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Research Article

Thermal Inertia and Energy Behavior of Buildings: A Global Bibliometric Analysis.

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ABSTRACT

The rapid growth of cities worldwide—expected to involve nearly 70% of the global population by 2050—means an increased need for energy, water, and resources, especially in the largest urban centers. Since buildings use a significant portion of energy and contribute notably to carbon emissions, making them more efficient is essential in our efforts to fight climate change. In this context, thermal inertia plays an important role because it influences how buildings respond to their environment and how effectively they can handle external weather changes. By improving thermal inertia, we can significantly reduce energy consumption and minimize the environmental impact of our buildings.

This study aims to provide a bibliometric knowledge map of thermal inertia and its effects on habitats, energy behavior, and building energy efficiency. Using a dataset of 171 journal articles indexed in the Scopus database, this analysis applies bibliographic coupling to titles, abstracts, keywords, and conceptual frameworks. The results reveal three main research themes: thermal inertia, energy behavior, and energy efficiency, and highlight the use of VOSviewer and Bibliometrix for trend analysis.

The most significant results are that research on thermal inertia in buildings has accelerated since 2010 in response to climate policies, focused on a few key journals and regions, such as Southern Europe and China, and developed into three main themes connecting thermal inertia, energy behavior, and energy efficiency. The results also show a strong scientific activity, mainly around studies on thermal bridges, modeling the dynamic behavior of walls, and improving energy efficiency through envelope optimization. However, the study points out several important gaps: the limited use of renewable energy in thermal inertia studies, the lack of economic and life-cycle approaches, and the absence of interdisciplinary work linking engineering, health, and energy policy. These gaps suggest future research directions for creating resilient, cost-effective, and carbon-neutral buildings.

Keywords: Thermal inertia, buildings, Energy behavior, Energy efficiency, VOSViewer, Bibliometix.

INTRODUCTION

Climate change is an urgent reality that cannot be ignored. In 2024, unprecedented temperatures significantly increased global energy demands, surpassing even those of 2023. According to the IEA (IEA, 2025), cooling degree days rose by 6% compared to the previous year and by 20% relative to the 2000–2020 average, highlighting the growing severity of climate extremes. This increasing climate stress is reflected in global energy consumption. Worldwide electricity use grew by about 4% in 2024, showing higher demand from both economic activities and households (Energy Institute, 2025).

Within this global context, the residential sector plays a crucial role. It accounts for about one-third of total final energy consumption and contributes nearly 39% of CO_2 emissions (Programme & Construction, 2025) . Improving the energy efficiency of buildings is therefore a key strategy for mitigating climate change and achieving sustainable development goals.

Among the various approaches to reduce building energy consumption, enhancing thermal inertia has emerged as a key passive strategy. Thermal inertia is the capacity of a building envelope to store heat and release it later, thereby moderating indoor temperature fluctuations, reducing energy demand, and reducing heating and cooling loads while improving thermal comfort (Akbari, Lodi, Muscio, & Tartarini, 2021) and (Delgado, Ramos, Domínguez, Ríos, & Cabeza, 2020).This property is particularly beneficial in climates with large day–night temperature swings.

Numerous studies have investigated various materials and design strategies to enhance the thermal inertia of buildings. (Delgado et al., 2020) analyzed building thermal storage technologies and their effectiveness in lowering energy consumption. This research builds upon earlier work by the same group, which explored the thermal performance of insulation materials combined with phase-change materials (PCMs), as well as the dynamic behavior of alveolar brick walls (Cabeza, Castell, Barreneche, De Gracia, & Fernández, 2011; Navarro, de Gracia, Castell, & Cabeza, 2015). (Akbari et al., 2021) introduced a new index for assessing building thermal performance and highlighted the potential of high thermal inertia structures. (Kim, Chang, Chung, Jeong, & Kim, 2014; Wi, Chang, & Kim, 2020) discussed advancements in enhancing thermal inertia, including the thermal properties of mortars containing PCMs. Recent research has concentrated on numerical modeling of PCM walls and how the placement of PCM affects thermal performance (Lajimi, Ben Taher, & Boukadida, 2023; Lajimi & Boukadida, 2023), along with innovative construction systems such as stay-in-place formworks with improved thermal properties (Bruno, Carpino, Bevilacqua, Settino, & Arcuri, 2022) and composite walls with dynamic hygrothermal behavior (Wu et al., 2022).

Despite these advances, the literature remains fragmented. Few studies have provided a comprehensive bibliometric overview of research on thermal inertia and energy behavior of buildings, mapping how topics, authors, and countries have evolved over time.

To address this gap, this study performs a bibliometric analysis of scientific publications. This method helps identify key trends, leading researchers, and future research directions. Specifically, the study aims to answer the following questions :

1. What is the distribution of publications on thermal inertia and the energy behaviour of buildings over the last four decades?
2. What are the most relevant journals and authors in this field?
3. Which countries have been the most productive?
4. What are the primary research keywords used in this area?

METHODS

Materials and Methods :

To identify the most prolific works on thermal inertia and the energy behavior of buildings, a bibliometric analysis was conducted in this study. The study was completed on July 13th, 2025, and used the Scopus Database as the method of analysis. The investigation identified 260 publications within the domain of « thermal inertia and the energy behavior of buildings », which were used as keywords in this research (KEY thermal inertia and the energy performance of buildings) and encompass the last four decades, from 1984 to 2025. Note that only publications in English and French were included. In this manner, 171 publications remained for additional analysis. The analytical research framework is illustrated in Figure 1.

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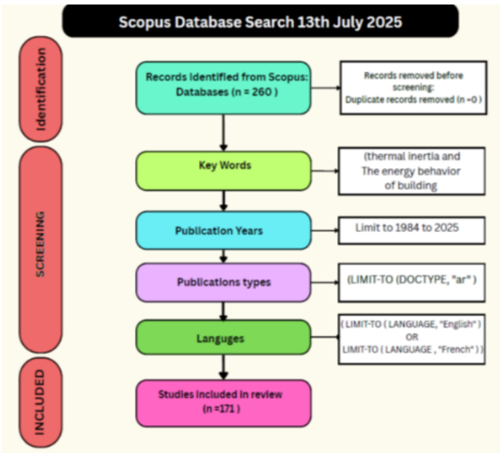

Fig.1 Analytic Framework of the study.

The bibliometric analysis :

The bibliometric analysis method was also employed in the study. Using bibliometric techniques, the most frequently used keywords, the most cited journals, the journals with the highest number of publications on the subject, the countries conducting the most research, international collaboration between countries, the keywords and their relationships, the most cited authors, the relationships among authors, the journals cited together, and the most active research areas were examined. VOSViewer is designed for "the construction and visualization of bibliometric maps" (Van Eck & Waltman, 2010) and has been employed to create the network visualization in the analysis. This review is based on the following objectives. First, exploring thermal inertia and its influence on building energy behavior is a significant and growing area of research. It is essential to analyze the field's structural elements to understand its complexities and subdomains. The goal is to highlight previous debates, common methods, and current trends in improving building energy efficiency by deepening understanding and application of thermal inertia. Additionally, this approach helps identify future research directions and challenges within this domain.

RESULTS

The results are discussed in relation to the research questions.

Distribution of publications per year

The first finding examines the distribution of publications from 1984 to 2024. As shown in **Fig. 2**, research output was very low between 1984 and 2000, rarely exceeding one publication per year. Starting in 2001, there was a steady increase, with occasional peaks in 2004 and 2008, though annual output still remained below five publications. A significant upward trend emerged after 2015, reaching a peak of 23 publications in 2021. This was followed by a decline in 2022, a slight rebound in 2023, and another drop in 2024.

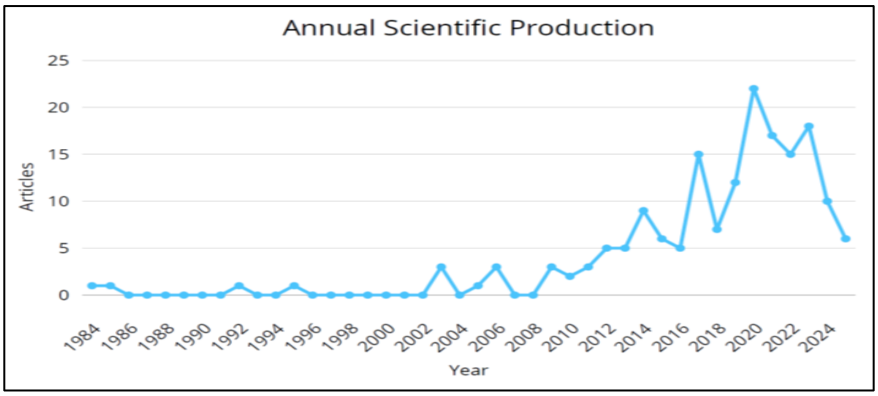

Fig.2 Distribution of publications by years (1984-2024).

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Most relevant journals :

Figure 3 illustrates the cumulative number of publications over time for the five most productive journals in the field of thermal inertia and the energy behavior of buildings. Energy and Buildings is the leading source, with a consistent rise starting around 2002 and a sharp increase after 2014, surpassing 30 publications by 2023. Building and Environment has shown steady growth since 2015, reaching approximately 18 publications. Applied Energy began contributing in the early 2000s, with numbers stabilizing at around 12 publications in recent years. Energies, which entered the field around 2016, demonstrates a strong upward trend, exceeding 10 publications by 2023. The Journal of Building Engineering began publishing in this area in 2018, with about 8 publications to date.

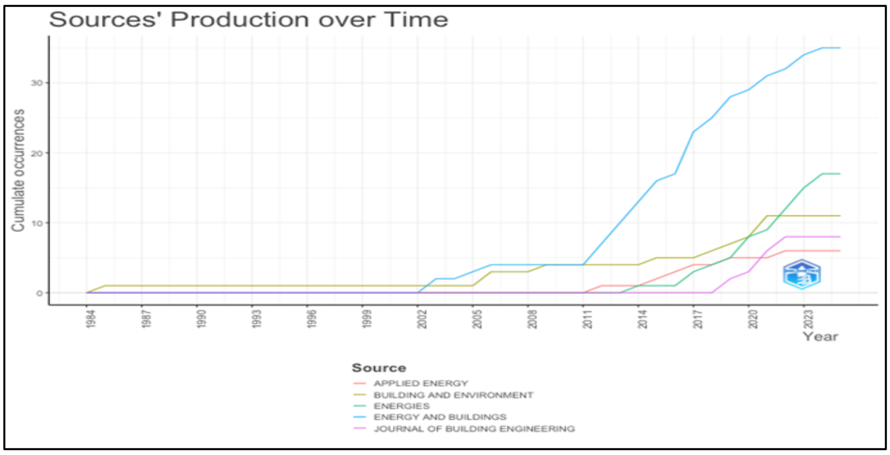

Fig.3 The top 5 highly productive journals on Thermal inertia and Energy behavior of buildings in the years 1984-2024).

Figure 4 shows the top 10 most relevant authors in the field of thermal inertia and the energy behavior of buildings. Cabeza LF tops the ranking with five publications, while Kim S and Muscio A each have four. The other authors — Arcuri N, Bennacer R, Boukhadida N, Bujalski W, Chang SJ, El Ganaoui M, and Evangelisti L — each have three publications.

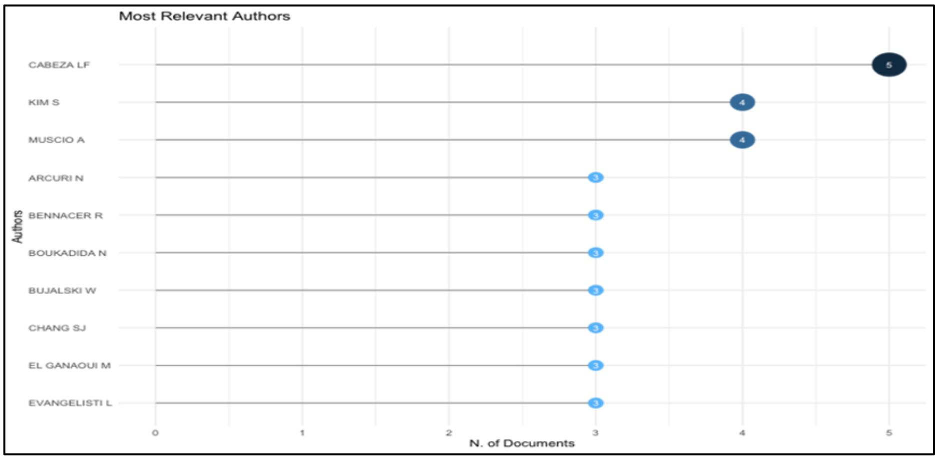

Fig.4 The top 10 most relevant authors in thermal inertia and energy behavior of buildings

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Author	Documents	Year	TC	Institution	Journal
AHMAD M,	Thermal testing and numerical simulation of a prototype cell using light wallboards coupling vacuum isolation panels and phase change material	2006	213	Tichrine University, Latakia, Syrian Arab Republic	Energy and Buildings
EUMORFOPOULOU EA,	Experimental approach to the contribution of plant-covered walls to the thermal behaviour of building envelopes	2009	196	Université Aristote de Thessalonique (AUTh.), Grèce	Building and Environment
YANBING K	Modeling and experimental study on an innovative passive cooling system—NVP system	2003	154	Energy Research Institute of the National Development Planning Commission, PR China	Energy and Buildings
PAUDEL S	A relevant data selection method for energy consumption prediction of low energy building based on support vector machine	2017	150	Eindhoven University of Technology, Eindhoven, Netherlands	Energy and Buildings
GOIA F	Experimental analysis of the energy performance of a full-scale PCM glazing prototype	2014	144	Norwegian University of Science and Technology, Norway	Solar Energy
SORGATO MJ	The effect of window opening ventilation control on residential building energy consumption	2016	134	Federal University of Technology – Paraná (UTFPR)	Energy and Buildings
ROYON L, 2013	Thermal energy storage and release of a new component with PCM for integration in floors for thermal management of buildings	2013	121	Paris Diderot University France	Energy and Buildings
ZHANG L	Building-to-grid flexibility: Modelling and assessment metrics for residential demand response from heat pump aggregations	2019	99	The University of Manchester, Ferranti Building, Manchester M13 9PL, UK	Applied Energy
BONTE M	Impact of occupant's actions on energy building performance and thermal sensation	2014	99	University of Toulouse III – Paul Sabatier, Toulouse, France	Energy and Buildings
MARTIN S	Study of thermal environment inside rural houses of Navapalos (Spain): The advantages of reuse buildings of high thermal inertia	2010	97	Polytechnic University of Madrid, Madrid, Spain	Construction and Building Materials
BADESCU V	Energies renouvelables pour le chauffage des maisons passives : II. Modèle	2003	73	University Politehnica of Bucharest, Bucharest	Energy and Buildings
DER RADJI L	A study on residential energy requirement and the effect of the glazing on the optimum insulation thickness	2017	73	Saad Dahleb University, Department of Renewable Energies, Blida, Algeria	Applied Thermal Engineering
KIM S	Thermal characteristics of mortar containing hexadecane/xGnP SSPCM and energy storage behaviors of envelopes integrated with enhanced heat storage composites for energy efficient buildings	2014	71	Yonsei University, Seoul, South Korea	Energy and Buildings

Table.1 The top 13 most cited Documents.

Note : TC = Total Citation

According to Table 1, the Top 13 Most Cited Documents table, the most referenced publication is by (Ahmad, Bontemps, Sallée, & Quenard, 2006), titled 'Thermal testing and numerical simulation of a prototype cell using light wallboards coupling vacuum isolation panels and phase change material,' published in _Energy and Buildings_, with 213 citations. It is followed by (Eumorfopoulou & Kontoleon, 2009), whose paper 'Experimental approach to the contribution of plant-covered walls to the thermal behaviour of building envelopes,' in _Building and Environment_, has 196 citations. The third most cited work is by (Yanbing, Yi, & Yinping, 2003), titled 'Modeling and experimental study on an innovative passive cooling system—NVP system,' also in _Energy and Buildings_, with 154 citations.

Other highly cited contributions include (Paudel et al., 2017) with 150 citations, (Goia, Perino, & Serra, 2014) with 144 citations, and (Sorgato, Melo, & Lamberts, 2016) with 134 citations, all focusing on innovative approaches to building energy performance. Additional influential works are by (Royon, Karim, & Bontemps, 2013) with 121 citations, (Zhang, Good, & Mancarella, 2019), and (Bonte, Thellier, & Lartigue, 2014) each with 99 citations, as well as (Martín, Mazarrón, & Cañas, 2010)with 97 citations.

The list also features (Badescu & Sicre, 2003) with Renewable energy for heating passive houses: II. Model, published in Energy and Buildings, which has 73 citations; (Derradji, Imessad, Amara, & Errebai, 2017) with A study on residential energy requirement and the effect of glazing on the optimal insulation thickness in Applied Thermal Engineering, also with 73 citations; and (Kim et al., 2014) with Thermal characteristics of mortar containing hexadecane/xGnP SSPCM and energy storage behaviors of envelopes integrated with enhanced heat storage composites for energy-efficient buildings, published in Energy and Buildings, which has 71 citations.

Most productive countries :

Figure 5 illustrates the global distribution of scientific research on thermal inertia and energy behavior of buildings. Spain leads with 120 publications, followed by France with 114, and Italy with 110. China ranks fourth with 80

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publications. Algeria and South Korea each have 22 publications. The United Kingdom (21), Portugal (20), and Morocco (18) are also significant contributors. Brazil, Austria, and Belgium produce between 13 and 14 publications, while Germany and Poland each have 10. Several countries, such as Australia, Ghana, and Tunisia, report eight publications, with many others contributing smaller yet meaningful outputs.

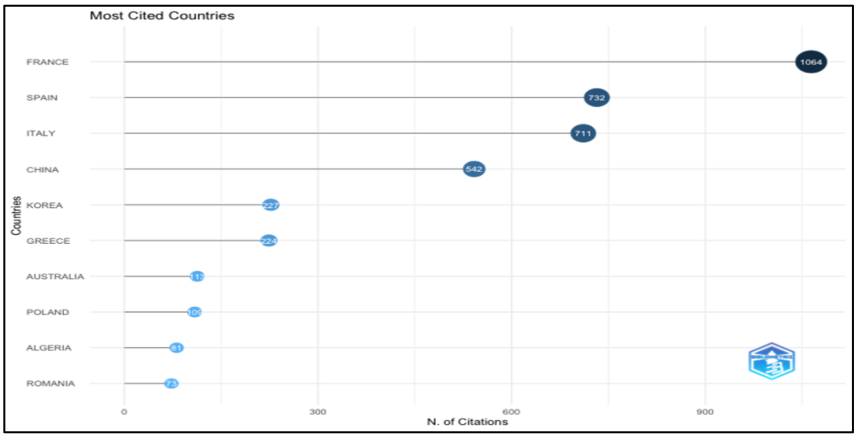

Fig.6 The top 10 most cited countries in thermal inertia and energy behavior of buildings.

Figure 7 displays the distribution of corresponding authors' countries, differentiating between single-country publications (SCP) and multiple-country publications (MCP). Spain leads with nearly 30 documents, followed closely by Italy and France, each with over 20. China has around 15 documents. Other significant contributors include Algeria, Korea, Australia, Belgium, Germany, Morocco, Poland, and Tunisia, each with fewer than 10. Countries like Austria, Brazil, Greece, Portugal, the United Kingdom, Bosnia, Burkina Faso, and Croatia are represented with even fewer publications. In most of these leading nations, MCPs make up a substantial portion of total publications, indicating active international collaboration.

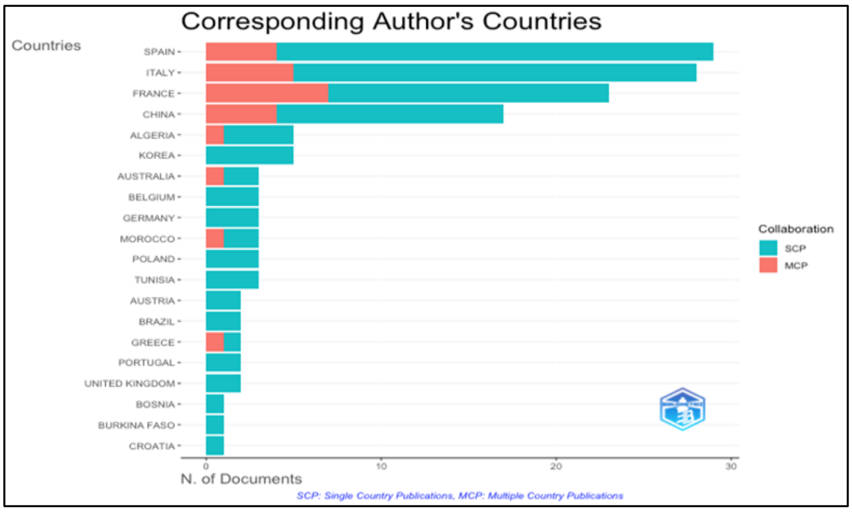

Fig.7 Corresponding Author's Countries.

The country collaboration network in Figure 8 illustrates international research partnerships, where node size represents publication output and link thickness indicates collaboration strength. France serves as a central hub with high productivity and strong connections to China, Spain, Italy, Algeria, and Morocco. China also maintains strong collaborations with the UK, France, and Germany. Spain and Italy form a close-knit cluster connected to France, Portugal, and Belgium, highlighting regional ties. North African nations, particularly Algeria and Morocco, are integrated into the French-led cluster, reflecting historical links. Portugal appears less central, indicating fewer collaborations. Overall, the network reveals geographically focused patterns, with Mediterranean and European countries forming dense clusters, and China and the UK acting as key intercontinental partners.

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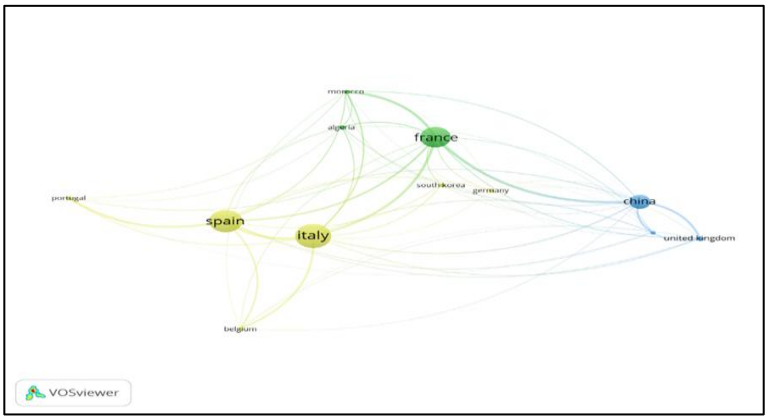

Fig.8 Countries' collaboration network.

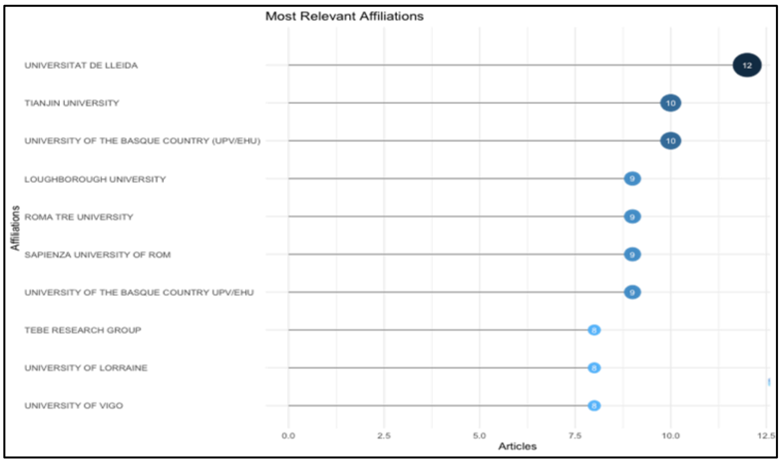

Fig.9 The most relevant Affiliations.

Figure 9 shows the research output of the most active universities and research groups in the studied field. The Universitat de Lleida clearly leads with 12 publications, demonstrating a strong research presence. Close behind are Tianjin University and the University of the Basque Country (UPV/EHU), each with 10 publications, indicating active engagement in Asia and Europe. Several other universities, including Loughborough University, Roma Tre University, Sapienza University of Rome, and UPV/EHU (which may represent different departments or a duplicate), have contributed 9 publications each. Additionally, a second group of institutions such as the TEBE Research Group, the University of Lorraine, and the University of Vigo have each produced 8 publications, showing broader international collaboration.

Primary keywords :

Figure 10 shows the total number of times the most common keywords appeared in research on thermal inertia and building energy behavior from 1984 to 2025. Energy efficiency has the highest growth, with over 50 total mentions by 2025, followed by thermal inertia with just over 45. Energy utilization ranks third with more than 40 mentions, while buildings and energy conservation each surpass 30 mentions. Keywords like phase change materials, walls (structural partitions), and thermal insulation each show steady increases, reaching between 25 and 30 mentions. Heat storage and heating have lower totals, ending the period with just over 20 mentions.

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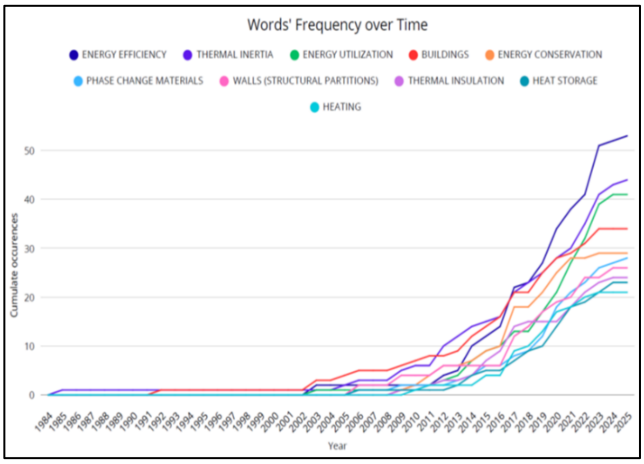

Fig.10 Word's Frequency Over Time.

Figure 11 shows the keyword co-occurrence network for publications on thermal inertia and the energy behavior of buildings. The most common and central keywords are thermal inertia, energy efficiency, buildings, and heat storage. Other significant terms strongly linked in the network include phase change materials, thermal insulation, energy utilization, energy conservation, heating, thermal performance, solar buildings, ventilation, air conditioning, and architectural design. Additionally, keywords like model predictive control, energy demands, thermal energy storage, district heating, energy storage, occupant behaviour, cooling, thermal behaviours, and solar energy are also well connected, reflecting a wide range of thematic relationships.

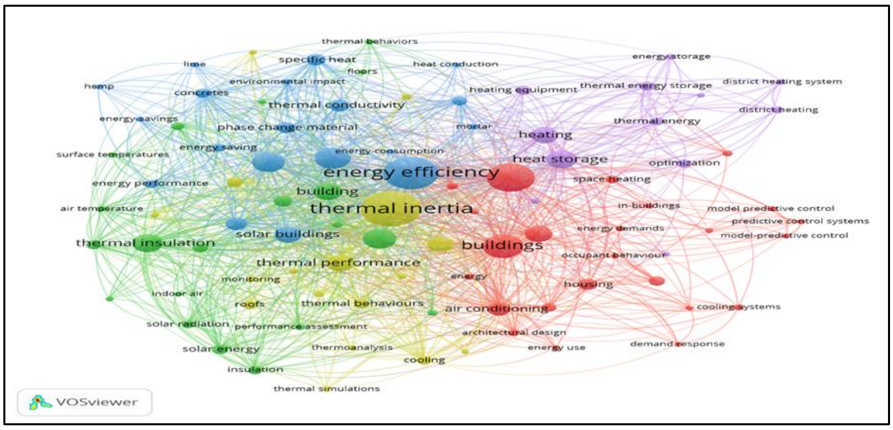

Fig.11 Analyze results of Keywords co-occurrence.

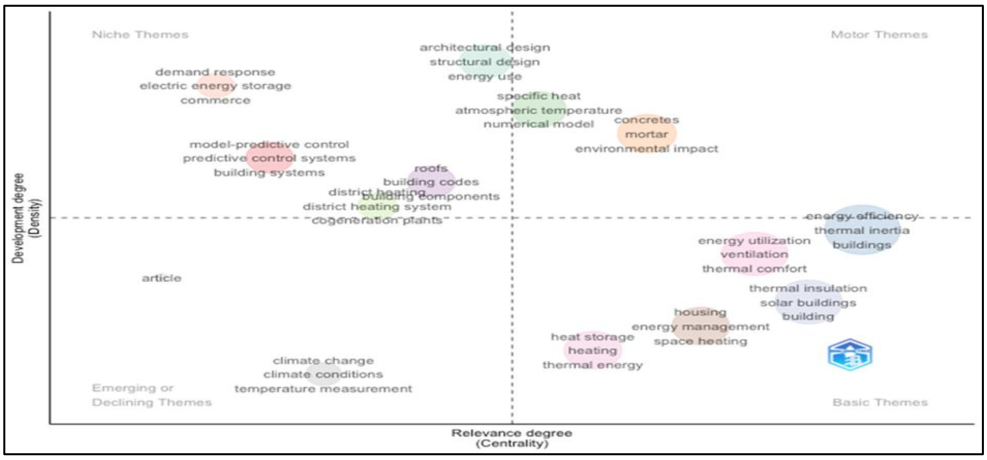

Fig.12 Thematic Map.

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The thematic map figure 12 illustrates the research area's structure by plotting keywords according to their relevance (centrality) and development (density). The analysis identifies four main thematic clusters. Motor themes, positioned in the upper-right area, include energy efficiency, thermal inertia, and buildings; these are highly relevant and well-developed, serving as the field's primary drivers. Niche themes, in the upper-left, such as demand response and predictive control systems, are specialized topics that are mature within themselves but less connected to the central network. Emerging or declining themes in the lower-left, such as climate change and temperature measurement, currently have low development and relevance, indicating topics that are either new or losing importance. Basic themes, in the lower-right, such as thermal insulation and solar buildings, are highly relevant but less developed, emphasizing fundamental subjects central to the field that require further research. This mapping provides valuable insights into the evolution of research topics and strategic positioning, guiding future investigation directions.

The map shows a balance between studies on construction materials and their environmental impact, emphasis on energy efficiency and thermal inertia as core topics, with emerging specialized technologies like control systems and storage gaining relevance.

DISCUSSION

Based on 171 research publications from the Scopus database, this review provides an overview of the thermal inertia and energy behavior of buildings through a bibliometric analysis, which highlights several key trends. Initially, the number of publications remained fairly steady, and decline in production between 1984 and 2010 mainly due to indexing artifacts, variations in terminology (e.g., « thermal mass », « PCM », « insolation »), and language/media biases, rather than a lack of scientific interest. However, from around 2010 onward, there was a noticeable increase, which peaked between 2018 and 2021. This growth likely reflects increased concern about climate issues, especially after the Paris Agreement was adopted in 2015. It also aligns with the global focus on energy policies and the development of new materials and innovative systems.

This analysis shows that the majority of research articles are published in only a few leading journals. The top journal is « Energy and Buildings », with « Building and Environment » and « Applied Energy » following. This trend indicates a concentrated focus within the field, with these journals serving as essential platforms for disseminating scientific research.

Geographically, the study reveals the dominance of Southern Europe (Spain, Italy, France), accompanied by the rise of China. These research hubs structure global production and rely on strong collaborative networks, particularly between Europe and Asia. Emerging countries such as Algeria are beginning to appear in these networks, reflecting a gradual opening up of research.

The results can be understood around a few key ideas: energy efficiency, thermal inertia, phase change materials (PCM), and thermal comfort. These ideas are central to current research and connect different approaches. For example, passive strategies include insulation, building envelopes, and thermal storage, while active approaches involve ventilation, heating and cooling, and predictive systems. There's also a broader view, which involves integrating these concepts into smart grids and adapting to climate change. The thematic map shows clear groups—some well-established, like energy optimization, and some emerging, such as smart technologies and dynamic management

While this analysis mainly uses data from Scopus, it is important to note that there is a significant amount of research on thermal inertia, phase-change materials, and passive building strategies that is not included in that database.For example, (Garg, 1991) looked at how thermal mass helps regulate indoor temperatures in hot climates. (Martín et al., 2010) (Martín et al., 2010) explored how features of building envelopes influence thermal inertia in Mediterranean regions. (Evangelisti, Battista, Guattari, Basilicata, & de Lieto Vollaro, 2014) discussed the role of thermal inertia in European energy performance standards, while (Allouhi et al., 2015) examined overall trends in building energy use and efficiency. More recent research outside of Scopus has connected thermal inertia to energy flexibility and resilience—such as studies by (Papadakis & Katsaprakakis, 2023) on decarbonization efforts, and (Martínez et al., 2021; Moshi, Guruvasanth, Samuel, & Billigraham, 2021) , which focus on energy resilience and reducing vulnerabilities related to fossil fuel prices. Taken together, these studies deepen the understanding of how factors like

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thermal mass, phase-change materials, insulation, and material choices influence the energy performance of buildings.

The co-occurrence and evolution maps not only confirm this complex, multi-layered structure but also highlight exciting new trends emerging in the field, such as the use of artificial intelligence to optimize processes and the concept of building-to-grid integration.

Finally, the analysis of authors and institutions indicates that scientific productivity is primarily led by a core group of influential researchers, such as Cabeza and Kim, and by renowned universities like Universitat de Lleida, UPV/EHU, and Tianjin University. The presence of numerous researchers with more modest output suggests an expanding scientific community, fostering diversification and the renewal of contributions.

CONCLUSION

Research on thermal inertia and energy behavior of buildings is a relatively new but rapidly growing field. Over the past 20 years, it has expanded quickly due to environmental concerns and the need for energy transition. Three main elements stand out: first, a strong thematic core centered on energy efficiency, thermal inertia, and PCMs. This core then expands to include digital and systemic approaches, reflecting dynamic and innovative research.

The research primarily focuses on Southern Europe and China, but it is also expanding to emerging countries. Lastly, the institutional and editorial structure is clearly defined, with leading journals and authors, while allowing for gradual diversification of participants—reflecting a sector that is quickly evolving.

The field is multidimensional, linking materials, architectural design, and energy strategies. PCMs and thermal inertia serve as key connections between material innovation and energy performance. In summary, this scientific area has evolved from mainly focusing on material and experimental solutions such as insulation, PCM, and prototypes, to adopting a more integrated and digital approach, including predictive control and smart grids. This development indicates the rise of smart, sustainable, and connected buildings.

While the current analysis based on Database Scopus identifies the main trends, it is limited by the database's scope and the chosen keywords. Future bibliometric studies could overcome this limitation by including more databases such as the Web of Science and expanding the set of search terms (e.g., thermal mass, insulation, PCM) to offer a more detailed and comprehensive view of the research landscape.

PROSPECTS

In light of this analysis, several avenues for future research emerge:

1. Examine the relationship between thermal inertia and energy efficiency by quantitatively assessing how inertia helps lower heating and cooling requirements across various climates.
2. Integrate both economic aspects (such as cost-benefit and profitability) and environmental factors (like carbon footprint).
3. Develop interdisciplinary approaches by integrating building engineering, energy policies, and social sciences to identify practical and applicable solutions.
4. Study the aging and durability of materials, since thermal inertia varies over time due to humidity and degradation.
5. Generalize findings using multi-scale simulations—ranging from walls and buildings to neighborhoods—better to link thermal inertia with urban energy transition strategies.
6. Studies frequently stay focused on local settings, like laboratories or specific case studies, and could benefit from broader generalization.
7. Research on directly incorporating renewables into thermal inertia analysis is limited.

8. Future bibliometric research could be extended by incorporating additional databases beyond just Scopus, like the Web of Science, to gain a wider view of publications. Adding search terms related to concepts such as thermal mass, insulation, PCM (phase change materials), and other related or emerging keywords can help create a more comprehensive picture of the field. This approach would enable a closer examination of publication trends, uncover previously hidden research areas, and enhance the reliability of the analysis.

These prospects open the door to innovative research that will strengthen thermal inertia's role as a key element in energy efficiency and sustainable building design.

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