivity, and circadian rhythm, potentially leading to discomfort and health issues.
5. **Air Quality Degradation:**
    a. **Challenge:** Increased construction, vehicular traffic, and industrial activities in urban areas contribute to higher levels of air pollutants, compromising indoor air quality.
    b. **Shortcoming:** Poor indoor air quality can lead to respiratory issues, allergies, and other health problems among residents.
6. **Increased Energy Consumption:**
    a. **Challenge:** Modern buildings with extensive use of mechanical systems for heating, cooling, and ventilation contribute to higher energy consumption.
    b. **Shortcoming:** Increased energy usage not only impacts the environment but also poses economic challenges for residents in terms of utility bills.
7. **Limited Integration of Traditional Wisdom:**
    a. **Challenge:** There's often a disconnect between modern architects and traditional architectural principles that have proven effective in Mumbai's climate.
    b. **Shortcoming:** Neglecting time-tested strategies, such as natural ventilation and the use of thermal mass, hinders the optimization of thermal comfort in contemporary designs.
8. **Insufficient Green Spaces and Vegetation:**
    a. **Challenge:** Modern residential developments may lack sufficient green spaces and vegetation, reducing the potential for natural cooling.
    b. **Shortcoming:** Inadequate greenery limits the opportunities for shade and natural cooling, contributing to elevated temperatures in and around residential units.
9. **Limited Community Engagement:**
    a. **Challenge:** The design process often lacks active engagement with the community, neglecting occupants' preferences and experiences.
    b. **Shortcoming:** Inadequate consideration of user behavior and preferences may lead to designs that do not align with the diverse needs and expectations of the inhabitants.

10. **Urban Heat Island Effect:**
    a. **Challenge:** The increasing density of urban areas in Mumbai contributes to the urban heat island effect, intensifying heat and reducing nighttime cooling.

   b. **Shortcoming:** This effect amplifies thermal discomfort, making it challenging to create a cool and comfortable microclimate within residential units.

11. **Retrofitting Challenges in Existing Structures:**
   a. **Challenge:** Retrofitting existing residential structures to enhance thermal comfort can be logistically and economically challenging.
   b. **Shortcoming:** The focus on new developments may overshadow opportunities to improve the thermal performance of the extensive existing housing stock in Mumbai.

Addressing these challenges requires a holistic approach that integrates sustainable design principles, incorporates traditional wisdom, and actively involves the community in the design process. By doing so, future residential units in Mumbai can aspire to achieve thermal comfort that is both effective and sustainable.

4.3 - Comprehensive list of elements of interior space that influence thermal comfort:

To formulate a comprehensive framework for regulating indoor comfort, it is imperative to scrutinize key elements within internal spaces, including wall finishes, fenestration, flooring, and ceilings, while incorporating principles rooted in traditional architecture. Wall finishes, when aligned with traditional principles, can utilize materials with high thermal mass and reflective properties, contributing to temperature stability and visual comfort. Fenestration, following traditional design, may incorporate strategically placed openings and shading devices to optimize natural light, and ventilation, and minimize heat gain. Traditional flooring choices, such as materials with natural insulation properties, contribute to underfoot comfort and thermal regulation. Ceilings designed with traditional principles, including ventilated designs or thermal mass materials, can further enhance indoor comfort by aiding in temperature control. Integrating these elements, informed by traditional architectural wisdom, into the framework ensures a holistic approach to regulating indoor comfort while embracing sustainability and cultural continuity.

5. Observation and analysis of case studies

1. **Case Study 1 - A residential flat in a building with contemporary interiors:** The first case study involves Mukund Apartments in Kalyan, featuring a 2 BHK flat with a carpet area of 650 sq. ft on the second floor. This non-rated contemporary building is located in an urban setting. The interior design of the house follows a contemporary style, incorporating conventional materials for a modern aesthetic.



Fig 4.1 - Interiors with contemporary style and materials. Source - Author

2. **A residential flat in a building with traditional interiors:** The second case study for this research focuses on an apartment named "**Atmaj" in Malabar Hills, Mumbai.”** This 3 BHK flat has a carpet area of 1600 sq. ft and is situated on the 2nd floor of the non-green-rated residential building known as "Atmaj Apartments." The unique aspect of this apartment is its owner's initiative to transform it into an eco-house. Traditional materials, technology, and artifacts enhance the interiors, reflecting the owner's commitment to living in harmony and simplicity. The finishing materials include limestone mortar and teak wood polished with linseed oil. Notably, the living room features cow-dung flooring and relies on castor oil lamps for lighting, with no electric connection, exemplifying a distinctive approach to sustainable living.

Fig 4.2 - Lime plastered walls and adobe-finished floor with traditional furniture and artifacts. Source Author

The surveys that will be administered to collect quantitative data in this study will focus on gathering information related to occupants' satisfaction with their thermal conditions and their perception of comfort. The survey will be designed to capture quantitative responses that can be analyzed statistically to provide insights into the overall thermal comfort experience of residents in existing residential apartments in Mumbai.

4.1 - Case study Findings:

Occupant well-being and comfort are directly related to Indoor Environmental parameters. Thermal comfort is defined as the state of mind that expresses satisfaction with the thermal environment in which it is located. Thermal comfort has a direct impact on the energy consumption of any building as any sense of discomfort of occupants leads to tweaking of controls to no optimal levels. Technical data was gathered through various machines for evaluation. The following parameters were studied:

1. **Temperature and Humidity:** Thermal comfort is primarily shaped by the ambient air temperature and relative humidity levels within a given environment. The combination of these two factors significantly influences how individuals perceive and experience the thermal conditions of a space. To assess thermal comfort

comprehensively, measurements of ambient air temperature and relative humidity were taken at various locations within a space. Questionnaires gauging how individuals perceive the thermal conditions were included in the survey for a more subjective assessment that complemented quantitative measurements.

2. **Air Circulation:** Effective air circulation contributes to the even distribution of temperature and helps prevent the stagnation of air, which can contribute to temperature variations and contribute to a more consistent and comfortable indoor temperature. Adequate air circulation assists in dispersing moisture, contributing to humidity control. This is crucial for preventing conditions that might lead to discomfort. To assess air circulation comprehensively, measurements of air movement were taken at various locations within a space. Questionnaires gauging how individuals perceived it were included in the survey.
3. **Daylight:** Daylight is a critical factor in indoor environments as it significantly influences not only our perception of comfort and productivity but also has a notable impact on indoor temperatures. To assess the daylight, measurements were taken at various locations within a space.
4. **Acoustic Comfort:** Acoustic comfort in buildings refers to the ability to shield occupants from high noise levels, which can be disruptive and lead to discomfort. To assess and evaluate the acoustic comfort, technical data was collected using various equipment.
5. **Visual Comfort:** Visual comfort plays a crucial role in the well-being and productivity of building occupants. To assess visual comfort, an aesthetic survey was conducted to evaluate its impact. The various factors contributing to visual comfort, such as lighting, color schemes, and overall aesthetics, were evaluated.
6. **Psychological Comfort:** Psychological comfort in buildings refers to an individual's perception of space, expression, and adaptability. To assess individual perceptions of comfort, a structured survey was conducted, and a comprehensive questionnaire was designed for data collection. The aim was to gain insights into how occupants perceive and experience psychological comfort within the built environment. The various factors contributing to psychological comfort, such as personal expression, adaptability, and the overall perception of space, were evaluated. The design elements, such as natural lighting, proper ventilation, and well-planned circulation areas were also considered.

Comfort parameters	**Case Study 1 (Contemporary Interiors)**	**Case Study 2 (Traditional Interiors)**
Temperature and Humidity	The external as well as internal temperatures were beyond the comfort range. The occupants expressed dissatisfaction with the majority of the parameters related to thermal comfort within their living environment. Despite the overall dissatisfaction, it was noted that many of these discomfort factors were either enhanced or moderated through the use of active systems.	Despite the elevated external temperatures, the internal temperatures within the building were effectively maintained within the comfort range. This case demonstrates the successful management of thermal conditions within the built environment, ensuring that the occupants experienced comfort despite challenging external temperatures.
Air circulation	The air changes were lower than the comfortable range. The baseline satisfaction was low due to discomfort factors, the implementation of active systems played a crucial role in mitigating these issues and improving the overall comfort of the occupants.	Occupants reported a general satisfaction within their living environment. However, it was observed that there were specific instances, such as in the dining area and bedroom 2, where the conditions were perceived as a little stuffy.

Day Light	In the living room and Bedroom 1, the presence of glare suggests an abundance of natural light, which, while beneficial for overall illumination, leads to discomfort and visual strain. Bedroom 2 and the kitchen were comparatively dark implying a lack of sufficient natural light in these areas.	All rooms, except the living room and Bedroom 2, enjoyed sufficient daylight for activities without experiencing glare. The living room had a mild glare, suggesting that while there was sufficient daylight, there were elements causing discomfort due to increased brightness. Bedroom 2 was noted as being very dark, indicating a lack of sufficient natural light in this particular room.
Acoustic Comfort	The noise originating from the outside was notably loud and disruptive.	The exterior sound resembled a subtle, continuous humming noise in the background.
Visual Comfort	While the occupants were generally content with the visual comfort parameters, it is important to note that achieving these results required the integration of active systems enhancing or moderating various aspects of visual comfort.	The occupants expressed a positive perception of visual comfort, indicating that the building successfully met their expectations and contributed to their well-being and productivity.
Psychological Comfort	The occupants expressed satisfaction with the majority of the parameters related to psychological comfort. However, it became evident that many of these aspects were either enhanced or moderated through the utilization of active systems. This suggests that, while certain elements contributed to baseline satisfaction, the reliance on active systems played a significant role in shaping and optimizing the overall psychological comfort of the occupants.	The occupants expressed a high level of satisfaction with the parameters related to psychological comfort. The building design and features succeeded in creating an environment that catered to individual expression, adaptability, and a positive perception of space, resulting in a psychologically comfortable experience for the occupants.

Table 4.1 - Comprehensive observation chart for Comfort Conditions. Source Author

4.2 - Discussion:

Inhabiting a contemporary flat with modern interiors often resulted in discomfort for occupants due to a lack of comfort criteria. Conversely, a residential flat treated with traditional interiors demonstrated the creation of a comfortable indoor environment despite challenging external conditions. This highlights that regardless of the construction materials and planning aspects of existing structures, creative retrofitting and changes in the material palette, inspired by traditional design principles at individual and micro levels, can enhance comfort conditions without relying on energy-consuming active systems. The study advocates for a reevaluation of current interior design approaches in residential apartments, which often prioritize aesthetics over comfort due to constrained planning and heavy reliance on energy-consuming systems. It underscores the importance of integrating traditional architectural principles into the finishing of interior spaces, even in smaller residential projects. Existing structures lacking such considerations often compel occupants to use energy-consuming appliances for partial comfort. The research suggests exploring interior design, retrofitting, and material choices at the individual level as cost-effective solutions. While the study's scope is limited to a small sample size in Mumbai, similar empirical studies in other cities could validate these findings. The research offers opportunities for achieving comfort through straightforward solutions, emphasizing the importance of interior design changes using traditional materials and techniques. The research identified crucial elements within interior spaces that significantly influence thermal comfort and can be retrofitted at the individual apartment level. The study focused on the inherent characteristics of the finishes applied to these elements. Additionally, specific criteria were identified to apply traditional architectural principles, enhancing the understanding of how these elements contribute to thermal comfort. The exploration of finishes and the application of traditional principles collectively contribute to a comprehensive understanding of how to improve thermal comfort in individual apartment settings.

1. **Wall and Ceiling Finishes:** The selection of wall and ceiling finishes affects thermal comfort by influencing heat absorption and reflection. Light-colored, reflective finishes contribute to a cooler environment, while materials with high thermal mass, such as certain natural stones, can stabilize indoor temperatures (Givoni, 1994; Humphreys, 2005).

   Inherent characteristics: Insulation and Conductivity, Heat Absorption, Emissivity and Reflectivity, Thermal Mass, Ventilation and Breathability, Aesthetic Impact on Perceived Comfort.

2. **Fenestration:** Fenestration, encompassing windows and doors, significantly affects thermal comfort by managing heat gain, maximizing natural light, and allowing for ventilation. Energy-efficient windows with low-emissivity coatings and proper shading devices contribute to improved thermal performance (Selkowitz et al., 2002; Humphreys, 2005).

   Inherent characteristics: Insulation and Thermal Conductivity, Solar Heat Gain Coefficient (SHGC), Visible Transmittance (VT), Frame Materials, Glazing Type and coatings, Operability and Ventilation Design, and Shading Devices.

3. **Flooring:** Flooring materials impact thermal comfort through their thermal conductivity and insulation properties. Materials like carpet or cork provide insulation, contributing to a more comfortable indoor temperature, while others with high thermal mass, like tile, can influence temperature stability (Givoni, 1994; Kwok & Grondzik, 2019).

   Inherent characteristics: Thermal Conductivity and Thermal mass, Insulation, Surface Reflectivity.

By integrating insights from the above, a comprehensive framework for designing interior spaces with a primary focus on prioritizing thermal comfort was developed. This carefully crafted framework considered findings from market surveys to ensure its practical applicability in real-world scenarios. The synthesis of insights, combined with market-driven input, formed the foundation for a well-rounded approach to designing interior spaces that not only meet aesthetic and functional standards but, more importantly, enhance thermal comfort for the occupants.

COMPREHENSIVE FRAMEWORK FOR DESIGNING INTERIOR SPACES TO PRIORITIZE THERMAL COMFORT					
Sr. No	**Elements of interior space & their properties**	**Contemporary Interiors**	**Traditional Interiors**	**Principals Applied**	**Alternatives that can be used in the present scenario**
1	**Wall and Ceiling Finishes**				

a	Insulation and Conductivity	Brick walls coated with POP plaster are finalized with emulsion paint in an assortment of contrasting shades.	Brick wall adorned with textured lime plaster completed with limewash in an array of white and cream hues	Insulating materials reduce heat transfer, improving thermal comfort. (Ochsendorf, J et al 2012)	**1- Spray Foam Insulation** **2- Reflective Insulation** **3- Cellulose Insulation** **4- Radiant Barrier** **5- Fiberglass Insulation** **6- Expanded Polystyrene (EPS) Insulation**
b	Heat Absorption, Emissivity, and Reflectivity			The emissivity is not very effective due to higher humidity, hence it is imperative to use materials that do not absorb heat and have higher reflectivity. Light-colored, reflective materials absorb less heat.	High albedo paints are formulated to have a high reflectance value, reflecting a significant amount of solar radiation instead of absorbing it. **1- Light Paints** **2- Cool Roof Coatings** **3- Ceramic-based Reflective Paint**s **4- Infrared-reflective (IR) Paints** **5 - Titanium Dioxide (TiO2) Paints** **6- Textured finish to increase diffusion**
c	Thermal Mass:			Materials with low thermal mass can help achieve cooler indoor temperatures by reducing the amount of heat absorbed and stored within the building. These materials can quickly release heat and maintain cooler surfaces.	**1- Lightweight Concrete** **2- Gypsum Board** **3- Processed Timber** **4- Expanded polystyrene (EPS) or polyurethane foam-insulated Panels** **5- Natural Fiber Insulation**
d	Ventilation and Breathability			Finishes that allow for natural ventilation and contribute to moisture control can greatly enhance indoor air quality and positively impact thermal comfort by reducing the risk of excessive humidity, mold growth, and stagnant air, (Givoni, B. 1994).	**1- Breathable Paints** **2- Lime Plaster** **3- Natural Clay Plaster** **4- Perforated or Porous Wall Panels** **5- Natural Fiber Wall Covering** **6- Open Weave or Mesh Curtains**
e	Aesthetic Impact on Perceived Comfort			Aesthetically pleasing finishes make spaces visually appealing and contribute to occupants' perception of comfort. Well-designed finishes can positively influence the overall comfort experience. (Zeisel, J. 2006).	**1- Colorful and Harmonious Paints** **2- Natural Materials** **3- Soft and Comfortable Textiles** **4- Thoughtful Lighting Design** **5- Attention to Detail** **6- Spatial Layout and Proportions**
2	**Fenestration**				

a	Insulation and Thermal Conductivity	Aluminum sliding windows with single glazing and clear glass, accompanied by an external horizontal chajja.	Windows are designed as single glazed, openable units set within wooden frames and featuring bajra glass. Additionally, these windows incorporate ventilators positioned above them. Windows on the west and south sides have boxed windows.	Materials with low thermal conductivity, provide better insulation, reducing heat transfer and improving thermal comfort (Santamouris, 2013).	**1- Double / Triple-Glazed Windows** **2- Low-Emissivity (Low-E) Coatings** **3- Insulated Glass Units (IGUs)** **4- Thermally Broken Frames** **5- Vacuum Insulated Panels (VIPs)**
b	Solar Heat Gain Coefficient (SHGC)			Panels with low SHGC values promotes reduced solar heat gain, preventing overheating and maintaining a comfortable indoor temperature (Selkowitz et al., 2002).	**1- Low-E Coatings** **2- Spectrally Selective Glazing** **3- Tinted Glass** **4- Insulated Glass Units (IGUs)** **5- Window Films** **6- External Shading Devices**
c	Visible Transmittance (VT)			Balancing visible transmittance ensures sufficient daylighting, enhancing visual comfort while minimizing glare and reducing the need for artificial lighting (Reinhart & Walkenhorst, 2001).	**1- Daylight-Responsive Windows** **2- High-Performance Glazing** **3- Light-Diffusing Glass** **4- Solar Control Films** **5- Exterior Shading Devices** **6- Interior Light-Redirecting Systems**
d	Frame Materials			Materials with thermal breaks reduce heat transfer through the frame, contributing to overall thermal performance and comfort (Curtin et al., 2010).	**1- Polyurethane Foam** **2- Polyamide Strips** **3- Fiberglass Reinforced Polyamide** **4- Thermally Broken Aluminum** **5- Thermoplastic Elastomers**
e	Glazing Type and coatings			Glazing materials and coatings that reduce solar heat transmission and glare, affect both indoor temperatures and visual comfort (Mallik & Smedley, 2007).	**1- Low-E Coatings** **2- Reflective Coatings** **3- Tinted Glass** **4- Dynamic Glazing** **5- Laminated Glass** **6- Spectrally Selective Coatings** **7- Ceramic Films** **8- Gas Fills** **9- Warm Edge Spacers**

f	Operability and Ventilation Design			Facilitating natural ventilation through operable elements supports indoor air quality and enhances thermal comfort (Humphreys, 2005).	**1- Smart Ventilated Facades with Composite Panels and Louvered Ventilation Systems** **2- Thermally Insulated Composite Ventilation Grilles** **3- Thermally Insulated Composite Operable Skylights** **4- Fiber-reinforced polymer (FRP) Transom Windows** **5- Composite Bi-fold Doors with Ventilation Panels** **6- Carbon Fiber-Reinforced Louvered Windows** **7- Composite Adjustable Ventilation Blades**
g	Shading devices			Shading devices play a crucial role in regulating natural light, preventing glare, and minimizing heat gain in buildings, contributing to enhanced thermal comfort and energy efficiency.	**1- Electrochromic glass** **2- Automated Exterior Blinds** **3- Dynamic Shading Systems** **4- Photovoltaic (PV) Integrated Shading Devices** **5- Perforated Metal Screens** **6- Kinetic Facades** **7- Intelligent Sun-tracking Systems** **8- Tensile Fabric Structures** **9- Exterior Shading Fins** **10- Biomimetic Shading** **11- Building Integrated Photovoltaic Shading**
3	**Flooring**				
a	Thermal Conductivity and Thermal mass			Materials with low thermal conductivity provide better insulation and reduce heat transfer between the floor and the living space. (Awbi, 2003). High thermal mass materials heat during the day and release it later adding to the heat load. Hence it is imperative to have a thermal barrier. (Givoni, 1994).	**1- Cork Flooring** **2- Carpet and Rugs** **3- Rubber Flooring** **4- Vinyl Flooring with Foam Underlayment** **5- Bamboo Flooring** **6- Linoleum Flooring** **7- Engineered Wood with Underlayment** **8- Porcelain Tile with Insulation** **9- Foam-backed Laminate Flooring**

b	Insulation			Insulating underlayments can be used beneath flooring materials to enhance thermal insulation.	**1- Extruded Polystyrene Foam** **2- Expanded Polystyrene Foam** **3- Polyisocyanurate (Polyiso) Foam** **4- Fiberglass Batts** **5- Mineral Wool** **6- Radiant Barrier Foil** **7- Reflective Foil Insulation** **8- Spray Foam & Cellulose Insulation**
c	Surface Reflectivity			Light-colored flooring materials reflect more light, contributing to a brighter space and minimizing heat absorption (Brager & de Dear, 1998).	

Table 4.2 - Comprehensive framework for designing interior spaces to prioritize thermal comfort. Source Author

5. Conclusions

This research aimed to bridge the gap between traditional architectural principles and modern building design in Mumbai's residential units, focusing on thermal comfort. By examining elements contributing to thermal comfort in both traditional and contemporary buildings, the study provided insights for architects and developers to create sustainable and occupant-friendly residential units.

In conclusion, the research explores the dynamics of traditional and contemporary interiors in Mumbai's residential flats, emphasizing the challenges and opportunities for thermal comfort. The findings highlight the strain introduced by mechanical systems in contemporary urban development and showcase sustainable solutions embedded in traditional architecture. The comparative analysis underscores the potential of harmonizing traditional principles with modern design approaches, offering a vision for sustainable urban development. The research's implications extend globally, challenging prevailing norms and encouraging a reconsideration of the balance between functionality, aesthetics, and environmental impact. This research contributes to the discourse on sustainable cities, envisioning a future where thermal comfort is seamlessly integrated into urban development. As Mumbai evolves, the study serves as a guide toward a more sustainable and harmonious urban existence

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