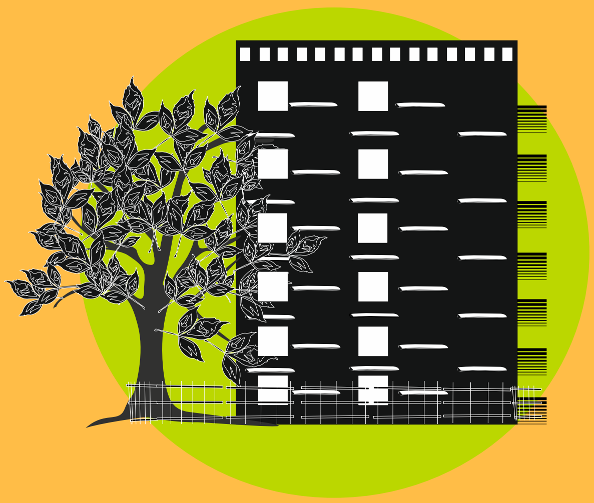

METHODOLOGY FOR STANDARD DEVELOPMENT

Development of Thermal Comfort Action Plan 2050 and Thermal Comfort Performance based Design Standard cum Guidelines for Affordable Housing in India. [REF: 8338 0638]

Environmental Design Solutions Private Limited

Wuppertal Institute for Climate, Environment and Energy GmbH

Hunnarshala Foundation for Building Technology and Innovations

Quality control log

Date	Version	Revision Description	Prepared by	Approved by
October 13, 2021	0		Vaibhav and Lakshmi	Gurneet
November 08, 2021	1	Minor typographical corrections. Table 3 updated	Piyush	Piyush
January 10, 2022	2	Figure 3 has been updated. A Way forward section has been included.	Piyush	Piyush

Disclaimer

This report is prepared by Consortium of Environmental Design Solutions Private Limited [EDS], Wuppertal Institute for Climate, Environment and Energy GmbH and Hunnarshala Foundation for Building Technology and Innovation (referred to as Consortium Partners from here on) for the Ministry of Housing Affairs (MoHUA) and the Deutsche Gesellschaft fur Internationale Zusammenarbeit (GIZ) GmbH. This report is part of the *"Development of Thermal Comfort Action Plan 2050 and Thermal Comfort Performance based Design Standard cum Guidelines for Affordable Housing in India. [REF: 8338 0638]"* project under the *Climate Smart Buildings Program* funded by GIZ India.

This report has been prepared for the purpose set out in Terms of Engagement between EDS and GIZ and is solely for the use of MoHUA and GIZ. Information contained in this report is current as at the date of the report and may not reflect any event or circumstances which occur after the date of the report. This report is an outcome of the best efforts and technical judgement of the consortium members. The Consortium Partners do not accept any duty, liability, or responsibility to any person or entity in relation to this Report.

Contents

Definitions

Acceptability limit: A thermal environment that a majority of the occupants find thermally acceptable.

Adaptive thermal comfort: The comfort that relates indoor design parameters or acceptable temperature ranges to outdoor parameters.

Clo value: A unit used to express the thermal insulation provided by clothing, where 1 clo = 0.88 sqft.h.°F/Btu [1]

Degree discomfort hours: Represents the total discomfort degree hours throughout the year. Cooling or heating discomfort degree hours are calculated from temperatures below or above the threshold winter or threshold summer temperatures respectively.

Economically weaker section house: A single unit or a unit in a multistoried super structure having carpet area of upto 30 sqm with adequate basic civic services and infrastructure services like toilet, water, electricity etc

Local thermal discomfort: The thermal discomfort caused by locally specific conditions such as vertical air temperature difference between feet and head, by radiant temperature asymmetry, by local convective cooling, or by contact with a hot and cold floor.

Low-income group house: A single unit or a unit in a multistoried super structure having carpet area of upto 60 sqm with adequate basic civic services and infrastructure services like toilet, water, electricity etc

Mean daily outdoor air temperature: Any arithmetic mean for a 24-hour period of temperature

Metabolic rate (met): The rate of transformation of chemical energy into heat and mechanical work by metabolic activities of an individual, per unit of skin surface area equal to 18.4 Btu/h.sqft, which is the energy produced per skin surface area of an average person seated at rest.

Middle-income group housing facility: A single unit or a unit in a multistoried super structure having carpet area from 60 sqm to 200 sqm with adequate basic civic services and infrastructure services like toilet, water, electricity etc.

Mixed-mode buildings: A hybrid approach to space conditioning that uses a combination of natural ventilation and mechanical systems. These building utilize mechanical cooling only when and where it is necessary to supplement the natural ventilation.

Naturally conditioned buildings: A building in which the ventilation system rely on opening and closing of window of the space to maintain the thermal comfort of the space rather than a mechanical system.

Occupant-controlled naturally ventilated spaces: Those spaces where the thermal conditions of the space are regulated primarily by occupant-controlled openings in the envelope.

Operative temperature: A uniform temperature of a radiantly black enclosure in which an occupant would exchange the same amount of heat by radiation and convection as in the actual non-uniform environment, it is the combined effect of mean radiant temperature and air temperature calculated as average of the two.

Outdoor running mean temperature: This temperature is defined in NBC 2016 which is based on the arithmetic average of the mean daily outdoor temperature for 30 days.

Predicted percentage of dissatisfied (PPD): An index that establishes a quantitative prediction of the percentage of thermally dissatisfied people determined from PMV

Predictive mean vote (PMV): An index that predicts the mean value of the thermal sensation votes (self-reported perceptions) of a large group of persons on a sensation scale expressed from –3 to +3 corresponding to the categories “cold,” “cool,” “slightly cool,” “neutral,” “slightly warm,” “warm,” and “hot.”

Prevailing mean outdoor air temperature: This temperature is defined in ASHRAE 55 which is based on the arithmetic average of the mean daily outdoor temperature over some period of days.

Standard effective temperature (SET): The temperature of an imaginary environment at 50% rh, <0.1 m/s (20 fpm) average air speed (Va), and, in which the total heat loss from the skin of an imaginary occupant with an activity level of 1.0 met and a clothing level of 0.6 clo is the same as that from a person in the actual environment, with actual clothing and activity level.

Thermal sensation: A subjective expression of an occupant’s thermal perception of the environment, commonly expressed using the categories “cold”, “cool”, “slightly cool”, “neutral”, “slightly warm”, and “hot”.

Abbreviations

AHP	Affordable Housing in Partnership
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BEE	Bureau of Energy Efficiency
BLC-N / BLC-E	Beneficiary-led construction or enhancement
BIS	Bureau of Indian Standards
CLSS	Credit Linked Subsidy Scheme
DDH	Degree Discomfort Hours
ENS	Eco Niwas Samhita
EWS	Economically Weaker Section
GRIHA	Green Rating for Integrated Habitat Assessment
IMAC	India Model for Adaptive Comfort
IGBC	Indian Green Building Council
ISHRAE	Indian Society of Heating, Refrigerating and Air Conditioning Engineers
LIG	Low-Income Group
MoHUA	Ministry of Housing and Urban Affairs
MIG	Middle-Income Group
NBC	National Building Code
NV	Natural Ventilation
PMAY-U	Pradhan Mantri Awas Yojana (Urban)
PMV	Predictive Mean Vote
PPD	Predicted Percentage of Dissatisfied
SET	Standard Effective Temperature
SHGC	Solar Heat Gain Coefficient
VLT	Visual Light Transmittance
WFR	Window to Floor area Ratio
WWR	Window Wall Ratio

Overview of the methodology

The Standard Development Methodology has been devised as a structured and systemic approach. This approach outlines the three key steps for developing a Design Standard for enhancing Thermal Comfort in Affordable Housing (AH). A brief description of each Step and expected outcomes is summarized as an overview here.

Step 1: Outline affordable housing typologies and their physical attributes

The existing PMAY-U schemes outline key attributes of affordable housing development that are eligible for financial incentives. Primary attributes include area and nature of development (slum redevelopment i.e. multi-family housing, or beneficiary led construction i.e. single family housing). These attributes are derived from definitions of Affordable Housing outlined by Task Force on *'Affordable Housing for All'*. A broad understanding of these physical attributes is critical to outline the scope of the standard. Secondary research is being undertaken to map the physical attributes of PMAY schemes and identify various typologies. The typology outcomes are being validated across case studies as well.

Outcomes: Key building typologies (based on area and nature of development) for affordable housing are expected. These typologies will be utilized in simulation studies as Reference buildings.

Step 2: Shortlist thermal comfort standards, and design measures (active and passive) that enhance thermal comfort

Although Thermal Comfort is a widely researched topic, it has limited application for affordable housing in Indian context. An extensive study to identify the Thermal Comfort Standard most suited to un-conditioned residential typology for Indian climatic conditions and relevant to Indian physiology is underway. In addition, technical review of rating systems, best practices and case-studies is being conducted as well to outline active and passive design strategies.

Outcomes: The shortlisted standard is expected to outline the performance metric/s and methodology to evaluate Thermal Comfort. The review of rating systems and case-studies will outline key passive measures by climate zone that enhance thermal comfort in affordable housing.

Step 1 and 2 will define the scope of standard in terms of building typologies and systems that the Standard will address. These will also serve as the building blocks of Reference building type and range of parameters used for simulation studies.

Step 3: Perform Simulation Studies to outline design recommendations for enhancing thermal comfort

The analysis of affordable housing characteristics outlined in Step 1, will be synthesized into Reference building types representative of the affordable housing building stock. These Reference building types will be modeled in EnergyPlus to derive thermal comfort performance across climate zones. The range of affordable housing characteristics will be parametrically applied to these simulation models to study their impact on thermal comfort. The outcomes of parametric analyses will be analyzed and presented as Design Recommendations.

Outcomes: Synthesis of data will provide reference buildings representative of affordable housing stock that serve as Reference buildings. Simulation of Reference buildings will outline baseline thermal comfort performance. Assessment of parametric studies will rank active and passive strategies based on their impact on thermal comfort performance.

Step 4: Synthesize design recommendations/strategies into Design Requirements

The design recommendations outlined in Step 3 will be synthesized into Design Requirements. The Design Requirements will inform the layout and structure of standard. The Scope of Standard, Compliance Criteria and Design Requirements will be integrated as a Draft Standard. The Draft Standard will be presented to the Steering and Technical Committee for comments and feedback. The comments will be incorporated.

Outcomes: Scope of standard (from Step 1 and 2), Compliance Path and Criteria, and Design Requirements (from Step 3) will be integrated into a Draft Standard.

Figure 1 provides an overview of methodology for developing Design Standard for enhancing Thermal Comfort performance of affordable housing.

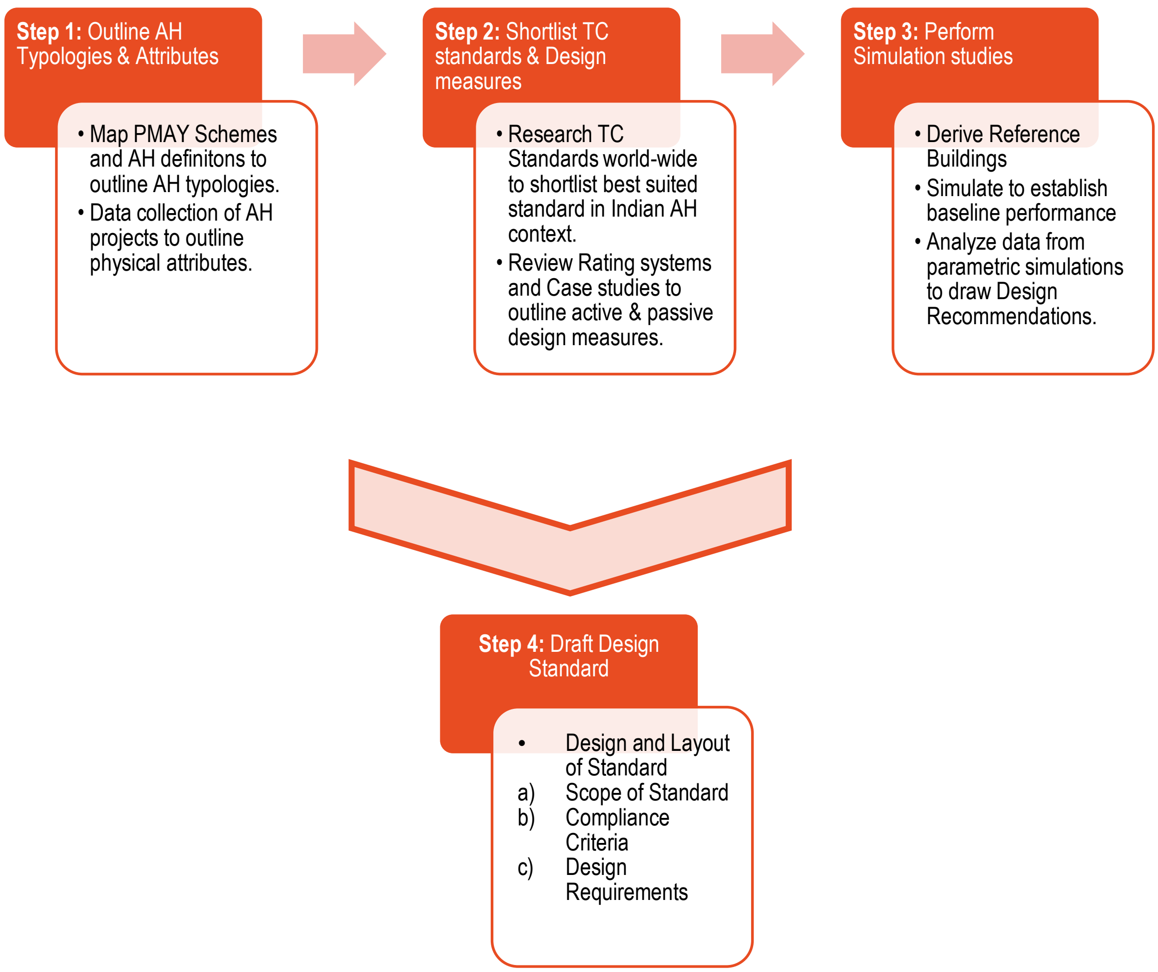

Figure 1 4 Step method for developing Design Standard for enhancing Thermal Comfort performance.

1 Characteristics (typologies & attributes) of affordable housing

The existing PMAY-U schemes outline key attributes of affordable housing development that are eligible for financial incentives. Primary attributes include area and nature of development (slum redevelopment i.e. multi-family housing, or beneficiary led construction i.e. single family housing). These attributes are derived from definitions of affordable housing outlined by Task Force on *'Affordable Housing for All'*. A broad understanding of these physical attributes is critical to outline the scope of the standard.

Preliminary research outcomes identify various typologies. These typology outcomes have been validated across case studies as well. Following section identifies definitions, building typologies (based on area and nature of development) for affordable housing and key building characteristics.

1.1 Defining 'Affordable Housing'

This assignment includes development of a **Standard for Thermal Comfort for Affordable Housing in India**. Hence, it is important to ascertain a working definition of "Affordable Housing". The definition of 'Affordability' is context specific and there is no universally accepted common definition of affordable housing. The definition and scope of affordable housing is contingent on a country/region's level of economic development and income levels. "Affordable housing refers to any housing that meets some form of affordability criterion, which could be income level of the family, size of the dwelling unit or affordability in terms of EMI size or ratio of house price to annual income." [2]. Therefore, affordable housing is a function of,

a) multiples of household income,
b) size of the tenement, or,
c) in case of rented accommodation, expressed as a fraction of household income.

The Task Force on Affordable Housing for All, recognizes the need to fix a definition for affordable housing. The Task Force has outlined the following conditions to define affordable housing:

a) Affordable housing for EWS/ LIG categories of households: A unit with a carpet area between 300-600 ft^2 (i.e. ~28 – 56 m^2) with,
    i. the cost not exceeding four times the household gross annual income, and,
    ii. EMI/rent not exceeding 30 percent of the household's gross monthly income.
b) Affordable housing for MIG category of households: A unit with a carpet area not exceeding 1,200 ft^2 (111.5 m^2) with,
    i. the cost not exceeding five times the household gross annual income, and
    ii. EMI/rent not exceeding 40 percent of the household's gross monthly income.
c) the size of the household as five members.

The standard uses the definition of "Affordable Housing" provided by the Task Force on Affordable Housing for All [3]. With specific emphasis on PMAY-U program, the following section reviews the various schemes of the program and how these translate into affordable housing Scope for the standard.

1.2 Mapping PMAY-U schemes to development typologies

The PMAY-U mission has four schemes, In-situ Slum Redevelopment (ISSR), Credit-linked subsidy scheme (CLSS), Affordable housing in Partnership (AHP) and Beneficiary-led construction (BLC). These schemes outline financial incentives for prospective homeowners, developers and planning/implementing authorities of state/UTs. These schemes shape not only the design of the development, but also the demand for affordable housing. A brief description of these policies and the developments they support are outlined below.

a) **In-situ slum redevelopment (ISSR):** using land as resource, the scheme provides houses to eligible slum dwellers by redeveloping the existing slums on public/ private land. Under this scheme, a grant of 1 lakh per house is provided by the central government to the planning and implementing authorities of the states/UTs.
b) **Credit-linked subsidy scheme (CLSS):** under this scheme, institutional credit is provided to EWS, LIG and MIG households for purchase of homes with interest subsidy credited upfront to the borrower's account through primary lending institutions (PLIs), effectively reducing housing loan and equated monthly instalments (EMI)
c) **Affordable housing in Partnership (AHP)**: provides financial assistance to private developers to boost private participation in affordable housing projects; central assistance is provided at the rate of 1.5 lakh per EWS house in private projects where at least 35 per cent of the houses are constructed for the EWS category.
d) **Beneficiary-led construction or enhancement (BLC):** this scheme involves central assistance of 1.5 lakh per family for new construction or extension of existing houses for the EWS/ LIG.

A review of the schemes described above explicitly identifies EWS, LIG and MIG as beneficiary categories and prospective homeowners, developers and planning/implementing authorities of state/UTs as the beneficiaries. While not explicitly defined, these schemes also indicate the nature of development. Schemes such as ISSR and AHP are essentially meant for multi-family dwelling units and can drive mass-scale housing developments. On the other hand, BLC scheme is meant for single family homes only. This is critical in developing reference building typologies for the standard.

Figure 2 and Table 1 illustrate the applicability of PMAY schemes and definition of affordable housing to building and development typologies to outline the scope of the standard.

It is noteworthy that the primary uptake of PMAY schemes has been led by BLC scheme. The BLC scheme accounts for nearly 70% of sanctioned funds of the overall allocated budget. (Source: PMAY)

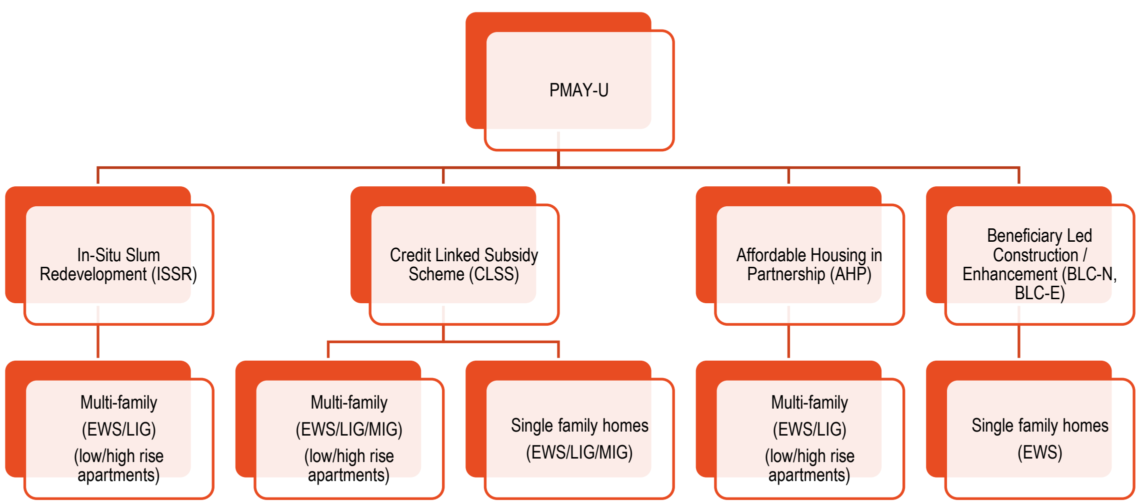

Figure 2 The PMAY-U schemes can be mapped to the typology of Dwelling Units and the nature of development

Table 1 Matrix mapping PMAY-U Schemes to dwelling unit characteristics

PMAY-U Schemes	ISSR	CLSS	AHP	BLC-N, BLC-E
Dwelling Unit (DU) Size (Carpet Area)				
EWS	Up to 30 sqm	Up to 30 sqm	21-27 sqm	Up to 30 sqm
LIG	Up to 60 sqm	Up to 60 sqm	-	NA
LIG-A	-	-	28-40 sq m	NA
LIG-B	-	-	41-60 sq m	NA
MIG-1	Up to 160 sqm	Up to 160 sqm	NA	NA
MIG-2	Up to 200 sq m	Up to 200 sq m	NA	NA
Economic Criteria (Annual Household Income)				
EWS	Up to 3 lakhs			
LIG	Between 3-6 lakhs			NA
MIG – 1	Between 6- 12 lakhs		NA	NA
MIG - 2	Between 12-18 lakhs		NA	NA
Affordable Housing Project			Projects using at least 60 percent of the FAR/ FSI for dwelling units of carpet Area not more than 60 sqm.	
Dwelling Characteristics				
Min. No. of DU			250	
EWS	Low-rise (G+3), High-rise, typically 1 BHK			Single- Family, G
LIG	Low-rise (G+3), High-rise, typically 2 BHK			NA
MIG	Low-rise (G+3), High-rise, typically 2.5 BHK		NA	NA

*NA = Not Applicable

1.3 Establishing affordable housing characteristics

Building geometry, Envelope characteristics, Occupancy schedules and Cost are key affordable housing characteristics that must be ascertained to develop Design Standard. This information is being collated from information available in the public domain (PMAY-U scheme, Lighthouse Projects, Demonstration Projects, PMAY Model Designs, etc.), Case Studies, existing projects and consultations with industry professionals. A brief description of activities being coordinated for key affordable housing characteristics are mentioned below.

Building geometry: Secondary research has been conducted to collate information on physical housing characteristics from data available in the public domain. Housing layouts, material assemblies and other information has been compiled from private developers, LHPs, DHPs and several other state funded programs. The compiled housing layouts and characteristics will be presented to the Technical Committee for approval. The approved layouts and specifications will serve as standard geometry of dwelling units for simulation studies in Step 3. presents typical building geometry for different typologies..

Envelope characteristics include roof and wall construction details (materials, technology), glazing type, window wall ratio, window floor area ratios.

- Roof, wall and glazing construction material are being determined through a preliminary market assessment (secondary research based on publicly available data). The construction materials / technologies will be categorized as per climate zone.
- Window Wall Ratio (WWR) and Window Floor Area Ratio (WFR) are being derived from typical model layouts.

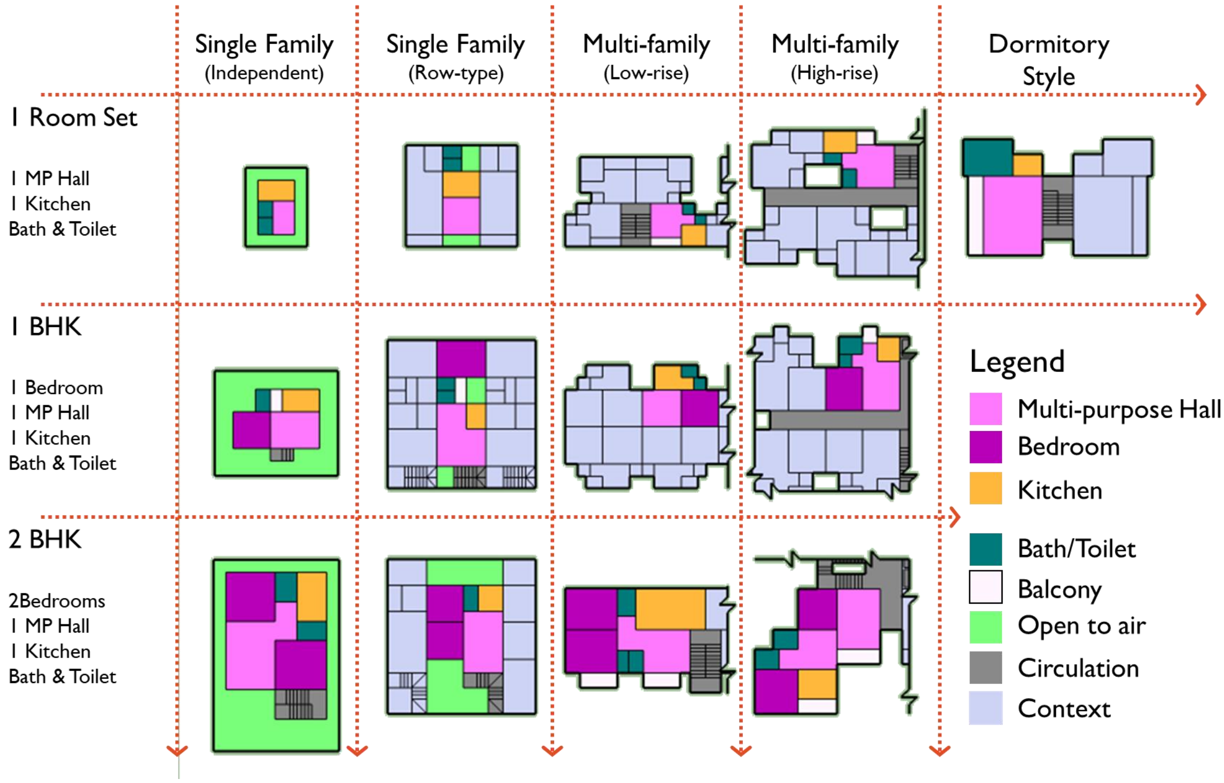

Figure 3 Housing Typologies derived from secondary research..

Lighting, Equipment, Occupancy, Schedules, Baseline Costs: This will be based on secondary research, detail case studies and consultation with developers / architects.

A data schema (refer Annexure-A) has been prepared to compile data from existing projects. The data schema includes project typologies, building design layout, envelope characteristics, glazing details, WWR, and WFR. The collected data will facilitate systematic data compilation of affordable housing characteristics and typical construction practices.

2 Identify applicable thermal comfort standards and passive design measures

The exposed façade to floor area ratio in residential buildings is relatively higher compared to other building typologies. This implies that envelope heat gains play a significant role in influencing thermal comfort and energy efficiency [4]. Keeping this in mind, the design standard for enhancing thermal comfort in affordable housing is anticipated to focus on envelope measures. In this context, a review of existing Thermal Comfort Standards and Performance Metrics has been undertaken. The review of standards is expected to,

1. identify Thermal Comfort standards and metrics applicable in the affordable housing context in India, and,
2. outline key passive measures that can enhance not only thermal comfort, but natural ventilation and daylighting as well.

2.1 Preliminary review of standards, codes and rating systems

Although Thermal Comfort is a widely researched topic, it has limited application for affordable housing in Indian context. An extensive study to identify the Thermal Comfort Standard most suited to un-conditioned residential typology for Indian climatic conditions and relevant to Indian physiology is underway. In addition, technical review of rating systems, best practices and case-studies is being conducted as well to outline active and passive design strategies. The shortlisted standard is expected to outline the performance metric/s and methodology to evaluate Thermal Comfort.

Table 2 outlines a list of standards and rating systems that have been considered for the review. The review analyzes Indian standards (NBC, SP-41, ISHRAE 100001), the Indian Model for Adaptive Comfort Model (2014) and relevant international standards. The International standards include widely accepted standards from ASHRAE, EN and ISO, that form the basis for other standards, as well as standards from tropical countries (Singapore and Malaysia) that are relatively representative of the Indian climatic and ethnic profile. Finally, a review of Indian Codes (ECBC and ENS) and Rating Systems (GRIHA and IGBC) facilitates the identification of passive strategies that can potentially improve thermal comfort performance.

Table 2 Standards and codes and their applicability towards improvement in Thermal Comfort, Natural Ventilation and Daylight performance.

Standards	Applicability	Thermal Comfort	Natural Ventilation	Daylight
ASHRAE 55: 2020	International	Requirements defined in the Standard	Requirements not defined in Standard	Requirements not defined in Standard
EN 16798-1: 2019	International	Requirements defined in the Standard	Requirements not defined in Standard	Requirements not defined in Standard
ISO 7730: 2015	International	Requirements defined in the Standard	Requirements not defined in Standard	Requirements not defined in Standard
ISSO 74: 2014	Netherlands	Requirements defined in the Standard	Requirements not defined in Standard	Requirements not defined in Standard
GB/T 50785: 2012	China	Requirements defined in the Standard	Requirements not defined in Standard	Requirements not defined in Standard
SS 554: 2016	Singapore	Requirements defined in the Standard	Requirements not defined in Standard	Requirements not defined in Standard
MS 1525: 2007	Malaysia	Requirements defined in the Standard	Requirements not defined in Standard	Requirements not defined in Standard
National Building Code: 2016	India	Requirements defined in the Standard	Requirements defined in the Standard	Requirements defined in the Standard
BIS, Special Publication 41: 1987	India	Requirements defined in the Standard	Requirements defined in the Standard	Requirements defined in the Standard
Energy Conservation Building Code: 2017	India	Indirect reference to requirements in Standard	Requirements defined in the Standard	Requirements defined in the Standard
Eco Niwas Samhita: 2021	India	Indirect reference to requirements in Standard	Requirements defined in the Standard	Requirements defined in the Standard
ISHRAE Standard-10001: 2019	India	Requirements defined in the Standard	Indirect reference to requirements in Standard	Indirect reference to requirements in Standard
SVAGRIHA	India	Indirect reference to requirements in Standard	Indirect reference to requirements in Standard	Requirements defined in the Standard
GRIHA for Affordable Housing	India	Indirect reference to requirements in Standard	Indirect reference to requirements in Standard	Requirements defined in the Standard
IGBC Green Affordable Housing	India	Indirect reference to requirements in Standard	Requirements defined in the Standard	Requirements defined in the Standard

Requirements defined in the Standard | **Requirements not defined in Standard** | **Indirect reference to requirements in Standard**

A brief description of the selected standards, building energy codes and rating systems has been included for reference in Box 1, Box 2 and Box 3 respectively.

Box 1 Brief description of Shortlisted Thermal Comfort Standards (International and National)

Brief description of Shortlisted Thermal Comfort Standards (International and National)
ASHRAE 55-2020: Thermal Environmental Conditions for Human Occupancy It was first published in 1966 and primarily used in USA but it has become a well-known standard which is widely used for designing, commissioning, and testing of indoor environments. It offers two methods for determining acceptable thermal environments in occupied spaces: an analytical comfort zone method and an elevated air speed comfort zone method [1]. The standard has a separate method for determining acceptable thermal conditions in occupant controlled naturally conditioned spaces i.e. the adaptive model. The adaptive comfort model embedded within ASHRAE 55 is global in scope because the field study research data sourced from 160 different buildings located all over the world across four different continents [5]. This model also recognized the effect of increased airspeed on occupant thermal comfort particularly in naturally ventilated spaces. Therefore, this adaptive model is regarded as a global implementation of the adaptive thermal comfort [6].
EN 16798-1, 2019: 'Energy performance of buildings - Ventilation for buildings, Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting, and acoustics It is the updated version of standard EN15251 [7] that is generally used for the design of residential and non-residential buildings. The European standard EN 15251 was firstly published in 2007 [8] and included both the PMV/PPD model and the adaptive comfort method [9] [10] developed. It has been renamed in 2015 as prEN-16798. In this standard, available range of outdoor running mean temperature of thermal zone extended from 15 to 30°C to 10 to 30°C. The predefined PMV and PPD calculations obtained through ASHRAE 55 and ISO7730 have been considered as the base for thermal criteria in EN16798-2019 [11]. This standard has also considered the variations for occupant's thermal expectations obtained for NV and MM spaces, in addition to year-round prediction of indoor thermal comfort [12].
ISO 7730-2015: Ergonomics of the thermal environment The ISO standards on thermal comfort were developed by the technical committee of physical environment ISO/TC/159 SC5 WG1 of which ISO7730 is the most notable that deals with analytical evaluation of thermal comfort. The standard presents methods for predicting the degree of general thermal sensation and thermal dissatisfaction of occupants exposed to moderate thermal conditions during the calculation of PMV and PPD and local thermal comfort criteria. The standard offers a method to estimate the air speed required to offset the thermal comfort range to compensate an increase in operative temperature [13]. However, the theory of adaptive comfort is still not considered particularly in natural ventilated spaces [11].
Dutch ISSO 74-2014: Netherlands ISSO 74 thermal comfort regulatory document This standard was established based on adaptive thermal comfort theory. It can be applied to both unconditioned, mixed-mode, and conditioned spaces. The ISSO algorithm for thermal neutrality was the same as that in the RP-884 project [5]. An "adapted running mean temperature" was used as the outdoor climate metric for this standard. The updated version of the standard used SCAT European comfort field study database to develop adaptive thermal comfort equation rather than ASHRAE RP-884, and the calculation method of outdoor reference temperature causing the adaptive thermal comfort equation to differ it from EN 16798 [14].
Chinese GB/T 50785-2012: Evaluation standard for indoor thermal environment in civil buildings The Chinese GB/T 50785 was issued in 2012 to provide an adaptive comfort model for the evaluation of the indoor thermal environment in free-running buildings at design and operational stages [15]. This standard does not specifically mention the type of buildings where the comfort model can be applied, but it includes two methods for assessing free-running buildings: a graphical method and a calculation method [6]. The graphical method is based on the adaptive comfort model appearing in ANSI/ASHRAE 55 [1]. This Chinese standard bears a resemblance to the comfort zone of ASHRAE 55 but there is a distinct difference between the upper and lower acceptability limit thresholds.
Singapore Standard SS 554-2016: Code of practice for indoor air quality for air-conditioned buildings Singapore standard code of practice was released in 2016 which applies to all air-conditioned buildings where air-conditioning is used intermittently or continuously [16]. It recommends the minimum ventilation rates for conditioned areas. Singapore government released a 'Thermal Comfort Guidelines and Policy' in 2012 to achieve

comfortable, healthy and safe environment by reducing the consumption of electricity from air-conditioning which define that a temperature range of 23°C to 26°C is generally comfortable in Singapore when wearing summer clothes. It also defines local control measures to control indoor air temperature such as opening of windows, clothing sense to ensure personal comfort, and increase the air movement without using air-conditioning.

Malaysian Standard MS 1525-2007: Code of practice of energy efficiency and use of renewable energy for non-residential buildings

Malaysian standard MS 1525 provides the criteria and minimum standards for energy efficiency in the design of new buildings, retrofit of existing buildings and methods for determining compliance with these criteria and minimum standards. It defines passive strategies to increase the thermal comfort in naturally ventilated buildings with the use of ventilation strategies such as stack ventilation and cross ventilation. Further, department of Standards Malaysia, 2007 has published a guideline for a standard indoor environment design for Malaysian climate recommends indoor temperature to be in the range of 23°C – 26°C [17].

National Building Code

The Indian National Building Code [18] defines three thermal comfort indices for our climate: Standard effective temperature (SET), Tropical summer index (TSI), and adaptive thermal comfort. Indoor design conditions as per adaptive thermal comfort are recommended for naturally ventilated buildings, mixed-mode buildings, and air-conditioned buildings. NBC recognize people's thermal comfort needs depend on their past and present context and these needs vary with the outdoor environmental conditions of their location.

Bureau of Indian Standard Special Publication 41

The standard SP 41 (1987): Handbook on Functional Requirements of Buildings (Other than Industrial Buildings) was released in 197 from Bureau of Indian Standards (BIS). The standard doesn't define the adaptive thermal comfort model and approach. It is applicable for air-conditioned building. It defines effective temperature and tropical summer index as two thermal comfort indices.

ISHRAE Standard-10001 2019: ISHRAE Indoor Environmental Quality Standard

ISHRAE released the first ever Indian standard on indoor thermal environmental quality in 2016 which identifies thermal comfort, indoor air quality, visual comfort and acoustic comfort. This standard is applicable for both residential and non-residential buildings of either naturally ventilated, mixed-mode or air-conditioned buildings. The ISHRAE IEQ standard recognizes the impact of air velocity on thermal comfort acceptability and defines operative temperature as a function of air velocity [19].

Box 2 Brief description of Shortlisted Building Energy Codes

Brief description of Shortlisted Building Energy Codes

ECBC 2017: Energy Conservation Building Code

the Energy Conservation Building Code (ECBC) was an initiative by Bureau of Energy Efficiency (BEE) to address energy management in large commercial buildings. ECBC 2017 refers to NBC 2016 ventilation guidelines for naturally ventilated buildings, but it does not recommend any set-point based on climatic conditions [16]. The new version of ECBC 2017 defines principles of adaptive thermal comfort and provides a methodology for calculating operating temperatures for naturally ventilated, mixed mode and air-conditioned buildings [20].

Eco Niwas Samhita (ENS) Part 1: Building Envelope (2018)

Eco Niwas Samhita (ENS) has been prepared to set minimum building envelope performance standards to limit heat gains/loss, as well as for ensuring adequate natural ventilation and daylighting potential. the code is applicable to all residential buildings and residential parts of 'mixed land-use projects', both built on a plot area of ≥500 sqm. This code focuses on minimizing heat transfer through the building envelope to achieve comfortable indoors. However, the code does not explicitly outline any set-point ranges [21].

Box 3 Brief description of Indian Model for Adaptive Comfort

Brief description of Indian Model for Adaptive Comfort

The India Model of Adaptive Comfort [22] which forms part of the Building Code of India [18] was based on a sample of 6,330 'right-here-right-now' thermal comfort questionnaires collected in 16 buildings located in all of the major climatic divisions of India. The research design was based on the ASHRAE RP-884 [5] project that formed the basis of the adaptive model in ASHRAE standard 55 [1]. A 30-day outdoor running mean air temperature was adopted as the outdoor climate independent variable in the adaptive regression model. The IMAC study models for neutral temperatures and acceptability limits for naturally ventilated and mixed mode buildings, and gives the thermal comfort acceptability equation derived through an empirical field study specific to the Indian context.

The shortlisted thermal comfort standards have been analyzed to identify applicable standard and metrics for evaluating performance. The thermal performance standards have been evaluated on their applicability:

1. for residential building typology,
2. for naturally ventilated, mixed mode operation and air-conditioned spaces, and,
3. to Indian climatic conditions and physiology (i.e. preferably based on field studies conducted in India).

Table 3 presents a comparative of thermal comfort standards across 6 parameters. Based on the outcomes, the NBC appears to be the best fit for serving as a reference towards the development of design standard for thermal comfort. The outcome from the comparative analysis indicates that the National Building Code has wider applicability to the Design Standard. Following are the key outcomes that suggest applicability of NBC for affordable housing:

1. The NBC is applicable to Residential and other Building typology.
2. The NBC outlines thermal comfort requirements for Air-conditioned, Mixed-mode and Naturally Ventilated buildings. The NBC includes both Adaptive Thermal Comfort and SET, which are applicable to un-conditioned/mixed-mode buildings and air-conditioned buildings respectively.
3. The equations for Adaptive Thermal Comfort and Mixed Mode application used in NBC reference IMAC. IMAC outcomes are based on research conducted in Indian context (climate and ethnicity and physiology).
4. The NBC is a national standard and is already being referenced by Eco-Niwas Samhita.

The NBC uses the Indoor Operative Temperature as metric to evaluate the Thermal Comfort with 90% acceptability limit. The equations are outlined below.

- For naturally ventilated buildings:

  Indoor operative temperature = (0.54 x outdoor running mean temperature) + 12.83

  The 90 percent acceptability range for the India specific adaptive models for naturally ventilated buildings is ±2.38°C.

- For mixed-mode buildings:

  Indoor operative temperature = (0.28 x outdoor running mean temperature) + 17.87

  The 90 percent acceptability range for the India specific adaptive models for mixed-mode buildings is ±3.46°C.

It must, however, be noted that the thermal comfort standards defined in NBC are not explicitly designed for residential buildings. Additionally, the equations reference IMAC model which is based on field studies conducted in the office environment. While no standard has direct applicability to affordable housing in Indian context, the NBC appears to be the best suited standard. The methodology acknowledges that other standards remain an option, and comparative evaluation of performance across other standards may yield some insights.

Table 3: Comparative analysis of thermal comfort standards. Source: [6], [23]

	ASHRAE 55	EN 16798-1	ISO 7730	NBC	GB/T 50785	SS 553	ISHARE 100001
Revised in	2020	2019	2015	2016	2012	2016	2019
Standard is developed specifically for Residential application ***-1:*** *Specifically excludes residential buildings.* ***0:*** *Not specifically designed for residential buildings.* ***1:*** *Specifically designed for residential buildings.*	0	1	1	0	0	-1	0
Standard applies to Naturally Ventilated buildings. ***-1:*** *Does not account for natural ventilation* ***0:*** *Accounts for natural ventilation* ***1:*** *Accounts for natural ventilation & occupant-control (windows)*	1	0	-1	0	0	-1	0
Standard applies to Mixed-mode operation in buildings. ***-1:*** *Does not account for mixed-mode operation in buildings.* ***0:*** ***1:*** *Accounts for mixed-mode operation in buildings.*	-1	1	-1	1	1	-1	1
Standard applies to Air-conditioned buildings. ***-1:*** *Does not account for Air-conditioned buildings.* ***0:*** ***1:*** *Accounts for Air-conditioned buildings.*	1	1	1	1	1	1	1
Data Source. ***-1:*** *SCATs (Europe).* ***0:*** *RP-884 (Continental Representation)* ***1:*** *Field Studies in India.*	0	-1	?	1	?	?	0
Comfort Indices - PMV and PPD for Air-conditioned Buildings ***-1:*** *No* ***0:*** ***1:*** *Yes*	1	1	1	-1	1	-1	-1
PMV Limits	(0.5) 0.5	(0.7) 0.7	(0.7) 0.7	? ?	(1.0) 1.0	? ?	NA NA
PPD Limits	10%	15%	15%	?	25%	?	NA NA
Note (PMV/PPD Limits): ***(1)*** *The most lenient class/acceptability limit has been used to map PMV/PPD, except,* ***(a)*** *Category IV for EN 16798 has not been included as it is meant for short occupancy periods only, and* ***(b)*** *Category III of GB/T has no limits so Category II has been used for defining limits.* ***(2)*** *ISHRAE 10001 does not specify criteria for the overall thermal comfort index value.*							
Comfort Indices - Operative temperature (Adaptive Comfort) for Mixed-mode operation or naturally ventilated building.	10.0 33.5	10.0 30.0	? ?	? ?	18.0 30.0	? ?	? ?

Note: *Temperature range for Hot summer/cold winter, hot summer/warm winter, mild zone, for Category II of GB/T 50785 has been used.*
'?' *indicates information not available.* ***'NA'*** *indicates metric/indicator Not Applicable.*

2.2 Passive design strategies and low energy comfort systems for enhancing thermal comfort performance

The affordable housing occupants do not have access to air-conditioners to ensure thermal comfort and hence it is important to evaluate no-cost design interventions for enhancing comfort performance. Passive design strategies, such as cross ventilation, appropriate orientation contribute to improved comfort without any additional cost. A number of strategies are being identified from the existing literature based on the applicability in the affordable housing and capability of simulation platform. The review of rating systems and case-studies will outline key passive measures by climate zone that enhance thermal comfort in affordable housing.

A preliminary review of applicable green rating standards such as IGBC Affordable Housing, GRIHA for Affordable Housing and SVAGRIHA was conducted to enumerate climate appropriate passive design strategies. Box 4 provides a brief description of the shortlisted rating systems.

Box 4 Brief description of Shortlisted Building Rating Systems

Brief description of Shortlisted Building Rating Systems
SVAGRIHA SVAGRIHA is a guidance-cum-rating system being developed for small standalone buildings like residences, commercial offices, motels, dispensaries, schools etc. and/or set of buildings with a cumulative built-up area of 2,500m2 or less.
GRIHA for Affordable Housing v1.0 With the purpose of taking sustainability to the masses, GRIHA has developed a new rating variant for "Affordable Housing" which is aligned to PMAY scheme. Through this framework GRIHA emphasizes the importance of no-cost design interventions for enhancing performance. All projects that are in-line with the PMAY requirements will be eligible for GRIHA for Affordable Housing Rating.
IGBC Green Affordable Housing The Indian Green Building Council (IGBC) has launched the Green Affordable Housing Rating system with the objective to ensure a high degree of sustainability with no/meagre additional cost to the developer or the occupant.

Table 4 is a comprehensive list of passive design strategies and low-energy comfort systems, mapped to respective climate zones, that can potentially enhance thermal comfort:

Table 4 Passive design measures classified by applicability in India's 5 Climate Zones

Measures	Composite	Cold	Warm-Humid	Temperate	Hot & Dry
Building Orientation	■	■	■	■	■
Cavity walls	■	■	■	■	■
Light shelves	■	■	■	■	■
Thermal Mass	■	■	■	■	■
Green Roof / Terrace Gardens	■	■	■	■	■
Buffer spaces on east & west facades	■		■	■	■
Ventilators	■		■	■	■
Earth berms	■	■	■		■
Cross Ventilation	■		■	■	
Cool Roofs, High-reflective paint surfaces	■				■
Geothermal cooling/heating	■	■			■
Solar Chimney/Wind Tower	■		■		■
Courtyards	■		■	■	■
Roof pond for evaporative cooling	■				■
Reduced Solar Access	■				■
Light colored external surfaces				■	
Passive Evaporative Cooling Structures					■

Water bodies					
Reduced solar access					
Dense vegetation					
Roof insulation					
Trombe Walls					
Solarium / Sun space					
Heat capturing wall panels					
Solar wall					
Solar heat collector-based ventilation/ thermal system					
Direct solar gain in rooms					
In-direct solar gain					
Air lock to prevent heat loss					
Glass covered atrium/ central spaces					
Direct Evaporative Cooler					
Indirect Evaporative Cooler					

Research on case studies showcasing application of passive design strategies and low energy comfort systems is being conducted to inform:

- feasibility of application (considering different typologies) and scale -up potential.
- cost-effectiveness, and,
- regional & climatic considerations.

3 Perform simulation studies to outline design recommendations

The analysis of affordable housing characteristics outlined in Step 1, will be synthesized into Reference building types representative of the affordable housing building stock. These Reference building types will be modeled in EnergyPlus to derive thermal comfort performance across climate zones. The range of affordable housing characteristics will be parametrically applied to these simulation models to study their impact on thermal comfort. The outcomes of parametric analyses will be analyzed and presented as Design Recommendations. Following sub-sections outline the process in detail.

3.1 Analysis for deriving reference building characteristics

Affordable housing characteristics compiled as per schema outlined in Annexure A: Preliminary Schema Templates, will be analyzed for representative values. For discrete variables such as envelope construction, the median values (of the dataset) will be utilized. For numerical variables (say WWR and WFR), data will be split into class intervals or bins. Grouped Frequency Distribution tables will be charted as histograms to study the skew in parameters. In case a skew is reported in parameters, the median value will be utilized, else either of median/mean may be chosen. Wherever possible discrete or qualitative data will be approximated to numerical values (say envelope assembly may be represented as U value). The range of parameters will provide opportunity for parametric simulations. Wherever necessary information will be classified and filtered by typology and/or climate zone.

From data compilation, the following typical characteristics are expected:

- Building layout
- Wall construction details including u-value and assembly
- Roof construction details including u-value and assembly
- Glazing details including u-value, SHGC and VLT
- Shading specifications
- Window wall ratio in each direction
- Window opening to floor area ratio in each direction

- Occupancy, lighting and schedules

3.2 Development of reference building models

After deriving reference building characteristics, detailed simulation models will be developed for each defined building typology. Following thermal modeling procedure will be followed:

1. Identify the representative cities for each climate zone.
2. Create building geometry and provide inputs (envelope characteristics, schedules of operation, internal loads, etc.) for each typology.
3. Simulate building models for each typology for every climate zone for 8,760 hours on EnergyPlus simulation engine.
4. Extract indoor operative temperature for each hour (normalized across occupied spaces in a typical unit) and identify comfort band based on temperature profile in the weather file and the thermal comfort equation outlined in NBC 2016 for 90% acceptability. The equations are outlined below:
    a. Indoor operative temperature = (0.54 x outdoor running mean temperature) + 12.83
    The 90 percent acceptability range for the India specific adaptive models for naturally ventilated buildings is ±2.38°C.
    b. For mixed-mode buildings:
    Indoor operative temperature = (0.28 x outdoor running mean temperature) + 17.87
    The 90 percent acceptability range for the India specific adaptive models for mixed-mode buildings is ±3.46°C.
5. For all hours when temperature is outside thermal comfort band calculate degree discomfort hours for cooling and heating by summing the difference between Indoor Operative Temperature and Comfort range limit for the respective hour.

3.3 Parametric simulation for thermal comfort enhancing measures (passive strategies and low energy comfort systems)

The reference building simulation will give degree discomfort hours for the reference building. The goal is to reduce the degree discomfort hours by at least 50% using potential measures to increase thermal comfort. The Thermal Comfort enhancement measures (or parameters) will be defined for each building component. The parametric simulation will be performed primarily for envelope measures and low energy comfort systems. Occupancy, lighting and equipment will be considered as fixed inputs for evaluation.

The list of potential envelope components that represent affordable housing in Indian context are highlighted in Table 5.

Table 5 Range of envelope components that reflect existing construction practices in affordable housing in India

Envelope Components	Expected range of parameters
Wall assembly	Primary material: Brick, Cored brick, Fly ash brick, Fly ash lime gypsum composite brick, AAC block, Interlocking block-work, etc. and other variations, Concrete Masonry Unit (CMU), Insulated CMU, etc. (Passive measures such as cavity wall, trombe wall, insulative properties, thermal mass and physical parameters such as color and roughness will be accommodated)
Roof assembly	Primary material: In-situ RCC, In-situ RCC with GGBS, Filler Slab, Filler Slab with insulation infill, etc. Passive measures such as false roof, vegetated roof, reflectivity, insulative properties, thermal mass, etc. will be accommodated)

Glazing	Glass types such as single glazed, double glazed and tinted
Window Wall Ratio (WWR)	Different WWR to maximize daylighting while minimizing heat gain.
Window opening to floor area ratio (WFR)	Different WFR to maximize natural ventilation while minimizing heat gain.
Shading devices	Balcony, Horizontal Overhangs, Vertical Fins, etc.

3.4 Evaluation of parametric simulations

The simulation will be performed using Combined Approach. The Combined Approach models combination of all possible measures (parameters) to account for cascading benefit of each component. These measures are applied over the Reference Building Case. The simulation outcomes for each combination will be recorded as Degree Discomfort Hours (DDH). Analytical tools for deriving outcomes from combined approach are being evaluated. Two possible approaches are,

1. obtained DDH metric for the simulated runs will be clustered based on climate and typology to outline envelope thermal performance requirements, OR
2. multi-variate analysis on filtered data-sets to establish correlation between DDH and envelope parameters.

Final recommendation will be based on reduction in the degree discomfort hours with respect to the reference building. The recommendations can take form of prescriptive requirements or an equation-based approach (as in EcoNIWAS). While prescriptive requirements are easy to understand, equation-based approach provides flexibility in compliance.

Figure 4 provides an overview of the combined approach. It is noteworthy that the Combined Approach is a *'Brute Force'* approach and to keep the number of simulations manageable, the resolution of parametric variations will have to be assessed.

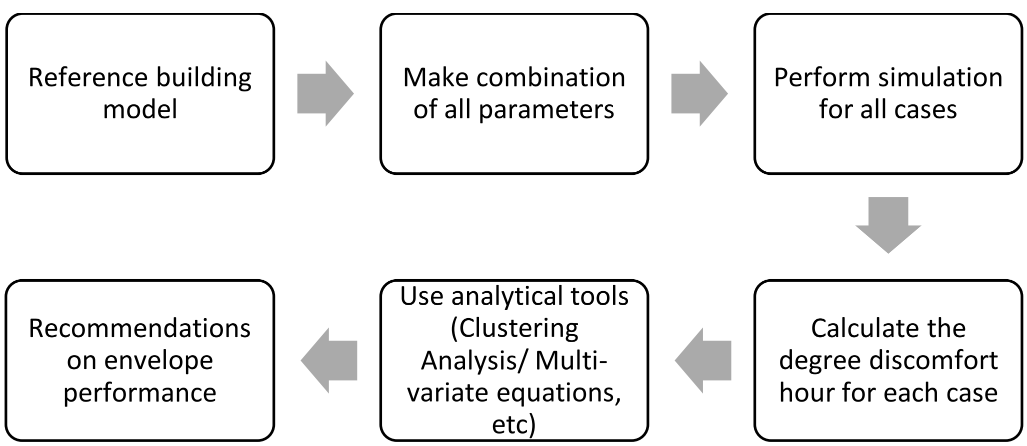

Figure 4: Steps for combined approach

4 Synthesize design recommendations/strategies into design requirements

The design recommendations outlined in Step 3 will be synthesized into Design Requirements. The Design Requirements will inform the layout and structure of standard. The Scope of Standard, Compliance Criteria and Design Requirements will be integrated as a Draft Standard. The Draft Standard will be presented to the Steering and Technical Committee for comments and feedback. Their comments will be incorporated to finalize the development of the Design Standard.

5 Way forward

The compiled approach towards standard development will be presented to a Stakeholder Committee for feedback and comments. The feedback and comments from the Stakeholder Committee will be incorporated and the updated approach will be submitted to the Technical Committee for a final review. Once the committee review process has been completed, the shortlisted typologies will be simulated for deriving design requirements and guidelines.

Reference

[1] ASHRAE, "Thermal Environmental Conditions for Human Occupancy," ASHRAE, Atlanta, GA, 2017.

[2] A. Palayi, N. Priyaranjan and A. Mukherjee, "Affordable Housing in India," Reserve Bank of India, New Delhi, 2018.

[3] A. Palayi, N. Priyaranjan and A. Mukherjee, "Affordable Housing in India," Reserve Bank of India, New Delhi, 2018.

[4] P. Jaboyedoff, S. Maithel, A. Lall, S. Chetia, P. Bhanware and B. Reddy, "Energy Efficient Building Envelope & Ventilation Strategies for Multi-Storey Residential Buildings in India," BEEP India, New Delhi, 2013.

[5] R. De Dear, G. Brager and D. Cooper, "ASHRAE RP-884: Developing an Adaptive Model of Thermal Comfort and Preference," ASHRAE, USA, 1997.

[6] S. Carlucci, L. Bai, R. D. Dear and L. Yang, "Review of adaptive thermal comfort models in built environmental regulatory documents," *Building and Environment,* vol. 137, pp. 73-89, 2018.

[7] CEN, "EN 15251, Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics," European Committee for Standardization, Brussels, Belgium, 2007.

[8] F. Nicol and M. Humphreys, "Derivation of the adaptive equations for thermal comfort in free-running buildings in European standard EN15251," *Building and Environment,* vol. 45, no. 1, pp. 11-17, 2010.

[9] K. McCartney and F. Nicol, "Developing an adaptive control algorithm for Europe," *Energy and Buildings,* vol. 34, no. 6, pp. 623-635, 2002.

[10] F. Nicol and L. Pagliano, "Allowing for thermal comfort in free-running buildings in the new European Standard EN15251," 2007.

[11] S. K. Sansaniwal, J. Mathur, V. Garg and R. Gupta, "Review of Studies on Thermal Comfort in Indian Residential Buildings," *Science and Technology for Built Environment,* vol. 26, no. 6, pp. 727-748, 2020.

[12] CEN, "EN-16798, Energy performance of buildings - Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics," European Committee for Standardization, Brussels, Belgium, 2019.

[13] O. B. Kazanci, D. Coakley and B. W. Olesen, "A Review of Adaptive Thermal Comfort Implementation in International Thermal Comfort Standards," in *2019 ASHRAE Annual Conference* , Kansas City, United States, 2019.

[14] d. Dear, Richard, J. Xiong, J. Kim and B. Cao, "A review of adaptive thermal comfort research since 1998," *Energy and Buidings,* vol. 214, 2020.

[15] MOHURD, "Evaluation standard for indoor thermal environment in civil buildings (GB/T 50785)," Ministry of Housing and Urban-Rural Development, Beijing, China, 2012.

[16] Singapore Standard Council, "Singapore Standard SS 554: Code of practice for indoor air quality for air-conditioned buildings," Enterprise Singapore, Singapore, 2016.

[17] N. Jamaludin, N. Mohammed, M. Khamidi and S. Wahab, "Thermal Comfort of Residential Building in Malaysia at Different Micro-Climates," *Procedia - SOcial and Behavioral Science,* vol. 170, pp. 613-623, 2014.

[18] BIS, "National Building Code of India - Volume 2," Bureau of Indian Standard, New Delhi, 2016.

[19] ISHRAE, "ISHRAE Standard 10001: 2019 - Indoor Environmental Quality standard," Indian Society of Heating, Refrigerating and Air Conditioning Engineers, New Delhi, India, 2019.

[20] BEE, "Energy Conservation Building Codes 2017," Bureau of ENergy Efficiency, New Delhi, 2017.

[21] BEE, "Eco-Niwas Samhita 2018 (Energy Conservation Building Code for Residential Buildings) Part I: Building Envelope," Bureau of Energy Efficiency, New Delhi, 2018.

[22] S. Manu, Y. Shukla, R. Rawal, L. E. Thomas and R. de Dear, "Field studies of thermal comfort across multiple climate zones for the subcontinent: India Model for Adaptive Comfort (IMAC)," *Building and Environment,* vol. 98, pp. 55-70, 2016.

[23] D. Khovalyg, O. B. Kazanci, H. Halvorsen, I. Gundlach, W. P. Bahnfleth, J. Toftum and B. W. Olesen, "Critical review of standards for indoor thermal environment and air quality," *Energy & Buildings,* vol. 213, pp. 1-19, 2020.

[24] S. Kumar, S. Sachar, S. Kachhawa, M. Singh, A. Goenka, S. Kasamsetty, G. George, R. Rawal and Y. Shukla, "Projecting national energy saving estimate from the adoption of adaptive thermal comfort standards in 2030," Alliance for an Energy Effcient Economy, New Delhi, 2018.

[25] "Report of the High Level Task Force on Affordable Housing for All," NAREDCO, New Delhi, 2008.

Annexure A: Preliminary Schema Templates

Project Details

	Units	
Project Name		
Location		
Project Typology		
Climate zone		
Gross floor area	sqm	
Number of floors	Number	
Dwelling units per floor	Number	
Floor to floor height	m	
Dwelling unit area	sqm	
Cost/ m^2	INR/sqm	

Envelope Details

Envelope	Units	Design Values
Roof u-value	W/sqm.K	
Construction/Material (Exterior to Interior with thickness)		
Roof area	sqm	
Roof reflectance	%	
Roof assembly cost	INR/sqm	
Wall u-value	W/sqm.K	
Construction/Material (Exterior to Interior with thickness)		
Partition wall u-value	W/sqm.K	
Construction/material		
Thickness	mm	
Wall assembly cost	INR/sqm (of façade area)	
Floor u-value	W/sqm.K	
Construction/Material (Exterior to Interior with thickness)		
Floor assembly cost	INR/sqm	
Window type (single, double etc)		
Window u-value (glass)	W/sqm.K	
Window SHGC	%	
Window VLT	%	
Frame type		
Frame u-value	W/sqm.K	
Window frame cost	INR/unit	
Glazing cost	W/sqm.K	

Envelope	Units	Design Values
Window opening to floor area ratio (WFR)		
Space type wise		
Shading Device (eg vertical shades, balcony etc)		
Space type wise	m	
Window Wall Ratio (WWR)	%	
Space type wise	%	