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Thermal Comfort Performance and Parameters in Educational Buildings

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Composition of the jury

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Dedication

I dedicate this research work to my beloved family, whose unconditional love, encouragement, and sacrifices have always been the driving force behind my academic journey. Their faith in my dreams gave me the strength to take on challenges far from home and to grow both personally and professionally.

I also dedicate this work to all the teachers who have inspired me—from my early education in India to my professors here in Portugal—especially during this exchange program. Their dedication to sharing knowledge and nurturing curiosity has shaped my path in civil engineering.

Lastly, I dedicate this to the spirit of global learning and cultural exchange. Participating in the CEPT–IPCB exchange program has been a life-changing experience, and this research stands as a symbol of what can be achieved when we step beyond our comfort zones to embrace new environments, new ideas, and new possibilities.

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A heartfelt thanks to all my peers and faculty members in both countries who encouraged dialogue, provided feedback, and made this international learning experience truly memorable. This research not only deepened my understanding of thermal comfort in buildings across different climates but also broadened my perspective as a global engineering student.

Título: Estudo Comparativo dos Parâmetros de Conforto Térmico em Edifícios de Portugal, França e Índia

Esta pesquisa foca na análise comparativa dos parâmetros de conforto térmico em edifícios residenciais e públicos em Portugal, França e Índia. A motivação por trás deste estudo surge da crescente importância da arquitetura responsiva ao clima e da eficiência energética no design de edifícios, especialmente no contexto das mudanças climáticas globais. O objetivo é entender como o conforto térmico é tratado em cada país e avaliar qual apresenta melhor desempenho térmico com base em parâmetros estabelecidos.

Inicialmente, os parâmetros de conforto térmico de cada país foram analisados. Em Portugal, o clima é predominantemente mediterrânico, com verões quentes e secos e invernos amenos e úmidos. Os edifícios geralmente são projetados com paredes espessas e massa térmica para regular a temperatura interna. Também são usados elementos como ventilação natural e sombreamento para melhorar o conforto durante os períodos mais quentes.

Na França, os padrões de conforto térmico são guiados por regulamentos rigorosos, como o RT 2012 e o mais recente RE 2020. O país possui um clima temperado, que varia de oceânico a continental. Os edifícios franceses costumam incorporar isolamento térmico, vidros duplos e sistemas de ventilação mecânica. O foco está em manter temperaturas internas estáveis com baixo consumo de energia.

Já a Índia apresenta uma grande diversidade climática, desde regiões tropicais no sul até alpinas no norte. As práticas de conforto térmico nos edifícios variam conforme a região. Em áreas quentes e úmidas, utiliza-se o resfriamento passivo por meio de tetos altos, varandas sombreadas e pátios. Recentemente, tem havido maior adoção de materiais eficientes e sistemas HVAC, especialmente em áreas urbanas.

A análise comparativa revelou vários pontos relevantes. Os edifícios franceses, apoiados por uma legislação forte, geralmente apresentam melhor desempenho no conforto térmico com baixo consumo energético. Portugal, com sua tradição de uso da ventilação natural e massa térmica, oferece bom conforto térmico, mas enfrenta desafios em eficiência energética, especialmente em construções antigas. Na Índia, o desempenho é bastante variável: a arquitetura tradicional se destaca em resfriamento passivo, mas muitas construções modernas carecem de regulação térmica adequada devido à fraca implementação das normas.

Contudo, cada país apresenta vantagens contextuais. A arquitetura vernacular da Índia adapta-se bem ao clima local. Portugal utiliza recursos naturais e soluções arquitetônicas eficazes. A França, por meio de tecnologias modernas e regulamentações, mantém o conforto térmico de forma estável e eficiente em diferentes regiões.A pesquisa conclui que, embora nenhum país possa ser considerado universalmente “melhor”, a França representa um exemplo de integração entre políticas e desempenho de edifícios. Portugal e Índia podem se beneficiar da modernização e do fortalecimento das normas, sem perder as soluções tradicionais eficazes. Este estudo sugere uma abordagem híbrida—combinando sabedoria tradicional e tecnologia moderna—para otimizar o conforto térmico em edifícios ao redor do mundo.

Palavras-chave:
Design de edifícios, Eficiência energética, Conforto térmico, , Arquitetura responsiva ao clima, Estudo comparativo

Abstract

Title: Comparative Study of Thermal Comfort Parameters in Buildings of Portugal, France, and India

This study focuses on the comparative analysis of thermal comfort parameters in residential and public buildings in Portugal, France, and India. The motivation behind this study stems from the increasing significance of climate-responsive architecture and energy efficiency in building design, particularly in the context of global climate change. The study aims to determine how thermal comfort is addressed in each country and evaluate which country demonstrates superior thermal performance based on established parameters.

The thermal comfort parameters of each country were thoroughly examined. For Portugal, the climate is predominantly Mediterranean, with hot, dry summers and mild, wet winters. Buildings are typically designed with thick walls and thermal mass to regulate indoor temperatures. Natural ventilation and shading elements are also employed to enhance comfort during warmer periods.

In France, thermal comfort standards are guided by stringent building codes and national regulations, including the RT 2012 and the newer RE 2020. France experiences a temperate climate, which varies from oceanic in the west to continental in the east. Building designs often incorporate insulation, double glazing, and mechanical ventilation systems. The emphasis is on maintaining consistent indoor temperatures with minimal energy usage.

India, by contrast, has a diverse climate ranging from tropical in the south to alpine in the north. Thermal comfort practices in Indian buildings vary accordingly. In hot and humid regions, buildings rely heavily on passive cooling techniques such as high ceilings, shaded verandas, and courtyards. In recent years, there has been an increased adoption of energy-efficient materials and HVAC systems, especially in urban settings.

The comparative analysis revealed several insights. French buildings, supported by strong regulatory frameworks, generally perform better in maintaining thermal comfort with low energy consumption. Portugal, with its traditional reliance on thermal mass and natural ventilation, provides decent thermal comfort but faces challenges in energy efficiency, especially in older constructions

However, each country has context-specific advantage. India's vernacular architecture excels in adapting to local climatic conditions. Portugal demonstrates effective use of natural resources and architectural features to regulate temperature. France, through legislation and modern technologies, maintains the most stable and energy-efficient thermal comfort across different regions.

The research concludes that while no single country can be deemed universally “better,” France sets an example in integrating policy with building performance. Portugal and India can benefit from improved regulation and modernization while preserving contextually appropriate traditional methods. This study encourages a hybrid approach—blending traditional wisdom with modern technology—to optimize thermal comfort in buildings worldwide.

Keywords:

Building Design, Energy Efficiency, Thermal Comfort, Climate-Responsive Architecture, Comparative Study

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Introduction to the Topic

Thermal comfort plays a critical role in shaping the design, energy performance, and indoor environmental quality of buildings across the globe. For this research, I have chosen to compare the approaches of **Portugal, France, and India —** three countries that differ greatly in climate, cultural practices, and regulatory development. **Portugal** was selected as a key focus because I am currently pursuing my studies here and have the opportunity to directly observe its regulatory and technical framework. **India**, being my home country, allows me to reflect on traditional and evolving building practices through a familiar lens. Lastly, **France** was included because it has a **diverse climatic range —** from Oceanic to Alpine — and is geographically and politically close to Portugal, yet operates a **more advanced, human-centered, and simulation-based system** for regulating thermal comfort.

These three countries exhibit a mix of **traditional wisdom and modern techniques** in managing thermal comfort. In **India**, traditional architecture often relies on passive design features such as courtyards, shaded verandas, thick walls, and natural ventilation — making it well-suited for adaptive comfort without mechanical systems. In contrast, **Portugal** blends historical construction methods like high thermal mass walls with modern updates such as **ETICS (External Thermal Insulation Composite Systems)** to meet performance targets. Meanwhile, **France** has shifted towards a more technical and **occupant-centered approach**, using **PMV/PPD models**, **adaptive comfort**, and **dynamic simulations** to ensure not just compliance, but user satisfaction. Studying these countries side by side helps us understand how thermal comfort regulations evolve based on **climatic context, regulatory maturity, and cultural adaptation**.

PART 1:- Portugal's Thermal Comfort and Energy Efficiency Legislation: RECS under Decree-Law No. 118/2013

Published by the **Agência para a Energia (ADENE)**
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Document Type: **National Regulation Overview** for Commercial and Service Buildings (RECS)

Introduction

The Portuguese government, in response to the European Union's Energy Performance of Buildings Directive (EPBD), established a comprehensive legislative framework known as **RECS (Regulamento de Desempenho Energético dos Edifícios de Comércio e Serviços)**. Enacted under **Decree-Law No. 118/2013**, this regulation sets out performance-based requirements for energy efficiency and thermal comfort in **commercial and service buildings**, including public schools, hospitals, offices and retail buildings.

The regulation mandates that buildings be designed and operated to ensure a high level of **thermal comfort** for occupants while minimizing **energy consumption**. It specifies detailed procedures for evaluating and certifying buildings based on their **thermal zones**, **building envelope**, **technical systems**, and **renewable integration**.

Thermal Comfort and Energy Performance Regulations in Portugal: A Detailed Overview

Portugal, located in Southern Europe, is influenced by a Mediterranean climate characterized by long, dry summers and short, mild winters. This climate necessitates a dual approach to indoor thermal comfort: buildings must be designed and maintained to provide both effective heating during winter and cooling during summer. In response, Portugal has established a robust regulatory framework to manage energy use in buildings and ensure indoor comfort—particularly in public institutions like schools—through the Regulation for the Energy Performance of Commercial and Service Buildings (RECS), under Decree-Law No. 118/2013.

This framework is part of the broader Energy Certification System (SCE), governed by the national energy agency ADENE. The regulation details technical requirements, assessment criteria, and strategies to reduce energy consumption while maintaining comfort. The rest of this overview presents the major components of the Portuguese approach to thermal comfort and energy performance in a structured manner.

1. Climate Context and Need for Thermal Comfort

Portugal's climate plays a central role in how its buildings are designed for thermal comfort. Due to the variations in seasonal temperatures, building systems must be capable of both heating and cooling functions.

- **Comfort Temperature Range**: According to RECS, a comfortable indoor temperature in Portugal should fall between 19°C in winter and 27°C in summer.
- **Building Categories Based on HVAC Dependency**:
  - *Passive Buildings*: These require heating or cooling for no more than 10% of their operational hours annually. These are usually designed with strong passive elements like insulation, thermal mass, and solar orientation.
  - *Hybrid Buildings*: These need HVAC assistance between 10% and 30% of the time. They typically incorporate both passive strategies and moderate active interventions.
  - *Active Buildings*: These depend heavily on HVAC systems, needing heating or cooling for more than 30% of the year.

This classification allows the regulatory framework to apply different standards and recommendations based on the actual energy dependence of a building.

2. Types of Buildings Covered Under RECS

Portugal's legislation clearly defines which types of buildings fall under RECS, with a focus on commercial, service, and public-use buildings, including schools and educational institutions.

- **Small Commercial and Service Buildings (PES)**:
  - These have a usable interior floor area less than 1000 m^2, or in specific cases like supermarkets and indoor pools, less than 500 m^2.
  - Within PES, two categories are further defined:
    - *PEScC*: Buildings with air conditioning systems having a nominal thermal power greater than 25 kW.
    - *PESsC*: Buildings without such systems or with systems below that threshold.
- **Large Commercial and Service Buildings (GES)**:
  - Buildings exceeding the PES thresholds fall under this category.
  - These must comply with more extensive energy assessment protocols and maintenance obligations.

These classifications help assign appropriate performance requirements and energy certification procedures based on building scale and complexity.

3. Strategies for Ensuring Thermal Comfort

Portugal employs both passive and active design strategies to regulate indoor thermal conditions and reduce energy usage.

- **Passive Strategies**: These are design-based interventions that reduce energy consumption by harnessing natural environmental features:
    - *Trombe Walls*: These use thermal mass and solar gain to store heat during the day and release it at night.
    - *Evaporative Cooling*: This utilizes water evaporation to cool indoor air, especially effective in drier regions.
    - *Natural Ventilation*: The strategic use of windows, vents, and building orientation promotes airflow without mechanical systems.
    - *Radiative Cooling*: Heat is emitted from the building surfaces (especially roofs) to the night sky.
    - *Subsoil Cooling*: This involves drawing cooler air from the ground through underground ducts to regulate indoor temperatures.
- **Active Strategies**: These involve mechanical or automated systems that control the indoor environment:
    - *Centralized and Individual HVAC Systems*: These include both single-room systems and large-scale networks.
    - *Solar Thermal Systems*: These are used for heating water and supplementing space heating.
    - *Urban Heating and Cooling Networks*: In some urban areas, shared district energy systems powered by cogeneration or trigeneration provide heating and cooling.
    - *Mechanical Ventilation with Heat Recovery (MVHR)*: This ensures a steady supply of fresh air while conserving thermal energy.

The combination of these strategies is chosen based on building type, location, and usage, creating a customized yet standardized approach to energy-efficient thermal comfort.

Figure 1 illustrates a typical natural ventilation strategy as outlined in Portugal's RECS regulation. It demonstrates how airflow can be managed to maintain thermal comfort without mechanical systems.

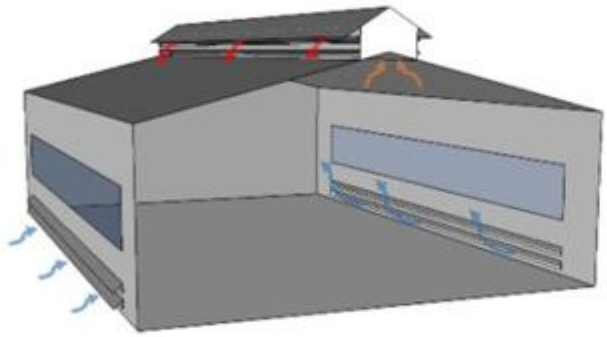

FIGURE 1 CROSS-VENTILATION LAYOUT FOR NATURAL AIRFLOW MANAGEMENT. ADAPTED FROM SISTEMA DE CERTIFICAÇÃO ENERGÉTICA, 2013.

The image below shows a Trombe wall system, a passive solar heating technique encouraged in Portuguese building practices to improve winter comfort while minimizing mechanical heating needs.

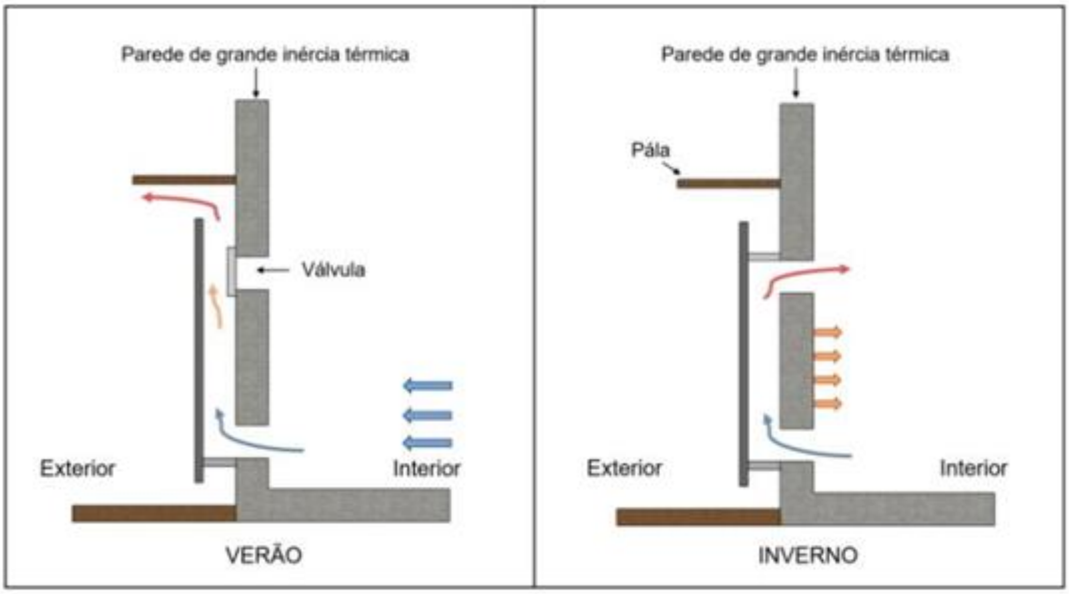

FIGURE 2 TROMBE WALL SYSTEM FOR PASSIVE SOLAR HEAT GAIN AND THERMAL STORAGE. ADAPTED FROM SISTEMA DE CERTIFICAÇÃO ENERGÉTICA, 2013.

4. Technical Systems and Renewable Integration

Technical systems in Portugal's energy regulations refer to all equipment contributing to a building's climate control, energy production, and energy use management. These systems include both traditional HVAC systems and renewable energy installations.

- **Air Conditioning Systems**: These can be centralized systems serving multiple zones or decentralized systems serving individual rooms or sections. Examples include VRF (Variable Refrigerant Flow) and rooftop units.
- **Solar and Geothermal Integration**: Portugal encourages the use of renewable energy sources in building design. Solar thermal panels are widely used for water heating, while photovoltaic panels generate electricity. Geothermal systems—both low and high temperature—are increasingly considered in newer developments.
- **Wind, Biomass, and Biogas**: These renewable sources are also part of the country's energy mix, particularly in rural areas where centralized power supply may be limited.
- **Lighting and Energy Management**: High-efficiency lighting systems, intelligent controls, and building automation systems contribute to energy reduction.
- **Vertical Transport Systems**: Elevators and escalators, especially in large service buildings, are also evaluated for energy consumption and efficiency.

The technical systems are not only evaluated during construction but must also meet performance requirements over time, ensuring continued compliance with RECS.

FIGURE 3 SYSTEM OF AIR CONDITIONING

5. Energy Performance Assessment and Certification

Portugal's RECS mandates that every eligible building be assessed for its energy performance. This is done through a structured certification system managed by ADENE under the SCE portal.

- **Primary Metrics**:
  - *Primary Energy Consumption*: Expressed in kWh per square meter per year, this metric includes all forms of energy used within the building.
  - *CO2 Emissions*: Assessed to determine the environmental footprint of the building.
  - *Energy Class*: Buildings are rated from A+ (most efficient) to G (least efficient), based on national benchmark values.

- **Thermal Zones and Interior Characteristics**:
    - Buildings are segmented into thermal zones depending on function, orientation, and equipment. Each zone is assessed for its own comfort and energy performance.
    - The certification takes into account internal features such as ceiling height and water tightness, as these affect the volume and ventilation efficiency of the space.

This assessment provides a transparent view of how energy-efficient a building is, and the certification is required for property sales, rentals, or public disclosure.

Additional Insight: Thermal Zones, Spaces, Building Envelope, and Energy Class Indicator

The classification and evaluation of spaces within a building are central to understanding its energy behavior. Portugal's RECS framework introduces the concept of thermal zones to better represent how different parts of a building respond to heating and cooling requirements. These zones are defined based on usage patterns, internal loads, orientation, and the presence or absence of air-conditioning systems. For example, a classroom with south-facing windows and no HVAC will perform very differently from a centrally cooled office room—each must be evaluated on its own terms.

Spaces within the building are considered thermally conditioned if they have systems for heating, cooling, or ventilation, or if they significantly contribute to energy use (like IT rooms or kitchen areas). These spaces are modelled carefully to assess their individual needs and overall impact on building energy demand.

The building envelope—which includes external walls, roofs, windows, and floors—acts as the barrier between internal and external environments. Its performance is key in controlling unwanted heat gains in summer and heat losses in winter. A well-insulated envelope reduces the building's dependence on mechanical systems, improves occupant comfort, and lowers energy bills. In Portugal's assessment, envelope quality is judged based on thermal transmittance (U-values), solar factor, shading devices, and airtightness.

All these elements ultimately contribute to the building's **Energy Class Indicator**. This classification is determined through a comparative analysis with a national reference model (RNt) for similar building types and sizes. The energy class not only informs occupants about the expected energy use but also encourages improvements. A building rated A+ signifies excellent energy performance, while one rated G indicates urgent need for upgrades. This simple yet powerful label supports informed decisions by owners, tenants, and public authorities.

With these comprehensive measures, Portugal has established a structured, science-based, and regulation-driven approach to thermal comfort and energy management in buildings. This framework is not only tailored to local climate and building practices but is also designed to meet long-term environmental and economic sustainability targets.

The diagram below represents the zoning of internal spaces based on thermal load, occupancy, and functional requirements. Portugal's RECS requires such zoning to simulate and manage comfort accurately.

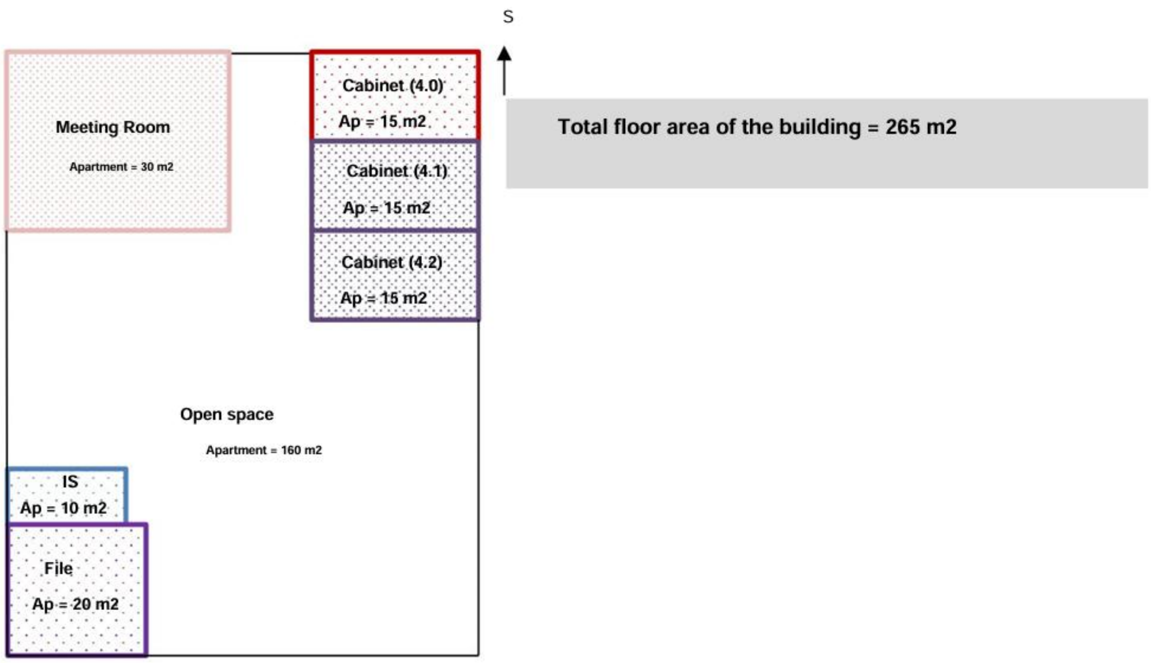

FIGURE 3 FUNCTIONAL THERMAL ZONING LAYOUT IN COMMERCIAL BUILDINGS. ADAPTED FROM SISTEMA DE CERTIFICAÇÃO ENERGÉTICA, 2013.

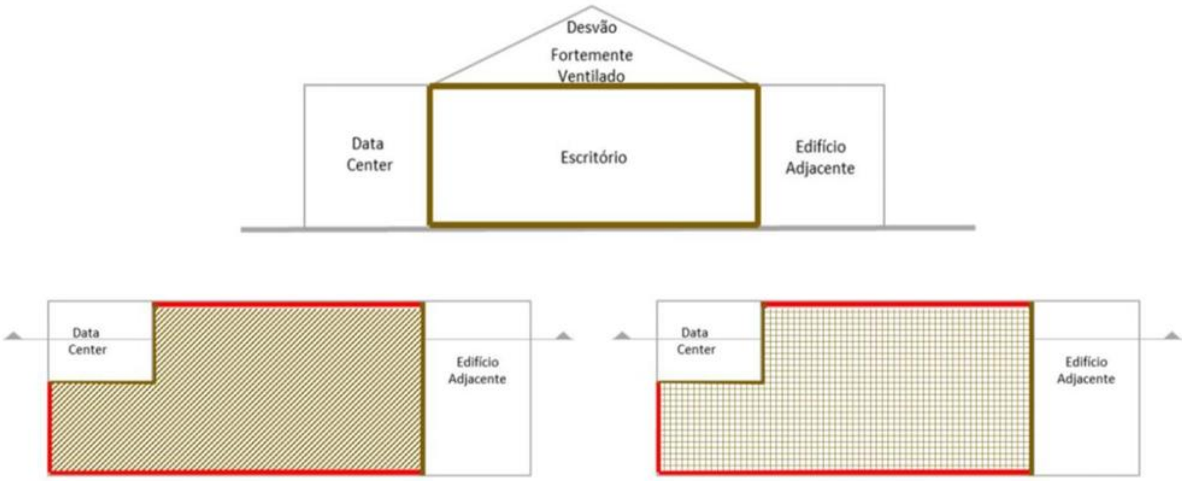

FIGURE 4 EXAMPLE OF PORTUGUESE ENERGY CERTIFICATE AND COMPLIANCE MARKING. ADAPTED FROM SISTEMA DE CERTIFICAÇÃO ENERGÉTICA, 2013

PART 2:- Indoor Environmental Design in France: Based on prEN 15251:2006

Title:

Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings – Addressing Indoor Air Quality, Thermal Environment, Lighting, and Acoustics
(French Implementation of the European Draft Standard prEN 15251:2006)

Introduction and Purpose

This European standard, adopted in France, is part of a broader strategy under the **EU Energy Performance of Buildings Directive (EPBD)**. It addresses the need to balance **thermal comfort**, **air quality**, **lighting**, and **acoustics** in buildings while minimizing energy use.

The core principle is that energy efficiency must **not compromise occupant comfort or health**. Therefore, indoor climate parameters are integrated directly into the **building design**, **system sizing**, **energy simulations**, and **performance evaluations**.

1. Climate Context of France

France has a diverse climate profile:

- **Oceanic** in the northwest
- **Mediterranean** in the south
- **Continental** in the northeast and central regions
- **Mountain climates** in the Alps and Pyrenees

This variability means buildings must accommodate both cold winters and hot summers depending on region. As a result, the French thermal regulation system must be flexible enough to ensure year-round comfort while minimizing reliance on energy-intensive systems.

2. Why Thermal Comfort Matters in France

The goal of France's thermal comfort framework is two-fold:

- **Ensure occupant health, productivity, and satisfaction**
- **Promote energy efficiency and reduce carbon emissions**

Thermal comfort in this context isn't limited to temperature alone. It includes air movement, humidity, radiation from surfaces, and the occupants' activities and clothing. Therefore, a building must balance passive strategies (design and materials) with active ones (mechanical systems) to meet comfort expectations.

The following diagram illustrates how EN 15251 interacts with other European standards under the Energy Performance of Buildings Directive (EPBD), highlighting the integrated approach to regulating indoor environmental quality, comfort, and building energy performance.

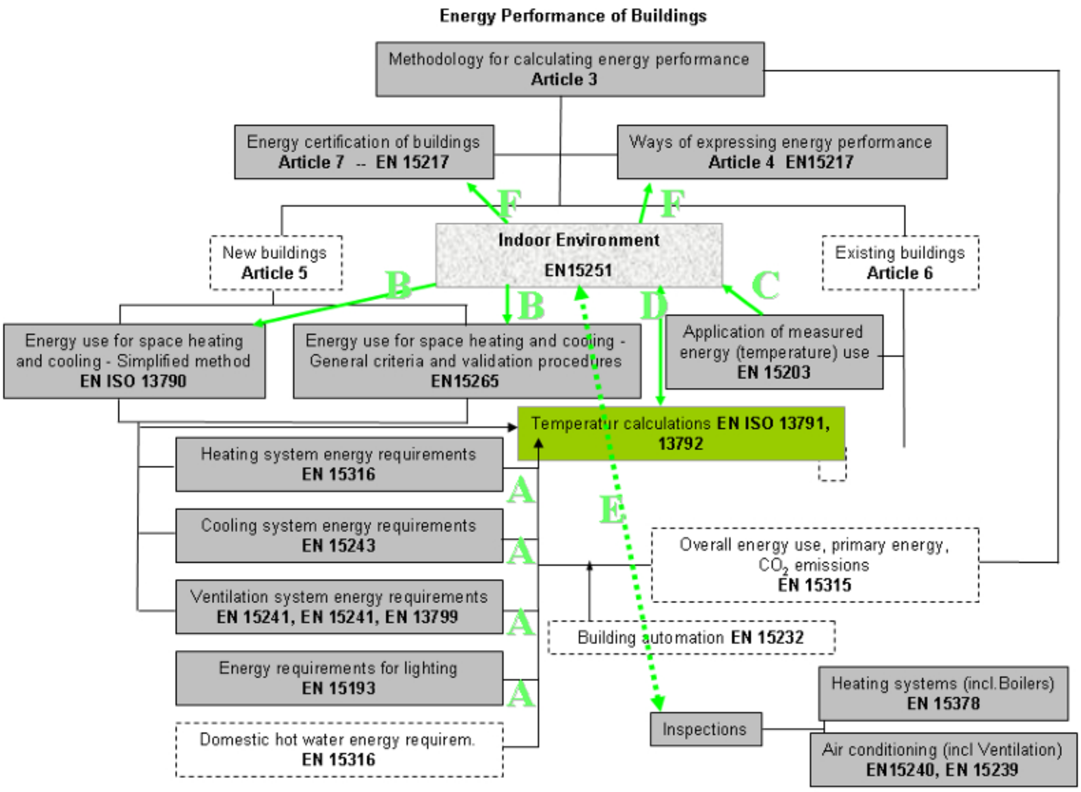

FIGURE 5 DIAGRAM SHOWING THE INTERACTION BETWEEN EN 15251 AND RELATED STANDARDS UNDER THE EPBD FRAMEWORK. ADAPTED FROM EUROPEAN COMMITTEE FOR STANDARDIZATION, 2007.

3. Comfort Categories and Expectations

France, through prEN 15251, defines **four categories of thermal comfort** to suit different types of buildings and users:

TABLE 1 CATEGORIES AND THERMAL COMFORT

Category	Application	Comfort Standard (Winter / Summer)
I	High-expectation users (e.g., elderly, hospitals)	21°C / 25.5°C
II	Normal-expectation (schools, offices)	20°C / 26°C
III	Moderate expectations (older buildings)	19°C / 27°C
IV	Temporary or limited-use buildings	No fixed target

These categories align with different **PMV (Predicted Mean Vote)** and **PPD (Predicted Percentage of Dissatisfied)** thresholds, ensuring that occupants' subjective comfort matches the objective indoor conditions.

4. Building Design and Comfort Strategy

To meet these comfort targets, French buildings follow a layered strategy of passive and active solutions.

Passive Design Measures:

- **Thermal Insulation**: Walls, roofs, and floors must meet minimum U-value standards to reduce heat loss/gain.
- **Window Orientation and Shading**: Prevent excessive solar heat in summer and retain warmth in winter.
- **Natural Ventilation**: Building form and operable windows are used to enhance air exchange

- **Thermal Mass**: Materials like concrete and brick store heat during the day and release it at night, helping regulate temperature swings.

Active Systems (when needed):

- **HVAC Systems**: Used in mechanically conditioned spaces to meet exact comfort targets.
- **Mechanical Ventilation with Heat Recovery**: Ensures fresh air without losing heating/cooling energy.
- **Automated Controls**: Sensors monitor indoor temperatures, humidity, and CO_2 to adapt HVAC output.

5. Assessment Methods for Thermal Performance

France uses multiple methods to **evaluate and certify** the thermal performance of buildings:

a) Design Calculations

These are used in the early design stage:

- Fixed comfort targets are plugged into design models
- Calculations include heat gains/losses, occupancy schedules, and equipment loads
- Standards like **EN ISO 13790** guide these evaluations

b) Dynamic Simulation

- **Hourly-based software** simulates indoor thermal conditions over the year
- Takes into account solar gains, night cooling, and varying occupancy
- Crucial for mixed-mode or naturally ventilated buildings

c) Degree-Hour Method

- Measures how many hours indoor temperature deviates from the comfort range
- Expressed in degree-hours: a measure of discomfort severity

d) Field Measurements

- Instruments are placed in classrooms or offices to log real-time data
- Parameters include air temperature, humidity, air speed, radiant temperature, and CO_2
- Standard **EN ISO 7726** defines the measurement protocols

e) Occupant Feedback (Subjective Validation)

- Users complete comfort surveys (Thermal Sensation Votes)
- These are compared to predicted values (PMV)
- Helps designers understand perception gaps

6. Naturally Ventilated vs Mechanically Conditioned Buildings

French regulation distinguishes between two main types of building control:

Mechanically Cooled Buildings

- Indoor temperatures must remain within a narrow band using HVAC

- PMV-PPD models dictate compliance

Naturally Ventilated Buildings

- Use the **adaptive model**, where acceptable indoor temperature changes with outdoor climate
- For example: when the outdoor running mean temperature is 25°C, the indoor comfort range may shift accordingly (e.g., 23°C–28°C)
- Equations are provided in the standard to calculate these limits

7. Air Quality and Ventilation Design

Ventilation is a key component of thermal comfort:

- **Fresh air supply** is based on occupancy (e.g., L/s per person)
- **CO_2 levels** must remain below 1000–1350 ppm for Category I and II spaces
- Building materials are classified for their emissions: low, medium, or non-low-polluting

8. Energy Certification and Comfort Integration

France integrates comfort evaluation into the **building's Energy Performance Certificate (EPC)**:

- Indicates comfort category (I–IV)
- Includes simulation and measurement data
- Tracks CO_2 emissions and annual energy consumption

This combined system ensures that comfort is not treated as separate from energy efficiency.

Partial Conclusion

France's thermal performance framework is a **balanced and flexible system** that:

- Adjusts to regional climates
- Embraces both passive and active design
- Uses scientific modelling and real-time data
- Considers occupant feedback and adaptation

The approach reflects a mature understanding that energy efficiency must support—not compromise—human comfort. Whether through adaptive models for naturally ventilated schools or precise HVAC control in hospitals, France's legislation helps create healthier, more sustainable built environments.

Comparative Analysis: Thermal Performance Regulations in Portugal vs. France

The following table presents a side-by-side comparison of the key regulatory and technical approaches to thermal comfort adopted by Portugal and France, highlighting differences in climate adaptation, comfort models, simulation methods, and user-centered strategies.

TABLE 2 COMPARATIVE ANALYSIS BETWEEN PORTUGAL AND FRANCE

Aspect	Portugal (RECS – Decree-Law No. 118/2013)	France (prEN 15251:2006 Implementation)
1. Climate Consideration	Mediterranean climate across most of the country; mild winters and hot summers	Diverse: Oceanic, Mediterranean, Continental, and Alpine; broader thermal design requirements
2. Regulatory Basis	National law aligned with EU EPBD, applied through SCE (Energy Certification System)	Based on European standard prEN 15251:2006, integrated into national EPC system
3. Building Types Covered	Commercial and service buildings (including schools, offices, hospitals)	Non-industrial buildings (offices, schools, hospitals, hotels)
4. Comfort Categories	Implicitly defined through building classification (Passive, Hybrid, Active) based on % hours HVAC is needed	Explicit categories I–IV based on PMV/PPD or adaptive comfort criteria; linked directly to building types and user needs
5. Thermal Comfort Models Used	Rational model (PMV/PPD) primarily; adaptive model not formally integrated	Both rational (PMV/PPD) and adaptive model (for naturally ventilated buildings); includes dynamic indoor setpoints based on outdoor climate
6. Space Classification	Divides buildings into thermal zones based on use, orientation, equipment; used for energy modeling	Similar zoning approach; zones defined for simulation and compliance purposes
7. Envelope and Passive Design	Strong emphasis on building envelope (U-values, shading, insulation); passive cooling/heating strategies encouraged	High-performance envelope required; thermal mass, shading, and natural ventilation used to meet adaptive comfort
8. HVAC and Technical Systems	Systems evaluated for energy class; includes HVAC, lighting, elevators, solar thermal, PV	HVAC sizing based on load calculations; supports heat recovery, natural and hybrid ventilation systems
9. Ventilation and Air Quality	Focus on maintaining indoor air quality; PREn plans encourage natural ventilation and system optimization	CO_2 thresholds and L/s per person requirements; direct comfort and health categories related to ventilation effectiveness
10. Performance Evaluation Methods	Static calculations + mandatory energy certification + field inspections; comfort evaluation mainly through compliance	Design-phase modeling, hourly dynamic simulations (especially for Category I/II), field measurements, and occupant feedback (TSV)
11. Energy Certification Integration	Buildings classified A+ to G; CE includes comfort conditions, energy usage, and emissions	EPC includes comfort category (I–IV), time outside comfort limits, energy data, and CO_2
12. User-Centric Feedback	Limited direct integration of occupant satisfaction in legislation	Explicit feedback methods (thermal sensation surveys) part of validation and comfort assurance
13. Adaptability Across Climate Zones	Zoning adjusts for different Portuguese regions; regional targets applied	Highly adaptable due to national climatic diversity; adaptive models widely supported
14. Special Considerations	Energy Rationalization Plans (PREn) required for large/poorly performing buildings	Use of dynamic setpoints, degree-hour analysis, and post-occupancy evaluation ensures buildings reflect real-use patterns

Key Similarities

- Both align with the **EU EPBD framework** and require energy certification.
- Both consider **thermal zoning**, although France ties this more directly to occupant usage and simulation parameters.
- **CO_2 thresholds and indoor air quality** are emphasized in both cases, though with stricter thresholds in France.

Key Differences

Below are the key differences between both of the countries in terms of modelling protocols and occupant feedback.

TABLE 3 KEY DIFFERENCE BETWEEN PORTUGAL AND FRANCE

Feature	Portugal	France
Comfort Modelling	Primarily PMV-based; adaptive not formalized	PMV + Adaptive model fully integrated
Feedback from Occupants	Not institutionalized in legislation	Surveys and thermal votes are part of evaluation
Field Measurement Protocols	Conducted for compliance; focused on energy performance	Detailed field testing using ISO 7726; includes comfort tracking
Flexibility by Occupant Type	Does not differentiate comfort by user sensitivity	Explicit comfort categories for different user groups (elderly, children, general office)

Partial Conclusion of the Comparative Analysis of France and Portugal:

Portugal and France both aim to achieve a balance between **energy efficiency and occupant comfort**, but their approaches differ in **depth, flexibility, and user engagement**.

- **France** takes a more **human-centered**, adaptive, and data-driven approach, integrating **real-world measurements** and **occupant feedback** alongside simulation and certification.
- **Portugal** focuses more on **compliance with efficiency targets**, integrating passive strategies and system efficiency under a more rigid, energy-class-based model.

For a research comparison, Portugal offers a model more aligned with **technical performance and envelope control**, while France showcases **adaptive comfort integration and personalized design—**especially relevant when assessing naturally ventilated educational buildings.

PART 3:- Guide for Heat Insulation of Non-Industrial Buildings (IS: 3792 – 1978)

Issued by: Bureau of Indian Standards (BIS)
Purpose: To guide architects, engineers, and planners in designing non-industrial buildings like homes, schools, hospitals, and offices to minimize heat gain and enhance thermal comfort without relying on mechanical cooling or heating systems.

1. Objective of the Standard

This guide aims to reduce **heat gain** in buildings located in India's diverse climates using **passive design** and **material-based insulation strategies**. The goal is to provide **thermal comfort** indoors, particularly during summer, by minimizing external heat transfer into the building.

2. Thermal Zones of India

India is categorized into four **climate-based zones**, each requiring a different heat insulation approach:

TABLE 4 THERMAL ZONES OF INDIA

Zone	Temperature–Humidity Characteristics	Example Cities
Hot & Arid	>38°C, RH <40%, low elevation	Delhi, Jaipur, Jodhpur
Hot & Humid	>32°C, RH >40%	Mumbai, Chennai, Kolkata
Warm & Humid	26–32°C, RH >70%, low elevation	Cochin, Trivandrum
Cold	<6°C during winter, elevation >1200m	Leh, Shimla, Srinagar

3. Core Thermal Parameters

These are essential metrics—such as U-value, time lag, and damping—that help quantify how heat flows through building elements and how effectively insulation performs.

TABLE 5 CORE THERMAL PARAMETERS

Term	Definition
U-value (W/m²K)	Rate of heat transfer through a surface; lower = better insulation.
R-value (m²K/W)	Thermal resistance; inverse of U-value.
Q/U (hours)	Thermal time constant; delay in heat entering indoors.
TPI (Thermal Performance Index)	Combined indicator of insulation quality; higher is better.
Damping (%)	Degree to which temperature swings are reduced.
Shade Factor	Efficiency of shading device in reducing solar gain.

The following figures are extracted from IS 3792:1978 – the Indian standard guideline for heat insulation in non-industrial buildings. These diagrams illustrate parameters used to assess the thermal performance of wall and roof components, as well as the relationship between thermal damping and time constant, which are fundamental in understanding how buildings respond to thermal loads in India's diverse climate conditions.

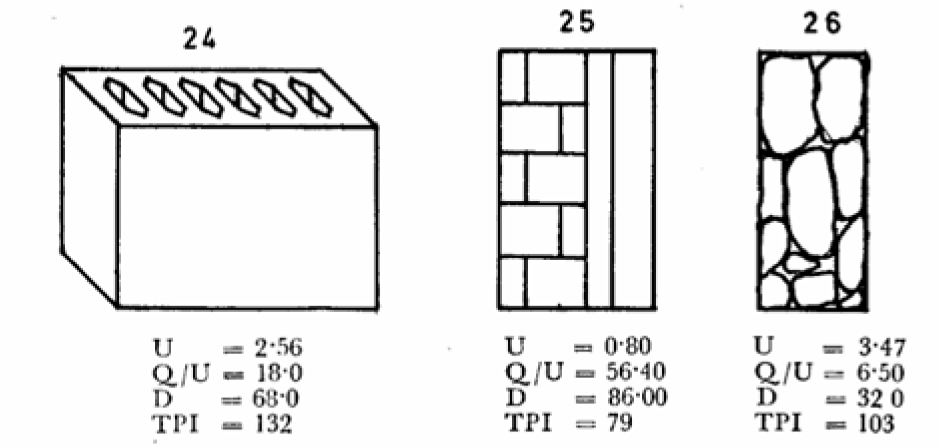

FIGURE 6 THERMAL PERFORMANCE PARAMETERS OF DIFFERENT WALL TYPES, INCLUDING U-VALUE, HEAT CAPACITY, DAMPING PERCENTAGE, AND THERMAL PERFORMANCE INDEX (TPI), USED TO ASSESS INSULATION EFFICIENCY. SOURCE: BUREAU OF INDIAN STANDARDS. (1978). IS 3792: GUIDE FOR HEAT.

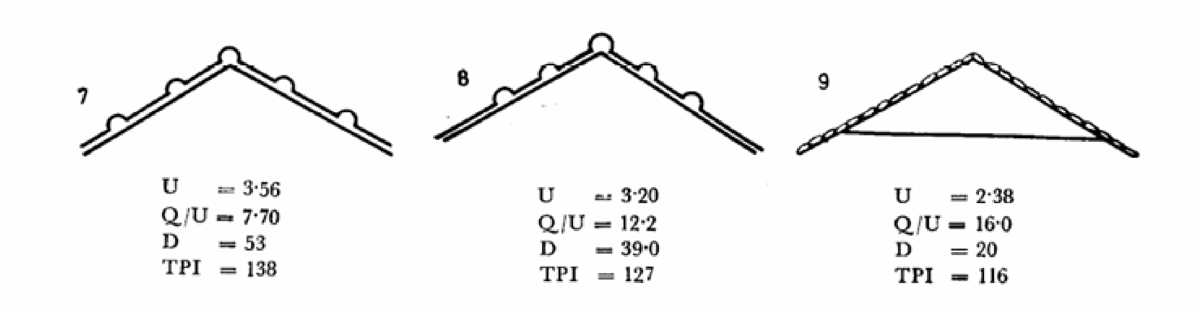

FIGURE 7 THERMAL PERFORMANCE PARAMETERS OF VARIOUS SLOPED ROOF DESIGNS EVALUATED USING METRICS SUCH AS U-VALUE, DAMPING, AND TPI, HIGHLIGHTING PERFORMANCE DIFFERENCES BASED ON GEOMETRY AND MATERIALS. SOURCE: BUREAU OF INDIAN STANDARDS. (1978). IS 3792: GUIDE

4. Thermal Performance Standards

These refer to defined thresholds or benchmark values—such as maximum allowable U-values, minimum TPI (Thermal Performance Index), and required time constants—that guide designers in ensuring thermal comfort and energy efficiency. These standards are often supported by graphs or limiting curves, such as the one below, which illustrates the relationship between thermal damping (%) and time constant (hours), helping to visualize how effectively a building envelope can delay and reduce heat transfer from the external environment.

TABLE 6 THERMAL PERFORMANCE STANDARDS

Component	Zone	U-max (W/m^2K)	TPI-min	Time Constant-min (hrs)	Damping-min (%)
Roof	All	2.33	100–125	20	75
Exposed Wall	Hot/Dry	2.56	125	16	60
	Warm/Humid	2.91	175	16	60

The relation between **damping** and **time constant** is shown graphically in the standard (Figure 8)

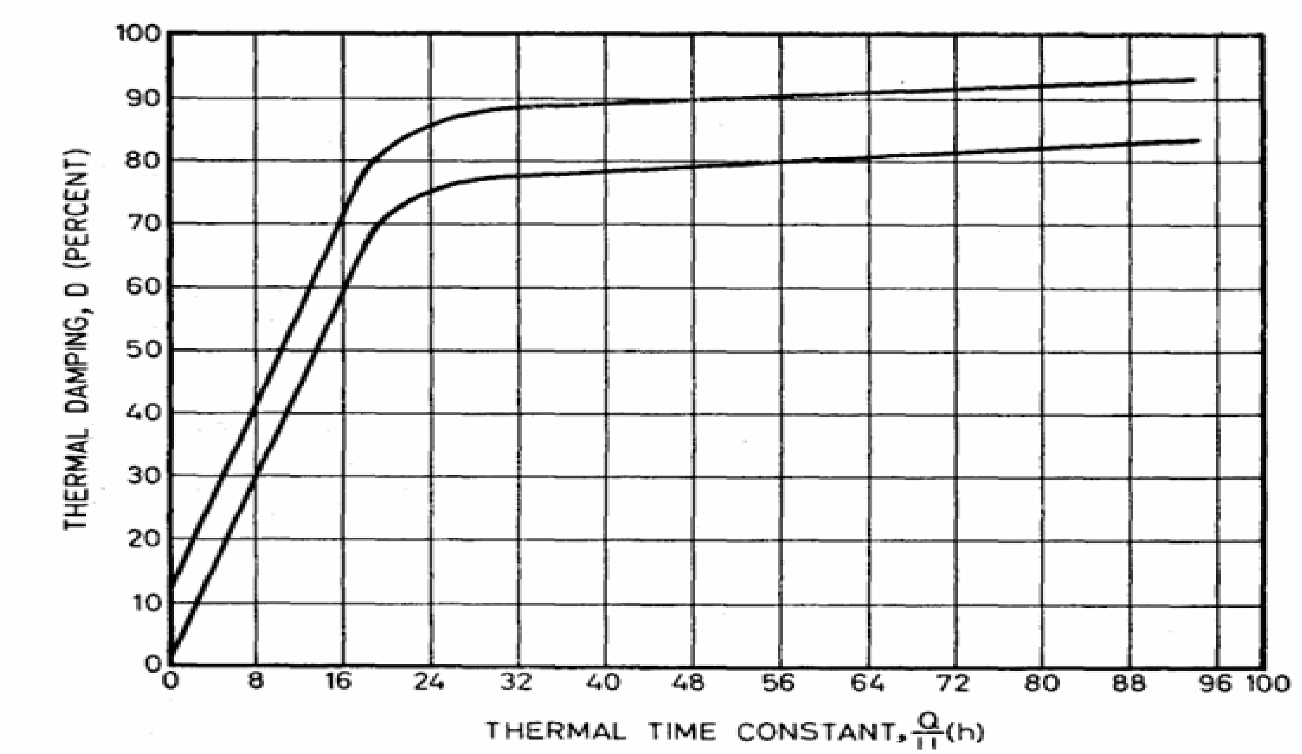

FIGURE 8 LIMITING CURVES SHOWING RELATIONSHIP BETWEEN THERMAL TIMES SOURCE: BUREAU OF INDIAN STANDARDS. (1978). IS 3792: GUIDE FOR HEAT INSULATION OF NON-INDUSTRIAL BUILDINGS.

5. Heat Insulation Methods

The following section outlines key heat insulation methods commonly used to improve thermal comfort and energy efficiency in buildings.

5.1 General Passive Strategies

- **Orientation:** Minimize solar heat gain by orienting major windows to north/south.
- **Shading:** Use external chhajjas, sun-breakers, and internal blinds.
- **Ceiling Height:** 1.0–1.3 m above occupants for reducing radiant heat impact.

5.2 Roof Insulation Techniques

- **External Insulation:** Layer under waterproofing (e.g., brickbat coba, mud phuska).
- **Internal Insulation:** Fixing insulation boards or using false ceilings.
- **Reflective Coatings:** Whitewashing or reflective membranes.
- **Water Sprays:** Cooling via evaporative loss.
- **Movable Covers:** Shade roofs during peak heat periods.

5.3 Wall Insulation Options

- **Increase wall thickness**
- **Use cavity wall design**
- **Apply insulation inside or outside** (with waterproofing if external)
- **Apply reflective paints or finishes**

5.4 Window & Door Insulation

- **Reduce solar incidence:** via chhajjas, blinds, louvres.
- **Reduce transmission:** via double glazing, reflective glass, or internal linings.

6. Material Properties

The thermal conductivity of construction materials plays a vital role in determining the insulation effectiveness of a building element. The following table lists commonly used materials in Indian construction, along with their conductivity values, to help in selecting appropriate combinations for better thermal performance.

TABLE 7 MATERIAL TYPE AND THEIR CONDUCTIVITY

Material Type	Conductivity (k in W/m·K)
Burnt Brick	0.81
RCC	1.58
Expanded Polystyrene	0.035
Cement Plaster	0.721
GI Sheet (Metal Roofing)	~61.06

Note: Lower conductivity = better insulation.

7. Calculation Methods and Formulas

To evaluate the thermal behaviour of building components, it is essential to understand key calculation methods such as thermal transmittance (U-value) and thermal time constant (Q/U). These formulas help quantify how much heat is transferred through a material and how long a building element takes to respond to external temperature changes.

7.1 Thermal Transmittance (U-value)

$$R = \frac{L}{k}$$

Step 1: Compute Resistance (R) of each material layer:

Where:

- LLL = Thickness in meters
- kkk = Thermal conductivity in W/m·K

Step 2: Compute total resistance:

$$R_T = \frac{1}{f_o} + R_1 + R_2 + R_3 + \ldots + \frac{1}{f_i}$$

Where:

- $f_o = 19.86$ W/m²K (outer surface)
- $f_i = 9.36$ W/m²K (inner surface)

Step 3: U = $\frac{1}{R_T}$

7.2 Thermal Time Constant (Q/U)

$$Q/U = \frac{\text{Total Heat Storage Capacity}}{\text{Thermal Transmittance (U)}}$$

- For composite walls:
- Storage capacity is calculated from:

Where:

- Li: Thickness (m), ρi: Density (kg/m^3), ci: Specific Heat (kJ/kg·K)

$$\sum (L_i \cdot \rho_i \cdot c_i)$$

7.3 Thermal Performance Index (TPI)

$$TPI_{\text{corrected}} = (TPI - 50) \cdot C + 50$$

To adjust for orientation or surface finish:

Where **C** is the correction factor from Table 6 for:

- Wall/roof type
- Orientation (N, E, S, W)
- Surface finish (light/dark)
- Shading presence

7.4 Damping and Time Lag

- Damping is determined by comparing inside temperature swings to outside.
- Time lag is the **delay** between peak outside temperature and peak inside temperature.

8. Pre-calculated Tables & Figures for Designers

The standard provides ready-to-use data for typical construction assemblies:

- **Walls**: U-values, damping %, TPI for various brick + plaster + cavity wall types
- **Roofs**: Flat and sloped roof data including tiles, thatch, softboard, AC sheets
- **Windows/Glazing**: U-values, shading efficiency
- **Figures 2–4**: Graphs visualizing wall, flat roof, and sloped roof performance

9. Key Takeaways from the Indian Legislation

The following section summarizes the core findings and insights derived from the comparative study of thermal comfort regulations and practices in India.

TABLE 8 KEY TAKEAWAY FROM INDIAN CONTEXT

Goal	Recommended Action
Reduce roof heat gain	External insulation, white paint, water spraying
Improve wall insulation	Cavity walls, external boards, reflective coatings
Limit solar gain through glass	Shading + reflective glazing
Optimize design	Use orientation, height, light finishes, and shade
Confirm performance	Use formulas to calculate U, Q/U, and TPI

Conclusion of Part 3 IS 3792:1978 – Heat Insulation in Indian Buildings

The Indian Standard IS 3792:1978 remains a cornerstone document in the domain of **climate-responsive architecture and passive thermal comfort design**. It offers a deeply contextual approach to mitigating heat gain in non-industrial buildings across India's diverse climatic regions, making it especially vital for structures that operate **without mechanical air-conditioning or heating**.

Key Messages from the Standard:

1. **Climate-Specific Design is Non-Negotiable**
   By classifying the country into four thermal zones—hot and dry, hot and humid, warm and humid, and cold—the standard highlights that **no one-size-fits-all** approach works in Indian climates. Every design must respond to its **regional thermal stress**.

2. **Passive Techniques are Primary Tools**
   The guide emphasizes **passive solutions—**orientation, shading, insulation layers, ventilation, thermal mass—as the first and most cost-effective strategy to improve comfort. It does **not rely on active mechanical cooling**.
3. **Quantified Thermal Performance is Essential**
   The standard introduces a scientific framework for evaluating thermal performance using **U-values, R-values, thermal time constants (Q/U), damping, and TPI (Thermal Performance Index).** These quantifiable metrics allow professionals to **design, assess, and compare** buildings for thermal efficiency.
4. **Material Science is Critical to Comfort**
   A wide range of **locally available construction materials** is evaluated in terms of their thermal conductivity, enabling practical and affordable insulation decisions based on data rather than guesswork.
5. **Flexible but Formula-Based Approach**
   IS 3792 provides formulas for composite U-value calculations, TPI corrections, and time constants—making it a **technical yet flexible tool.** Designers can adjust materials, thickness, and finishes to meet performance goals, with **correction factors** for orientation and shading.
6. **Design Guidelines are Holistic**
   The document doesn't isolate insulation from architecture—it ties it into the **building's form, roof type, openings, ventilation strategy, and surface color**, presenting a **whole-building perspective** on thermal comfort.
7. **Still Relevant in Modern Sustainable Design**
   Although published in 1978, its emphasis on **thermal performance without energy-intensive systems** aligns well with modern concerns about **climate change**, **net-zero buildings**, and **energy conservation** in the built environment.

Part 3 Summary:

IS 3792:1978 is not just a manual for insulation—it's a **climate-sensitive design philosophy** wrapped in data. It empowers architects, engineers, and planners to design **thermally comfortable spaces** for India’s varied climates, using **minimal energy** and **maximum design intelligence**.

Its continued relevance lies in its focus on **thermal performance as the first step toward sustainable architecture**, especially important in today's era of **rapid urbanization, climate challenges, and resource constraints**.

PART 4:- Comparative Analysis of Heat Insulation Standards and Practices in France, Portugal, and India

1. Introduction

With the global emphasis on sustainable development and climate-responsive architecture, the thermal performance of buildings has emerged as a critical area of focus. In regions with extreme temperature variations, particularly hot summers or cold winters, heat insulation plays a vital role in enhancing indoor comfort and reducing energy consumption.

This comparative analysis investigates the methods, legislation, and metrics associated with **heat insulation in buildings** across three countries: **France**, **Portugal**, and **India**. While France and Portugal operate under the umbrella of the European Energy Performance of Buildings Directive (EPBD), India uses its own climate-specific standards, notably **IS 3792:1978**. This study evaluates their respective frameworks in terms of climate response, comfort modelling, insulation metrics, materials, and compliance mechanisms.

To understand the differences in thermal insulation practices across France, Portugal, and India, it is essential to compare them across multiple parameters including climate conditions, regulatory frameworks, technical solutions, and sustainability priorities. This comparative assessment begins with the climatic context (Table 10), which influences thermal needs and design responses in each country. It is followed by a review of each nation's regulatory framework (Table 11), and the building envelope and insulation practices adopted in response (Table 12). The comparison then covers the modelling approaches and calculation methods used for heat transfer and U-value estimation (Table 13), thermal zoning and use-specific criteria (Table 14), and finally, preferences for sustainable materials and carbon-conscious design (Table 15).

1. Climatic Context

TABLE 9 COMPARISON BASED CLIMATE CONTEXT FOR ALL THREE COUNTRIES

Aspect	India	France	Portugal
Climate Type	Tropical to arid and temperate (high variability)	Oceanic, continental, Mediterranean	Mediterranean and oceanic
Major Challenge	Overheating in hot-dry regions, humidity elsewhere	Insulation in winters, rising summer temperatures	Cooling in summers, efficient winter heating
Seasonal Variation	Extreme (heat waves in summer, cold in some winters)	Distinct seasons, especially cold winters	Mild winters, long warm summers

2. Regulatory Framework

TABLE 10 COMPARISON BASED ON REGULATORY FRAMEWORK OF ALL THREE COUNTRIES

Criteria	India	France	Portugal
Main Standard	IS 3792:1978 (Code of practice for heat insulation)	RT2012 / RE2020 Thermal Regulation	Decreto-Lei nº 118/2013 (SCE, REH, and RECS)
Nature of Regulation	Guideline-based (non-mandatory in many states)	Legally binding national regulation	Mandatory for new buildings and renovations
Enforcement Mechanism	Local/state-level implementation, not strictly monitored	Through energy audits and certificates	Certification under SCE system (A–G energy labels)

3. Building Envelope and Insulation Practices

TABLE 11 COMPARISON BASED ON BUILDING ENVELOPE AND INSULATION PRACTICES

Feature	India	France	Portugal
Wall Insulation	Common materials: brick, lime concrete, fibre boards	Multi-layered insulation with polyurethane, glass wool	Use of ETICS (External Thermal Insulation Composite System)
Roof Insulation	Lime concrete, insulating bricks, reflective coating	Sloped/flat roofs with rigid insulation boards	Insulated roofs using thermal bridges and reflective sheets
Openings	Use of shading, double-glazing rare	Triple/double-glazing mandatory in colder zones	Double-glazing with thermal breaks
Orientation Consideration	Suggested but not always enforced	Strongly integrated in building simulation tools	Required for compliance (heating/cooling demand)

4. Calculation Methods and Modelling

TABLE 12COMPARISON BASED ON THE CALCULATION METHODS AND MODELLING

Parameter	India	France	Portugal
Heat Transfer Coefficients	Manual estimation (basic formula: Q = U × A × ΔT)	Dynamic simulation using software like Th-BCE, RT-EXP	Simulation under REH with designated software tools
U-Value Reference	Yes (basic tabular form)	Strict U-value limits for all envelope parts	Required to meet set values for roofs, walls, and openings
Dynamic Simulation Models	Not required in standard	Required for RE2020 compliance (thermal + environmental impact)	Required for assessing class and verifying design under REH

5. Thermal Zoning and Use-Specific Guidelines

TABLE 13 COMPARISON BASED ON THERMAL ZONING AND SPECIFIC GUIDELINES

Parameter	India	France	Portugal
Thermal Zones	No formal zoning in IS 3792; ECBC defines 5 climate zones	8 thermal zones based on geographical and climatic regions	National-level zoning for internal gains and HVAC modelling
Space Usage Types	Generalised approach	Detailed categorization (schools, offices, homes, etc.)	Specific usage types included (residential, educational, etc.)
Applicability to Schools	Not explicitly targeted	Specific insulation criteria and air change rates defined	Separate benchmarks for school buildings

6. Material Preferences and Sustainability

TABLE 14 COMPARISON BASED ON MATERIAL PREFERENCES AND SUSTAINABILITY

Criteria	India	France	Portugal
Sustainable Material Use	Encouraged (mud bricks, lime, stone) but not enforced	Focus on eco-friendly insulation (wood fiber, cellulose, etc.)	Mandatory LCA (Life Cycle Assessment) under REH
Renewable Integration	Passive solar rarely adopted	Solar panels and passive design promoted under RE2020	Solar water heating and passive cooling incentivized
Embodied Carbon Accounting	Not addressed	Central to RE2020	Included in simulation and evaluation

7. Strengths and Weaknesses

India

Strengths: Flexible and affordable; ideal for diverse climatic zones; uses local, low-cost materials.
Weaknesses: Outdated (IS 3792:1978); lacks enforcement, thermal zoning, and modern sustainability measures

France

Strengths: Technically advanced; legally enforced; integrates lifecycle analysis and dynamic simulations.
Weaknesses: Complex to implement; high cost; requires skilled professionals and digital tools.

Portugal

Strengths: Balanced and practical; clearly zoned; strong energy certification system; encourages passive design.
Weaknesses: Less suitable for tropical climates; relies on digital platforms; may lack enforcement in rural areas.

8. Observations and Thematic Insights

- **France** leads in **adaptive comfort modelling**, especially for naturally ventilated buildings. It integrates occupant surveys, dynamic hourly simulation, and environmental measurements, enabling a highly flexible and human-cantered design process.
- **Portugal** focuses on aligning with EU energy efficiency goals. While it promotes passive and active design, it leans heavily on the **energy certification system (CE)**, primarily driven by system performance rather than user experience or adaptive behavior.
- **India's IS 3792** takes a **fundamentally passive design approach**, focusing on **zone-specific climate responses**, quantified through insulation performance indicators like **TPI, U-values**, and **thermal damping.** It does not integrate human thermal sensation models but is **deeply rooted in affordable and material-specific strategies**.

PART 5:- Conclusion of Comparative Analysis

Each country's standard reflects its **local climate**, **economic conditions**, and **regulatory priorities**:

- **France** offers the **most holistic** approach by combining adaptive thermal models, precise performance metrics, and real occupant feedback. It is suitable for **advanced buildings** with access to simulations and monitoring.
- **Portugal** delivers a **balanced framework** with strong regulatory compliance, structured performance benchmarks, and integration into EU energy goals. It is optimal for **urban service buildings** where HVAC is prevalent.
- **India's IS 3792** is a **resource-friendly, climate-sensitive model** focused on passive design. It is best suited for **developing regions** where **affordability**, **local material use**, and **low-energy solutions** are priorities.

Here is the overall conclusion of the study in a tabular form with reasoning.

TABLE 15 OVERALL COMPARISON AND REASONING

Criteria	Winner	Reason
Most Scientifically Advanced	**France**	Dynamic modeling, lifecycle analysis, and sustainability integration
Most Practical and Adaptive	**Portugal**	Easier compliance, scalable for Mediterranean climates, strong enforcement
Most Cost-Effective	**India**	Low material cost, simple construction practices (but needs modernization)
Best for Educational Buildings	**France / Portugal**	Due to specific guidelines for school usage, zoning, and ventilation standards

France leads in thermal performance due to its scientific rigor, sustainability integration, and strong legal enforcement, making it ideal for long-term energy goals. Portugal follows closely with a well-structured but more practical and flexible system, particularly suited to Mediterranean conditions. India, while functional for local conditions and cost-sensitive projects, urgently needs an updated and more comprehensive regulatory framework that includes modern materials, simulation tools, and enforceable zoning and energy labels—especially for educational and institutional buildings.

Overall Research Conclusion:-

The comparative analysis of heat insulation standards and thermal performance frameworks in **India**, **France**, and **Portugal** reveals a spectrum of approaches—each uniquely shaped by climate, economic context, policy priorities, and technological capabilities.

France **stands at the forefront of thermal comfort regulation.**

With its scientifically rigorous and data-driven approach, France leads in incorporating **adaptive comfort models**, **dynamic simulations**, **life cycle assessments**, and **occupant feedback systems** into its building performance framework. It doesn't just measure energy use—it redefines comfort itself through real-world adaptability, making it ideal for **technologically advanced and environmentally conscious projects**. However, its complexity and high compliance cost limit its universal applicability, particularly in low-resource settings.

Portugal offers a well-structured and implementable middle path.

Portugal's regulatory system provides **clear guidance**, a robust **energy certification mechanism**, and promotes both **active and passive strategies**. It successfully integrates into the EU's broader energy goals while remaining **practical and accessible** for both new constructions and retrofits. It is well-suited for **Mediterranean and temperate climates**, but may require further adaptation for regions with **extreme heat** or **high humidity**, like many parts of Asia or Africa.

India, while operating with an older standard, showcases the importance of contextually relevant, cost-effective solutions.

IS 3792:1978 emphasizes **passive design**, **local materials**, and **climate-specific strategies** that make it valuable for a country with high climate diversity and economic disparity. Its simplicity ensures wider applicability, especially in **rural or low-income housing**, but the absence of enforceable energy certification, updated modelling tools, and occupant-cantered metrics makes it **inadequate for modern sustainable development targets**. India has the opportunity to modernize its framework by blending its rich passive design tradition with **modern performance evaluation systems**.

Final Reflection: No One-Size-Fits-All

Each framework reflects the realities of its region:

- **France** excels in innovation and precision.
- **Portugal** balances structure with practicality.
- **India** prioritizes accessibility and cost-efficiency.

Rather than labelling one approach as the best, the ideal path forward may lie in **integrating the best elements** from each:

- Adopt **India's passive design wisdom**,

- Apply **Portugal's scalable enforcement and certification**, and
- Embrace **France's adaptive modelling and sustainability tools**.

Such a hybrid model would support **globally applicable, climate-resilient, and occupant-centric** buildings that meet the challenges of both today and tomorrow.

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