प्रधान मंत्री आवास योजना-शहरी
Pradhan Mantri Awas Yojana-Urban

GLOBAL HOUSING TECHNOLOGY CHALLENGE INDIA

Ministry of Housing and Urban Affairs
Government of India

Azadi Ka Amrit Mahotsav

bmtpc

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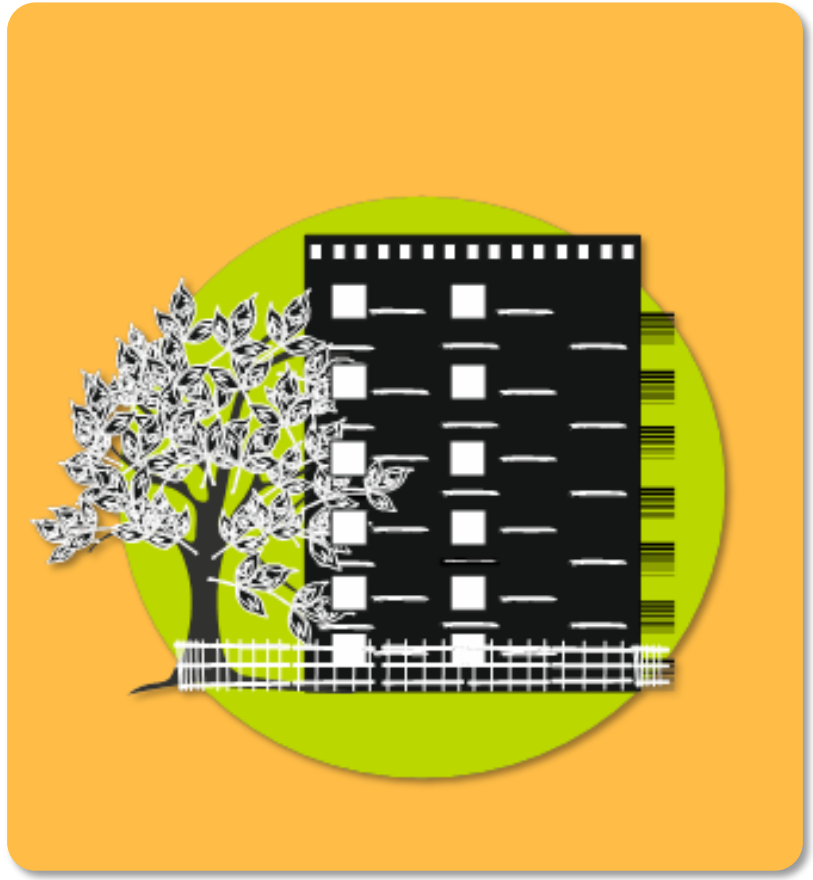


Thermal Comfort Performance based Design Standard for Affordable Housing in India

BUILDING STANDARDS & CODES FOR THERMAL COMFORT

eds environmental design solutions

Wuppertal Institut

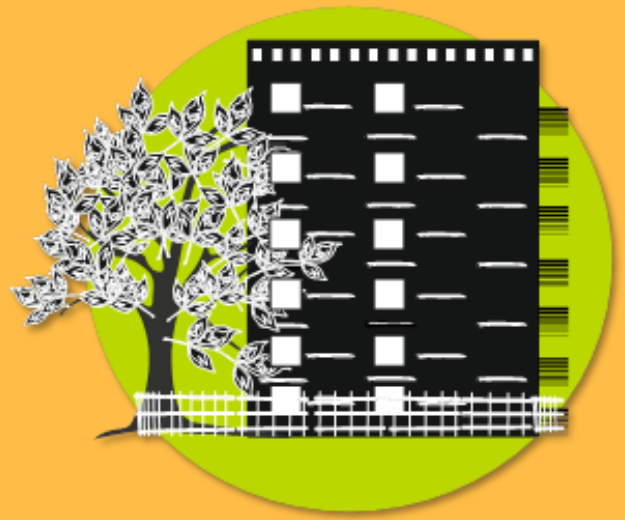
hunnarshālā FOUNDATION

Key Objectives

1) Ascertain the code and standards framework in India vis-à-vis thermal comfort
2) Identify global standards and codes for achieving thermal comfort
3) Review indices and metrics for evaluating thermal comfort in residential context

Expected Outcomes

- Shortlist of suitable standards and codes with reference to development of design standard for thermal comfort in affordable housing in India
- Highlight Best practices across global codes
- Comparative assessment of standards, thermal comfort indices and thermal comfort metrics



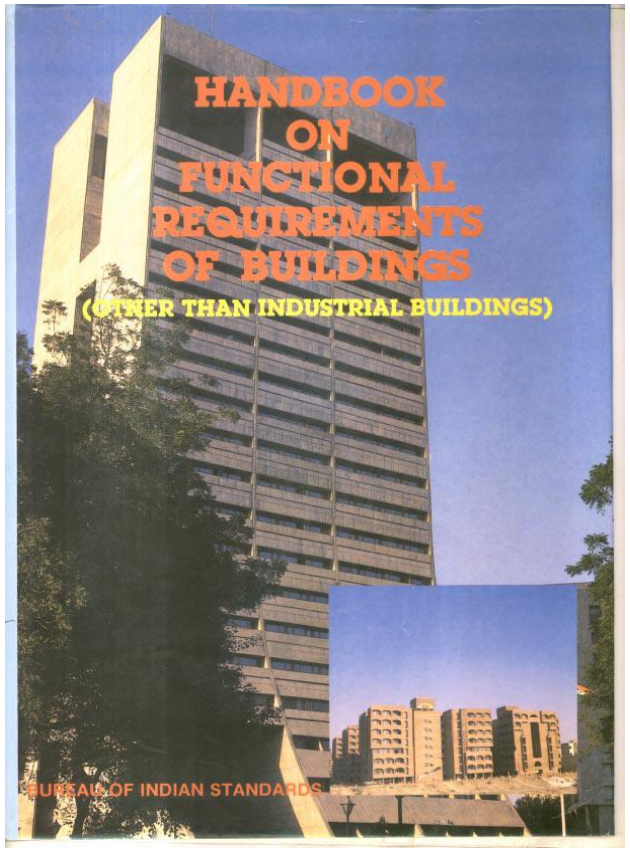
Standards, Codes and Rating Systems: Indian Context

Analysis of Thermal Comfort requirements in context of Standards, Codes and Rating Systems prevalent in India.

Indian Context – Standards and Codes

- IS 2440: Guide for daylighting of buildings
- IS 3362: Code of practice for natural ventilation of residential buildings
- IS 3792: Guide for heat insulation of non-industrial buildings
- IS 8888: Guide for requirements of low-income housing, Part 1: Urban areas
- IS 13727: Guide for requirements of cluster planning for housing
- IS SP 41: Handbook on Functional Requirements of Buildings
- IS SP 7: National Building Code of India
- Eco-Niwas Samhita
- ISHRAE Standard-10001: Indoor Environmental Quality Standard

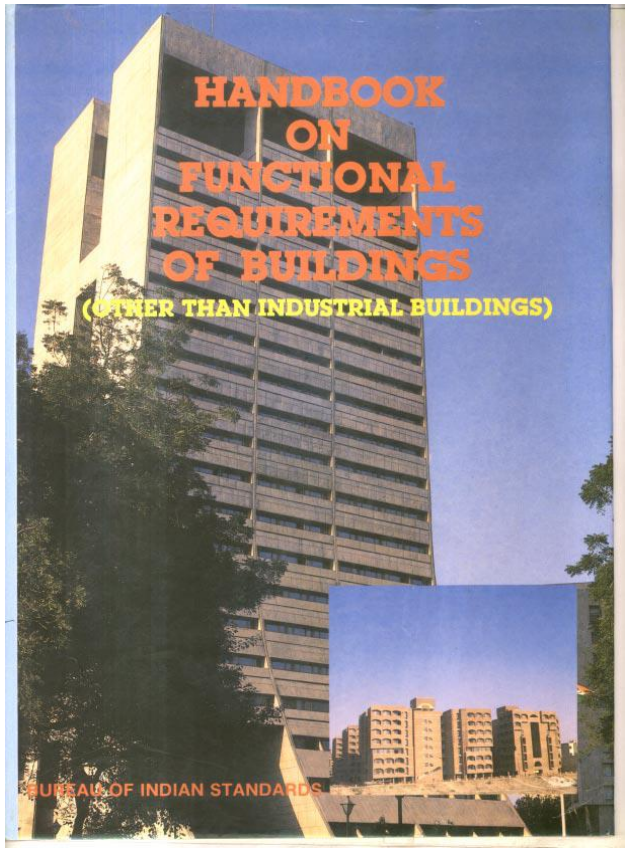
Key Highlights: SP 41



Part 1: Climatology

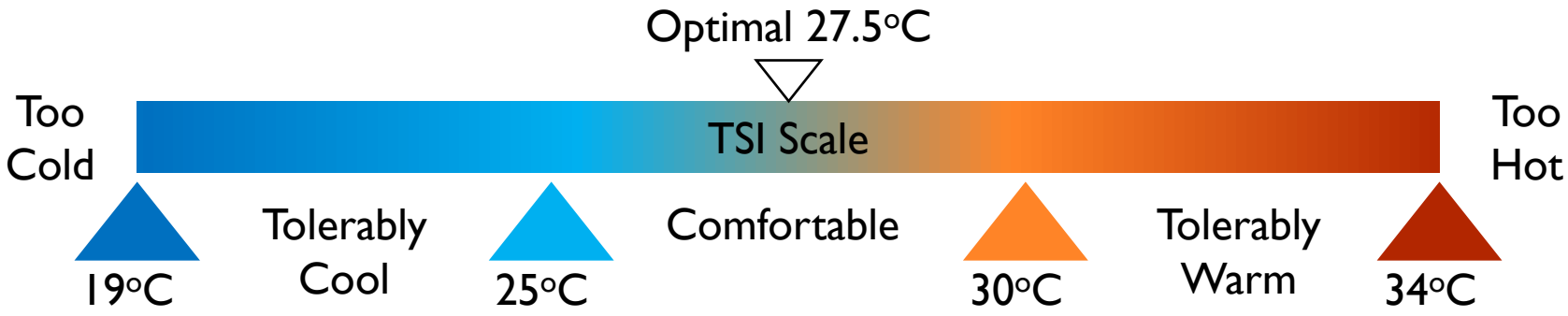
- Clause 2.3: Indices of Thermal Comfort
  - Handbook identifies 2 indices of thermal comfort for hot environments:
    - Effective Temperature (acceptable for low to moderate heat stress)
    - Tropical Summer Index (TSI) (simple to compute and based on relevant climatic conditions, living habits and clothing patterns in the country)
  - Among environmental factors, globe temperature and air temperature have the best correlation with thermal sensation.

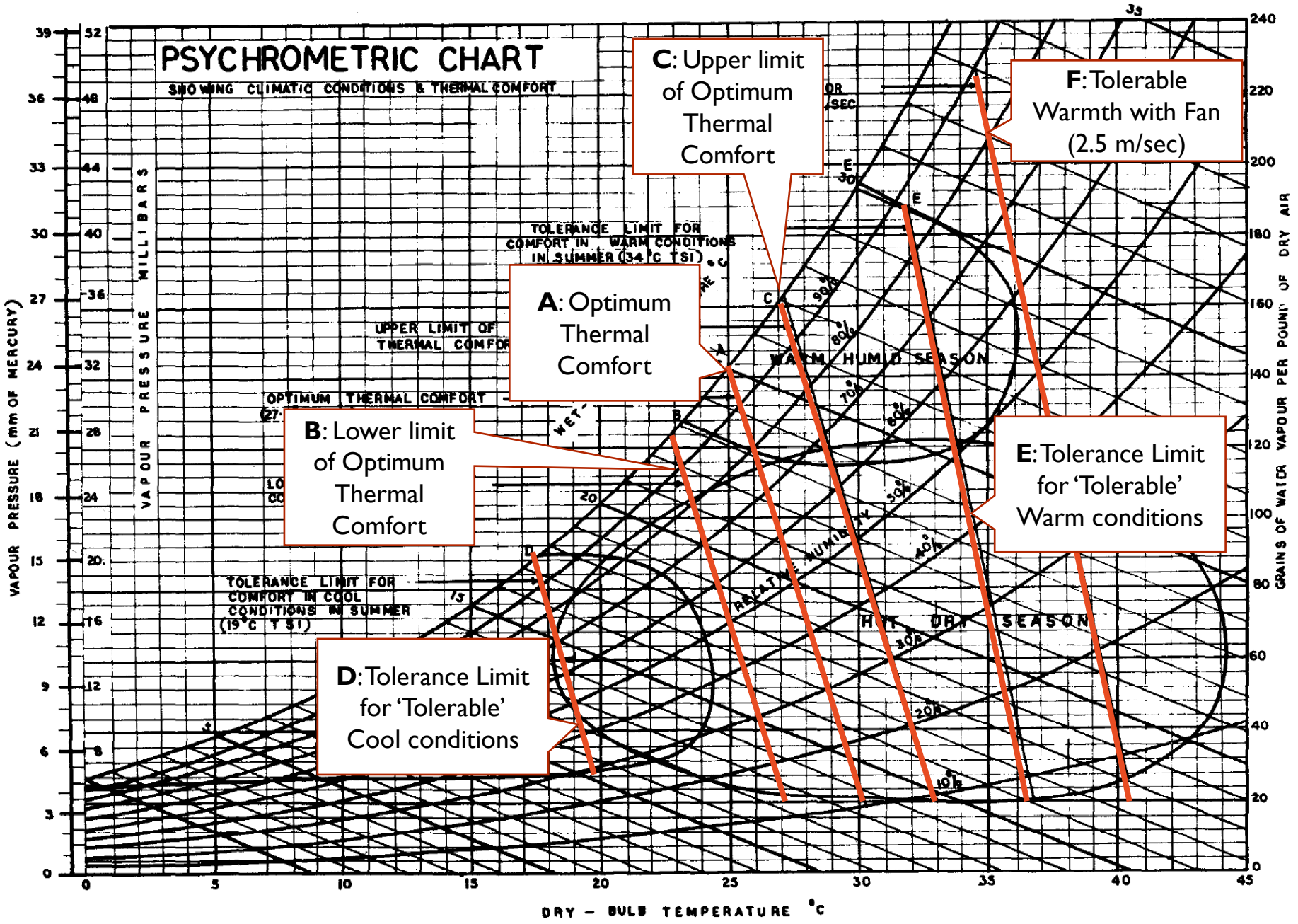
Key Highlights: SP 41



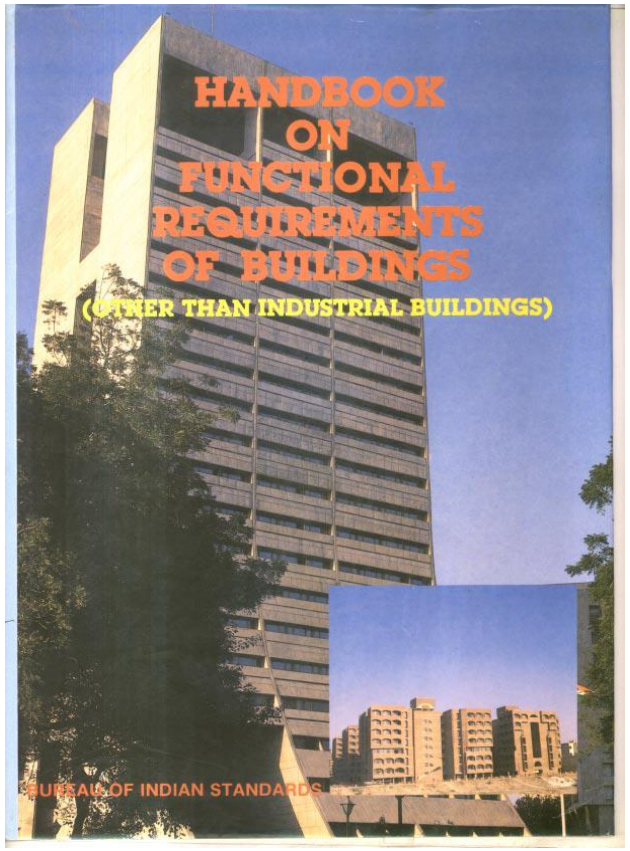
Part 1: Climatology

- $TSI = {}^{1}/_{3}\, t_w + {}^{3}/_{4}\, t_g - 2\sqrt{V}$,
  - where t_w is wet-bulb temperature in °C, t_g is globe temperature in °C and V is air velocity in m/sec.
- TSI Applicability:
  - Globe Temperature: 20-42°C
  - Wet-bulb Temperature: 18 - 30°C
  - Air speed: 0-2.5 m/sec
  - TSI: 15 - 40°C




PSYCHROMETRIC CHART
SHOWING CLIMATIC CONDITIONS & THERMAL COMFORT
C: Upper limit of Optimum Thermal Comfort
F: Tolerable Warmth with Fan (2.5 m/sec)
A: Optimum Thermal Comfort
B: Lower limit of Optimum Thermal Comfort
E: Tolerance Limit for 'Tolerable' Warm conditions
D: Tolerance Limit for 'Tolerable' Cool conditions
TOLERANCE LIMIT FOR COMFORT IN WARM CONDITIONS IN SUMMER (34°C TSI)
UPPER LIMIT OF THERMAL COMFOR
OPTIMUM THERMAL COMFORT
TOLERANCE LIMIT FOR COMFORT IN COOL CONDITIONS IN SUMMER (19°C TSI)
WARM HUMID SEASON
HOT DRY SEASON
VAPOUR PRESSURE (mm OF MERCURY)
VAPOUR PRESSURE MILLIBARS
GRAINS OF WATER VAPOUR PER POUND OF DRY AIR
DRY - BULB TEMPERATURE °C

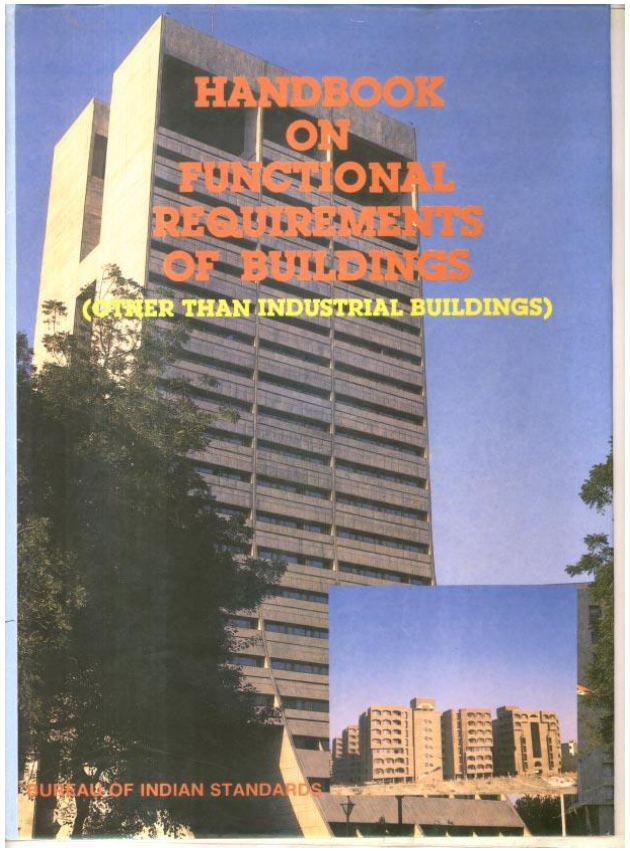
Key Highlights: SP 41



Part 1: Climatology

- Clause 4.2: Limits of Thermal Comfort
  - For summer comfort, precise control of indoor temperature is not necessary.
  - Observations indicate increasing air motion from 0.5 to 1.5 m/s is equivalent to decreasing air temperature by 3°C.

Key Highlights: SP 41

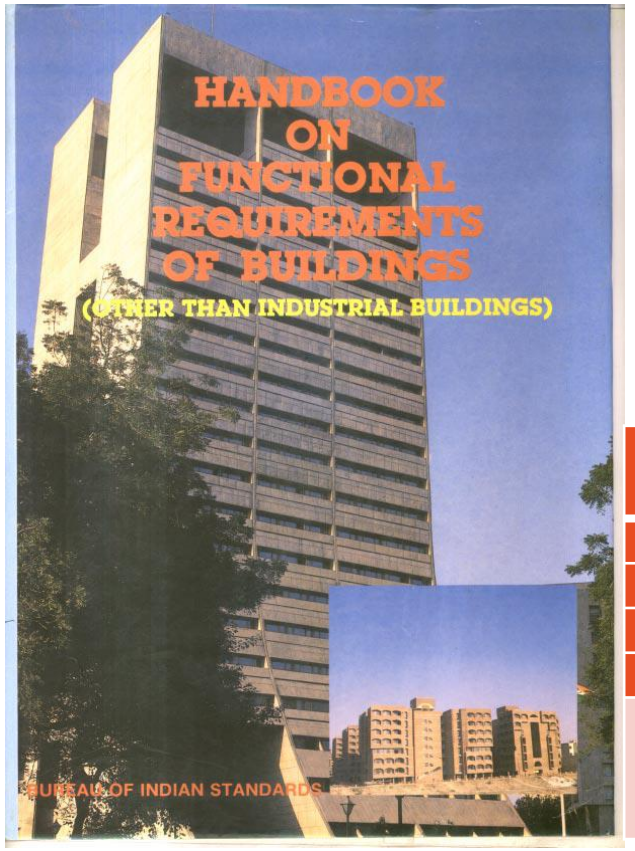


Part 1: Climatology

- Clause 4.4.1.3: Evaporative Cooling
  - Exhaust fan-type coolers perform better compared to blower-type
  - Based on experimental studies at CBRI, design parameters have been optimized.

Diameter	Revolution per minute	Power Consumption	Noise Level	Air Volume	Suitable Application
mm		**Watts**	**dB**	**m^3/h**	
300	1,400	90	56	1,900	Residential
400	900	90	52	2,460	Residential
400	1,400	160	62	4,000	Residential
450	900	145	56	4,340	Residential

Key Highlights: SP 41



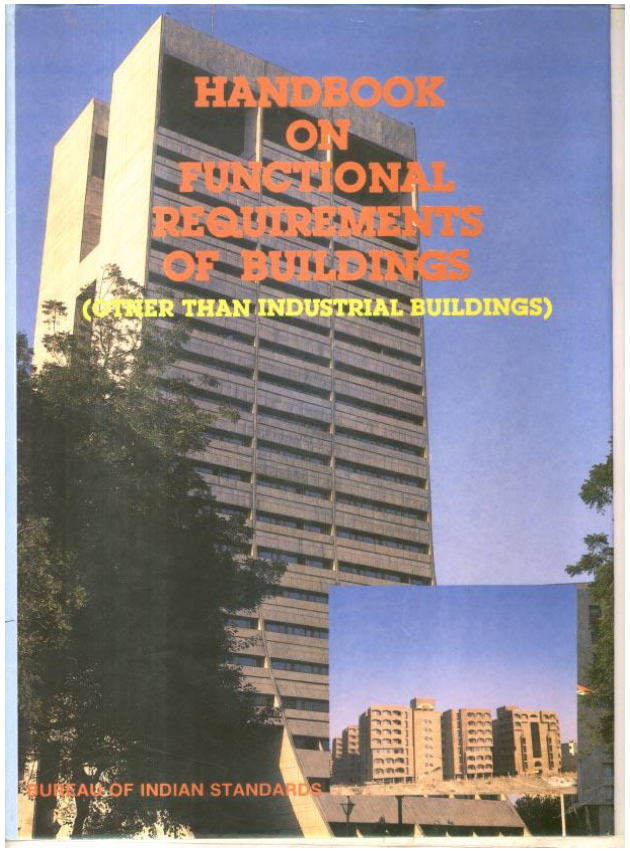
Part 2: Heat Insulation

- Clause 3.1: Thermal Performance Requirements
  - Envelope Performance requirements for 3 climate zones has been expressed as Thermal Transmittance (U), Thermal Performance Index (TPI), Thermal Time Constant (T) and Thermal Damping (D).
  - Thermal Transmittance (U) and Thermal Time Constant (T) are performance indicators applicable under steady state conditions.

Building Component	Hot-Dry and Hot-Humid Zones				Warm-Humid Zone			
	U (max) (W/m^2K)	TPI (max)	T (min) (h)	D (min)	U (max) (W/m^2K)	TPI (max)	T (min) (h)	D (min)
Roof	2.33	100	20	75	2.33	125	20	75
Exposed Wall	2.56	125	16	60	2.91	175	16	60

Note:
Thermal Performance Index (TPI) is indicative of heat gain on peak day through building section. Uses 30°C as base temperature.
Thermal Time Constant (T) is the ratio of heat stored to thermal transmittance of the structure expressed in hours.
Thermal Damping (D) is expressed as percentage and is an indicator of reduction in temperature swing on peak cooling day.

Key Highlights: SP 41



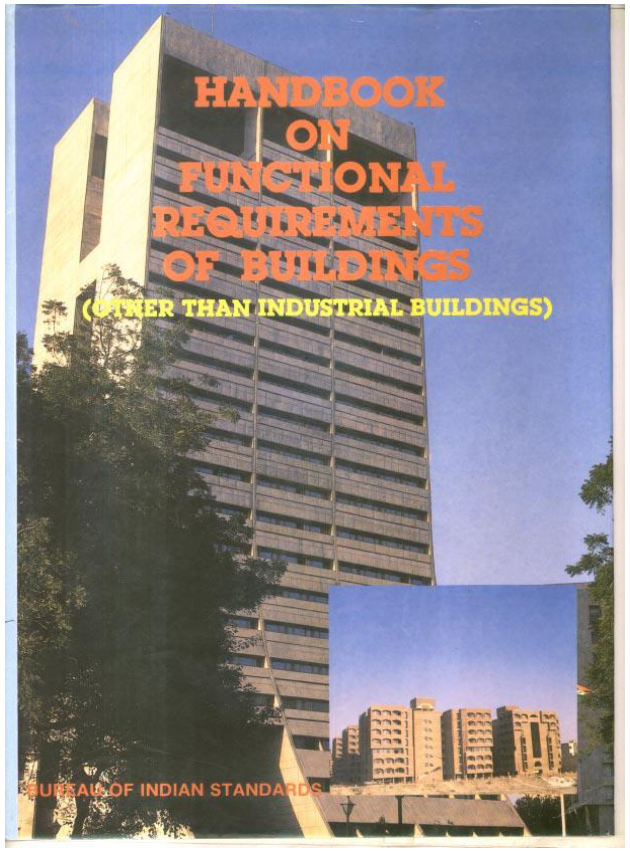
Part 2: Heat Insulation

- Clause 4.1.3.7: Criteria for Thermal Performance Rating
  - In tropical climate, thermal performance is function of solar temperature, which in turn is influenced by climate data, surface color and orientation.
  - For unconditioned buildings, Peak Degree Hours (PDH)* are the underlying basis for rating of thermal performance of building. For AC buildings Peak Heat Gain Factor (PHGF) is used.

* Temperature above 30°C

Thermal Performance Index				Class	Quality of Performance
Unconditioned		Air-Conditioned			
	<=75		<=50	A	Good
>75	<=125	>50	<=100	B	Fair
>125	<=175	>100	<=150	C	Poor
>175	<=225	>150	<=200	D	Very Poor
>225		>200		E	Extremely Poor

Key Highlights: SP 41



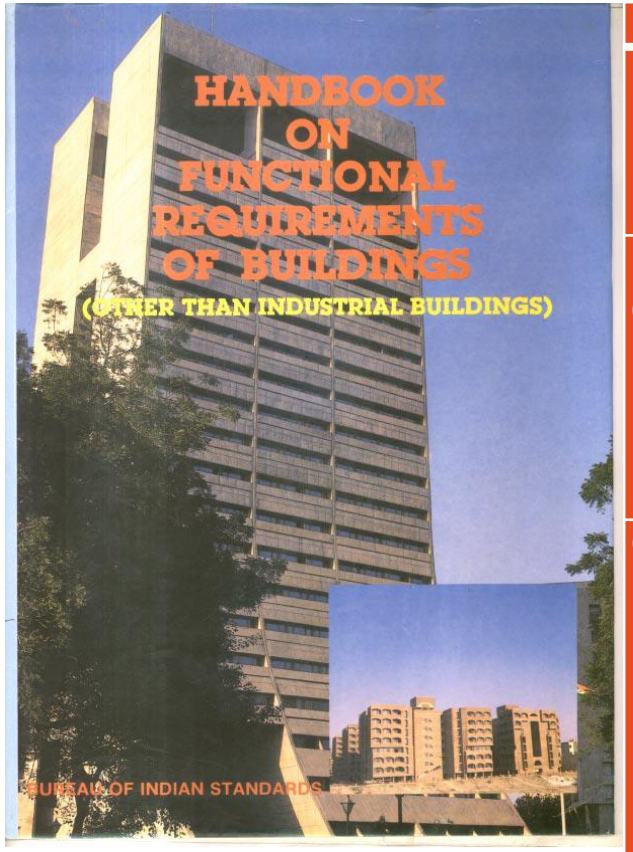
Part 2: Heat Insulation

- Clause 8.3: Selection of shading device & 8.4: Selection of building components
  - Shade factor of windows for hot-dry and hot-humid climates must be less than 0.5.
  - References Thermal Performance Index thresholds
- Clause 9.1: Building Index (Thermal Performance Metric coupled with Comfort)
  - Building Index is the ratio of peak heat gain averaged over the enclosure's surface area to an acceptable heat gain limit.
  - 46 W/m^2 is threshold for acceptable limit of heat gain. Relaxation to 50 W/m^2 with fan operation.

Building Index	Indoor Air Temperature (in ^{O}C)	Comfort Conditions with Fan
0-50	32	Comfortable
51-100	32-36	Slightly Warm
101-150	36-40	Hot

Key Highlights: SP 41

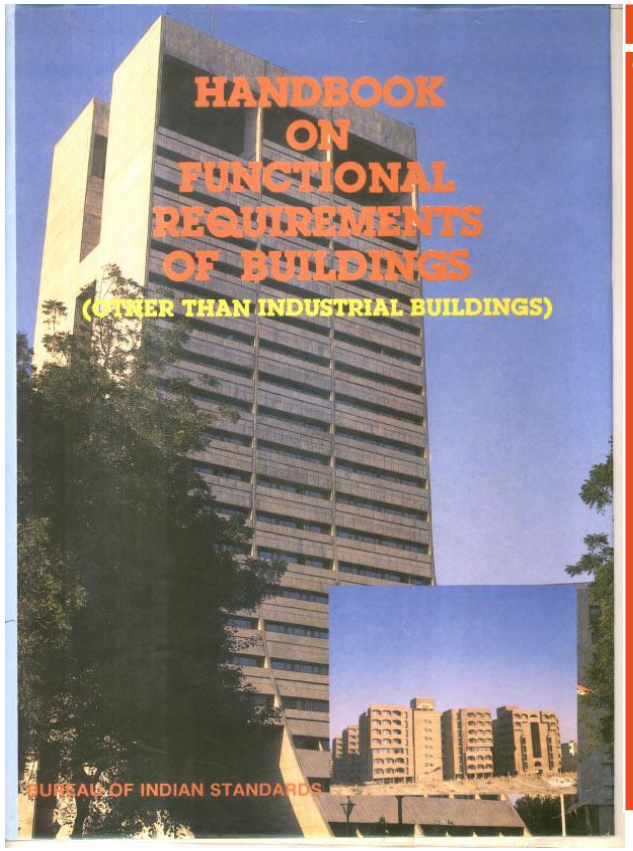
Part 2 (Heat Insulation), Clause 7: Recommended building characteristics for various climates



	Hot-Dry	Hot-Humid	Warm-Humid	Cold
External Walls	# Constructed of bricks or similar locally available materials. # Thickness of external wall >= 22.5 cm. # Cavity walls, hollow block, insulation etc.		# 11.25 cm brick, hollow blocks 10 cm, Light weight conc blocks 10 cm,	# 11.25 cm brick with 2.5 cm of insulation on the inner side.
Roof (Flat/Sloping)	# 10 cm RCC or reinforced brick cement (RBC) over which 7.5 cm thick mud phuska or cinder or any other equivalent insulating material laid with waterproofing.		# Lightweight roof. Protection against heavy rainfall.	# Cement or GI sheets backed by false ceiling of wood, 2.5 cm wood- wool board or equivalent material.
Glazing	# 15-20% of floor area as fenestration. # Shutters that can be tightly closed during summer days or winter nights. # External and Internal shading. # Heat resistant glasses, double and painted glasses.		# 15-20% of floor area as fenestration. # Windows in the direction of wind. # Windows in horizontal direction with low sill height. # Cross ventilation.	# Up to 25% of floor area as fenestration. # Longer axis facing N-S. # Double glazing to avoid heat losses.

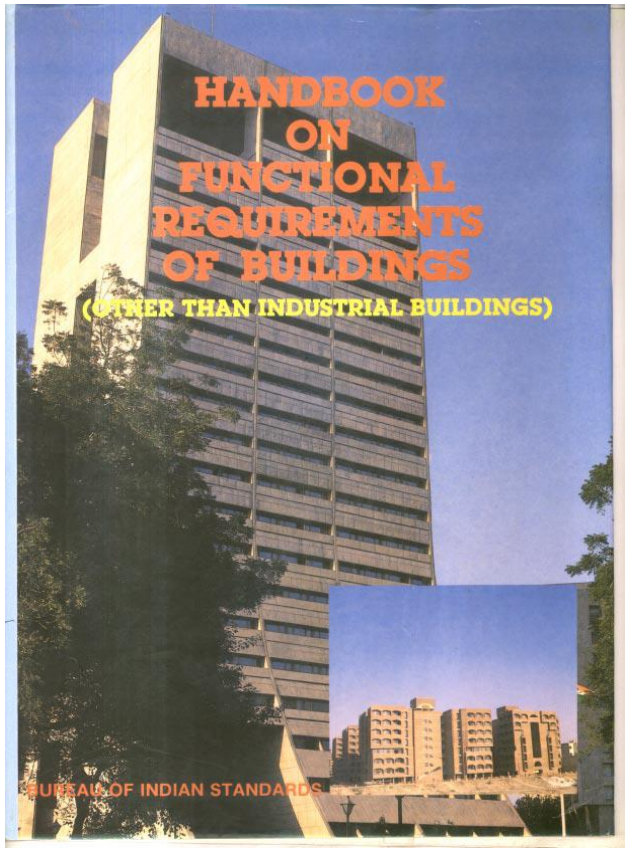
Key Highlights: SP 41

Part 2 (Heat Insulation), Clause 7: Recommended building characteristics for various climates



	Hot-Dry	Hot-Humid	Warm-Humid	Cold
Special Needs	# Outdoor sleeping areas for summer nights are essential. # Cooling building by spraying water on roofs, white painted reflective surfaces and shading. # Use of ceiling fans. # Desert coolers, may be used in summer. # Unit type room heaters may be required during winter months.	# Outdoor sleeping areas for summer nights are essential. # White painted reflective surfaces and shading. # Use of ceiling fans is desirable. # Desert coolers are not suitable in these areas.	# Building axis preferably along E-W or NE-SW axis to reduce solar heat gains by walls and improve wind movement. # Good rain-water drainage is essential. # Desert coolers are not suitable in these areas.	# Protect wall and roof surfaces against heavy rain and snowfall. # Use vapour barrier to protect insulation against condensation. # Artificial heating is essential during winter. # Ceiling fans may be used during summer.

Key Highlights: SP 41



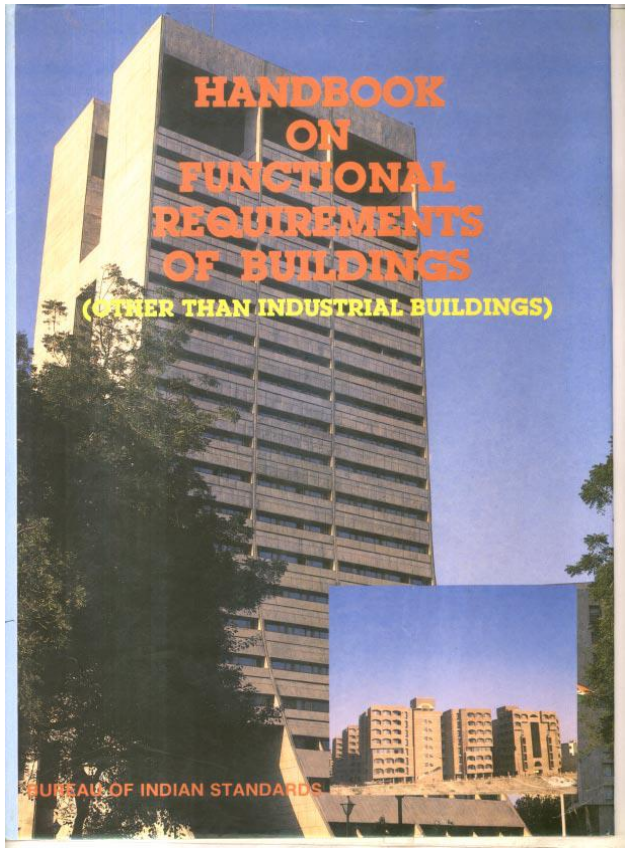
Part 3: Ventilation

- Clause 4: Minimum standards of ventilation

Space type	Air changes per hour
Bed Rooms/ Living Rooms	3-6
Bath/Toilets	6-12
Kitchen (Domestic)	3-6

- Clause 5.3.1: Design guidelines for comfort ventilation
  - Orient building to take advantage of prevailing windows. Orient building b/w 0 and 30° of prevailing winds.
  - Openings at lower level on windward side and higher level on leeward side.
  - Maintain cill height at 85% of critical height (say head level).
  - Maintain inlet and outlet area of nearly equal area.
  - Maintain area of openings b/w 20 and 30% of floor area
  - Minimize shielding effect (of obstructions) by keeping distance b/w 2 rows equal to 8 and 10 times the height for semi-detached and row type homes respectively.

Key Highlights: SP 41

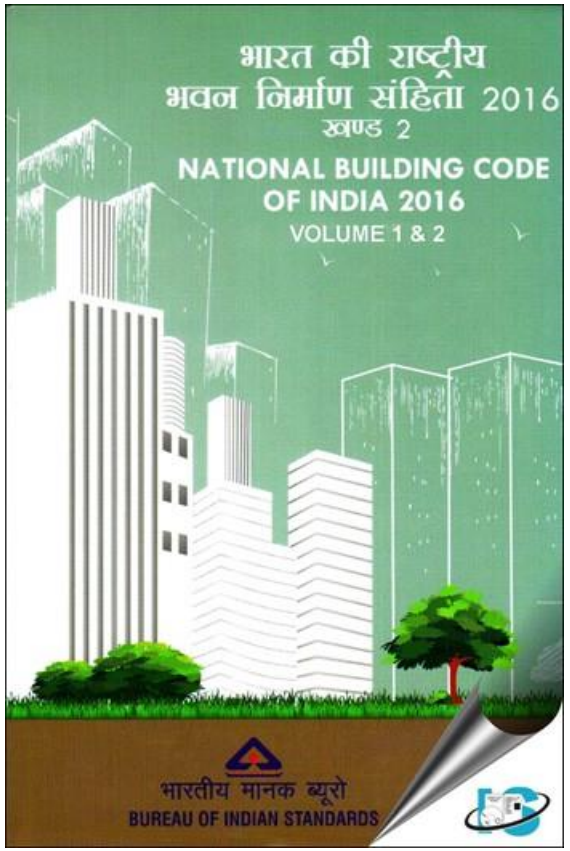


Part 4: Lighting

- Recommended illumination levels in lux and daylight factor for residential use are defined.

Space type	Illumination (Lux)	Daylight Factor (percent)
Kitchen	200	2.5
Bathroom	100	
Stairs	100	
Living Room		0.625
Homework/sustained reading	300	
Reading casual	150	
Study Room		1.9
Circulation		0.313
Note: Wherever applicable, Illumination and Daylight Factor values must be ensured at horizontal work plane, room centre and other specific locations. 1% DF=80 lux		

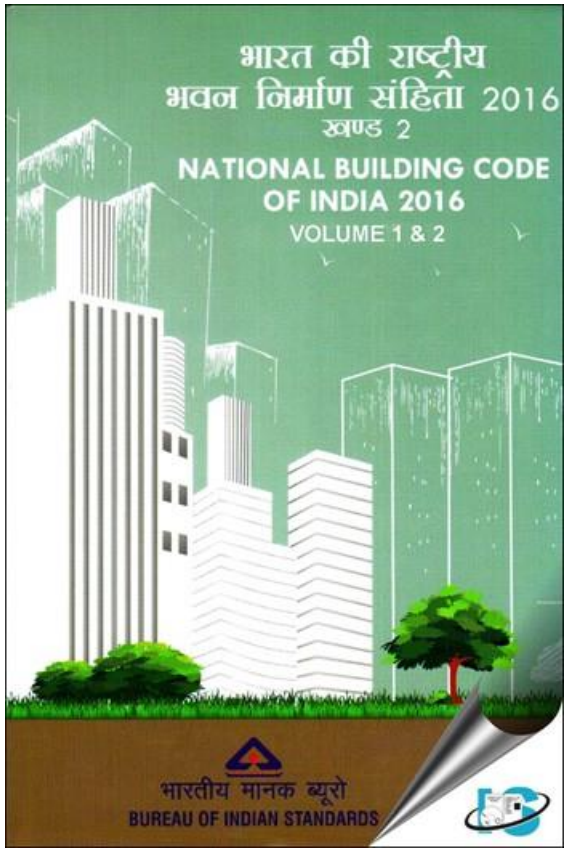
Key Highlights: NBC 2016



Vol 2: Part 8: Section 1: Lighting and natural ventilation

- Clause 5.2.3.1: Indices of thermal comfort
  - Effective Temperature (ET), Tropical Summer Index (TSI) and Adaptive Thermal Comfort
- Clause 5.4.3: Design guidelines for natural ventilation
  - 29 strategies outlined to improve natural ventilation.

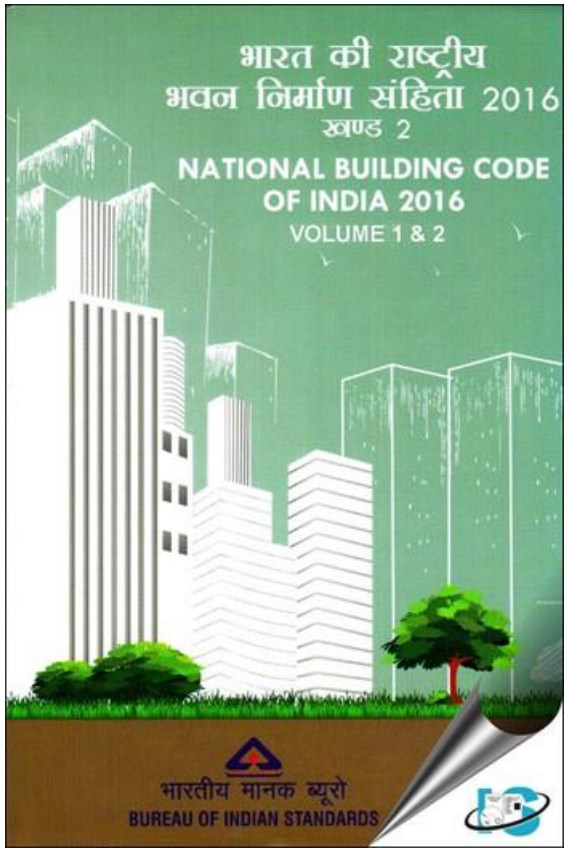
Key Highlights: NBC 2016



Vol 2: Part 8: Section 3: AC, heating and mechanical ventilation

- Clause 6.2: Design of Indoor Conditions as per Adaptive Thermal Comfort Model.
  - Operative temperature is a suitable index to measure thermal comfort in the building having low indoor air velocities ($\leq$ 0.5 m/sec).
  - Effective temperature is the recommended index for indoor air velocities exceeding 0.5 m/sec.

Key Highlights: NBC 2016



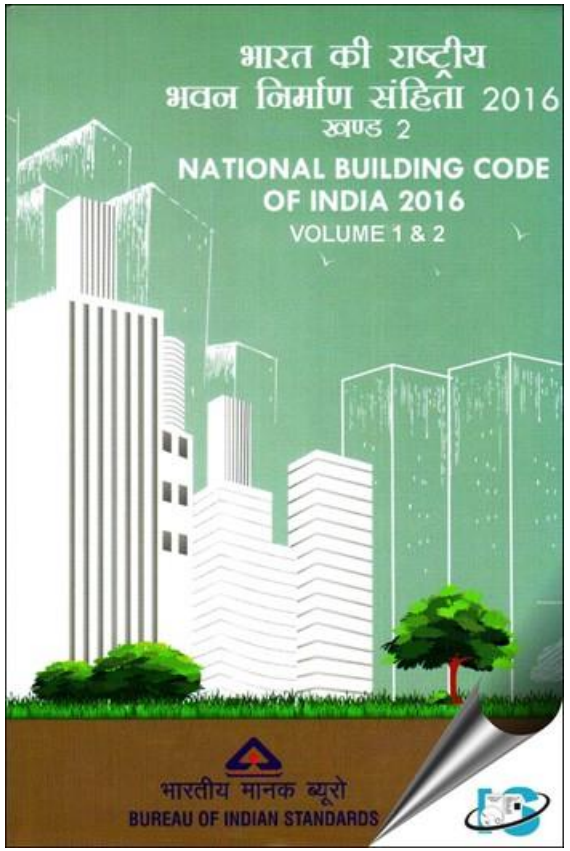
Vol 2: Part 8: Section 3: AC, heating and mechanical ventilation

- Clause 6.2: Design of Indoor Conditions as per Adaptive Thermal Comfort Model.

Adaptive Comfort approach recognizes

- People's thermal comfort needs depend on their past and present context, that vary with outdoor environment
- People living year-round in AC spaces are likely to develop high expectations for cool temperatures
- People in naturally ventilated buildings with access to controls can adapt & have tolerance to wider range of temperatures

Key Highlights: NBC 2016



Vol 2: Part 8: Section 3: AC, heating and mechanical ventilation

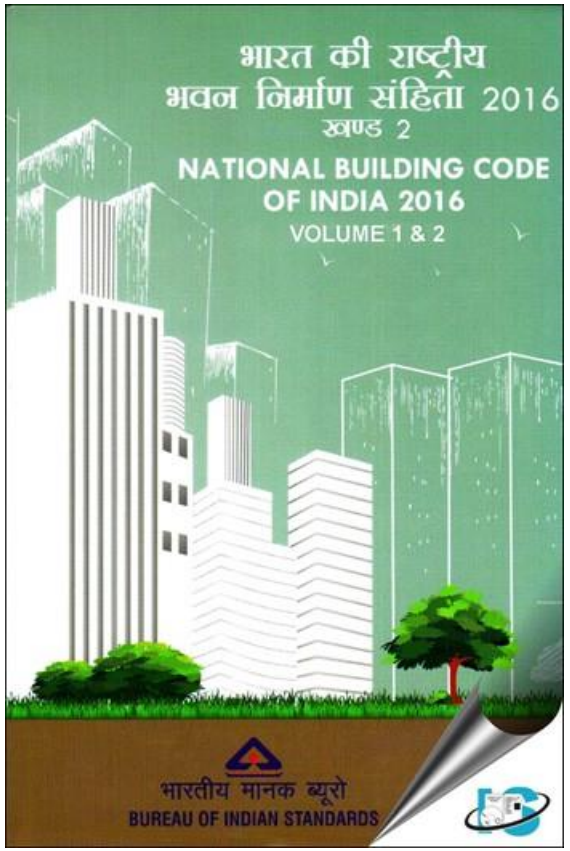
- Clause 6.2: Design of Indoor Conditions as per Adaptive Thermal Comfort Model.
  - Adaptive Thermal Comfort Model for NV Building
    - Equation based on 30-day outdoor running mean temperature.
    - Equation does not apply when running mean temperature is below 15 °C.
  - For neutral temperature,

$T_{neutral} = 0.54 \times T_{out} + 12.83$, where

    - $T_{neutral}$ is the indoor operative temperature for neutral sensation
    - T_{out} is the 30-day outdoor running mean temperature
  - Comfort band for 90% acceptability

$$T_{neutral} \pm 2.38$$

Key Highlights: NBC 2016



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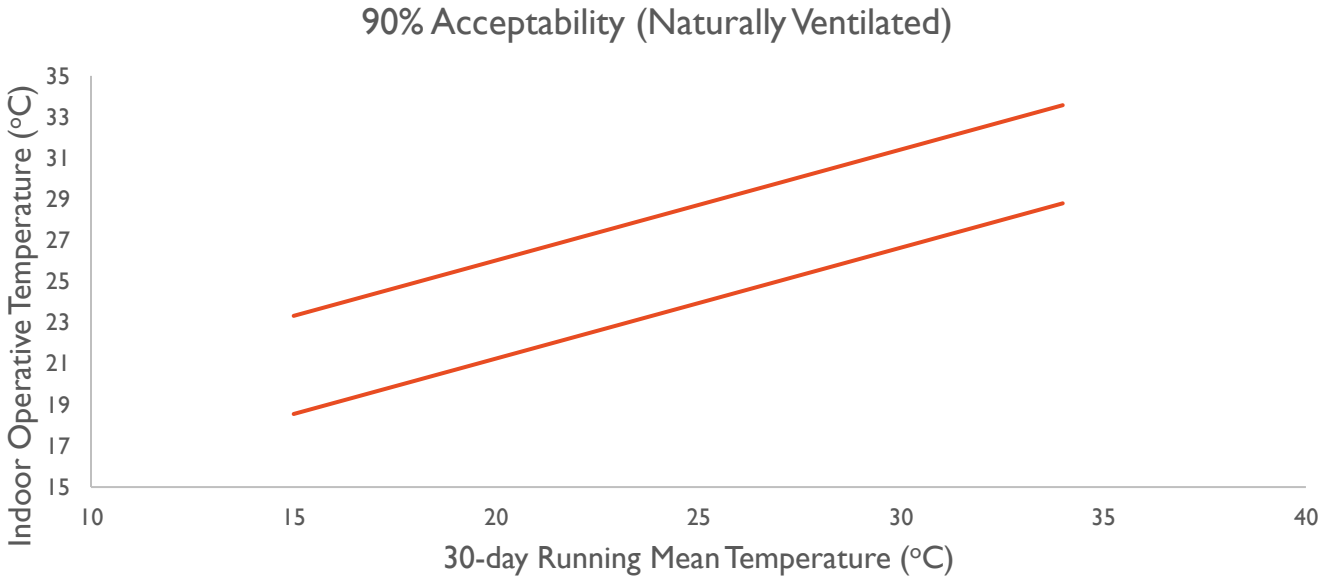


Key Highlights: IS 8888 (Part 1): 1993, Requirements of Low-Income Housing – Guide

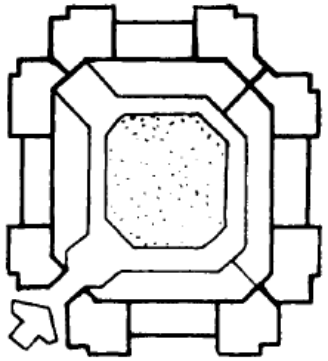
- Applicable to dwelling units of maximum plinth area of 40 m^2
- Minimum plot size, ground coverage, FSI & size of room are outlined for metro & non-metro cities
- Lighting and Ventilation guidelines: Windows and ventilators shall meet
  - 1/10th of the floor area in Hot-Dry climate
  - 1/6th of the floor area for Wet-Hot climate
- Guide discourages plotted development (except in case of incremental housing) & recommends row housing and group housing on cluster planning approach

Key Highlights: IS 13727: 1993, Requirements of Cluster Planning for Housing – Guide

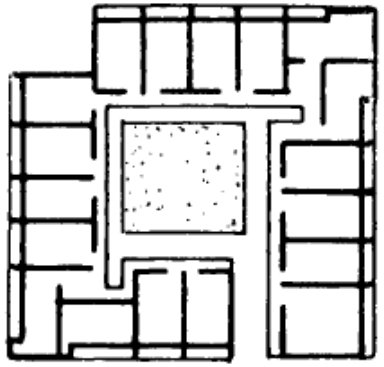
- The Guide "rediscovers the virtues of low-rise, high-density development in the context of affordability and incremental growth"
- Highlights 'Cluster Planning' as a powerful urban design tool
- Acknowledges conventional byelaw provisions hinder efficient planning.
- Standard prescribes clusters of 20 homes (and not more)
- Standard prescribes cluster openings (or courtyard)
  - minimum courtyard width 6m or 3/4th height
  - maximum courtyard width and breadth 13 m
  - area of cluster court shall not be less than 36m^2
- Clusters are typically designed around courtyards

Indicative of low-rise (G+3) development

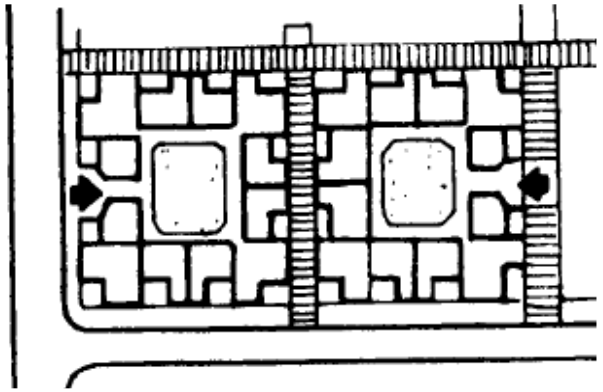
Key Highlights: IS 13727: 1993, Requirements of Cluster Planning for Housing – Guide



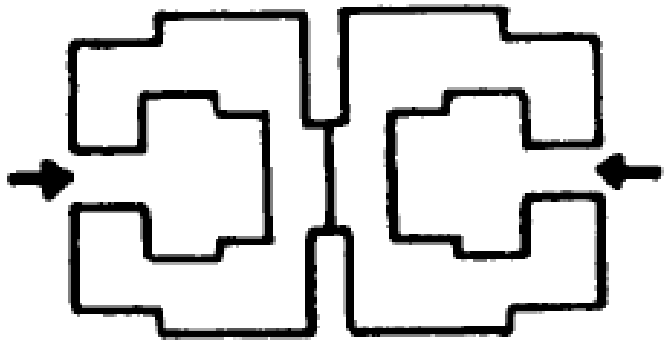
Cluster Group Housing



Cluster Court Town House

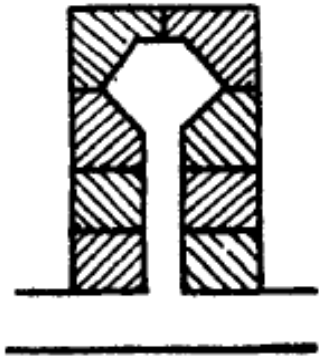


Independent Cluster

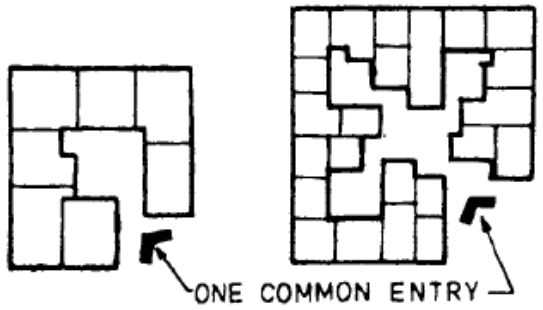


Back-to-back Cluster

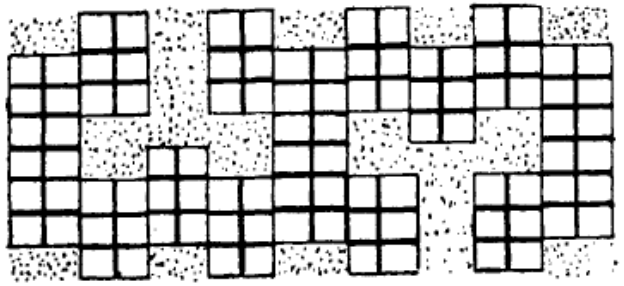
Interlocking Cluster



Cul-de-sac Cluster



Closed Cluster



Open Cluster

Key Highlights: ECO-NIWAS Samhita

- Applicable to residential buildings developed on minimum plot area of 500 m^2
- Code acknowledges building envelope as central to
  - maintaining thermal comfort,
  - improving energy efficiency, and,
  - reducing life cycle environmental impact

Key Highlights: ECO-NIWAS Samhita

Openable Window-to-Floor Area Ratio (WFR_{op})
Referenced from NBC 2016

Climate Zone	Climatic zone Minimum WFR_{op} (%)
Composite	12.50
Hot-Dry	10.00
Warm-Humid	16.66
Temperate	12.50
Cold	8.33

Visible Light Transmittance (VLT)
Referenced from NBC 2016

Window-to-wall ratio (WWR)	Minimum VLT
0–0.30	0.27
0.31–0.40	0.20
0.41–0.50	0.16
0.51–0.60	0.13
0.61–0.70	0.11

Key Highlights: ECO-NIWAS Samhita

- Code advises
  - WWR ≤ 0.15 (or at least limit to 0.40), and,
  - VLT ≥ 0.4
- Envelope Performance
  - Maximum Thermal Transmittance of Roof: 1.2 $W/m^2.K$
  - Residential Envelope Transmittance Value (except roof) limit 15 W/m^2
  - RETV is not applicable for Cold climate
  - Maximum Thermal transmittance for Cold climate (all surfaces except roof): 1.8 $W/m^2.K$
- References NBC 2016 for guidelines for enhancing natural ventilation

Key Highlights: SVAGRIHA

- Applicable to,
  - stand-alone buildings
  - developments with built up area up to 2,500 m^2
- CR#2
  - Integrate at least 2 passive design measures
- CR#3:
  - Maximum allowable WWR 60%
  - Meet/exceed daylit area of 25% (As/ECBC 2007 and references Daylight Factors from SP41)
  - Minimum insolation reduction (over base case)

Points	Composite/Warm & Humid/Hot & Dry	Moderate*
1	30%	10%
2	45%	20%
3	60%	30%

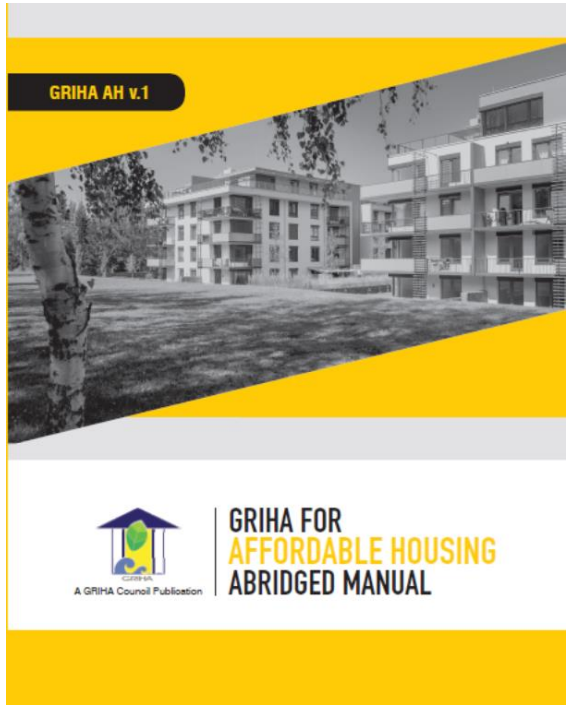
* Moderate refers to Temperate climate.

Key Highlights: SVAGRIHA

- CR#5
  - Maximum allowable Thermal Load (in W/m^2). Includes external and internal gain sources.

Climate Zone	City	> W/m^2 (1 point)	> W/m^2 (2 points)
Moderate	Bengaluru	135	115
Hot-Dry	Jodhpur	135	110
Composite	Allahabad	165	125
Composite	New Delhi	135	115
Composite	Chandigarh	135	110
Composite	Hyderabad	125	110
Warm-Humid	Chennai	135	110
Warm-Humid	Pune	125	100
Warm-Humid	Kolkata	125	100
Warm-Humid	Mumbai	115	95

Key Highlights: GRIHA for Affordable Housing



- Applicable to developments approved as per PMAY guidelines
- CR#1
  - At least 2 passive design and low-impact site planning strategies
  - Demonstrate use of active, low-energy cooling/heating systems

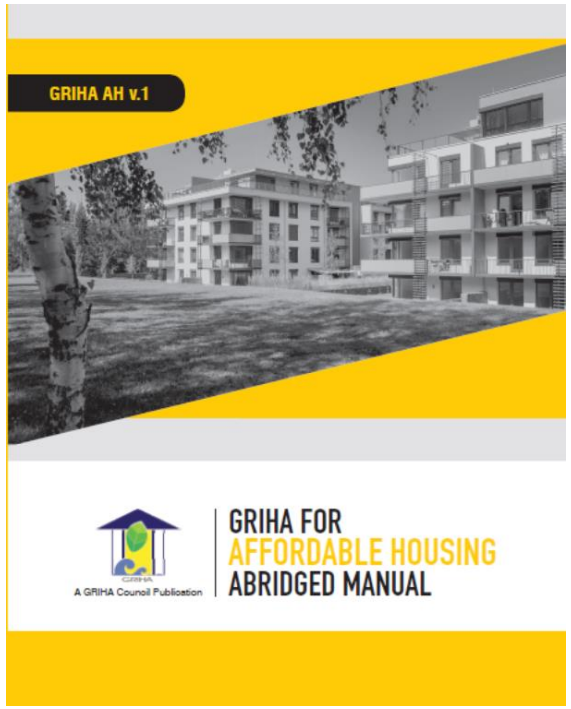
Key Highlights: GRIHA for Affordable Housing

- List of potential passive design measures

Strategy	Climate Zone	Strategy	Climate Zone
Wind tower	Co, HD, WH	Solarium/Sun space	Cold
Courtyard	Co, HD, Mo, WH	Openings (for gain)	Cold
Roof Pond (Evap cooling)	Co, HD	Air-lock	Cold
Reduced solar access	Co, HD	Glass covered atrium	Cold
Orientation (for X Vent)	Co, Mo, WH	Orientation (heat gain)	Cold
Thermal Mass	Co, Cold, Mo, HD, WH	Rock bed	Cold
Vegetation Cover	Co, HD, Mo	Light colored external	Co, HD, Mo, WH
Response to Topography	Cold, Co, Mo, HD	High ceiling/Ventilated roof	Co, WH
Light Shelf	Co, Cold, Mo, HD, WH	Shaded window	HD, Mo, WH
Buffer Spaces	Co, HD, Mo, WH	Shaded verandah	Co, HD, WH
Cool Roof	Co, Cold, Mo, HD, WH	Solar chimney	HD, WH
Trombe Wall	Cold	Passive evap cooling struct	Co, HD
Direct Solar Gain	Cold		

Cold: Cold | **Co**: Composite | **HD**: Hot Dry | **Mo**: Moderate (or Temperate) | **WH**: Warm Humid

Key Highlights: GRIHA for Affordable Housing

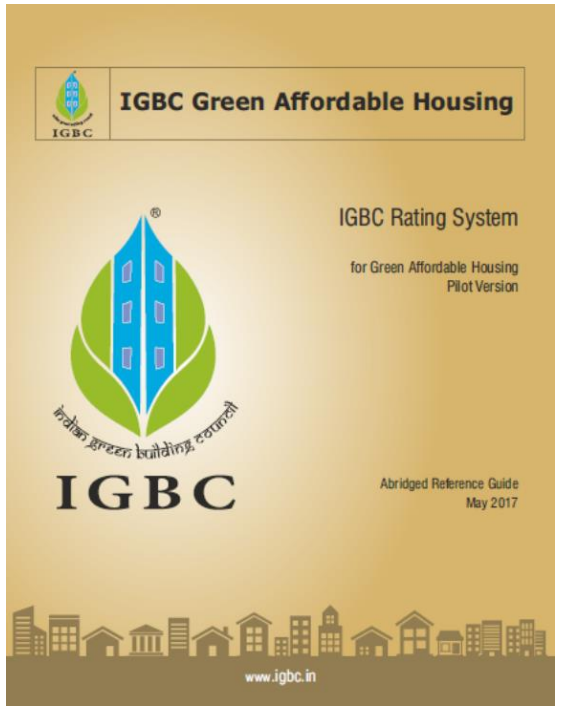


- CR#2
  - Mitigate Urban Heat Island Effect (UHIE): SRI > 0.5
- CR#6
  - Thresholds for allowable peak envelope gain

Climate Zone	Peak Envelope Heat Gain Factor (W/m^2) (2 points)
Composite	55
Hot-Dry	50
Warm-Humid	40
Moderate	30

- CR#8
  - Minimum 25% area meeting the UDI requirements for at least 90% of daylight time

Key Highlights: IGBC Affordable Housing

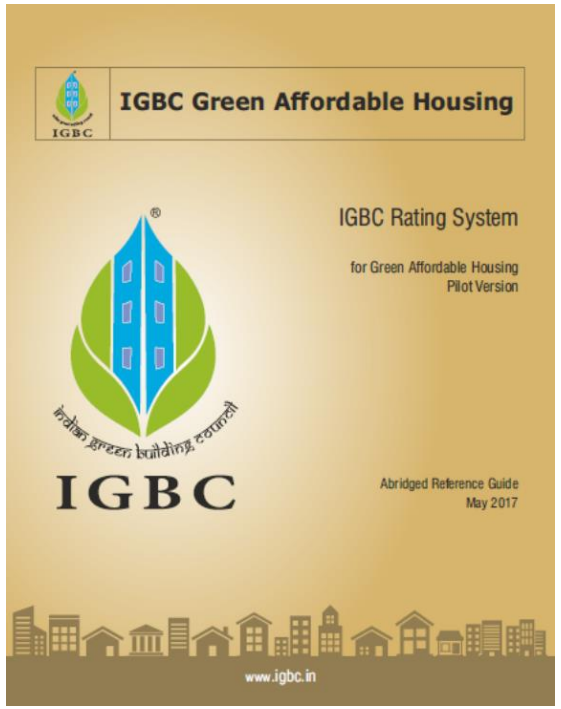


- Applicable to housing projects with at least 70% dwelling units with maximum carpet area of 60m^2.

	Maximum 'U'-Value of the overall assembly (W/m^{2}K)		
Climate Zone	Wall	Roof	Glazing
Composite	2.5	1.2	5.7
Hot and Dry	2.5	1.2	5.7
Warm and Humid	2.5	1.8	5.7
Moderate	1.1	1.2	5.7
Cold	2.5	1.2	-

	Maximum SHGC Value	
Climate Zone	WWR < 20%	WWR < 20%
Composite	0.50	0.42
Hot and Dry	0.50	0.42
Warm and Humid	0.50	0.42
Moderate	0.60	0.48
Cold	0.80	0.80

Key Highlights: IGBC Affordable Housing

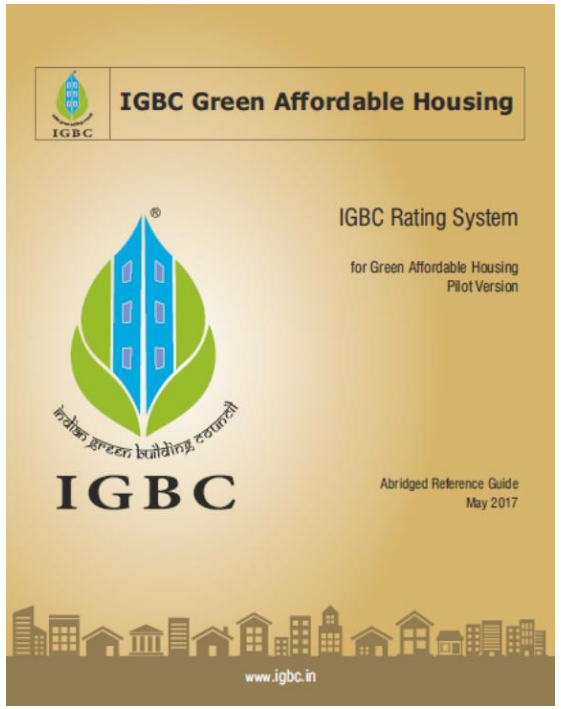


- Daylight Compliance Approach
  - Option 1
    - Simulation based approach demonstrating 110 lux for more than 50% of regularly occupied spaces with clear sky condition on Sep 21, 12 PM at 2'6" height.
  - Option 1
    - Meet or exceed glazing factor requirements for regularly occupied spaces.
    - Constant for vertical and horizontal window surface are 0.2 and 1.0 respectively
    - Exclude windows that are obstructed from daylight calculations

$$Glazing\ Factor = {(Window\ Area \times Visible\ Transmittance \times Constant \times 100)}/{Floor\ Area}$$

Type of Regularly Occupied Space	Minimum Glazing Factor (GF)
Living/Bed Room	1
Multi-purpose Room	1
Kitchen	2
Note: For other regularly occupied spaces which are not listed in the table above, a minimum glazing factor of 1 should be achieved.	

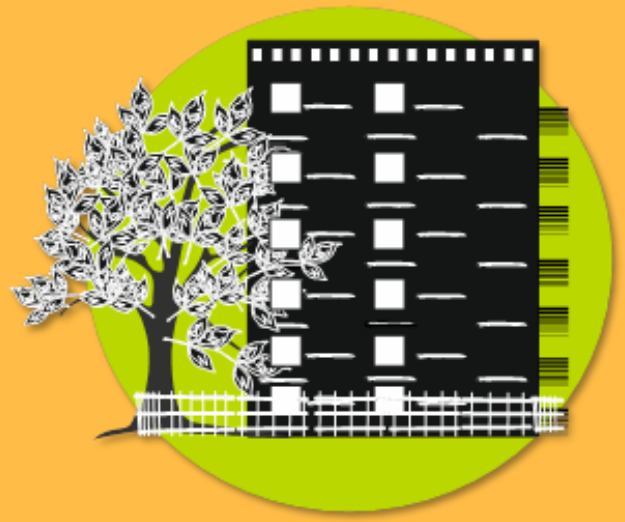
Key Highlights: IGBC Affordable Housing



- Ventilation requirements are specified as
  - Net openable area as a percentage of floor area
  - Minimum exhaust requirement

Space type	Net openable area as percentage of total carpet area [100 X Openable Area/Total Carpet Area]
Living Room	10%
Kitchen	8%
Bathrooms	4%

Space Type	Floor Area	Minimum Airflow
Bathroom	≤ 4.64 m^2 (50 ft^2)	50 cfm
Kitchen	≤ 9.3 m^2 (100 ft^2)	100 cfm



Standards and Codes : Global Context

Analysis of Thermal Comfort requirements in context of global Standards and Codes.

Global Context – Standards and Codes

Image by Clker-Free-Vector-Images from Pixabay

- Building Codes:
  - Australia: Building Code of Australia (Vol 2)
  - Singapore: Code for Environmental Sustainability of Buildings
  - South Africa: SANS 204: Energy Efficiency in Buildings
  - Spain: Código Técnico de la Edificación
  - US (California): Building Energy Efficiency Standards for residential and Non-residential Buildings
  - Brazil: NBR 15220-3: Thermal performance in buildings. Part 3: Brazilian bioclimatic zones and building guidelines for low-cost houses
  - EU Member states
  - Malaysia: MS 2680-2017: Energy efficiency and use of renewable energy for residential buildings - Code of practice
- Thermal Comfort Standards
  - ASHRAE 55: Thermal Environmental Conditions for Human Occupancy
  - ISO 7730: Ergonomics of the Thermal Environment
  - CEN 16798: Energy Performance of Buildings – Ventilation for Buildings
  - ISSO 74: Thermal Comfort Regulatory Document
  - CIBSE TM 52: The Limits of Thermal Comfort
  - GB/T 50785: Evaluation Standard for Indoor Thermal Environment in Civil Buildings

Global Context – Standards and Codes

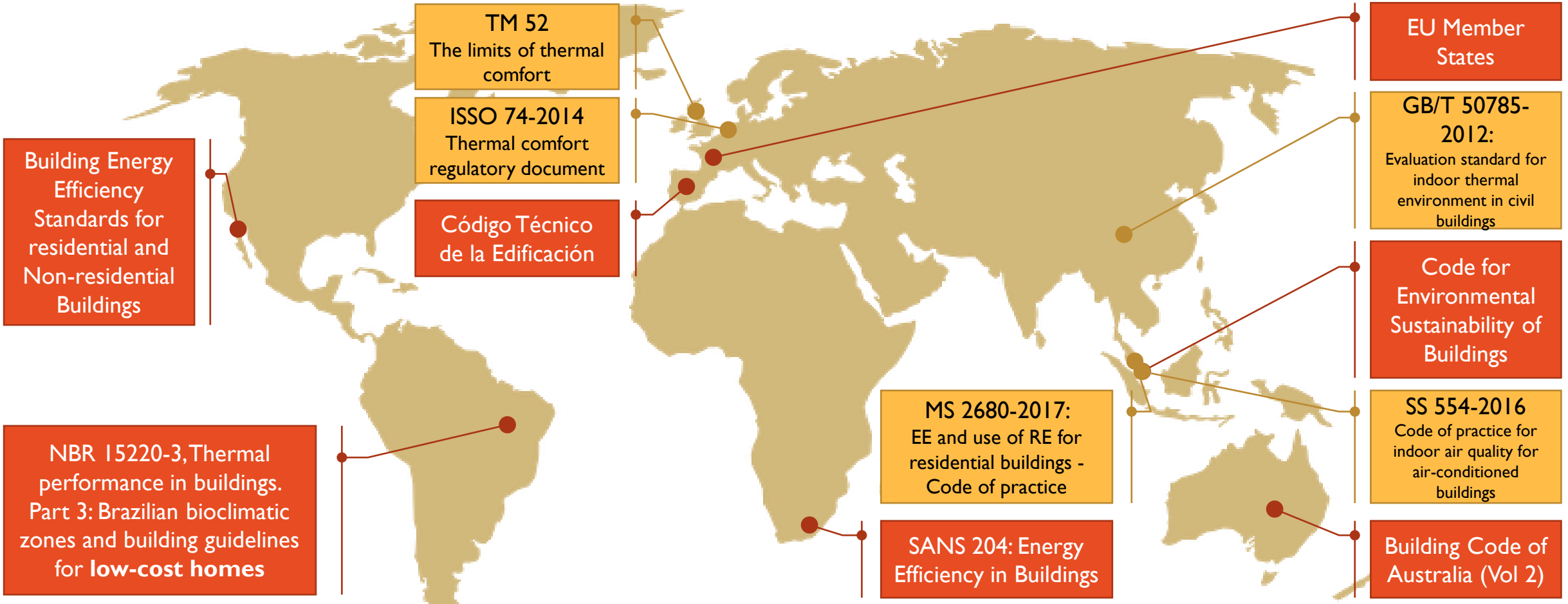


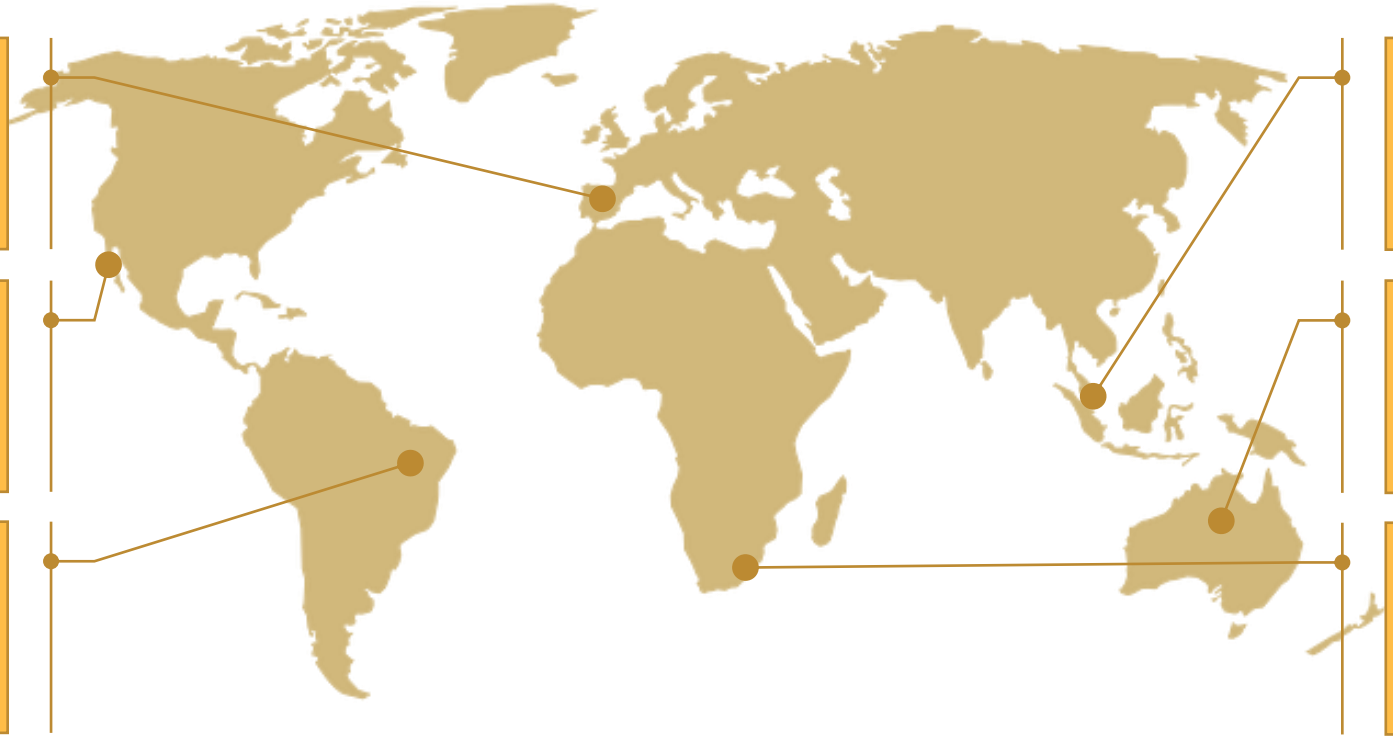
Image by Clker-Free-Ve

Envelope and ventilation requirements as proxy for Comfort

Spain
Code prescribes:
- max conductance for envelope
- **max value for the building's global heat transfer coefficient 'K lim [W/m²K]'**

California (USA)
Code prescribes:
- maximum distance from an operable window as a function of ceiling height
- Opening size at least 4% of floor area.

Brazil (Building Guide)
Guidelines for 8 bioclimatic zones outlined:
- opening for ventilation (min 10% of area)
- **envelope thermal properties- delay 6.5 h**
- **Passive design strategies**



Singapore
Code prescribes
- **Max RETV of 25 W/m²**
- Establish satisfactory natural ventilation design through simulation or testing or provision for Cross Ventilation

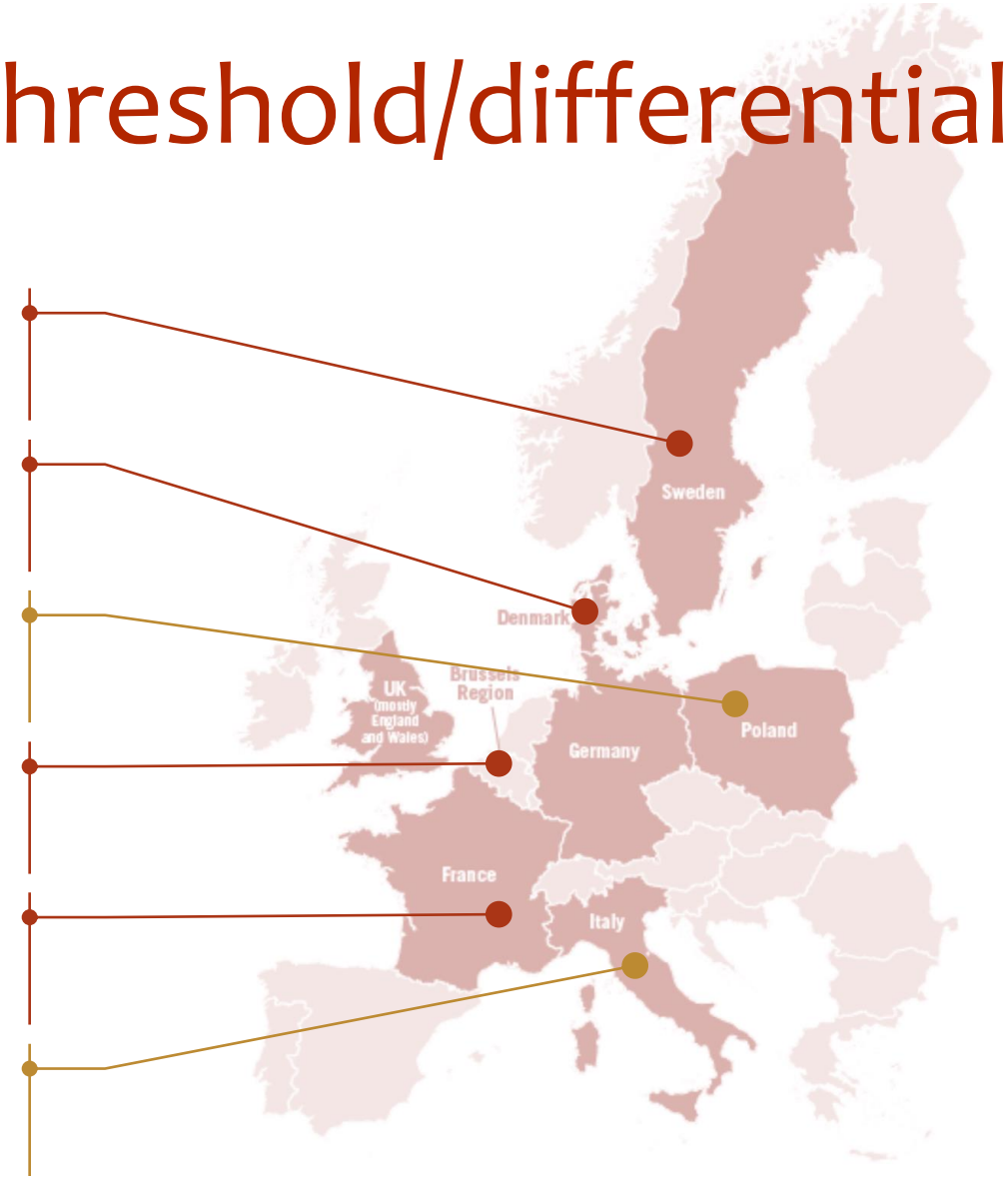
Australia
Code prescribes
- minimum R-values & SHGC for envelope components, and total load limits
- window opening area for ventilation,
- provision of ceiling fan and evap cooler.

South Africa
Code prescribes
- **mini permissible CR-value for walls**
- minimum R-values & SHGC for envelope assemblies, considering climate & direction of heat flow.

Image by Clker-Free-Vector-Images from Pixabay

Comfort evaluated as threshold/differential

Temperature Threshold & Differential	**Sweden** Recommended Minimum operative temperatures <=18°C (relaxed to 20°C for old people) & difference b/w rooms <5 °C.
Temperature Threshold + Allowance	**Denmark** Indoor temperatures, **(1)** Not more than 100 hours above 26°C and **(2)** Not more than 25 hours above 27°C.
Heat Gain Threshold	**Poland** Equation to limit surface area of windows prescribed. Upper limit for solar gains in Summer specified at 0.35.
Temperature Differential	**Brussels Region** Maximum difference between internal and external temperature should be between 5°C and 7°C (in summer).
Temperature Threshold	**France** TIC-the max. operative temperature should not exceed TIC_{ref} for more than 5 consecutive days. In NV zones TIC_{ref} is based on OT.
Transmittance and Thermal Mass	**Italy** **Wall**: YIE < 0.12 W/m^{2}K OR surface thermal mass > 230 kg/m2 **Floor/Roof**: YIE < 0.20 W/m2K **Window**: SF<0.5



Requirements specify comfort and envelope

UK

For non-air-conditioned dwellings, CIBSE specifies general indoor comfort temperatures.

- **Living areas** should be at an operative (maximum) temperature of **25°C**.
- **Bedrooms** should be at an operative (maximum) temperature of **23°C**, **noting that sleep may be impaired above an operative temperature of 24°C.**

As per TM 52:

- **Duration of Overheating**: Hours of exceedance ≤ 3% of Occupied hours
- **Severity of Overheating**: Weighted exceedance ≤ 6
- **Temperature Upper Limit (°C)**: $\Delta T > 4°C$

As per CIBSE Guide A

- Hours of exceedance ≤ 3% of Occupied hours

Germany

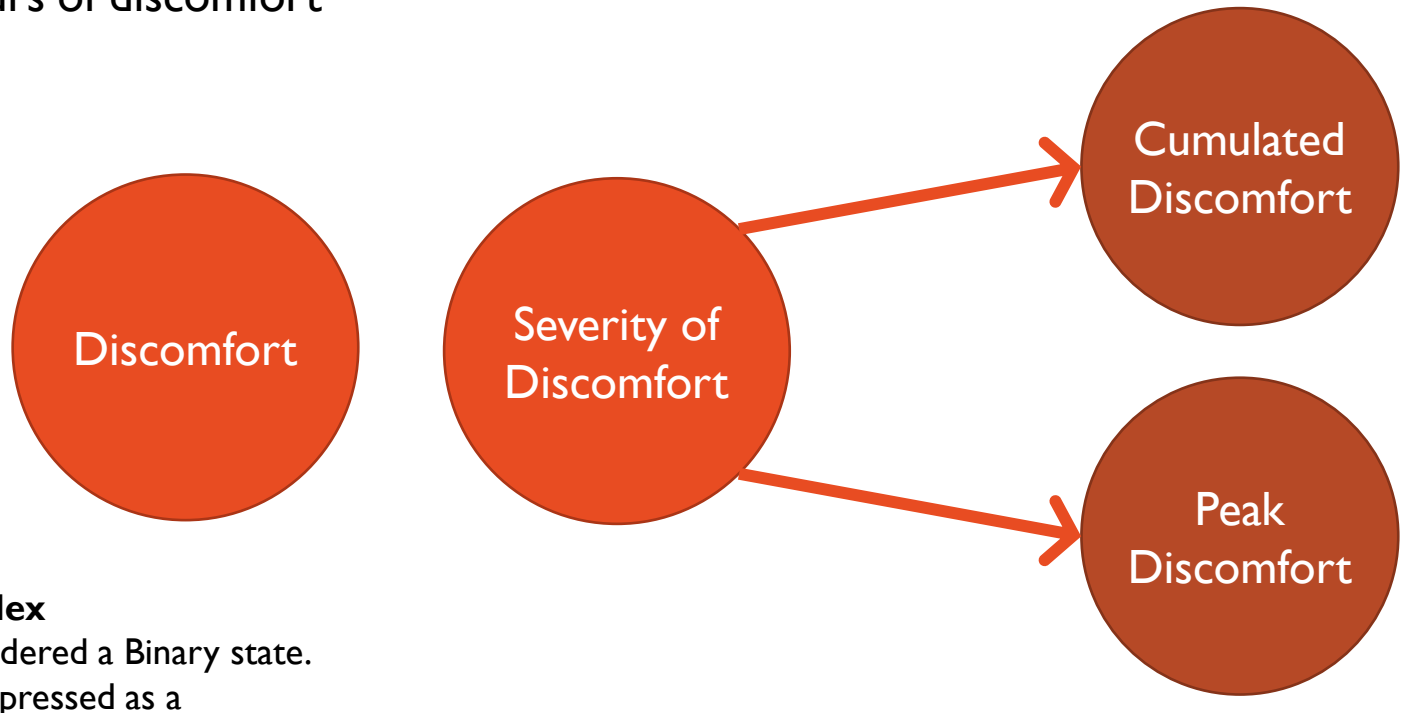
"Sonneneintragskennwert", an indicator of max solar gains must be checked for each room **to avoid overheating for more than 10% hours.** Recommended Indoor Temperature ranges (b/w 25-27 °C), thermal capacity of envelope and strategies vary depending upon climatic region (A, B or C)
Temperature in apartments and bathrooms should be at least 20 and 22 °C respectively.
Landlords are responsible for providing equipment to maintain conditions

Best practices across the globe

- Brazil: Thermal Performance Standard (ABNT NBR15220-3) is **based on Bio-climatic principles.**
- Sweden: **Minimum guarantee** of satisfactory thermal comfort required by Building Code.
- UK: Regulations identify **distinct comfort requirements in sleeping and living rooms.**
- Italy and South Africa: **Envelope performance requirements account for thermal capacity**
  - Italy utilizes periodic thermal transmittance (YIE) that accounts for thermal transmittance and decrement factor.
  - South Africa sets CR value for envelope, i.e. product of thermal capacity of wall and its thermal resistance
- Germany: Regulations require the **lessor to guarantee an indoor temperature** of at least 19 °C in winter.

Thermal Comfort Metrics

Hours of Exceedance
Eg: CIBSE TM 52 - 3% of occupied hours of discomfort allowed



Percentage Index
Comfort is considered a Binary state. Discomfort is expressed as a percentage of occupied hours outside a comfort threshold with respect to the total number of occupied hours.

Degree-Hours
Eg: EN 15251 Annex F – Weighting discomfort by the number of degrees above the comfort temperature.

Cumulative Index
Total accumulated discomfort as a sum of uncomfortable periods, typically hours.

Peak Discomfort
Heat stress experienced on peak day or peak periods.

Peak Temp/Peak Gain
Eg: Passive Survivability Credit, LEED Maintain a maximum (90°F/32.2°C) degree (the "Extreme Caution" threshold) heat index temperature during the hot season.

Thermal Comfort Standards – Suitability of Adaptive Models

	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		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
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	0	1		0	0
Comfort Indices - Operative temperature (Adaptive Comfort) for Mixed-mode operation or naturally ventilated building.	10.0 – 33.5	10.0 – 30.0	? – ?	15 – 34	18.0 – 30.0	? – ?	? – ?

Field studies are based in office context which may be more stringent context.

Applicable to Naturally Ventilated, Mixed Mode and Air-conditioned Buildings

Field Studies are representative of Indian physiology and climate.

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.*

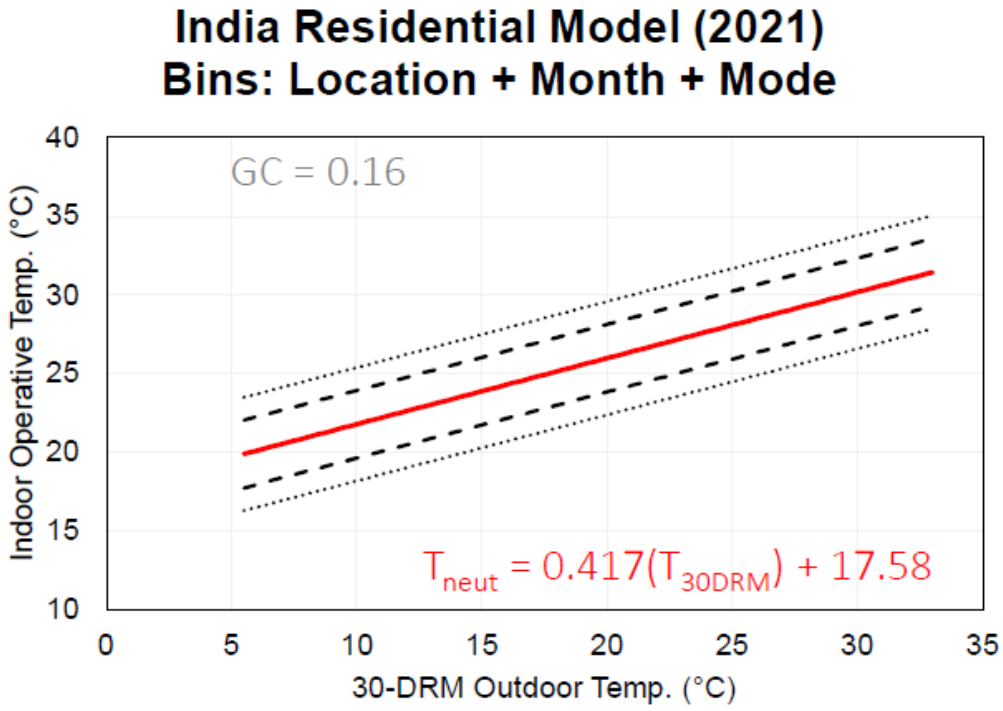
NBC Adaptive Model's applicability is more suitable to Indian context

	Indoor Operative Temperature in °C (Naturally Ventilated Buildings)																								
Adaptive Comfort Models	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
GB/T 50785									A	A	A	A	A	A	A	A	A	A	A	A	A				
ISO 17772, EN 16798	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A				
ISO 7730	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A							
ASHRAE 55 (80% Acceptability)	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
NBC 2016						A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A

Legend A Standard applicability

Note:
1. Thresholds for both summer and winter season have been considered.
2. Thresholds for residential application used wherever applicable.
3. Some values have been rounded up/down to the nearest integer.
4. For ISO 17772, EN 16798 comfort range has been considered only till Category III.
5. Comfort range for NBC 2016 has been referenced from IMAC model for Naturally Ventilated Buildings (Manu et al., 2016).

India Residential Model 2021



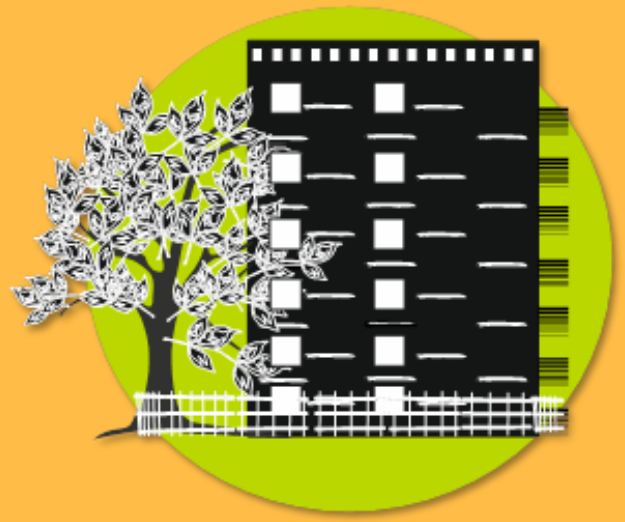
Field studies are from Residential context that is representative of all Indian Climate Zones

Study indicates wider range of temperature tolerance, Even more than displayed in NBC

80% Acceptability at ± 3.60 °C

90% Acceptability at ± 2.15 °C

Note: The India Residential Model has been developed under the IGEN-EERB project. This is currently un-published and a work under progress. This information is being presented for the purpose of Expert Consultation ONLY and may not be reproduced elsewhere.



Thermal Comfort Indices & Metrics

Analysis of Thermal Comfort requirements in context of global Standards and Codes.

Thermal Comfort Indices

Thermal Comfort Index	Suitability	Limitation
Indoor operative Temperature 	• Adaptive comfort models evaluate comfort based on Indoor Operative Temperature. • Available for evaluating comfort on multiple adaptive models • Amenable to computations of cumulative (degree discomfort hour) and point in time (peak discomfort) metrics.	• Does not account for personal factors like clothing, metabolic rate. However, field studies on which these adaptive models are based, account for personal factors as adaptation. • Unsuitable for air velocities higher than 0.5 m/sec
Tropical Summer Index 	• Compared to other indices (CET, ITS, WBGT, ECI, HIS, etc.), TSI has the highest correlation with Thermal Sensation Votes. • Based on field trials conducted in India in unconditioned setting. • Accommodates Relative Humidity and capable of accounting radiant asymmetry. • Amenable to computations of cumulative (degree discomfort hour) and point in time (peak discomfort) metrics.	• Field trials limited to a particular season, location and respondent group. • Does not account for personal factors like clothing, metabolic rate. However, field studies on which this index is based, account for personal factors as adaptation..

Thermal Comfort Indices & Associated Metrics

Thermal Comfort Index	Units	Peak Exceedance	Exceedance Hours	Exceedance Degree Hours
Operative Temperature (OT)	°C	Max and Min indoor OT recorded.	A value of indoor OT outside comfort band (established hourly using equations for adaptive comfort models) is considered uncomfortable.	The deviation in Indoor OT for the respective exceedance hour cumulated over the period of a year.
Standard Effective Temperature (SET)	°C	Max and Min SET recorded.	A value of SET outside comfort band (established for each hour) is considered uncomfortable. SET Comfort band as/LEED ranges between 12.2 – 30 °C.	The deviation in SET for the respective exceedance hour cumulated over the period of a year.
Tropical Summer Index (TSI)	°C	Max and Min TSI recorded.	A value of TSI outside comfort band (established for each hour) is considered uncomfortable. TSI Comfort band as/NBC ranges between 19 – 34 °C.	The deviation in TSI for the respective exceedance hour cumulated over the period of a year.

Thermal Comfort Metrics

Thermal Comfort Index	Unit	Metrics		
		Peak Exceedance	Exceedance Hours	Exceedance degree hours
Operative Temperature (OT)	^{o}C	Max and Min indoor OT recorded	Number of occupied hours Indoor OT is outside comfort band	Deviation in Indoor OT for the respective exceedance hour cumulated over a year
Tropical Summer Index (TSI)	^{o}C	Max and Min TSI recorded.	Number of occupied hours TSI is outside comfort band TSI Comfort band as/NBC ranges between 19 – 34 ^{o}C.	Deviation in TSI for the respective exceedance hour cumulated over year

Thermal Comfort Indices & Associated Metrics

Thermal Comfort Index	Units	Peak Exceedance	Exceedance Hours	Exceedance Degree Hours
Operative Temperature (OT)	°C	Max and Min indoor OT recorded.	A value of indoor OT outside comfort band (established hourly using equations for adaptive comfort models) is considered uncomfortable.	The deviation in Indoor OT for the respective exceedance hour cumulated over the period of a year.
Standard Effective Temperature (SET)	°C	Max and Min SET recorded.	A value of SET outside comfort band (established for each hour) is considered uncomfortable. SET Comfort band as/LEED ranges between 12.2 – 30 °C.	The deviation in SET for the respective exceedance hour cumulated over the period of a year.
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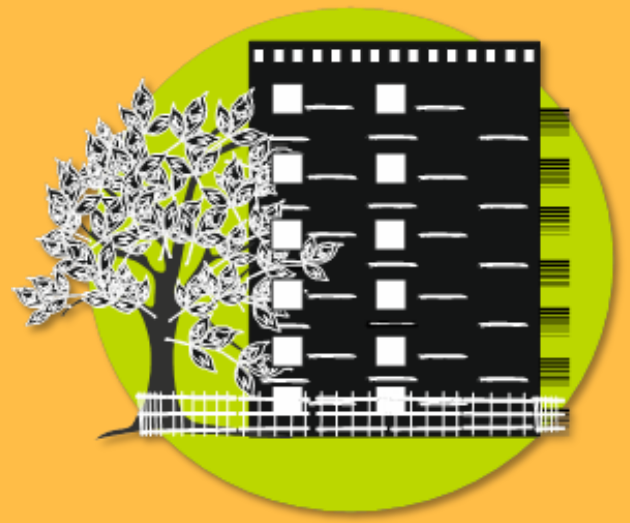

Thanks!