ENERGY EFFICIENCY WITHIN HISTORIC BUILDINGS:

A MUMBAI-BASED STUDY OF OCCUPANT COMFORT AND ENERGY MAPPING

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Introduction

Historical structures are representatives of various periods of significance with values embedded in history, architecture, socio-political movements, regional environments and more. Their continued presence in contemporary times is a testimony to their great building technology, design sensitivity and traditional knowledge systems assimilated within the structures. Their ability to adapt and evolve to meet the current needs makes them an interesting area of study, specifically in the climate change field and resilience of our cities' built fabric. In India, the pattern of consumption is often overlooked in the discipline of conservation practice as the focus is more on the restoration of the built fabric and adaptive reuse of the building.

The architectural form and structure of historic buildings are a direct response to the climate of their setting and are designed using natural ventilation systems for good indoor environmental quality. This built heritage is not stuck in time but rather imbibes the change over a period in time, witnessing patterns of occupation and consumption which have drastically altered within the last few decades. Thus, making the building envelope one of the critical aspects to achieve visual as well as thermal comfort. A thorough understanding of the external and internal environments is necessary to arrive at an informed design decision with respect to any intervention, adaptive reuse or modernization of the historic building (Feilden, 2016). However it is been observed that; no such pre-assessment of the building envelope and environmental indoor conditions is carried out before proposing design strategies for historic building interventions in India, and if an approach is considered it merely takes into consideration assessing HVAC (Heating Ventilation Air conditioning) systems devoid of building performance to achieve occupant comfort. This does not necessarily focus on the building's physics and its function to ensure good and safe environments indoors for its occupants. The factors that ought to be considered for energy efficiency and sustainability include orientation analysis, appropriate material selection, occupant zoning, passive design tools and minimal incorporation of mechanical systems to ensure energy efficiency, low environmental impact design and low carbon footprint. All these factors required to be studied monitored and analysed to measure occupants' comfort indoors and the Energy Performance Index (EPI) of a building to calculate energy consumption.

It is been observed through preliminary studies that sporadic breakdown of engineering solutions often exerts pressure on the structural well-being of the heritage buildings considering the percentage of natural building material used. The study forms a conceptual base for a methodology to assess the impact of HVAC systems installed within heritage buildings during adaptive reuse or refurbishment and their pattern of energy consumption; their relation to the life cycle of a building and conservation processes adopted for heritage buildings. With the framework of an integrated approach to achieving energy efficiency and sustainability for heritage buildings, the paper introduces tools of assessment and analysis to mark out energy consumption patterns within historic buildings. It evolves a systematic method to create an energy benchmarking system exclusive for heritage structures using empirical data from on-field monitoring of indoor conditions of conserved heritage buildings coupled with the study of building physiology (building envelope, construction systems etc) and energy performance patterns. It urges cultural heritage conservation to look beyond just material conservation and propagates an integrated holistic approach especially when theoretically conservation has imbibed within itself the ideas of sustainability and resilience. Thus, forming an efficient tool for every conservation architect practising in India.

Establishing a Relationship between Climate & Building Physiology

The understanding of local knowledge of climate and topography and respecting the context of the region the design is built, helps one determine the character of the building. Historic buildings are constructed with an innate understanding of the material of construction with a knowledge of thermal mass; breathability; sacrificial skin largely dependent on the type of construction (Forsyth 2008). The thick walls in some cases double walls with cavities assist in thermal mass that is keeping interiors cool in summer and warm in winter. The lime mortar is also a sacrificial skin layer which is permeable allowing the structure to breathe. Lime mortar used in pointing also serves the same purpose of allowing evaporation through the joints. However, the unsympathetic repairs carried out for historic buildings using incongruous materials that are alien to the nature of the building are reasons for failure in the performance of the heritage structures also resulting in their degradation. An intensive thermo-hygric analysis using climate factors is required for a better understanding of the effects of climate and the impact of the proposed intervention strategy on heritage buildings. The findings from these assessments inform the design team to adopt strategies and implementation plans to achieve good indoor environmental standards, reduced energy consumption and the health and well-being of occupants.

Phase 01: Tools for real-time Data Monitoring and Assessment during the Documentation Process

a: Character Analysis for the current state of the buildings (using buildings as examples to display the use of various tools and not as case studies to collect and analyse data)

b: Inventory mapping

c: On-field monitoring to assess indoor environmental conditions using environmental instruments

d: Thermal imaging of building physiology using thermal imaging camera to study building envelope performance with respect to energy exchange between indoor and outdoor conditions.

Table 1: Type of equipment for survey

Type	Parameters	Instrument	Specifications
Thermal Comfort	Dry bulb temperature in Degree Celsius and Relative Humidity in % (percentage)	Thermohygrometers (Dataloggers)	1. Logs data as per set timings. 2. Smallest reading taken should be minimum for 48 hours within a closed environment. 3. Ideally should be mounted within the occupant zone
	Surface Temperature readings in Degree Celsius	Thermographic Camera (Thermal Camera) Creates an illustration of temperatures across the space selected in the frame using ultraviolet technology	This instrument is used to study building facades in detail for heat exchanges, air leakages in mechanical equipment, water leakages within structures and identifying patches of worn out or completely destroyed insulation within building envelopes.
	Surface temperature	The temperature in Degree Celsius	This instrument is used to map surface temperatures to monitor material behaviour change with respect to heat gain external as well as indoor environments. It allows the researcher or a practitioner to understand and assess the efficiency of the time lag and thermal mass properties of the building envelope
	Wind velocity in m/s	Anemometer	This instrument registers the air draft from mechanical instruments installed within an indoor environment. Easy to identify direct draft impacted occupants within a designed space. The readings coupled with mathematical models also help identify dead and stagnant air pockets within designed spaces
	Sound in Decibels	Sound meter	This instrument is used to log sound entering the building, especially when placed on a heavy traffic junction. Measures noise pollution. Directs in addressing acoustical requirements.
Daylight Comfort	Amount of daylight in LUX	Light Meter	1. This instrument is used by mounting it horizontally over a work plane to register the amount of daylight present. Artificial lights have to be turned off completely. 2. The photocell capturing the readings should not be shadowed by any object or person taking the reading
Indoor Air Quality	Amount of air contamination present in the indoor environment in terms of ppm (particulate per minute)	Carbon dioxide meter	Should be placed in occupant zone for 30 sec for it to calibrate after switching it on. Records the amount of C02 (PPM) in the air. Beyond a permissible limit, the instrument starts beeping to inform the high level of contamination of indoor air.

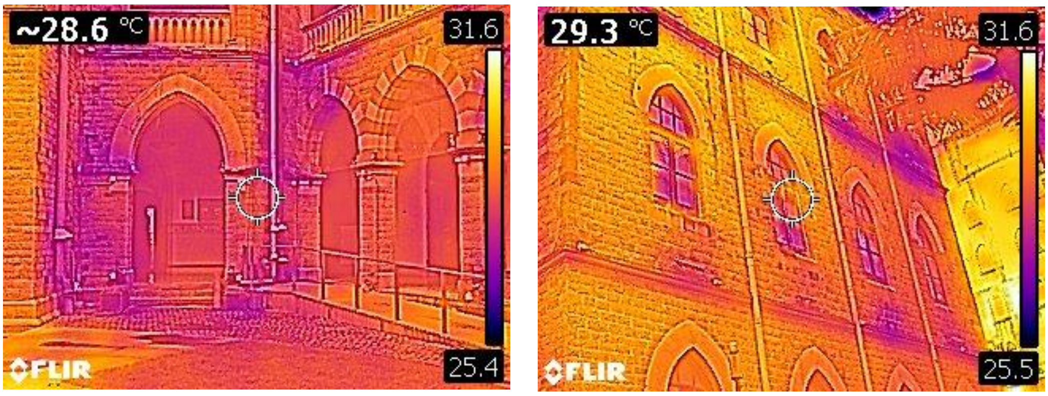

Figure 2 & 3: Thermal images of the façade from the inner courtyard, Source: Author

Phase 02: Assessment of energy efficiency within the built structure

(To be used with respect to design decisions taken during the conservation process.)

a. Environmental Performance Index (EPI) and Environmental impact assessment (EIA)[1]

b. Life cycle Assessment (LCA)

The interrelationship between Occupant Comfort and Indoor Environmental Conditions

Mumbai holds a strong case with 633 listed buildings not including the precincts (Mumbai Heritage Conservation Committee listing). It is important to look at this historic building stock, not as mere conservation of culture and heritage but to estimate their contribution to the energy demand, Green House Gas (GHG) emissions and the indoor environmental conditions that directly impact the occupant's health and well-being. Often buildings are retrofitted and refurbished to reduce the energy demands and greenhouse gas emissions, however, they might fail to achieve good Indoor Environmental Quality (IAQ). (Shrusbole et, 2019)

The study involves understanding building physics, various materials, and occupant requirements. These listed parameters are often associated with the energy consumption pattern of buildings and are closely associated with the quality of the indoor environment. Adaptive occupant control is an essential key driver to assess the ability to create comfortable indoor environments. Highly Controlled environments prescribed in air-conditioned buildings to formulate energy conservation often result in a poor level of occupant satisfaction. The qualitative survey undertaken as part of the pilot case study reveals these insights to support the occurrence of such experiences on site.

[1] EPI is a scale which indicates whether the buildings qualify to be energy efficient or not.
EIA is a tool to assess the environmental impact of building form in the form of CO2 emissions.

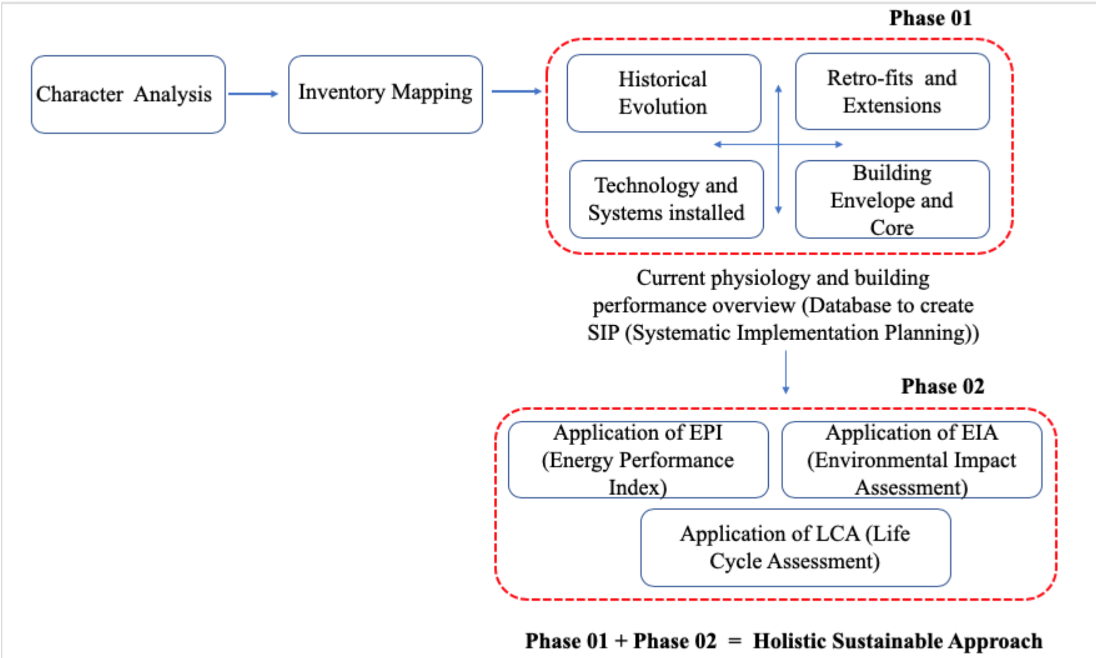

Figure 1: Phase 1 & 2 of Holistic Sustainable Approach, Source: Authors

It is evident that heritage structures are vulnerable to climate change not only pertaining to the material and physiology of the building as well to the occupant's comfort and well-being. Anecdote observations over discussions and exchange of notes often talk about discomfort amongst the occupants, its impact on their health and the degradation of natural building materials. The methodology establishes the scientific evidence and emphasizes the need to integrate energy efficiency with heritage conservation practice. Phase 01 is derived from the framework best suited to evaluate the historic environment depending on its values through the listing process using conservation expertise. Phase 02 stems from using the environmental lens to achieve a sustainable approach. The two-part process involving indoor and building physiology study help understand and propose interventions for historic building in the contemporary context.

Formulating a Framework Methodology

The aim of the study is to emphasise sustainable energy solutions for heritage buildings, their relevance today and the need for more research in the conservation field in the Indian context. Conservation, sustainability and energy efficiency should not be considered mutually exclusive terms but rather a part of an integrated holistic approach for heritage studies. Energy efficiency retrofit shall not only revive the existing building and neighbourhoods, and provide economic regeneration within the area but also enhance the built environment, protect the cultural heritage, curb the uncontrollable urban sprawl and augment the quality of life.

Conservation of a building in order to reuse is more energy-efficient and sustainable than new construction and restoration more efficient than demolition. Building envelope and indoor environment form a symbiotic relationship to help achieve a successful rehabilitation scheme for historic buildings. Energy efficiency cannot be achieved by analysing them devoid of each other. Energy retrofitting for heritage buildings can give them new lease of life and revive historic areas by pumping new use and hence new revenue in the urban areas. Economic viability should be considered before proposing energy retrofitting schemes, balancing it with the understanding that any alteration or modifications should not hamper any values or significance of the structure. Reducing energy consumption, recycling existing materials and reusing existing heritage stock should be the mantra for all urban interventions.

Author Contributions

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