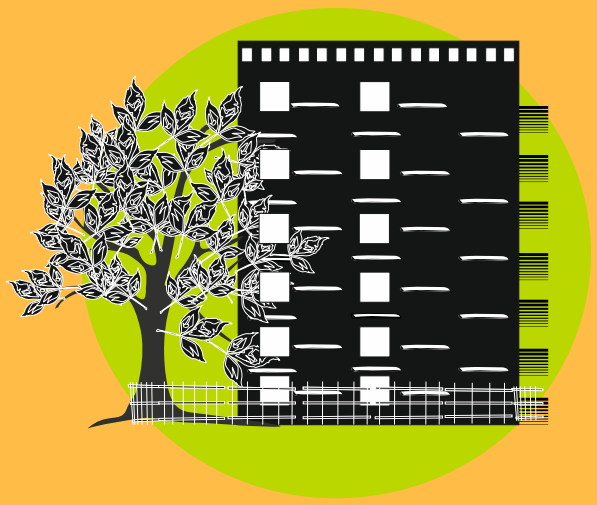

REPORT ON BENCHMARKING OF DESIGN GUIDELINES

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
August 31, 2021	0		Piyush	Gurneet

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.

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Contents

Abbreviations

AAC	Autoclaved Aerated Concrete	LCC	Life Cycle Cost
CFD	Computational Fluid Dynamics	MM	Mixed Mode
CLSS	Credit Linked Subsidy Scheme	NV	Natural Ventilation
DRY	Design Reference Year	OVE	Optimum Value Engineering
ECBC	Energy Conservation Building Code	PMAY (U)	Pradhan Mantri Awas Yojana (Urban)
EU	European Union	RTB	Rat Trap Bond
GBPN	Global Buildings Performance Network	SDC	Swiss Development Cooperation
GCCDS	Gulf Coast Community Design Studio	SIP	Structural Insulated Panel
IAQ	Indoor Air Quality	TMY	Typical Meteorological Year
ICAP	India Cooling Action Plan	UHI	Urban Heat Island
ICF	Insulated Concrete Form		
IMAC	Indian Model for Adaptive Comfort		
LECaVIR	Low Energy Cooling and Ventilation in Indian Residences		

1 Intent and expected outcomes

This report includes analyses existing design guidelines with special emphasis on thermal comfort. Based on program requirements, the benchmarking of these guides is qualitative in nature, i.e., the intent is to deconstruct the structure and content of existing guidelines with respect to target audience and identify,

1. key components and aspects of design guideline document,
2. key criteria to implement comfort, and,
3. features for organization and design of guidebooks.

The synthesis of existing design guidelines is expected to inform and shape the development of comprehensive design guidelines for thermally comfortable residential buildings in the Indian context. This document will yield a blueprint for the development of design guidelines.

The manner of conducting this research, the analyses and above-mentioned outcomes are outlined in the subsequent sections of this report.

2 Research methodology

Extensive secondary research has been undertaken to identify design guidelines from India and other parts of the world. The research identified key aspects that were essential for benchmarking. These are identified and explained in detail. Desk research found that design guidance has been propagated as Design Guidelines, Research Papers, White Papers and Reports. These guides are primarily issued by think tanks, research and development labs, and development and government agencies. A review of these documents, especially with respect to the key aspects led to shortlisting of guides and documents for further review. The detailed review is a compilation and analyses of the content. Finally, the synthesis of the analyses are the takeaways that are expected to shape the guidebooks. A brief overview of secondary research process is outlined in Figure 1.

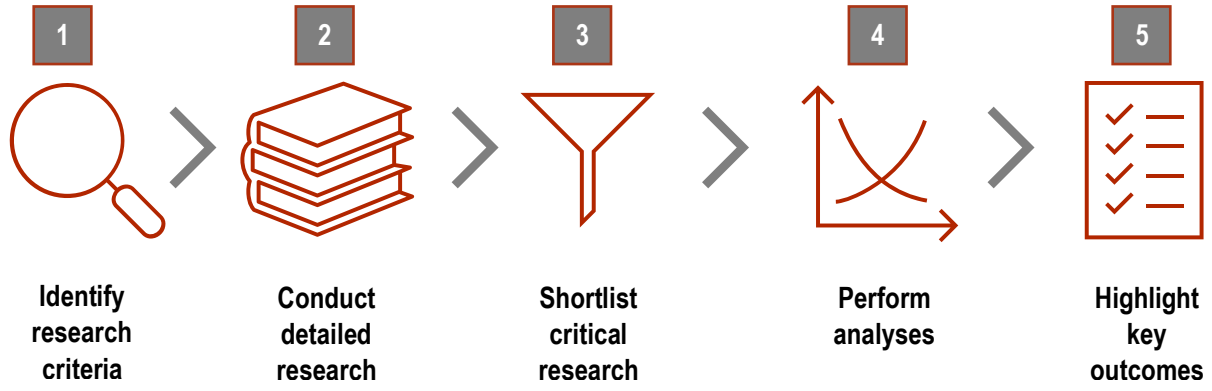


Figure 1 Overview of secondary research process.

An intensive review has been undertaken to direct the development of design guidelines. Since, there are few examples converging on thermal comfort in residential context, this review combines outcomes from design guidelines on subjects including passive design, thermal comfort, urban design and alternative housing practices. Guidebooks from these wider themes were reviewed from across the globe. Of these, the ones having bearing on development of design guide have been shortlisted and presented in this report for consideration in design and planning of guidebooks. Further initial analyses revealed that these guidebooks catered to various user groups such as Designers, Contractors, Construction workers, Policy makers and End users. This has also been a key shortlisting

criterion. This preliminary review led to the identification of key aspects that are critical for analysing the shortlisted guidebooks.

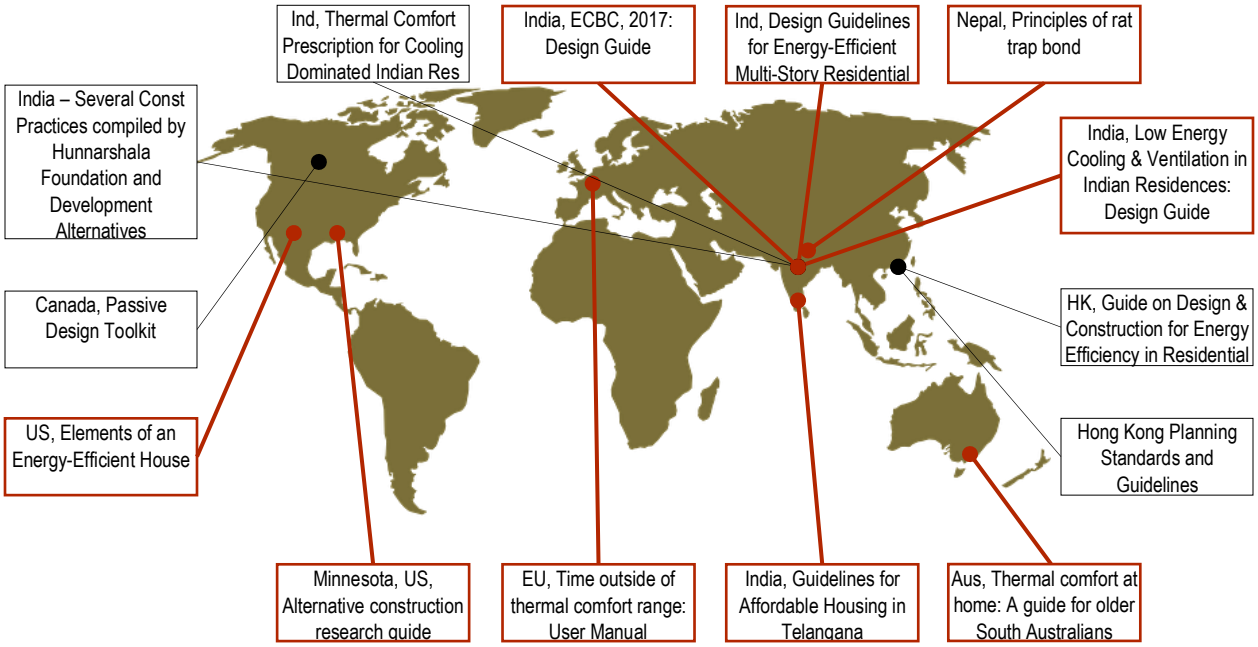


Figure 2 Design guidelines relevant to thermal comfort from across disciplines of Building Design, Alternative Construction Practices, Urban Design, Energy Efficiency, etc, have been analysed from across the globe.

2.1 Key aspects

In line with the program brief, the Design guide for thermal comfort has been envisioned as a document that facilitates, low-cost and passive design principles that utilize local materials to enhance thermal comfort without conventional mechanical cooling. Further, these guides are envisaged to primarily cater to design professionals and construction agencies in the Indian context. Keeping this in mind the desk research focused on the following key aspects while shortlisting design guides for detailed review.

Applicability

The desk research identified the applicability in terms of:

- Subject matter (energy efficiency, thermal comfort, passive design, low-cost design, etc.)
- Geographic context, i.e. applicability to country and climatic context
- Typological context (residential and various residential sub-types – units, clusters, etc.)
- Macro context, i.e. urban design related issues that may translate to siting guidance
- User groups, i.e. design professionals, home-buyers, construction agencies or policy and planning agencies

Design

Design aspects pertain to passive design principles focused on form, orientation, shading, and choice of materials. In addition, design for natural ventilation and design features for cooling/heating the building through natural means have been outlined.

Construction

Construction detailing and quality is critical to meet thermal comfort performance in buildings. Furthermore, passive design features (say, rat-trap bond, vaulted ceiling, trombe wall, filler slab, etc.) aren't conventionally practiced. The analyses highlights guidelines that outline best construction practices for such alternative practices.

Operation, Maintenance and Monitoring

Adaptive thermal comfort principles expressly tie outdoor conditions and thermal comfort perception. Therefore, maintaining thermal comfort in a dynamic environment requires a control strategy. The analyses reviews design guidelines for operating, maintaining, and monitoring of space and its various components to maintain thermal comfort.

Fundamentals

The guide will provide necessary details for designing, constructing, operating, maintaining, and monitoring for optimal thermal comfort performance. However, in absence of understanding of fundamentals of building physics and principles of thermal comfort, these guides run the risk of being misinterpreted leading to implementation challenges. Therefore, sound fundamentals to back the proposed guidelines are critical for successful uptake of guidelines.

Case studies and examples

Along with fundamentals, case studies, and examples complement the design guidelines and facilitate uptake of guidelines.

Features (to aid interpretation)

Finally, the organization of guidelines, highlighting the key extracts, presenting data as visual infographics and other features aid in understanding and interpretation of guides. The detailed review outlines key features of design guidelines.

3 Review of existing design guides

The short-listed design guidelines are presented as sub-sections. The detailed review is preceded by a summary of analyses.

3.1 EU Publication (v1.0, 2020) Time outside of thermal comfort range: User manual, overview, instructions and guidance (Dodd et al., 2020)

Figure 3 Technical report on indicator 4.2: Time outside thermal comfort range, issued by the European Commission.

Overview

The guidelines focus on health, *comfort*, *life cycle cost* and *potential future risks to performance*. It covers six macro-objectives; energy, material use and waste, water and indoor air quality.

Applicability

- Office and residential buildings
- Guidelines are applicable to buildings having full or mixed mode mechanical systems.

Reference to standards

Refers Annex F of EN 15251 (for thermal performance category), Annex A.2 of EN 16798-1 (for dynamic simulation method), ISO EN 52000-1 (for advanced calculation method), EN ISO 7730 (for PPD assessment) and Annex G of EN 13790 (for default data)

Country and climate

European Union, various climatic zones.

Target Audience

Architect, service engineers, energy auditor quantity surveyor, building owner/operator, and energy/sustainability consultants.

Design and process

- Design process: Identifies the design process as conceptualization, detailed design and post occupancy monitoring. The manual does not explicitly outline an integrated design process that involves all disciplines.
    - Goal Setting: Guidelines suggest *determining the required level of thermal comfort necessary/required for the spaces within the building*.
    - Conceptualization: Guidelines recommend identifying and assessing risk factors before design. Guidelines outline site related factors such as, location, orientation, obstructions and urban microclimate as potential risk factors.
    -
- Passive design principles
    - Guidelines outline building design factors such as glazing ratio, insulation, thermal mass, shading and solar glass as key determinants of solar gain.
    - *Guidelines outline high performance envelope, natural ventilation and integrated heating and cooling design as key measures to maintain thermal comfort and minimize impact of seasonal swings.*

    - Guidelines recommend nature-based solutions vegetation, water features etc. for improving thermal performance.
- Design Evaluation
    - *Guidelines require calculating the time out of (comfort) range using established methods. For residential developments, calculations may be performed for representative selection of designs.*
- For adaptive reuse, renovation and retrofits, the guidelines suggest gathering detailed information on; orientation and exposure of roofs, floor layouts, ventilation pathways, existing solar control features and existing technical features.

Construction technique
No explicit mention.

Space cooling, heating, and exhaust
Nature based solutions recommended, but no other mention of strategies for cooling, heating or exhaust.

Operation, maintenance, and monitoring
No explicit mention.

Case studies
Not included.

Features (to aid interpretation)
The User Manual provides checklists and indicators. It defines levels based on user readiness (or project stage):

- Level 1 for assisting users new to sustainability in design conceptualization,
- Level 2 for assisting users in developing detailed design and construction based on performance assessments.
- Level 3 for Advanced users who are ready to apply and use sustainability indicators on as-built and in-use facilities using commissioning, testing, and metering.

Special remarks
- In addition to health and, thermal and visual comfort, it includes guidelines for Indoor Air Quality (IAQ) performance, acoustics, water consumption reduction, adaptive reuse and Life Cycle Costs (LCC).
- Focuses on risk of extreme weather events.
- Recommends using Design Reference Year (DRY) weather data. In case these are not available Typical Meteorological Year (TMY) weather data may be used.
- Recommends using site specific weather data to reflect Urban Heat Island (UHI) effects in specific locations.

3.2 Thermal comfort at home: A guide for older South Australians (Soebarto et al., 2021)

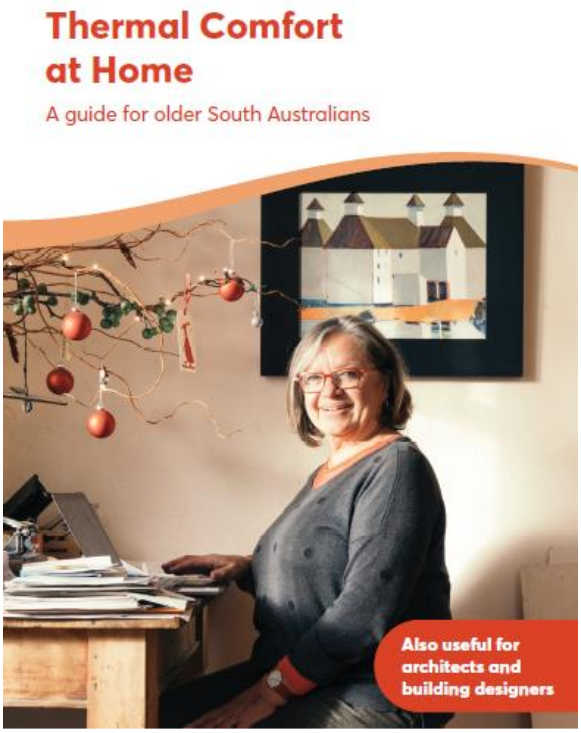
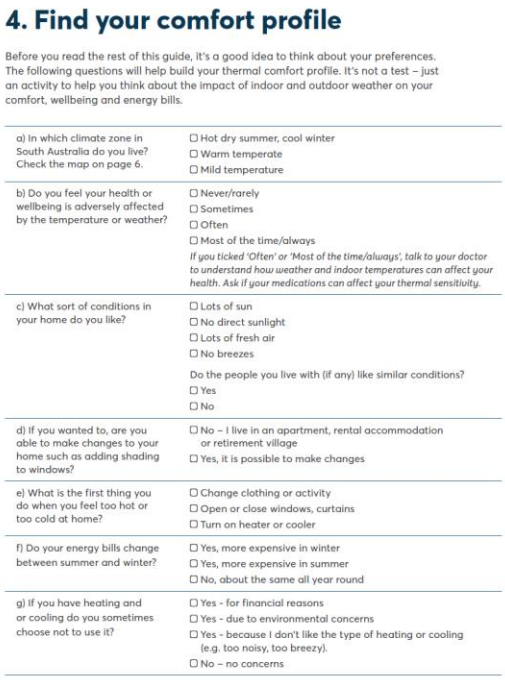


Figure 4 A guide for assisting the aging South Australians in maintaining thermally comfortable homes for overall health and well-being



4. Find your comfort profile

Before you read the rest of this guide, it's a good idea to think about your preferences. The following questions will help build your thermal comfort profile. It's not a test – just an activity to help you think about the impact of indoor and outdoor weather on your comfort, wellbeing and energy bills.

a) In which climate zone in South Australia do you live? Check the map on page 6.	☐ Hot dry summer, cool winter ☐ Warm temperate ☐ Mild temperature
b) Do you feel your health or wellbeing is adversely affected by the temperature or weather?	☐ Never/rarely ☐ Sometimes ☐ Often ☐ Most of the time/always *If you ticked 'Often' or 'Most of the time/always', talk to your doctor to understand how weather and indoor temperatures can affect your health. Ask if your medications can affect your thermal sensitivity.*
c) What sort of conditions in your home do you like?	☐ Lots of sun ☐ No direct sunlight ☐ Lots of fresh air ☐ No breezes Do the people you live with (if any) like similar conditions? ☐ Yes ☐ No
d) If you wanted to, are you able to make changes to your home such as adding shading to windows?	☐ No – I live in an apartment, rental accommodation or retirement village ☐ Yes, it is possible to make changes
e) What is the first thing you do when you feel too hot or too cold at home?	☐ Change clothing or activity ☐ Open or close windows, curtains ☐ Turn on heater or cooler
f) Do your energy bills change between summer and winter?	☐ Yes, more expensive in winter ☐ Yes, more expensive in summer ☐ No, about the same all year round
g) If you have heating and or cooling do you sometimes choose not to use it?	☐ Yes - for financial reasons ☐ Yes - due to environmental concerns ☐ Yes - because I don't like the type of heating or cooling (e.g. too noisy, too breezy). ☐ No – no concerns

Figure 5 Structured questionnaire for understanding comfort expectations

Overview

This guide has been funded by the Australian Research Council for improving thermal environment of housing for older Australians. This guide,

1. outlines the fundamentals of thermal comfort,
2. facilitates understanding of thermal comfort and comfort expectations,
3. presents strategies for improving comfort by behaviour modification, design and mechanical comfort systems, and lastly,
4. presents six avatars who represent the aging population and solves their comfort issues within constraints and to their expectations.

Applicability

The guide is applicable to residential developments in South Australia. In particular this guide focuses on thermal comfort, health and wellbeing of older population living in South Australia. The guidance is for building new homes and retrofitting existing homes.

Country and climate

Australia. South Australia is defined by 3 climate types: hot-dry summer and cool winter, warm temperate, and mild temperate.

The authors highlight that the guidelines are also applicable to other parts of Australia with similar climate.

Target Audience

Homeowners. Also useful for Architects and Building Designers.

Design and process

Since the guideline is targeted towards homeowners the process focuses on first understanding comfort expectations through a structured questionnaire, and second by understanding space through energy review. Understanding the orientation of windows, hot and cold spots, etc., constitute as review/audit. Sources of relevant toolkits to facilitate the review are included.

Design principles and building specifications are included. Key design strategies include shading, ventilation, and draught sealing.

Construction techniques and practices

There is no explicit guidance on construction techniques and practices.

Space cooling, heating, and exhaust

Guidance has been provided on choice of heating and cooling equipment. With respect to cooling, the guide also explains low-energy cooling systems like ceiling fans and evaporative coolers. The provided guidance is for selection of equipment and not design. The guidance outlines the function of comfort systems, their applicability and key considerations for their selection.

Operation, maintenance, and monitoring

- The guide makes recommendations for use of spaces by time-of-year and time-of-day to maximize comfort.
- Information such as periodic maintenance and servicing of equipment has been outlined.
- A brief overview of practical (from homeowner's perspective) equipment controls have been discussed. Further, the guide points towards other relevant guides issued by the government for heating and cooling equipment.

Case studies

Six case studies have been outlined. Refer the next section for more details.

Features (to aid interpretation)

Along with providing guidance, this project collected data from older South Australians through telephone surveys, focus group discussions, detailed occupant surveys and monitoring 57 homes across 3 climate zones for 9 months. This data included personal factors such as income, age, living arrangement, health and wellbeing status, housing type and heating and cooling arrangements. Based on statistical analyses of personal factors, this dataset has been reduced to 6 clusters. Each cluster is represented as a persona with distinct thermal comfort scenarios. These scenarios are discussed as case studies where the occupant's housing conditions, their expectations/goals, proposed solution and outcomes are discussed.

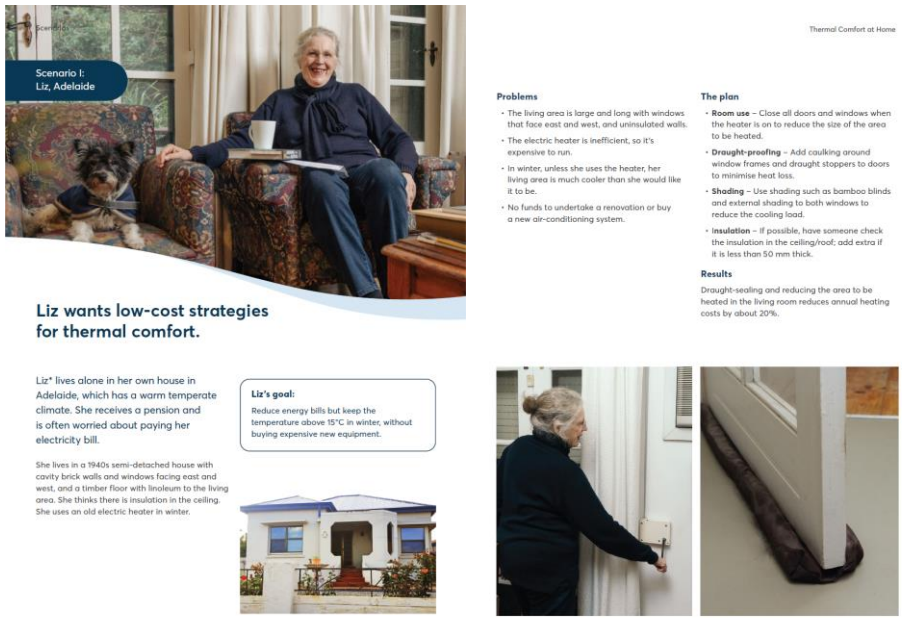


Figure 6 Liz is one of the six personas that is representative of the South Australian aging population.

Age-appropriate behavioral aspects and other tips from experience have been included in the guidance to aid occupants in meeting thermal comfort. Some aspects of this guidance are climate specific. This is most practical as these are easy to incorporate in daily life.

Special remarks

The study found that perception of thermal comfort correlated strongly with the wellbeing of the occupants. To quote the study, "The study found that *the perception of having 'very good' health and wellbeing occurred mostly when the thermal environment was perceived by the participants to be comfortable and satisfactory*. However, it also discovered some *concerning outcomes*. *Some participants expressed feeling thermally comfortable at temperatures lower than 15°C or higher than 28°C, but when researchers asked about their wellbeing (without the participants knowing the temperature at the time), they actually perceived wellbeing to decline.*"

3.3 Design guidelines for energy-efficient multi-story residential buildings (*BEE*, 2014)

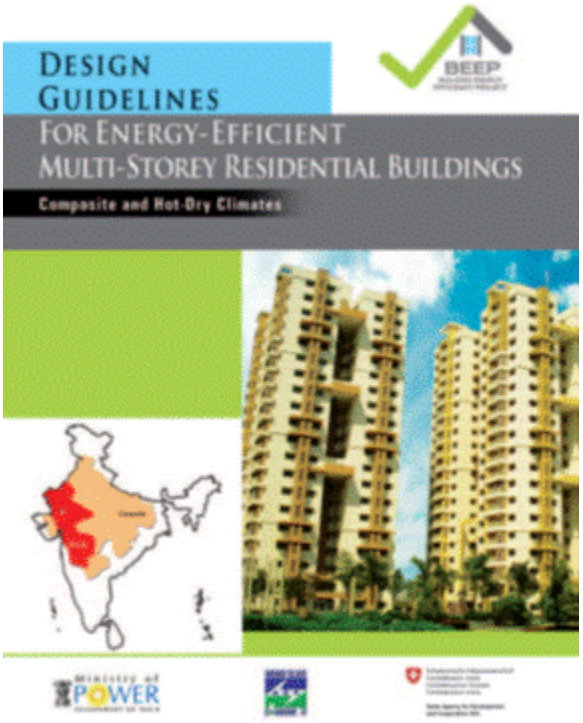


Figure 7 Design guidelines for energy efficient multi-story residential buildings developed as part of BEEP initiative

Overview

The guidelines focus on energy efficiency with *special emphasis on thermal comfort*. The guidelines are based on dynamic thermal simulation analyses. The thermal simulations are complemented with survey and detailed monitoring studies from sample households. The outcomes are detailed in six sections that include **(1)** building massing and spatial configuration, **(2)** building envelope, **(3)** building space cooling, **(4)** appliances, **(5)** common services, and **(6)** integration of renewable energy.

Applicability

- High-rise residential typology.
- Naturally ventilated and mixed mode buildings

Country and climate

India, Composite and Hot-Dry.

Target Audience

Developers and builders, architects and other design professionals, and Urban Local Bodies (ULBs).

Design and process

- Design process: No explicit discussion on integrated design process for developing thermally comfortable homes.
- Passive design principles
    - Building form, envelope properties and spatial configuration

Construction technique

No explicit mention.

Space cooling, heating and exhaust

Efficient air-conditioners, set-points based on adaptive cooling and low-energy cooling systems based on evaporation phenomenon have been recommended. Natural and mechanical ventilation for kitchen exhaust have been recommended as well.

Operation, maintenance, and monitoring

No explicit mention of operation, maintenance, and monitoring practices. However, it is noted that energy and environmental parameters were monitored for the development of guidelines.

Case studies

Not included.

Features (to aid interpretation)

Summary of each chapter provided as 'At a glance' section. This also includes the key recommendations. Some chapters (Building Envelope) include package of measures with different performance levels.

Special remarks

- The guide includes context of electricity consumption in residential sector and methodology for the development of design guidelines for user's reference.
- Guidelines also outline:
    - electricity use in common services.
    - renewable energy integration.
    - choice of appliances
    - solar water heaters

3.4 Elements of an Energy-Efficient House (*Elements of an Energy-Efficient House*, 2000)

DOE/GO-10200-1070
FS-207
July 2000

ENERGY EFFICIENCY AND RENEWABLE ENERGY CLEARINGHOUSE

Elements of an Energy-Efficient House

You have much to consider when designing and building a new energy-efficient house, and it can be a challenge. However, recent technological improvements in building elements and construction techniques also allow most modern energy-saving ideas to be seamlessly integrated into house designs while improving comfort, health, or aesthetics. And even though some energy-efficient features are expensive, there are others that many home buyers can afford.

While design costs, options, and styles vary, most energy-efficient homes have some basic elements in common: a well-constructed and tightly sealed thermal envelope; controlled ventilation; properly sized, high-efficiency heating and cooling systems; and energy-efficient doors, windows, and appliances.

Thermal Envelope

A thermal envelope is everything about the house that serves to shield the living space from the outdoors. It includes the wall and roof assemblies, insulation, air/vapor retarders, windows, and weatherstripping and caulking.

Wall and Roof Assemblies

Most builders use traditional wood frame construction. Wood framing is a "tried and true" construction technique that uses a potentially renewable resource—wood—

This house in Illinois has many energy-efficient features, including advanced framing techniques, insulated sheathing, and an advanced ductwork system. It was built by Town and Country Homes as part of DOE's Building America Program.

This document was produced for the U.S. Department of Energy (DOE) by the National Renewable Energy Laboratory (NREL), a DOE national laboratory. The document was produced by the Information Services Program, under the DOE Office of Energy Efficiency and Renewable Energy. The Energy Efficiency and Renewable Energy Clearinghouse (EREC) is operated by NCI Information Systems, Inc., for NREL/DOE. The statements contained herein are based on information known to EREC and NREL at the time of printing. No recommendation or endorsement of any product or service is implied if mentioned by EREC.

Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 20% postconsumer waste

Figure 8 Element of an energy efficient house issued by the US Department of Energy

Overview

This document, issued by the Department of Energy, is a brief guide targeted towards educating end-users on energy efficient design and home improvement measures. It provides key definitions, statistics (such as 'the typical home loses 25% of its heat through windows'), descriptive images, pros & cons of measures and a list of resources for the benefit of the user. The guide is a concise 8-page document with advice on thermal envelope and controlled ventilation.

Applicability

The guidelines advise on energy efficiency while also referencing thermal comfort. The guidelines are relevant for the residential context with specific emphasis on sealed air-conditioned buildings capable of mixed-mode buildings operation.

Country and climate

US, several climates

Target Audience

Homeowners

Design and process

- Design process: No explicit discussion on integrated design process for developing thermally comfortable homes. However, the guide highlights the importance of careful siting and climate evaluation before initiating the design process. The use of computer software programs for evaluations have been recommended.
- The guide identifies importance of, insulation, air/vapor retarders, windows and shading. *The guide acknowledges that even for the warmest climates mechanical conditioning systems are not essential.*

Construction techniques and practices

- The guide stresses on Optimum Value Engineering (OVE). In connection with this, the guide suggests optimal use of lumber in construction. The guide identifies sustainably farmed wood-framed construction as "tried and true", cost-effective and long lasting.
- Although construction techniques have not been outlined, the guide highlights the use of,
    - *Structurally insulated Panels (SIPs)* are laminate of Oriented Strand Board (OSB), Insulation board - 4 to 8" thick and Plywood. This method is recognised for quality of construction and speed.
    - *Insulating Concrete Forms (ICFs)* are two layers of extruded foam board that act as the form for a steel-reinforced concrete center. This technique is recognized for speed and strength.

Space cooling, heating, and exhaust

- For summer cooling, the guide quantifies that light-colored materials and coatings (paint) on the exterior surfaces can reduce cooling requirements by up to 15%.
- The guide identifies vegetation (appropriately selected and placed) as a measure to reduce heating and cooling loads.
- The guide identifies importance of controlled ventilation, optimally sized heating and colling systems.
- Heat Recovery Ventilators in residential application are outlined as effective means for maintaining controlled ventilation. Trickle events have been mentioned as well albeit with limited application in only Cold climates.
- Sunshine is identified as the primary source of heat (complemented by radiant heating) as elements of energy efficient home.
- The guide highlights the role of labels (EnergyGuide) as equipment selection guides.

Operation, maintenance, and monitoring

Operation, maintenance, and monitoring activities have not been explicitly outlined.

Case studies

Case studies have not been explicitly identified.

Features (to aid interpretation)

Key messages for homeowners are repeated and highlighted along margins for emphasis.

Special remarks

The guide identifies the benefits of energy efficiency in homes. The outlined benefits include:

- *Comfortable and stable temperatures indoors along with better control over indoor humidity.*
- Lower operating costs and *higher market value for the real estate.*

The guide identifies potential risks such as, increase in costs, lack of builder familiarity with construction techniques and products available in the market and building community's resistance towards unfamiliar practices.

Guide informs the users about federal government's programs (Building America, Energy Star Homes, etc.). Guide also outlines other attractive home finance options such as 'Energy-efficient' mortgages.

3.5 Energy Conservation Building Code, 2017: Design Guide (BEE, 2017)

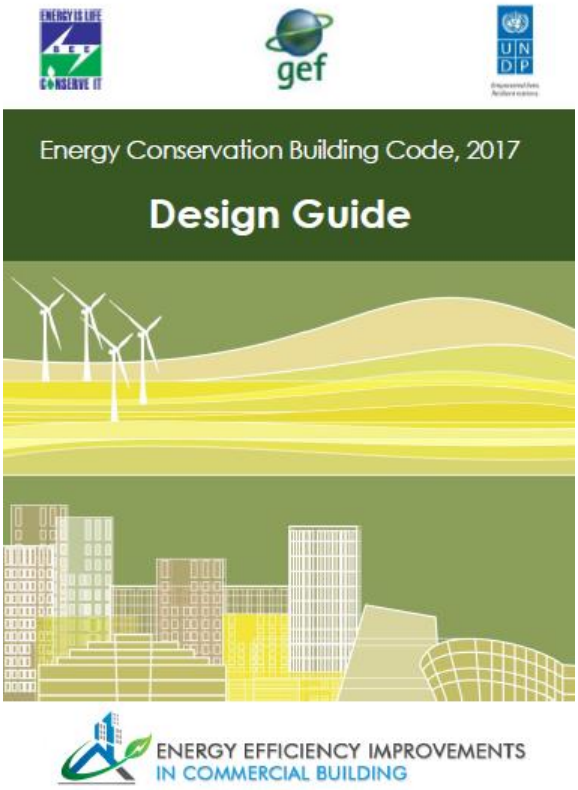


Figure 9 Design guide for commercial buildings in India.

Overview

The design guide to ECBC 2017 enables design of code compliant buildings for design professionals. This guideline, issued by state agencies (Bureau of Energy Efficiency, Ministry of Power), promotes the implementation of ECBC by facilitating easy comprehension using worked out examples, content supported with graphics and explanation of underlying fundamentals. The guide stresses on thermal comfort and has a section dedicated to understanding of thermal comfort.

The Guide is organized into 6 chapters. Key themes outlined the guide are,

- fundamentals of building physics, comfort (thermal and visual) and integrated design process,
- passive design strategies,
- active design strategies, and,
- design guidelines matrix

Applicability

- These guidelines are for energy efficiency while maintaining thermal comfort.
- This guide is applicable in commercial buildings that have a connected load of 100 kW or greater or a contract demand of 120 kVA.
- These guidelines are applicable to air-conditioned, naturally ventilated, and mixed-mode buildings. The guideline references Adaptive Comfort models outlined in the National Building Code 2016 as well.
- Primary focus of guidelines is on new buildings, while some recommendations may apply to existing buildings/retrofits.

Country and climate

India, all climate classifications applicable to India.

Target Audience

Design professionals.

Design and process

- A chapter is dedicated to Integrative Design Process.
- A chapter is dedicated to general architectural design guidelines and climate specific passive strategies. This is complemented with a chapter explaining the fundamentals of building science.
- Recommended passive design strategies include orientation (for sun and wind), vegetation, mutual shading, building form (surface area to volume ratio), spatial configuration (buffer spaces), shading, daylighting, natural ventilation, thermal mass, reflective surfaces, etc.

- Guidance on visual comfort and contributing factors has been outlined.

Construction techniques and practices

- The guideline does not outline any construction practices and techniques.

Space cooling, heating, and exhaust

- A chapter explaining active mechanisms is included. This also includes low energy systems such as evaporative cooling (direct, indirect and two-stage direct-indirect).

Operation, maintenance, and monitoring

- The document includes guidance on operation, control, maintenance, and monitoring of electrical and mechanical equipment only.

Case studies

- Case studies are not included.

Features (to aid interpretation)

In addition to technical content the Guide provides a section that explains how the readers should use this guide. The guide also provides detailed description of climate and an associated design matrix. Among other helpful features is a summary page that provides a content layout of the chapter.

3.6 Guidelines for Affordable Housing in Telangana (CSE, 2021)

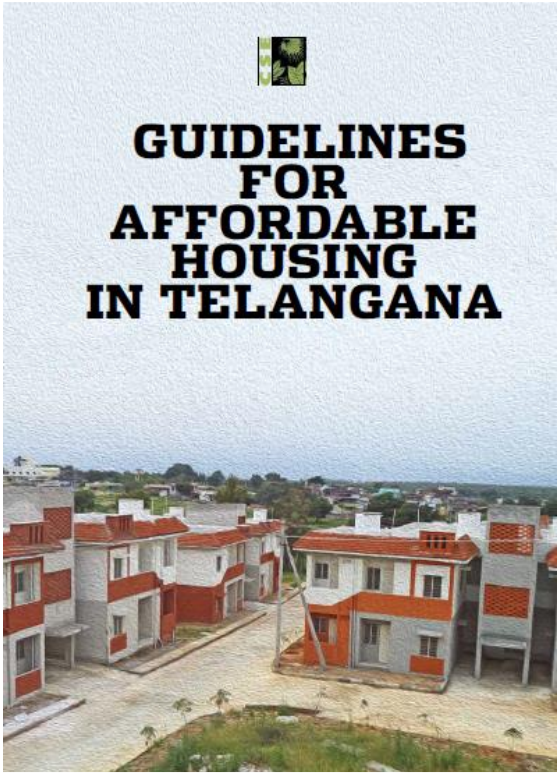


Figure 10 Guidelines for affordable housing in Telangana provides strategy guidance for agencies formulating and implementing policies

Country and climate

Telangana (India), Composite and Warm-Humid climate.

Overview

This guideline has been produced by Center of Science and Environment, an independent NGO, with the aim of improving thermal comfort and livability of buildings under the Pradhan Mantri Awas Yojana (PMAY). The guide acknowledges the interconnectedness of energy efficiency and thermal comfort aspects with health and life expectancy of occupants. The guide recognizes thermally comfortable affordable housing as a significant cog in achieving post COVID recovery and meeting ICAP goals as well.

This guide looks at existing affordable housing programs as attest bed to explore design strategies and presents design and strategy guidance.

Applicability

- Guidelines for affordable housing typology.
- Targeted towards Telangana, but may be applied to Composite and Warm-humid climates in India.
- This guide is not positioned as design guidelines, but overall strategy guidance for Telanaga.

Target Audience

Government and Implementation Agencies

Design and process

- No specific guidance on integrative design process.
- This guide makes design recommendations based on analyses of case studies. Recommendations target,
    - Building envelope (conductance, thermal mass, operable window to floor area ratio and envelope factor)
    - Cluster layouts informed by CFD analyses of wind flow patterns and daylight analyses

Construction techniques and practices

The guide does not explicitly provide guidance on construction techniques and practices.

Space cooling, heating, and exhaust

The guide does not explicitly provide guidance on cooling, heating and exhaust design.

Operation, maintenance, and monitoring

The guide does not explicitly provide guidance on operation, maintenance, and monitoring.

Case studies

The guideline provides design guidance by way of analyses on case studies. The case studies analyse 2 BHK schemes across 10 locations in Telangana that are in Composite and Warm humid climate.

3.7 Low Energy Cooling and Ventilation for Indian Residences - Design Guide (Cook et al., 2020)

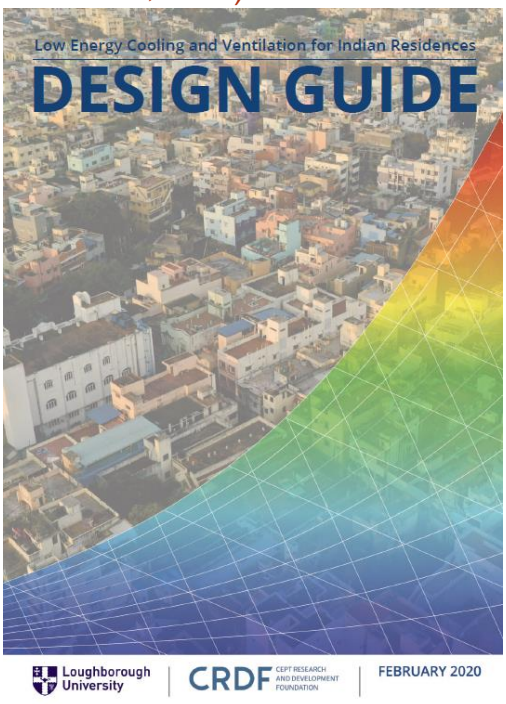


Figure 11 Design guide for low-energy cooling and ventilation in Indian residences, developed by Loughborough University, UK and CEPT Research and Development Foundation (CRDF), India

Overview

This guide proposes the LECaVIR concept that is an acronym for Low Energy Cooling and Ventilation for Indian Residences. This guide is a 2-part document, wherein the first part focuses on equipping practitioners with fundamentals of natural ventilation and thermal comfort, and the second part enables practitioners in design and operation of naturally ventilated and mixed-mode buildings.

Applicability

This guide is applicable to residential buildings that are naturally ventilated and undergo mixed mode operation.

This document provides guidance on low energy cooling and ventilation strategies with focus on apartment buildings 3-16 stories in height. The guide uses Indian Model for Adaptive Comfort (IMAC-NV and IMAC-MM) for analyses.

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Country and climate

India, Hot-Dry, Warm-Humid and Composite climate Zones

Target Audience

Design professionals, building operators *Design and process*

- The guide includes a detailed process including flow-charts to guide the design process. The design process stresses on climate analyses, dynamic thermal simulation, and sizing windows for natural ventilation.
- Design guidelines include solutions to deliver full potential of natural ventilation (LECaVIR) and also solutions to extend beyond the full potential of natural ventilation by employing ceiling fans (NV+)
- The guide discusses opening designs and configurations and their impact on comfort. Sizing of openings is supported by easy-to-use design charts. The document provides guidance on buoyancy- and wind-driven flows.
- Case examples have been provided that demonstrate application of design charts and impact of Purpose Provided Openings (PPOs).
- The outcomes include recommended ventilation rates for thermal comfort based on case examples.

Construction techniques and practices

There is no explicit mention of construction techniques and practices.

Space cooling, heating, and exhaust

- To accommodate mixed mode buildings guidance on mechanical ventilation and centralized systems has been outlined as well.

Operation, maintenance, and monitoring

The guide highlights control strategies for natural and mixed-mode ventilation in detail. There is no explicit mention of maintenance and monitoring practices.

Case studies

The guide uses 2 representative examples from a GBPN commissioned study as case studies for this guide. The case studies have 60 and 68 m^2 carpet area. These have been evaluated for performance across 8 cities.

Features (to aid interpretation)

Complex equations for sizing for windows for natural ventilation are translated to 'easy to use' design charts that reliably approximate performance while also simplifying design process.

Special remarks

The guide presents in detail,

- the principles of thermal comfort and natural ventilation,
- the Indian context for thermal comfort which includes,
    - climate context of India along with detailed analysis of 8 most populous cities in India,
    - housing typologies in Indian context,
    - Indian behavioral aspects including clothing and adaptive behavior.
- Detailed design process along with control strategies for mixed mode operation (Change-over mode).

3.8 Principles of rat trap bond, (SDC, 2008)

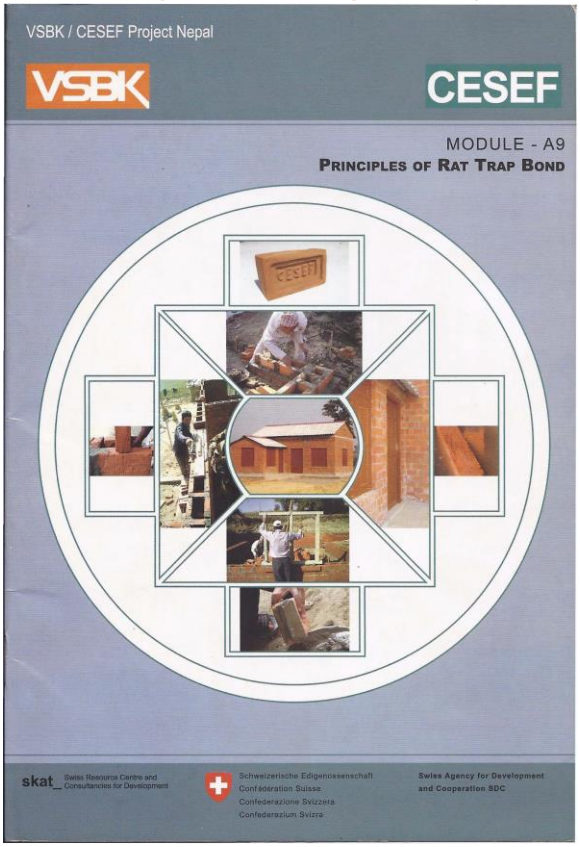

Figure 12 Design guide explaining Rat Trap Bond construction

Construction techniques and practices

The guide includes,

- selection of material,
- preparation of material,
- tools required,
- specification of material and construction,
- quality control processes,
- design considerations and rules of application,
- estimation of material quantities, and,
- graphics and technical drawings of construction details, and images from site for easy comprehension of application processes.

Features (to aid interpretation)

Graphic representation, worked out examples for quantity estimation, quality control checks and material specifications have been included. The guide clearly outlines advantages and limitations of adopting RTB. It also outlines how some of the limitations can be overcome.

Overview

The manual is a part of knowledge transfer package developed for Nepal. This manual outlines the fundamental knowledge of,

- raw material, i.e, bricks in this case,
- potential and limits of Rat-trap Bond (RTB) construction, and,
- step-by-step working process, construction techniques and practical working tips.

Applicability

The RTB construction is applicable to load bearing structures up to 3 stories in height. If used as an infill in Reinforced Cement Concrete (RCC) framed construction, the limit of 3 stories is not applicable.

Country and climate

This manual has been produced in Nepal. The manual is not limited to any country or climate as such.

Target Audience

Designers, specifiers, contractors, and masons.

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3.9 Alternative construction research guide (GCCDS, n.d.)

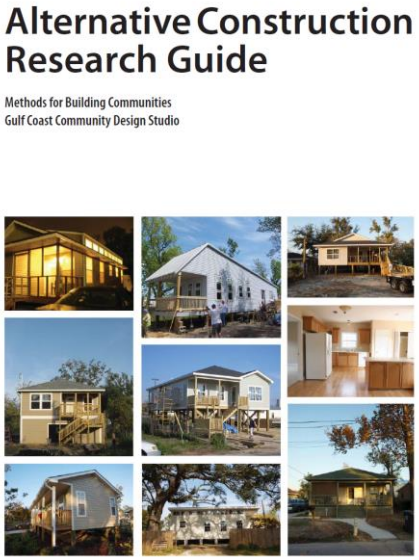


Figure 13 Alternative construction research guide

Overview

The guide provides alternative construction systems to expand choices housing providers use. The guide divides housing choices based on construction strategy. The construction strategies include whole house systems, large component systems, and small assembly systems. Each strategy is further divided into smaller components of methods of construction such as panels, framing, roofs or floors. The guide also presents a template that can be used to expand the existing guide with additional construction technologies.

Each construction technology is detailed to include categories for installation, performance, design, and local availability. In context of this report the various categories discuss energy performance, thermal comfort, speed of construction, affordability, code compliance and availability of local materials

Applicability

The guide is applicable to residential construction. It focuses on construction technology and methods of construction.

Country and climate

United States, Warm and temperate.

Target Audience

Designers, specifiers, and contractors.

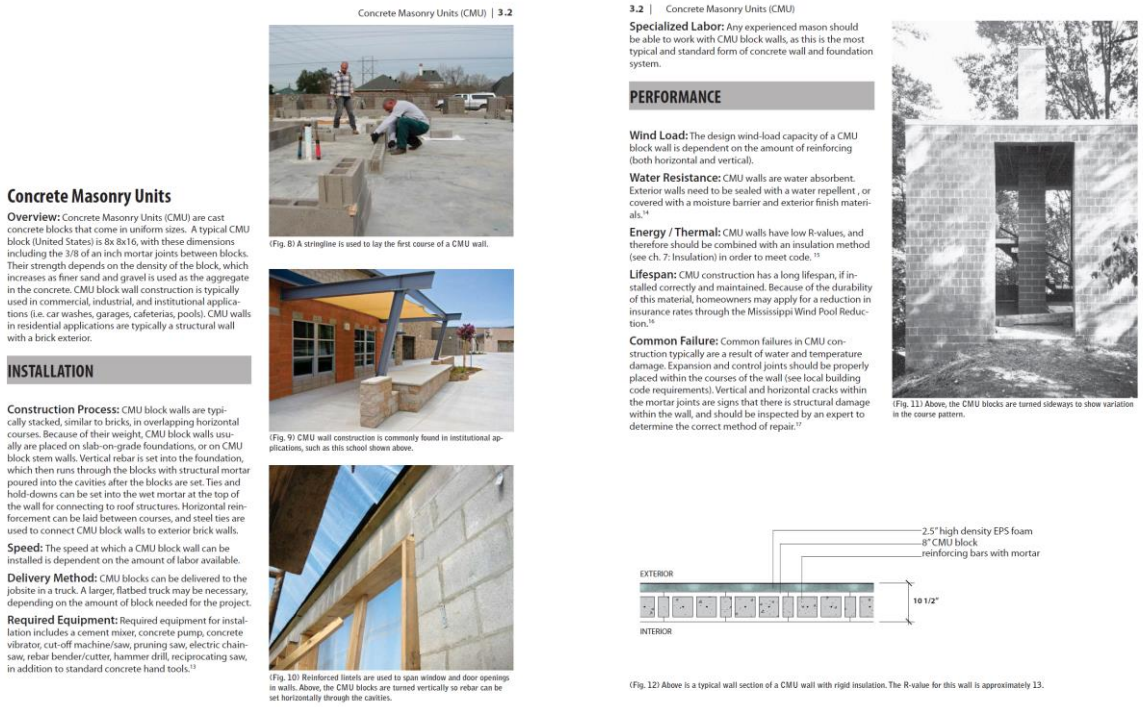
Design and process

There is no explicit mention of design process. While this guide outlines design related issues, largely it is focused on construction practices.

The guide has an appendix dedicated to energy efficiency in homes. This section outlines thermal comfort and the environmental parameters that affect it. This section outlines strategies such as shading building surfaces, maintaining adequate ventilation, efficient building envelope, etc.

Construction techniques and practices

The guide outlines construction process, required equipment, speed of construction and requirements of specialized labour. Other details about delivery are included as well in case the products will be assembled away from site. Images of work in progress, completed site pictures and detail drawings are included for benefit of the reader.



Concrete Masonry Units (CMU) | 3.2

Concrete Masonry Units

Overview: Concrete Masonry Units (CMU) are cast concrete blocks that come in uniform sizes. A typical CMU block (United States) is 8x 8x16, with these dimensions including the 3/8 of an inch mortar joints between blocks. Their strength depends on the density of the block, which increases as finer sand and gravel is used as the aggregate in the concrete. CMU block wall construction is typically used in commercial, industrial, and institutional applications (i.e. car washes, garages, cafeterias, pools). CMU walls in residential applications are typically a structural wall with a brick exterior.

INSTALLATION

Construction Process: CMU block walls are typically stacked, similar to bricks, in overlapping horizontal courses. Because of their weight, CMU block walls usually are placed on slab-on-grade foundations, or on CMU block stem walls. Vertical rebar is set into the foundation, which then runs through the blocks with structural mortar poured into the cavities after the blocks are set. Ties and hold-downs can be set into the wet mortar at the top of the wall for connecting to roof structures. Horizontal reinforcement can be laid between courses, and steel ties are used to connect CMU block walls to exterior brick walls.

Speed: The speed at which a CMU block wall can be installed is dependent on the amount of labor available.

Delivery Method: CMU blocks can be delivered to the jobsite in a truck. A larger, flatbed truck may be necessary, depending on the amount of block needed for the project.

Required Equipment: Required equipment for installation includes a cement mixer, concrete pump, concrete vibrator, cut-off machine/saw, pruning saw, electric chainsaw, rebar bender/cutter, hammer drill, reciprocating saw, in addition to standard concrete hand tools.[13]

(Fig. 8) A stringline is used to lay the first course of a CMU wall.

(Fig. 9) CMU wall construction is commonly found in institutional applications, such as this school shown above.

(Fig. 10) Reinforced lintels are used to span window and door openings in walls. Above, the CMU blocks are turned vertically so rebar can be set horizontally through the cavities.

3.2 | Concrete Masonry Units (CMU)

Specialized Labor: Any experienced mason should be able to work with CMU block walls, as this is the most typical and standard form of concrete wall and foundation system.

PERFORMANCE

Wind Load: The design wind-load capacity of a CMU block wall is dependent on the amount of reinforcing (both horizontal and vertical).

Water Resistance: CMU walls are water absorbent. Exterior walls need to be sealed with a water repellent , or covered with a moisture barrier and exterior finish materials.[14]

Energy / Thermal: CMU walls have low R-values, and therefore should be combined with an insulation method (see ch. 7: Insulation) in order to meet code. [15]

Lifespan: CMU construction has a long lifespan, if installed correctly and maintained. Because of the durability of this material, homeowners may apply for a reduction in insurance rates through the Mississippi Wind Pool Reduction.[16]

Common Failure: Common failures in CMU construction typically are a result of water and temperature damage. Expansion and control joints should be properly placed within the courses of the wall (see local building code requirements). Vertical and horizontal cracks within the mortar joints are signs that there is structural damage within the wall, and should be inspected by an expert to determine the correct method of repair.[17]

(Fig. 11) Above, the CMU blocks are turned sideways to show variation in the course pattern.

(Fig. 12) Above is a typical wall section of a CMU wall with rigid insulation. The R-value for this wall is approximately 13.

Figure 14 Installation and performance information for concrete masonry units outlined in design guide along with supporting graphics.

In context of this study, construction techniques for structural insulated panels, insulated concrete forms, concrete masonry units, autoclaved aerated concrete blocks, etc. have been discussed.

Features (to aid interpretation)

- The guide is organized as whole house systems, structural component systems, and small assembly systems.
- The guide includes a glossary of construction items for reader's reference. Further, for curious readers who would like to enhance their knowledge beyond this guide, a list of resources and further reading has been included as well.
- It includes necessary matrices for facilitating comparison across technologies.

stacked units	construction process	speed	delivery method	required equipment	specialized labor	wind resistance	water resistance	fire resistance	thermal performance	life span	environmental impact	product versatility	market exposure	code approval	affordability	coastal considerations
insulated concrete forms		+		−		+			+						−	+
concrete masonry units	+	+			+			+				−				
autoclaved concrete	+		+	+	+			+			+	+	−	−		

*Figure 15 Qualitative comparison of stacked unit technologies for 16 parameters including **(i)** speed of construction, **(ii)** thermal performance, **(iii)** environmental impact, **(iv)** code approval and **(v)** affordability, among other things.*

- Thermal insulation values of various walling systems has been compared for the convenience of the reader.

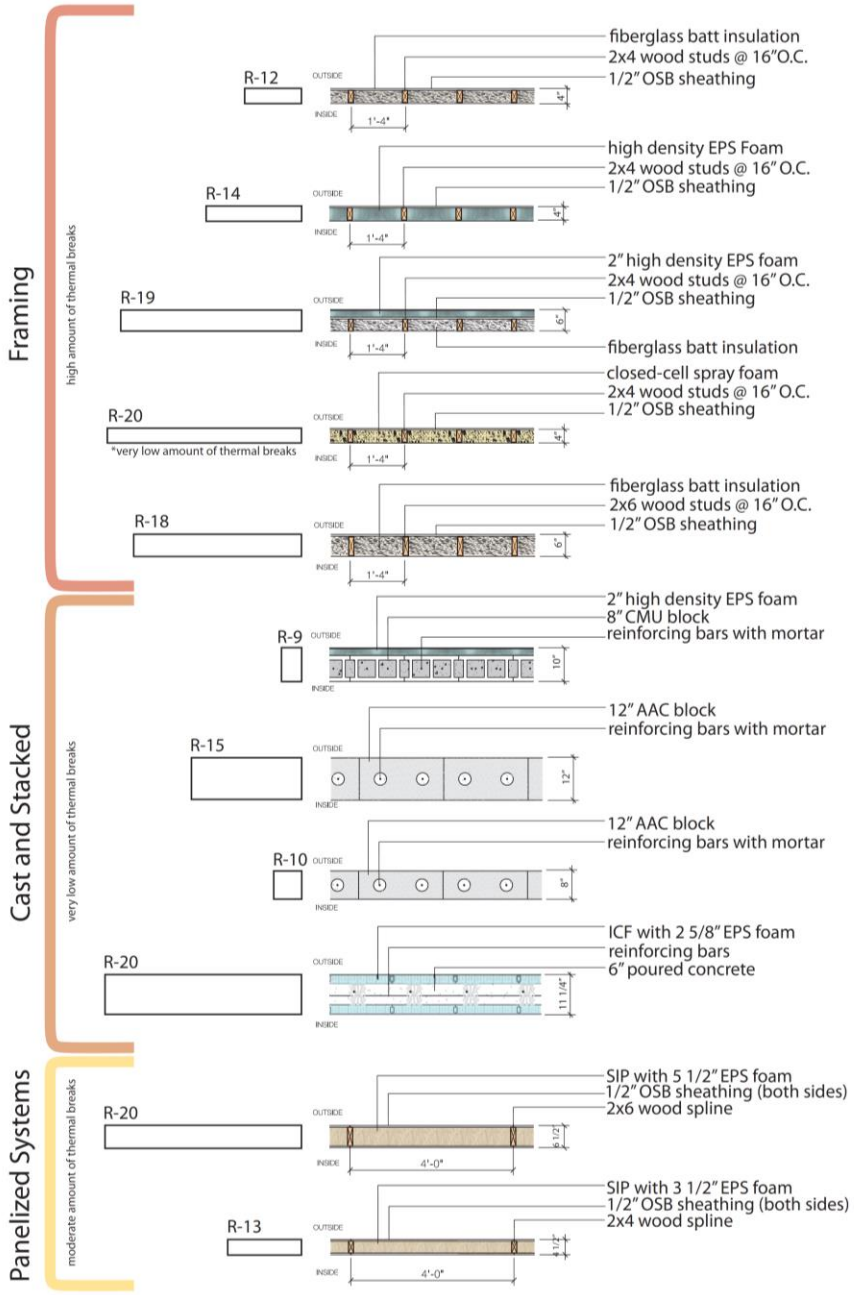


Figure 16 Comparison of R-Values of walling assemblies across different construction systems

4 Key takeaways

The review of design guides provides several aspects that may be included in the development of design guides for thermally comfortable homes. These aspects have the potential of aiding interpretation and in turn improving the uptake and application of these guidebooks.

One of the key takeaways is that the requirements of each target user group are distinct. While homeowners require easy to implement practical advice, design professionals require analyses backed design strategies. The construction workers and contractors on the other hand require detailed step-by-step instructions. The government agencies

require a macro view that provides a bird's eye perspective to implementation challenges and developmental goals. Table 1 outlines the nature of content anticipated from guidebooks for each user group.

Table 1 Key aspect that may be accommodated in guidebooks for various target groups.

User Group	Nature of content
All user groups	Need for the development of thermally comfortable affordable housing. The relevance of thermal comfort on health, wellbeing and productivity.
Design Professionals	Comprehensive description of fundamentals and concepts to complement the interpretation of design strategies. Analysis backed design, operation, and maintenance strategies. Handy formulae, tables, and charts for evaluating designs. Explicit thresholds and metrics for evaluation of design/intervention. Worked out examples and case studies for illustration of concepts. Other handy tool-kits including performance parameters, cost information (material, construction) and customizable BOQs, specifications, construction details, etc. for developing construction documents. List and contact information of service providers and material suppliers that are approved by competent authorities. A general understanding of urban design and development related issues for siting of potential projects.
Building operators and Maintenance professionals	Maintenance schedules and control sequences for operation of systems. In context of affordable housing, there is little scope for institutional operation and maintenance.
Contractors and construction workers	Matrix of climate-appropriate construction strategies. Details on preparation of site, required resources (tools and equipment, man-power, etc.), step-by-step instructions along with detailed drawings, quality control processes. Tool kits for quantity estimation, material procurement, etc. List and contact information of service providers and material suppliers that are approved by competent authorities.
Agencies in policy development and administration	Understanding of urban design and development related issues ranging from access to livelihood, access to basic services, tenure of land, etc. Recognizing the impact of thermally comfortable affordable housing in meeting development goals and international commitments. Guidance on design of implementation and monitoring frameworks, design financial incentives, development of key planning documents (city action plan, detailed project reports, etc.).
Homeowners	Simple, practical yet effective guidance that is implementable. Some design guides prescribe pragmatic and behavioral adjustments driven by rational. Relatable examples provided as experiences are helpful too. Identifying aspects which require engaging experts (designers/contractors). List and contact information of service providers and material suppliers that are approved by competent authorities. Links to further reading for those who are interested.

The takeaways indicated above are reflected in the summary of the design guides. Key highlights of each guide book are summarised in Table 2.

Table 2 Highlights of detailed review of design guides

Guide	Summary
EU Publication (v1.0, 2020) Time outside of thermal comfort range: User manual, overview, instructions and guidance	This guide aims to promote life cycle thinking. Unlike others, this guide defines comfort evaluation metrics. Comfort is measured as the percentage of the time out of range from defined maximum and minimum temperatures during the heating and cooling seasons. The reference temperature range shall be 18 °C to 27 °C. Heat wave intensity is measured as the frequency of intense heat wave events during which 27 °C or an upper temperature of 31 °C are exceeded.
Thermal comfort at home: A guide for older South Australians, 2021	Lays focus on the relationship between health, well being and thermal comfort. The guide includes practical advice that homeowners can follow and apply. Notable among the guidance are suggestions on behavioral aspects. Finally, the personas make the guidebook relatable for the readers.
Design Guidelines for Energy-Efficient Multi-Story Residential Buildings	This guide is developed for practitioners. The analyses methodology and analyses outcomes that form the basis for outlining strategy are included in the guide. This is useful for advanced users in the interpretation of design strategies.
Elements of an Energy-Efficient House, 2000	The guide is developed for use by homeowners. The guide identifies use of vegetation as a passive measure for improving comfort indoors. More importantly, the guide outlines the benefits and risks in energy efficient homes and, possible funding mechanisms and federal schemes available for financing energy efficient homes.
Energy Conservation Building Code, 2017: Design Guide	This design guide is meant for use by design professionals to design code compliant buildings. This guide talks at length about the significance of integrated design and various milestones of this process.
Guidelines for Affordable Housing in Telangana	This document is developed as a strategy guidance for the agencies engaged in formulation and implementation of policies. At the outset, the guide recognizes that thermally comfortable affordable housing (especially PMAY) is a vital component in meeting ICAP goals, mitigating impacts of COVID and recovering from economic setbacks post COVID.
Low Energy Cooling and Ventilation for Indian Residences - Design Guide	The guide is developed for design professionals. The guide provides step-by-step process for designing for natural ventilation. It provides guidance on sizing windows for natural ventilation based on easy-to-use design charts. For advanced users, the guide also includes control logic for optimizing window operation.
Principles of Rat-trap bond	This guide outlines best construction practices for construction workers. The guide progresses in a systematic way, expressing key characteristics of the raw material (i.e. brick), site preparation, tools, key details (with drawings and images), quality control processes and sample working of material estimation. The guide also expresses benefits of using Rat-trap bond masonry over conventional masonry.
Alternative construction research guide	Alternative construction guide is a standard and systematic framework that provides information on key aspects such as installation, performance, design, and local availability. This guide is replicable to any context and its can be evolved to accommodate from construction technologies with the passage of time.

In addition to the key takeaways from guidelines detailed in this report, other background analyses also reveals that guidance on siting and developing guidelines in local language, at least for the construction workers and homeowners, are important considerations.

4.1 Proposed outline

The detailed review analyses design guides from various perspectives: by topic, by user group and by geographical context. This analysis has been synthesized to develop an outline for the proposed design guides. Since the program brief focuses on design of thermally comfortable home, the outline lays emphasis on developing the content for design professionals and construction agencies. The proposed outline is as below:

1. Fundamentals
    a. Key concepts of thermal comfort, heat transfer, wind flow in context of climate and building physics.
    b. Definitions explaining terminology to complement key concepts
2. Integrated design process
    a. Structured process that specifically looks at setting thermal comfort goals and enables design and validation practices to ensure the thermal comfort performance criteria is met.

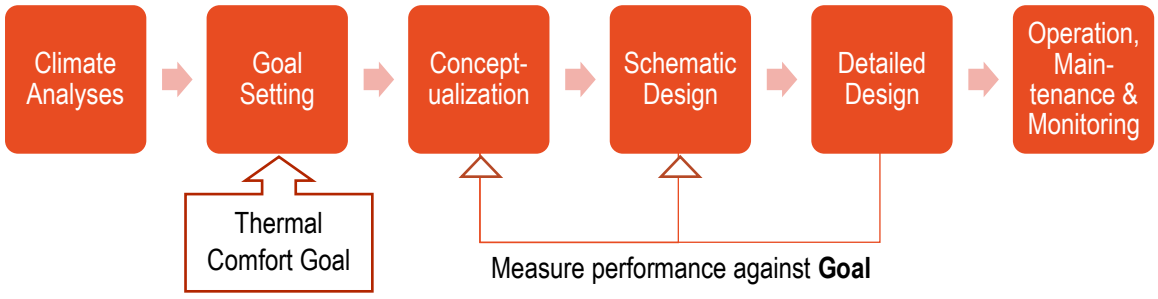


Figure 17 Integrated design process

3. Provide guidance by climate type. Climate and geography specific guidance will include
    a. Discussion on climatic features and geographical context.
    b. Discussion on siting buildings
    c. Discussion on passive building strategies and methods of evaluation. In addition to passive features, the guide will also lay emphasis on using low impact materials and construction technologies. Any discussion on alternative construction practices will be included here to complement the passive design strategies.
    d. Discussion on low energy active strategies and methods of evaluation.
4. Resources
    a. Resources are anticipated to include appendices which may include,
        i. case-studies exemplifying strategies
        ii. link to resources that provide further guidance on building physics concepts, design tips, design tools, etc.
        iii. database of suggested assemblies along with information about their thermal performance and cost.
5. Features

a. Provide an overview of chapter and expected learning outcomes for each user group at the beginning of the chapter.
b. Identify guidance with respective user group.
c. Provide bundled packages and associate with case studies to showcase as case examples.
d. Cross reference text with fundamentals for easy navigation through the guidebook.

5 References

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