Solar Energy
And Sustainable Development
Refereed, biannual scientific journal issued by:
The Libyan Center for Solar Energy Research and Studies

A Bibliometric Analysis of Outdoor Thermal Comfort Research in Smart Cities: Trends and Methodologies

Safae Ahsissene[1*], Fatima Zahrae Rhziel[2], Naoufal Raissouni[3].
[1,2,3]Remote Sensing, Systems and Telecommunications Research Laboratory, National School of Applied Sciences, of Tetuan, Abdelmalek Essadi University, Tetuan 2121, Morocco.
E-*mail:* [1] ahsissene@etu.uae.ac.ma .

SPECIAL ISSUE ON:
The 2024 1st International Conference on Materials Sciences and Mechatronics for Sustainable Energy and the Environment
October 1-3, 2024 at Béni-Mellal, Morocco

KEYWORDS
Thermal comfort; Smart Cities; CiteSpace; Energy Efficiency; Bibliometrics.

ABSTRACT

In recent years, maintaining thermal comfort in urban environments has become a key concern, as cities grow rapidly and climate change intensifies. This study presents a bibliometric analysis to examine how thermal comfort is addressed in smart city research, categorizing the methodologies employed. A total of 300 papers from Scopus and 107 from Web of Science were collected. After removing duplicates across both datasets, 314 papers remained for analysis. A final dataset of 314 papers was analysed using Python, with the 300 from Scopus further examined using CiteSpace due to the 300-record limit of the basic version of the software.

CiteSpace analysis reveals key trends, research networks, and methodological shift. With 15% of studies utilizing questionnaires, 35% employing simulation tools, and 50% relying on alternative methods. Python analysis highlights China and the USA as the most prolific countries in publishing research on this topic. This study emphasizes the evolving nature of research in the smart city sector and underscores the importance of integrating both conventional and innovative methodologies. Findings offer critical insights for urban planners and policymakers, particularly in relation to sustainable urban development and the mitigation of urban heat island effects. By mapping the intellectual configuration of thermal comfort research in smart cities, this paper not only addresses existing knowledge gaps but also provides a framework for future research to enhance the resilience and liveability of urban environments.

*Corresponding author.

DOI: https://doi.org/10.51646/jsesd.v14iSI_MSMS2E.396

تحليل ببليومتري لأبحاث الراحة الحرارية الخارجية في إطار المدن الذكية: التوجهات والأساليب

صفاء احسيسن، و فاطمة الزهراء اغزيل، نوفل الريسوني .

ملخص: في السنوات الأخيرة، أصبح الحفاظ على الراحة الحرارية في البيئات الحضرية مسألة رئيسية مع النمو السريع للمدن وتفاقم تغير المناخ. تقدم هذه الدراسة تحليلاً ببليومتريًا لفحص كيفية معالجة الراحة الحرارية في أبحاث المدن الذكية، وتصنيف المنهجيات المستخدمة. تم جمع 300 ورقة بحثية من قاعدة بيانات Scopus و 107 من Web of Science. وبعد إزالة التكرارات بين المجموعتين، تبقى 314 ورقة لتحليلها. تم تحليل مجموعة البيانات النهائية المكونة من 314 ورقة باستخدام Python، بينما تم فحص الـ 300 ورقة من Scopus بشكل أعمق باستخدام برنامج CiteSpace بسبب الحد الأقصى المسموح به للإصدار الأساسي من البرنامج. يكشف تحليل CiteSpace عن الاتجاهات الرئيسية، وشبكات البحث، والتحولات المنهجية، حيث استخدمت 15% من الدراسات استبيانات، و35% اعتمدت على أدوات المحاكاة، بينما اعتمدت 50% على أساليب بديلة. يُبرز تحليل Python أن الصين والولايات المتحدة هما الأكثر إنتاجًا في نشر الأبحاث حول هذا الموضوع. تؤكد هذه الدراسة على الطبيعة المتطورة للبحث في قطاع المدن الذكية وتُبرز أهمية دمج الأساليب التقليدية والمبتكرة. تقدم النتائج رؤى حاسمة لمخططي المدن وصناع السياسات، خاصة فيما يتعلق بالتنمية الحضرية المستدامة وتخفيف تأثيرات الجزر الحرارية الحضرية. من خلال رسم خريطة البنية الفكرية لأبحاث الراحة الحرارية في المدن الذكية، لا تُعالج هذه الورقة الفجوات المعرفية الحالية فحسب، بل توفر أيضًا إطارًا للبحوث المستقبلية لتعزيز مرونة وعيش المدن.

الكلمات المفتاحية -- الراحة الحرارية، المدن الذكية، CiteSpace، كفاءة الطاقة، التحليل الببليومتري.

1. INTRODUCTION

Urbanization has emerged as a significant policy concern in recent decades, driving the need for innovative solutions to manage the growing demands of urban populations [1], [2]. One such solution is the development of smart cities, which leverage the advancements of the Fourth Industrial Revolution [3].

However, unsustainable urban sprawl, deforestation, increased vehicular use, high energy consumption, impervious surfaces, and air pollution have collectively exacerbated the urban heat island (UHI) effect[4], [5]. This phenomenon results in elevated temperatures and drier conditions in urban areas compared to their rural counterparts, ultimately diminishing both thermal comfort and the overall quality of life for residents.

To address this, thermal comfort is increasingly recognized as a key priority for urban dwellers. Not only can it be achieved naturally, without significant energy consumption, but it can also be enhanced through the strategic use of climate-sensitive building materials and natural ventilation systems. Additionally, integrating trees[6] and water bodies[7] into urban design has proven effective in reducing thermal discomfort by leveraging natural cooling effects.

The notion of a smart city is a modern conceptualization of urban development that entails the collection, analysis, and sharing of data across different settings within a city [8], [9]. These cities leverage information technology to enhance traditional sectors and create strategic emerging industries, with a focus on green and efficient production [10].

A well-designed urban environment is one that adapts to the multifaceted needs of its citizens, ensuring comfort across various dimensions [11]. As smart cities evolve, guaranteeing optimal thermal comfort becomes increasingly complex, especially as urbanization accelerates and climate change intensifies. Beyond its impact on human health and productivity [12], thermal comfort also plays a vital role in the energy dynamics of cities, where the demand for cooling and heating can strain urban energy systems [13], [14]. Maintaining optimal thermal conditions, both indoors and outdoors, is thus crucial for fostering liveable, resilient urban spaces. However, this is complicated by persistent challenges such as the UHI effect, extreme weather events, and the escalating energy demands required to control urban climates.

Numerous literature reviews have explored various facets of smart cities, often focusing on technological integration, governance [15], and sustainability. Reviews like [16] and [17] provide comprehensive insights into smart city development, emphasizing dimensions such as Smart Economy, Environment, and Mobility. While consistently defining smart cities as technology-driven solutions to enhance urban infrastructure and quality of life, they frequently overlook thermal comfort as a key aspect of urban livability. Studies like [18] and [19] focus primarily on energy management, efficiency, and citizen engagement but inadequately address how thermal comfort contributes to the human experience in these advanced environments.

Moreover, systematic reviews such as [20]and [21]highlight a tendency toward fragmented, technology-centric research that often neglects human-centered needs like comfort and livability. This gap is particularly concerning as urbanization and climate change increasingly challenge the ability to maintain thermal comfort. Although articles like [22] and [23] emphasize clean energy and IoT in smart city development, they fall short of integrating thermal comfort into the broader framework. Topics like data privacy and security are well-explored explored [24], yet the critical role of thermal comfort in residents' well-being remains under examined.

Despite the significance of thermal comfort, there is still a gap in the literature regarding its integration into the larger context of smart city research. While various studies have explored thermal comfort [25], [26] and smart cities [20], [27] independently, few have systematically analyzed the intersection of these fields. Although recent reviews on smart cities acknowledge comfort to some extent [28]–[30], they often do not explore thermal comfort as a distinct focus, and some omit the concept of comfort altogether [19], [31]. This study seeks to address this gap by conducting a comprehensive bibliometric analysis of the existing literature on thermal comfort within smart cities.

This study addresses a critical gap previously identified in the literature [32], which highlights that while smart city research focuses on broad concepts, particularly the integration of technology to enhance urban livability, it neglects smaller-scale applications such as smart neighborhoods and streets. Although much of the smart city discourse emphasizes large-scale technological solutions, there is a noticeable lack of attention to localized aspects, one of the most important being thermal comfort. By exploring this overlooked dimension, this study seeks to fill that gap and contribute to a more holistic understanding of smart city development.

The aim of this study is to methodically evaluate and refine research that links the fields of thermal comfort and smart cities. By doing this, we hope to obtain a thorough understanding of the current research in this field and identify emerging trends that could guide future advancements in these critical areas of study and innovation. In addition to classifying the methods used, our analysis highlights important themes and possible directions for future research that could guide the creation of more resilient and sustainable urban environments.

By identifying key trends and methodologies, this research aims to provide practical insights for urban planners and policymakers, enabling the design of cities that are not only technologically advanced but also thermally comfortable, energy-efficient, and resilient to climate change impacts. Additionally, by offering a comprehensive framework of how thermal comfort is being studied within the context of smart cities, this study seeks to support and encourage future researchers in the field. We hope to provide valuable insights that will help them better incorporate thermal comfort considerations into their work, ultimately leading to more sustainable and livable urban environments.

2. METHODOLOGY

2.1. Data Collection

This section outlines the methodological approach employed to explore the relationship between smart city research and thermal comfort. The procedures for data collection, selection, and analysis are described in this section. These procedures were designed to ensure a thorough and objective review of relevant literature. By combining manual screening procedures with bibliometric analysis tools, this research seeks to identify important trends, approaches, and new areas of study related to thermal comfort in smart cities.
To conduct a thorough examination of research on thermal comfort in smart cities, this study employed two prominent academic databases: Scopus and Web of Science (WoS). These databases are widely recognized for their extensive coverage of peer-reviewed journals, conference proceedings, and scholarly books[33] across diverse disciplines, such as environmental science, urban studies, and engineering. Their rigorous indexing standards and inclusion of high-impact journals make them particularly well-suited for identifying relevant studies in the areas of smart city development and thermal comfort.
The search strategy was designed to identify the intersection of thermal comfort and smart city research. The keywords were selected from commonly used terms in the literature and refined through preliminary searches and expert consultation. The primary search terms were:
• "Thermal Comfort" AND "Smart Cities" OR "Smart City".
• "Thermal Sensation" AND "Smart Cities" OR "Smart City".
Boolean operators such as AND were applied to ensure that the retrieved articles included both concepts (thermal comfort/sensation and smart cities). To ensure that the results were as relevant as possible, the search was limited to the title, abstract, and keyword sections. Filters were also used to limit the search to peer-reviewed journal articles and conference papers, ensuring the inclusion of high-quality studies.
Selection Criteria:
• Articles that explicitly addressed the intersection of thermal comfort or thermal sensation and smart cities.
• Studies where the chosen keywords were present in the title, abstract, or keyword sections.
Exclusion Criteria:

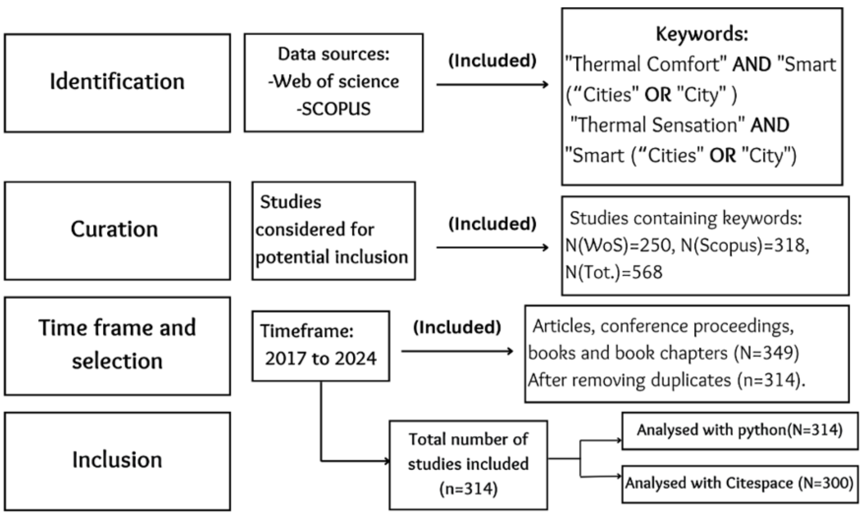

Figure 1. Research Criteria and Selection Process.

• Articles from journals or conference proceedings that had "Smart City/ Cities" or "Thermal

Comfort" in the title, without further relevant discussion of the intersection of these fields.
The research criteria and selection process are visually depicted in Figure 1, which outlines the systematic steps taken during the data collection phase, including identification, curation, selection, and inclusion of studies.
The literature search concentrated on studies published between 2017 and 2024. This timeframe was selected to capture the most recent advancements and trends in the rapidly changing fields of smart city technology and thermal comfort research. By focusing on this time period, the study aimed to provide an up-to-date analysis of how these concepts have been integrated into academic research, reflecting latest developments and emerging challenges in urban planning and environmental management. Several bibliometric analysis techniques were applied in this study to provide a comprehensive understanding of thermal comfort within the context of smart cities:
(a) Scientific Production: This technique was used to examine the evolution of research output over time, tracking how the focus on thermal comfort and smart cities has developed between 2017 and 2024.
(b) Co-Authorship: Countries were analyzed as the unit of study to assess international collaboration on thermal comfort and smart cities. This provided insights into the leading nations contributing to this research area and their partnerships.
(c) Co-occurrence for the identification of the most frequently used keywords in the study articles.
A total of 568 articles were initially identified for analysis. After removing duplicates and manually skimming through the abstracts and titles to ensure relevance, this number was reduced to 314 articles. Of these, 314 articles were selected for further analysis using both Python and CiteSpace. However, due to the limitation of the free version of CiteSpace, which restricts analysis to a maximum of 300 articles, we opted to analyze 300 articles from the Scopus database in CiteSpace. The full dataset, including the remaining 14 articles, was analyzed using Python to ensure comprehensive coverage. Detailed findings from each analysis will be provided in the subsequent sections.

2.2. Data Analysis

The collected data were analysed using CiteSpace; (Download address: https://citespace.podia.com/), and Python, with a dual approach to ensure comprehensive results. Initially, the plan was to analyse all data using CiteSpace; however, due to the limitations of the free version, which restricts the analysis to 300 records, only the Scopus dataset was analysed in CiteSpace. This allowed us to identify key publications, authors, and trends within a smaller, more focused dataset. CiteSpace operates systematically and scientifically, with terms and keywords defined, data collected, terms extracted, time zones segmented, thresholds selected, networks simplified and merged, visual knowledge maps displayed, maps edited, and key nodes verified. CiteSpace offers distinct advantages over other software, particularly in its ability to identify emergent terms, explore research hotspots, and track research trajectories [34]. This algorithm excels at detecting significant shifts in terminology in the literature, assisting users in identifying areas of increasing interest. This capability aligns perfectly with the goals of our research, which focused on identifying emerging terms and hotspots in the field, making CiteSpace the ideal choice for our analysis.
CiteSpace offers three main visualization methods, the Cluster View being the default, which emphasizes cluster structural features such as key nodes and significant connections. The
CiteSpace offers three visualization methods—Cluster View, which focuses on cluster structure and key connections; Timeline View, which depicts temporal relationships within clusters; and Time-zone View, which tracks the evolution of knowledge across time. Clustering is done

automatically using a spectral clustering algorithm.
CiteSpace employs several algorithms for extracting cluster labels, including the Mutual Information (MI) algorithm, which computes the correlation between co-occurring terms, the Log-Likelihood Ratio (LLR) algorithm, which evaluates association rule similarity, and the Latent Semantic Indexing (LSI) algorithm, which employs Singular Value Decomposition (SVD) to reduce the word-document matrix to its most significant patterns. These features, made CiteSpace the best option for our research, which focused on emerging terms and research hotspots[35].
The extracted Scopus data was converted into a format compatible with CiteSpace, ensuring accurate importation and analysis. This conversion process included the standardization of author names, keywords, and publication details to maintain consistency throughout the analysis.
CiteSpace (version 6.3.R1 basic) was utilized for the analysis, with specific parameters adjusted to ensure the robustness of the bibliometric analysis:
Time Slicing: The time slicing parameter was set to span from 2017 to 2024, with a one-year interval to capture temporal shifts in research trends.

Node Types: Keywords and references were selected as node types for this analysis. Keywords were chosen because they highlight the primary themes, concepts, and trends emphasized by authors, making them critical for understanding the focus areas of the research field. References were used to construct co-citation networks, which reveal relationships between foundational studies, showing how certain works have shaped the intellectual structure of the field. These node types, available in the basic version of CiteSpace, offered a valuable perspective on the evolution of key topics and influential publications in the literature.
Links Strength: The analysis used the Cosine similarity measure for link strength, which helps to determine the strength of connections between nodes, ensuring that similar items are closely linked. This method effectively captures relationships within each time slice, allowing for a precise mapping of influential studies and thematic clusters.
Scope Within Slices: The analysis maintained the scope within each time slice to ensure that temporal trends were accurately represented. This approach allowed for the visualization of changes in research focus over the study period, highlighting emerging topics and shifts in methodologies.
g-index Scaling Factor: The g-index was applied with a scaling factor k=25k=25k=25. This index prioritizes highly cited items, ensuring that both influential and emerging works are given appropriate weight in the analysis. The scaling factor was set to balance the focus on highly cited works while allowing for the inclusion of newer, impactful studies.
Top N Selection: The Top N setting was configured to select the top 50 levels from each time slice, ensuring that the most significant studies or keywords were included in the analysis, providing a comprehensive view of critical contributions to the field.
Top N% Selection: Additionally, the Top N% option was used to select the top 10% of the most cited or frequently occurring items from each time slice. This ensured that the analysis captured the most relevant and impactful research items, providing a robust overview of the major trends and key studies within each time period.
Bibliometric Indicators used :
• Co-citation Analysis: This indicator was crucial for identifying key publications and mapping the intellectual structure of the field. It allowed the identification of clusters representing thematic areas and highlighted influential works that have shaped discussions on thermal comfort and smart cities. This helped in understanding the historical and contemporary foundations of the field.
• Keyword Clustering: By grouping frequently co-occurring keywords, this analysis revealed thematic trends and emerging topics. It provided insights into research priorities, such as

"adaptive thermal comfort" and "IoT," and helped in visualizing the research landscape.

• Burst Detection: Burst detection identified keywords and references with sudden increases in frequency, signaling emerging research interests. This function was particularly useful for detecting new areas of focus, such as the rise of "Internet of Things (IoT)" and "energy management," which reflect the shifting priorities in the field of smart cities and thermal comfort.

• Timeline Visualization: The timeline view illustrated the temporal evolution of key topics and methodologies, showing how themes like "simulation" and "machine learning" have gained prominence in recent years. It provided a clear picture of methodological shifts and evolving research trends.

These settings and indicators enabled a detailed analysis of research trends in the field of thermal comfort in smart cities, allowing the study to highlight significant contributions, track shifts in research focus, and identify emerging areas. By combining these functions, the study offers a comprehensive understanding of the intellectual structure and evolving landscape within this domain, ensuring transparency and reproducibility.

The rest of the analysis was carried out in Python, with several key libraries for data processing, statistical analysis, and visualization. Pandas was used for data manipulation tasks such as importing datasets from Web of Science and Scopus, merging them, removing duplicates, and applying keyword-based filtering to identify research trends. To create visual representations of the findings, Matplotlib was used to generate bar charts, which Seaborn improved for clarity and aesthetics.

Data from Excel files were imported using Openpyxl, allowing external datasets to be seamlessly integrated into the analysis pipeline. Furthermore, the Counter class from the Collections module was used to count the occurrences of specific keywords in the dataset, allowing for a quantitative analysis of the prevalence of different research methodologies and simulation tools. These combined tools provided a solid foundation for efficiently processing large amounts of data, identifying key trends, and presenting findings in a clear and understandable manner.

3. RESULTS

3.1. Citespace Results

3.1.1. Overview of Reaseach Themes

This CiteSpace cluster analysis identifies key research themes in the area of thermal comfort in smart cities. Each cluster represents a distinct area of focus, as identified by co-citation networks, and demonstrates how different aspects of urban thermal environments are being studied.

In this analysis, keywords were extracted directly from the abstracts of research articles published between 2017 and 2024. The goal was to capture the main themes and topics raised by the authors. By focusing on the abstracts, this analysis sheds light on the primary research questions, methodologies, and findings that have been highlighted in the literature.

3.1.2. Temporal Evolution of Themes

The resulting visualization (Figure 2) depicts the temporal evolution of these topics, emphasizing how certain themes have gained or lost importance over time. Clusters are collections of related topics that provide a high-level overview of the research landscape in smart cities and thermal comfort.

Figure 2. Temporal Evolution and Cluster Visualization of Key Research Topics in Smart Cities and Thermal Comfort (2017-2024) - Abstract-Based Keywords.

3.1.3. Key Research Clusters

Cluster #1 on "Fuel Poverty" emphasizes the link between energy access and thermal comfort, particularly for vulnerable populations. Cluster #2 emphasizes Phase Change Materials' role in thermal environment management through material science innovations. Cluster #3, "Demand Flexibility," investigates how smart city technologies can optimize energy consumption to improve thermal comfort. "Smart FM Tool" (Cluster #4) and "Refined Zoning Systems" (Cluster #5) are centered on digital and advanced techniques for managing indoor environments and energy efficiency. Cluster #6, "Natural Ventilation," investigates the use of natural forces to improve comfort while conserving energy. "Thermal Sensation" (Cluster #7) explores the psychological aspects of thermal perception and how smart designs can meet a variety of needs.

Cluster #8, "Shading Design," focuses on the use of shading strategies to control heat gain and improve comfort, while Cluster #9 investigates the use of the Physiologically Equivalent Temperature (PET) index in urban planning to optimize thermal comfort.

3.1.4. Insights and Trends

Overall, the clusters cover a wide range of topics, from technical innovations like Phase Change Materials and Demand Flexibility to social issues like Fuel Poverty, demonstrating different approaches to improving urban thermal environments. The analysis also reveals temporal trends, which show how research priorities have changed over time, with newer clusters indicating emerging areas of study. These clusters show how smart city technologies, such as refined zoning systems and shading design, can be used to improve thermal comfort while also taking into account environmental and human factors. The findings point to an increasing interest in interdisciplinary approaches that combine technical, social, and environmental strategies to improve thermal comfort in smart cities.

3.1.5. Keyword-Based Analysis with CiteSpace

The second analysis (Figure 3) focuses on the keywords explicitly used by the authors in their publications. These keywords typically represent the core concepts or areas of interest that the authors wish to highlight. By analyzing these keywords, this study identifies specific areas of focus within the larger field, as intended by the authors. The temporal evolution and clustering of these keywords reveal popular and emerging research trends in smart cities and thermal comfort between 2017 and 2024. This approach frequently reflects the strategic framing of research topics, revealing how authors connect their work to larger trends and disciplinary priorities.

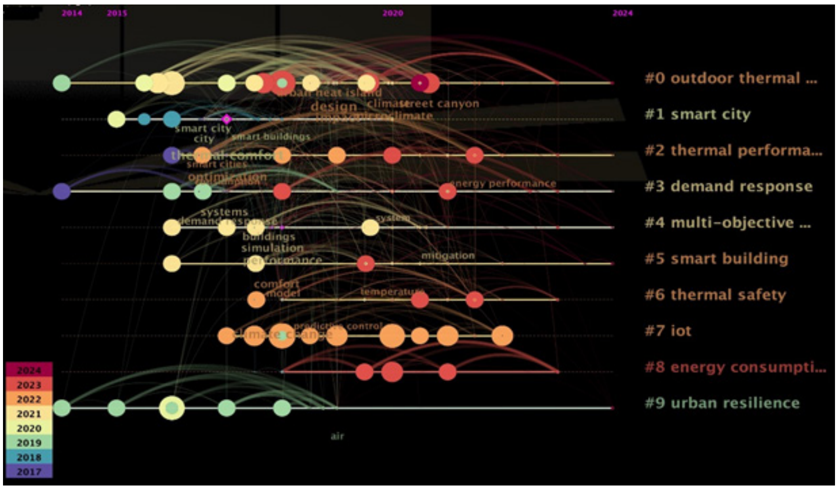

Figure 3. Temporal Evolution and Cluster Visualization of Key Research Topics in Smart Cities and Thermal Comfort (2017-2024) - Keyword-Based Extraction.

Cluster #2 focuses on "Thermal Performance," which investigates how materials, design, and technology improve buildings' thermal properties. Cluster #3, "Demand Response," focuses on the operational management of energy consumption in response to supply conditions, which is critical for maintaining thermal comfort during peak demand periods. "Multi-Objective Optimization" (Cluster #4) is the process of balancing thermal comfort, energy efficiency, cost, and environmental impact in smart city planning using optimization algorithms. Cluster #5, "Smart Building," investigates the use of advanced technologies like sensors and automation to improve building efficiency and thermal comfort. "Thermal Safety" (Cluster #6) is concerned with ensuring safe thermal conditions, particularly during extreme weather events, whereas Cluster #7, "IoT," emphasizes the use of connected devices to monitor and maintain optimal thermal environments.

The "Energy Consumption" cluster (Cluster #8) investigates the balance between thermal comfort and energy efficiency, while Cluster #9, "Urban Resilience," focuses on strategies for cities to adapt to and recover from thermal challenges, particularly in the context of climate change.

3.2. Python analysis

3.2.1. Trends in Research Activity (2017-2024)

Data from Scopus and Web of Science were analyzed to identify trends in publications about smart cities and thermal comfort. After merging the datasets, duplicates were removed using Python's pandas library to ensure the analysis's accuracy. The first trend examined was the number of publications over time, with a focus on publication years to identify key patterns and shifts in research activity between 2017 and 2024.

In terms of the number of publications per year, the graph(Figure 4) shows a dynamic trend in publications about smart cities and thermal comfort from 2017 to 2024. There was a significant increase in publications from 2017 to 2018, with a peak in 2018 and a slight stabilization through 2020. A renewed interest is observed, with another peak in 2022, most likely due to global events such as the COVID-19 pandemic and associated technological or policy developments. However, the data show a sharp decline in 2023 and 2024, which could be attributed to insufficient data for 2024 or a shift in research priorities. Overall, the field has experienced periods of growth and fluctuation, which reflects its changing nature.

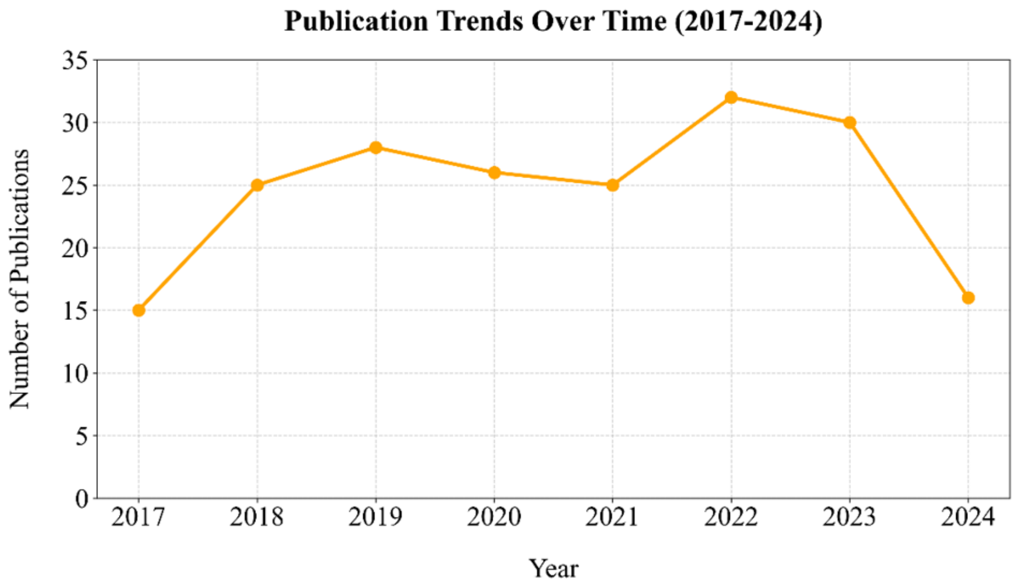

Figure 4. Recent Publication Trends in Smart Cities and Thermal Comfort Research (2017-2024).

3.2.2. Geographical Analysis of Research Contributions

A geographical analysis was carried out (Fig 5) to identify the leading nations contributing to research on thermal comfort and smart cities. The data indicate that China, the United States, and Englad are the most active, with significant contributions also from Italty. These countries represent the forefront of research in this domain, with China leading in the volume of publications, followed by the USA and England. Notably, another study on smart cities similarly identified China and the USA as the top two countries with the highest research contributions [36]. It is also important to highlight that Africa remains underrepresented, as none of the top 10 contributing countries are from the continent. This observation aligns with findings from previous research on smart cities [36], as well as in a review of studies on outdoor thermal comfort [37], both of which pointed out the lack of focus on African regions.

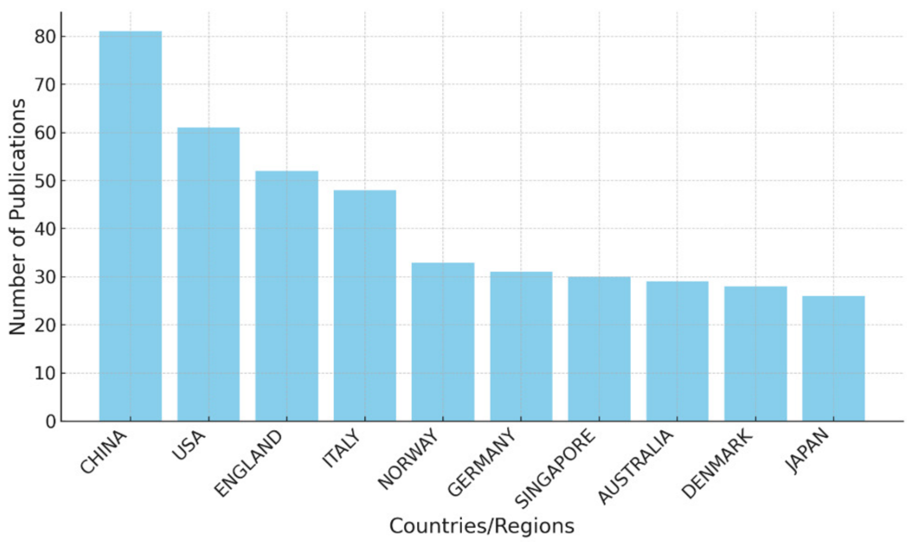

Figure 5. Top Countries by Number of Publications on Thermal Comfort and Smart Cities.

Recognizing that research on smart cities covers a wide range of disciplines, we further examined the trends in scientific contributions from the United States, China, Italy, and England.

Broadly, research across these countries focuses on optimizing thermal comfort while balancing energy consumption, cost, and sustainability. China and the USA have a strong focus on IoT (Cluster #7, Figure 3), Smart Buildings (Cluster #5, Figure 3), and Demand Flexibility (Cluster #3, Figure 2), utilizing machine learning and optimization algorithms. These efforts highlight how energy consumption is managed in response to supply conditions, particularly during peak periods.

In contrast, Italy and England prioritize building performance, shading strategies (Cluster #8, Figure 2), and natural ventilation (Cluster #6, Figure 2), blending traditional and modern approaches to enhance energy efficiency. Both countries also show notable interest in Phase Change Materials (Cluster #2, Figure 2), which plays a crucial role in improving energy efficiency through innovations in material science.

Additionally, Fuel Poverty (Cluster #1, Figure 2) is a significant topic in England, aligning with broader discussions on energy access and equity. Meanwhile, Urban Resilience** (Cluster #9, Figure 3) has become an increasingly prominent research focus in Italy and China, as they develop strategies to help cities adapt to and recover from thermal challenges, especially in the context of climate change.

3.2.3. Methodological Analysis

Next, we examined the methodologies used in the publications, focusing on the frequency of various approaches such as questionnaires, simulation tools, and other methods. This helped us understand the dominant techniques used in the research, and how they evolved over time.

Figure 6 depicts the percentage distribution of various methodologies used in studies on smart cities and thermal comfort. The analysis reveals that "Other Methods" dominate the research landscape, accounting for more than half of the studies. Simulations are the second most popular methodology, accounting for roughly 35% of publications. Questionnaires, while still significant, are the least used approach, accounting for approximately 15%. This distribution demonstrates the breadth of research approaches in the field, with a particular emphasis on methods other than traditional questionnaires and simulation.

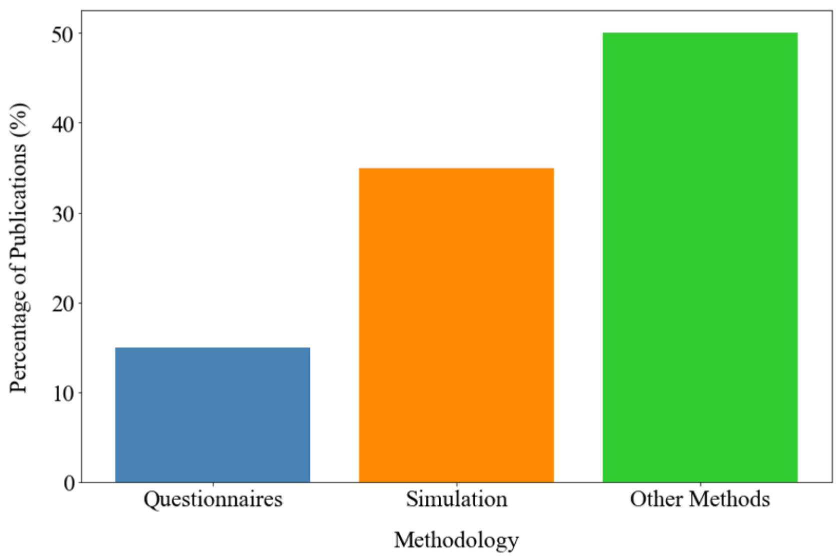

Figure 6. Distribution of Methodologies Used in Smart Cities and Thermal Comfort Research.

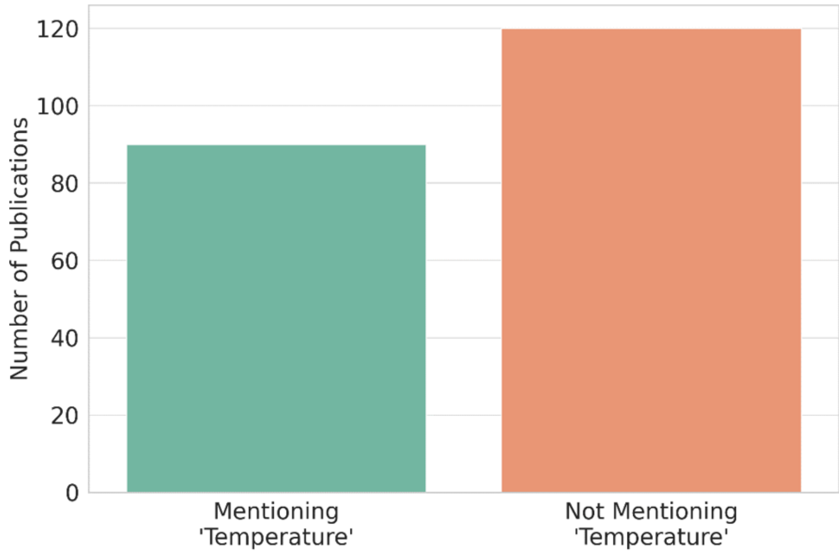

Figure 7. Inclusion of Temperature Data in Smart Cities and Thermal Comfort Studies.

Through the analysis of the dataset, it is evident that many studies have utilized questionnaires to assess thermal comfort, linking subjective perceptions with measured or simulated environmental conditions. These questionnaires include Subjective Thermal Comfort Surveys, which aim to capture occupants' perceptions of comfort—such as feeling too hot, cold, or neutral—and play a critical role in validating simulation results or assessing building performance. For example, the study in [38] used a questionnaire survey to compare thermal comfort in mechanically ventilated and non-mechanically ventilated spaces. Similary, [39] employed questionnaires to gather data across various climate zones, improving predictive accuracy through machine learning models using transfer learning across cities. Questionnaires can also serve as a validation tools, linking simulated outcomes with real-world occupant comfort, in this study[40], they were used to assess the accuracy of machine learning models predicting comfort based on indoor conditions, such as temperature and humidity.

These studies illustrate the versatility of questionnaires in thermal comfort research, providing essential data that complements simulations and informs the development of comfort standards across diverse settings. By capturing subjective experiences and validating predictive models, questionnaires serve as a valuable tool in understanding and optimizing thermal comfort in various environmental contexts.

Further investigation was conducted, focusing on the use and lack of temperature data. Figure 7 compares the number of articles mentioning "temperature" to those that do not in the context of smart cities and thermal comfort research. The analysis reveals that, while approximately 45% of studies include temperature data, the majority (55%) do not explicitly mention it. This demonstrates the varying emphasis on temperature as an important factor in this research domain.

Finally, the simulation tools used in the studies were evaluated to determine their prevalence.

The pie chart (Figure 8), illustrates the distribution of simulation tools used in various studies for thermal comfort analysis. The most commonly utilized tools include "Other Simulations" (35.1%), followed by EnergyPlus (27.0%), ENVI-met (24.3%), and CFD (13.5%). While these tools are effective in modeling environmental conditions and predicting thermal comfort, they are often used in combination with questionnaires to validate their outcomes with real-world occupant data, as seen in studies [39] and [40]. This approach allows for a more comprehensive understanding of thermal comfort by aligning simulated results with subjective perceptions. However, simulation tools are also frequently employed independently to model scenarios and assess thermal environments without direct feedback from occupants.

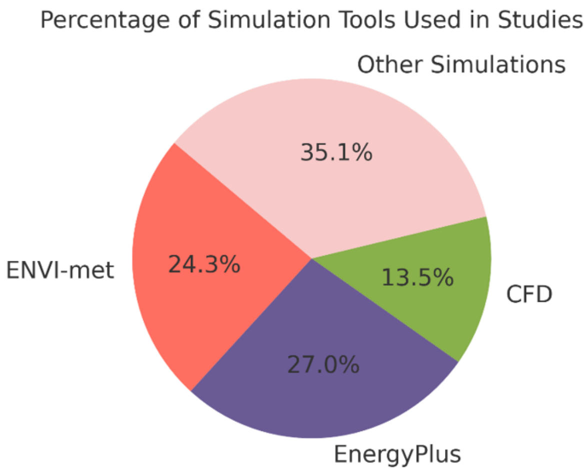

Figure 8. Distribution of Simulation Tools Used in Smart Cities and Thermal Comfort Research.

4. DISCUSSION

4.1. Key Insights from CiteSpace

This study's analysis of thermal comfort research in smart cities from 2017 to 2024, utilizing CiteSpace and Python, highlights a dynamic and evolving field shaped by various research themes and methodological approaches. The CiteSpace analysis, which draws keywords from abstracts, identifies clusters that span technical, social, and environmental dimensions. For instance, clusters like "Fuel Poverty," "Phase Change Materials," and "Demand Flexibility" shed light on different aspects of urban thermal comfort, ranging from energy access and material innovations to advanced technologies for optimizing energy use in smart cities. The temporal evolution depicted in the CiteSpace clusters shows how certain topics, such as "Shading Design" and "Urban Resilience," have gained prominence over time, reflecting an increased focus on climate adaptation and sustainable urban development. These findings underscore the interdisciplinary nature of thermal comfort research, where solutions blend technical precision with considerations of social equity and environmental sustainability.

4.2. Insights from Keyword-Based Analysis

The second component of the analysis, which focuses on keywords explicitly chosen by authors, complements these findings by offering insights into the strategic framing of research questions. Clusters such as "Thermal Performance," "Smart Building," and "IoT" (Internet of Things) illustrate a growing emphasis on leveraging digital technologies to enhance urban thermal environments. This trend aligns with the broader global push towards smart cities, where real-time data collection and building system integration support more efficient management of energy consumption and occupant comfort. The identification of clusters like "Multi-Objective Optimization" further highlights the need to balance various goals, such as energy efficiency, cost reduction, and environmental impact, in the planning of smart urban environments.

4.3. Broader Trends and Temporal Analysis Using Python

In contrast, the Python-based analysis offers a view of broader publication trends, providing a temporal overview of research activity in this field. The analysis revealed significant growth in publications from 2017 to 2018, followed by a peak in 2022, likely influenced by the global drive towards resilient and sustainable cities in response to challenges such as the COVID-19 pandemic. However, the observed decline in publications in 2023 and 2024 could indicate either a genuine shift in research focus or limitations due to incomplete data for the latter years. This temporal analysis highlights the fluctuating nature of the research landscape, reflecting how global events can accelerate shifts in academic focus.

The methodological analysis using Python also reveals the diverse approaches employed in thermal comfort studies. The prevalence of "Other Methods" suggests that, while traditional tools like simulations and questionnaires remain vital, there is increasing use of specialized or emerging techniques. Furthermore, the analysis of temperature data usage uncovered a notable gap, with many studies failing to directly address temperature as a critical factor, despite its importance in thermal comfort. This could indicate a need for more comprehensive approaches in certain research areas or varying perspectives on the role of temperature in urban thermal environments.

4.4. Methodological Evolution in Thermal Comfort Research

The analysis identifies evolving preferences in research methods:

• Increasing Focus on Simulation and Data-Driven Approaches: From 2017 onward, studies have increasingly embraced simulations and AI methods, with notable growth in the use of CFD (Computational Fluid Dynamics) and neural networks. For example, [41] integrates EnergyPlus with machine learning to achieve over 20% reductions in energy consumption through adaptive control systems.

• Shifts Toward Bioclimatic and Passive Design: Methods like those used in the [42] have shown consistent application in regions with extreme climates, where energy-efficient strategies like high thermal mass and natural ventilation are crucial.

• Model Predictive Control (MPC) and Decision Support Frameworks: MPC has emerged as a crucial approach for optimizing complex indoor environments. For instance, the study [40] demonstrates the application of MPC in managing temperature regulation in large buildings, showcasing its scalability and ability to enhance energy efficiency in diverse settings.

4.5. The Importance of a Multidisciplinary Approach

Addressing thermal comfort in smart cities necessitates a convergence of expertise from engineering, urban planning, and environmental sciences:

• Engineering plays a central role in refining predictive models and control systems, such as AI and machine learning applications for building performance optimization. The study [43] exemplifies how predictive control can dynamically manage indoor climates.

• Urban Planning focuses on the strategic design of outdoor spaces, employing passive cooling strategies like shading and natural ventilation to mitigate urban heat islands. The emphasis on "Shading Design" in CiteSpace clusters demonstrates the critical role of spatial planning in enhancing outdoor thermal comfort.

• Environmental Sciences contribute essential insights into climate dynamics and urban heat flow, helping tailor strategies to specific regions. This is evident in studies that use CFD for urban layout modeling, such as [44]in Niigata, Japan, which used CFD simulations to evaluate the thermal comfort of cyclists under varying wind conditions and predicted mean vote (PMV) values.

4.6. Practical Implications for Urban Planners and Policymakers

The insights gained from this analysis can inform policy and urban planning strategies to improve thermalcomfort:

• Adopting Passive Design Strategies: In high-temperature regions, urban planners can draw from strategies outlined in [42], which optimize comfort while reducing reliance on energy-intensive cooling systems.

• Utilizing Predictive Models for Dynamic Control: Findings from [43]can guide urban managers in implementing dynamic building management systems, achieving energy efficiency without compromising occupant comfort.

• Addressing Regional Research Gaps: Recognizing disparities in research focus, such as the limited attention given to regions like Africa, is essential for developing more inclusive and context-specific solutions. This approach helps ensure that thermal comfort strategies are equitable and tailored to meet the diverse needs of urban residents across different geographic areas.

4.7. Most Effective Methods for Thermal Comfort Optimization

A comparison of different methods reveals several that stand out for their effectiveness:

1. Electrochromic Glazing: Allows for larger window-to-wall ratios (WWR) without a significant increase in energy consumption, achieving a 54.88% reduction in energy consumption compared to traditional laminated glazing at a 90% WWR[45].

2. Green Roofs: Achieves a 12% reduction in cooling energy consumption, improving outdoor thermal comfort and reducing mean radiant temperature [46].

Community Energy Storage: Reduces energy costs by 28.48% through an energy cooperation framework between photovoltaic prosumers and a smart Community Energy Storage (CES) system, while also improving end-user comfort levels ([47]).

The growing reliance on simulation and AI techniques illustrates the shift towards advanced, data-driven solutions, while the sustained relevance of bioclimatic design underscores the importance of tailored, region-specific approaches. This blend of methods highlights the value of interdisciplinary research, ensuring that smart city designs are not only technologically advanced but also responsive to the unique needs of each urban context.

5. CONCLUSIONS

This study offers a detailed overview of the evolving landscape of thermal comfort research in smart cities between 2017 and 2024, highlighting key research themes, methodologies, and emerging tools. Through a combined analysis using CiteSpace and Python, this research has illuminated both the technical and social dimensions of thermal comfort, underscoring the importance of interdisciplinary approaches in shaping more resilient and comfortable urban environments.

The CiteSpace analysis reveals the temporal evolution of research themes, with emerging interest areas such as "Shading Design," "Urban Resilience," and "Demand Flexibility." These clusters highlight how research is increasingly focused on adapting urban spaces to the challenges posed by climate change and urban heat islands. For example, studies like those on bioclimatic design [42] demonstrate how passive strategies like high thermal mass and natural ventilation can reduce energy demand in high-temperature regions. Meanwhile, the growing emphasis on smart technologies, such as those explored in [43], showcases how dynamic building management can optimize energy use while maintaining indoor comfort.

The Python-based analysis further reveals shifts in publication trends, showing peaks of interest in 2018 and 2022, likely driven by global events like the COVID-19 pandemic, which brought renewed attention to resilient urban environments. However, the observed decline in publications

in 2023 and 2024 suggests either a shift in focus or limitations in data availability, emphasizing the need for continuous research in this field.
Practical Implications for Urban Planners and Policymakers
The insights from this study have significant practical implications for urban planners and policymakers. First, the adoption of passive design strategies, as seen in [42], can help regions with extreme climates reduce their reliance on energy-intensive cooling systems, promoting more sustainable and cost-effective building designs. Additionally, the integration of predictive control systems, such as those explored in [43], can guide urban managers in implementing dynamic HVAC systems that adapt to real-time conditions, optimizing energy efficiency while maintaining thermal comfort. These approaches can be particularly valuable for retrofitting existing urban structures, providing a pathway towards more energy-efficient cities.
Moreover, the study's findings on regional disparities, such as the underrepresentation of African contexts, highlight the need for more inclusive research. Addressing these gaps can ensure that thermal comfort strategies are not only technologically advanced but also responsive to the diverse needs of urban residents. Policymakers should prioritize research initiatives in underrepresented regions to develop context-specific solutions that improve thermal comfort across different geographic areas.
Future Directions and Research Recommendations
Several areas require further exploration to advance the field of thermal comfort in smart cities:
1. Enhanced Focus on Emerging Topics: Research on themes like "Shading Design" and "Urban Resilience" is still in its early stages and would benefit from more empirical studies. Future research should explore the long-term impact of shading strategies on urban microclimates and the role of adaptive urban design in building resilience against extreme weather events.
2. Integration of Temperature Data: The analysis revealed that while many studies incorporate advanced simulation tools, approximately 55% do not explicitly use temperature data. Future research should focus on integrating precise temperature measurements with subjective comfort surveys to provide a more holistic understanding of thermal comfort, as demonstrated in studies like [48].
3. Adopting Data-Driven and Simulation-Based Approaches: The shift toward AI and machine learning techniques offers promising avenues for predictive accuracy in thermal comfort studies. Researchers should consider adopting methodologies such as those in [49] which combine large datasets with adaptive algorithms for more precise thermal environment management.
4. Standardization of Methodologies: The diversity of methods identified in this study—ranging from questionnaires and simulations to advanced machine learning models—suggests the need for more standardized approaches. Standardizing data collection and analysis methods, such as those used in community energy storage models [47], would enable better cross-study comparisons and improve the generalizability of findings.
5. Focus on Vulnerable Populations: While technical aspects of thermal comfort have been extensively studied, there is a need for more research focused on the social dimensions of thermal comfort, especially for vulnerable populations. Studies like those examining "Fuel Poverty" highlight the importance of addressing energy access disparities. Future research should prioritize understanding how thermal comfort interventions can be made more equitable.
This study underscores the importance of a multidisciplinary approach in advancing thermal comfort research, combining engineering, urban planning, and environmental sciences to create holistic solutions for smart cities. Addressing regional research gaps, emphasizing practical applications, and exploring new methodologies can help the field meet the challenges of climate change and urbanization. Researchers and policymakers must collaborate to ensure that smart cities are not only energy-efficient but also comfortable and inclusive.
However, certain limitations should be acknowledged. The use of the basic version of CiteSpace

restricted access to advanced clustering features, which may have limited the depth of the analysis. Additionally, relying on keywords from abstracts might overlook nuanced details of research themes and methodologies. The observed decline in research activity in 2023 and 2024 could also be due to incomplete data rather than a true shift in research focus. Addressing these limitations in future studies can enhance the understanding of thermal comfort in smart cities, enabling more targeted and effective strategies.

Authors contribution: Safae Ahsissene: Conceptualization, Methodology, Software, Formal Analysis, Investigation, Resources, Data Curation, Writing – Original Draft, Visualization. Fatima Zahrae Rhziel: Software, Formal Analysis. Naoufal Raissouni: Supervision, Project Administration, Methodology, Writing–Review & Editing.

Funding: No funding was received to support this study.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare that they have no competing interests.

REFERENCES

[1] A. I. Almulhim and P. B. Cobbinah, "Can rapid urbanization be sustainable? The case of Saudi Arabian cities," Habitat Int., vol. 139, no. July, p. 102884, 2023. https://doi.org/10.1016/j.habitatint.2023.102884.

[2] X. Zeng, Y. Yu, S. Yang, Y. Lv, and M. N. I. Sarker, "Urban Resilience for Urban Sustainability: Concepts, Dimensions, and Perspectives," Sustain., vol. 14, no. 5, pp. 1–27, 2022. https://doi.org/10.3390/su14052481.

[3] M. Xu, J. M. David, and S. H. Kim, "The fourth industrial revolution: Opportunities and challenges," Int. J. Financ. Res., vol. 9, no. 2, pp. 90–95, 2018. https://doi.org/10.5430/ijfr.v9n2p90.

[4] M. Zou and H. Zhang, "Cooling strategies for thermal comfort in cities: a review of key methods in landscape design," Environ. Sci. Pollut. Res., vol. 28, no. 44, pp. 62640–62650, 2021. https://doi.org/10.1007/s11356-021-15172-y.

[5] F. Grilo et al., "Using green to cool the grey: Modelling the cooling effect of green spaces with a high spatial resolution," Sci. Total Environ., vol. 724, 2020. https://doi.org/10.1016/j.scitotenv.2020.138182.

[6] D. Lai, Y. Liu, M. Liao, and B. Yu, "Effects of different tree layouts on outdoor thermal comfort of green space in summer Shanghai," Urban Clim., vol. 47, no. August 2022, p. 101398, 2023. https://doi.org/10.1016/j.uclim.2022.101398.

[7] H. Gajjar and J. J. Devi, "Assessment of Role of Water Body on Thermal Comfort in Ahmedabad, India," in 2019 3rd International Conference on Environmental and Energy Engineering (IC3E 2019), vol. 281, 2019. https://doi.org/10.1088/1755-1315/281/1/012023.

[8] M. Batty et al., "Smart cities of the future," Eur. Phys. J. Spec. Top., vol. 214, no. 1, pp. 481–518, 2012. https://doi.org/10.1140/epjst/e2012-01703-3.

[9] U. B. Vito Albino and R. M. Dangelico, "Smart Cities: Definitions, Dimensions, Performance, and Initiatives," J. Urban Technol., vol. 22, no. 1, pp. 3–21, 2015. https://doi.org/10.1080/10630732.2014.942092.

[10] A. M. Shahat Osman and A. Elragal, "Smart cities and big data analytics: A data-driven decision-making use case," Smart Cities, vol. 4, no. 1, pp. 286–313, 2021. https://doi.org/10.3390/smartcities4010018.

[11] L. N. Kondrat'eva, N. R. Stepanova, and P. V. Bochkov, "The Formation of a Comfortable Urban Environment," IOP Conf. Ser. Mater. Sci. Eng., vol. 972, no. 1, 2020. https://doi.org/10.1088/1757-

899X/972/1/012021.

[12] W. Song and J. K. Calautit, "Inclusive comfort: A review of techniques for monitoring thermal comfort among individuals with the inability to provide accurate subjective feedback," Build. Environ., vol. 257, no. March, p. 111463, 2024. https://doi.org/10.1016/j.buildenv.2024.111463.

[13] S. Yazdi Bahri, M. Alier Forment, A. Sanchez Riera, F. Bagheri Moghaddam, M. J. Casañ Guerrero, and A. M. Llorens Garcia, "A literature review on thermal comfort performance of parametric façades," Energy Reports, vol. 8, pp. 120–128, 2022. https://doi.org/10.1016/j.egyr.2022.10.245.

[14] A. H. Rosenfeld et al., "Mitigation of urban heat islands: materials, utility programs, updates," Energy Build., vol. 22, no. 3, pp. 255–265, 1995. https://doi.org/10.1016/0378-7788(95)00927-P.

[15] R. Sánchez-Corcuera et al., "Smart cities survey: Technologies, application domains and challenges for the cities of the future," Int. J. Distrib. Sens. Networks, vol. 15, no. 6, 2019. https://doi.org/10.1177/1550147719853984.

[16] A. Arroub, B. Zahi, E. Sabir, and M. Sadik, "A literature review on Smart Cities: Paradigms, opportunities and open problems," in 2016 Int. Conf. Wirel. Networks Mob. Commun. WINCOM 2016 Green Commun. Netw., 2016, pp. 180–186. https://doi.org/10.1109/WINCOM.2016.7777211.

[17] H. Kim, H. Choi, H. Kang, J. An, S. Yeom, and T. Hong, "A systematic review of the smart energy conservation system: From smart homes to sustainable smart cities," Renew. Sustain. Energy Rev., vol. 140, no. September 2020, p. 110755, 2021. https://doi.org/10.1016/j.rser.2021.110755.

[18] T. Singh, A. Solanki, S. K. Sharma, A. Nayyar, and A. Paul, "A Decade Review on Smart Cities: Paradigms, Challenges and Opportunities," IEEE Access, vol. 10, no. June, pp. 68319–68364, 2022. https://doi.org/10.1109/ACCESS.2022.3184710.

[19] J. S. Gracias, G. S. Parnell, E. Specking, and E. A. Pohl, "Smart cities—A Structured Literature Review," Smart Cities, pp. 1719–1743, 2023.

[20] A. van Twist, E. Ruijer, and A. Meijer, "Smart cities & citizen discontent: A systematic review of the literature," Gov. Inf. Q., vol. 40, no. 2, p. 101799, 2023. https://doi.org/10.1016/j.giq.2022.101799.

[21] F. Zhao, O. I. Fashola, T. I. Olarewaju, and I. Onwumere, "Smart city research: A holistic and state-of-the-art literature review," Cities, vol. 119, no. May 2020, p. 103406, 2021. https://doi.org/10.1016/j.cities.2021.103406.

[22] B. N. Silva, M. Khan, and K. Han, "Towards sustainable smart cities: A review of trends, architectures, components, and open challenges in smart cities," Sustain. Cities Soc., vol. 38, no. August 2017, pp. 697–713, 2018. https://doi.org/10.1016/j.scs.2018.01.053.

[23] A. Razmjoo, A. H. Gandomi, M. Pazhoohesh, S. Mirjalili, and M. Rezaei, "The key role of clean energy and technology in smart cities development," Energy Strateg. Rev., vol. 44, no. August 2021, p. 100943, 2022. https://doi.org/10.1016/j.esr.2022.100943.

[24] E. Ismagilova, L. Hughes, N. P. Rana, and Y. K. Dwivedi, "Security, Privacy and Risks Within Smart Cities: Literature Review and Development of a Smart City Interaction Framework," Inf. Syst. Front., vol. 24, no. 2, pp. 393–414, 2022. https://doi.org/10.1007/s10796-020-10044-1.

[25] X. Su, Y. Yuan, Z. Wang, W. Liu, L. Lan, and Z. Lian, "Human thermal comfort in non-uniform thermal environments: A review," Energy Built Environ., vol. 5, no. 6, pp. 853–862, 2024. https://doi.org/10.1016/j.enbenv.2023.06.012.

[26] Y. Sun, C. Zhang, Y. Zhao, J. Li, Y. Ma, and C. Zhu, "A systematic review on thermal environment and thermal comfort studies in Chinese residential buildings," Energy Build., vol. 291, no. December 2022, p. 113134, 2023. https://doi.org/10.1016/j.enbuild.2023.113134.

[27] Y. Alshamaila, S. Papagiannidis, H. Alsawalqah, and I. Aljarah, "Effective use of smart cities in

crisis cases: A systematic review of the literature," Int. J. Disaster Risk Reduct., vol. 85, no. July 2022, p. 103521, 2023. https://doi.org/10.1016/j.ijdrr.2023.103521.

[28] P. Pandiyan, S. Saravanan, K. Usha, R. Kannadasan, M. H. Alsharif, and M.-K. Kim, "Technological advancements toward smart energy management in smart cities," Energy Reports, vol. 10, pp. 648–677, 2023.https://doi.org/10.1016/j.egyr.2023.07.021.

[29] N. U. Huda, I. Ahmed, M. Adnan, M. Ali, and F. Naeem, "Experts and intelligent systems for smart homes' Transformation to Sustainable Smart Cities: A comprehensive review," Expert Syst. Appl., vol. 238, p. 122380, 2024. https://doi.org/10.1016/j.eswa.2023.122380.

[30] A. van Twist, E. Ruijer, and A. Meijer, "Smart cities & citizen discontent: A systematic review of the literature," Gov. Inf. Q., vol. 40, no. 2, p. 101799, 2023. https://doi.org/10.1016/j.giq.2022.101799.

[31] I. Yaqoob, K. Salah, R. Jayaraman, and M. Omar, "Metaverse applications in smart cities: Enabling technologies, opportunities, challenges, and future directions," Internet of Things, vol. 23, p. 100884, 2023. https://doi.org/10.1016/j.iot.2023.100884.

[32] G. Keshavarzi, Y. Yildirim, and M. Arefi, "Does scale matter? An overview of the 'smart cities' literature," Sustain. Cities Soc., vol. 74, no. December 2020, p. 103151, 2021. https://doi.org/10.1016/j.scs.2021.103151.

[33] R. Agrifoglio, C. Metallo, and P. di Nauta, "Understanding Knowledge Management in Public Organizations through the Organizational Knowing Perspective: a Systematic Literature Review and Bibliometric Analysis," Public Organ. Rev., vol. 21, no. 1, pp. 137–156, 2021. https://doi.org/10.1007/s11115-020-00480-7.

[34] B. Markscheffel and F. Schröter, "Comparison of two science mapping tools based on software technical evaluation and bibliometric case studies," COLLNET J. Sci. Inf. Manag., vol. 15, no. 2, pp. 365–396, 2021. https://doi.org/10.1080/09737766.2021.1960220.

[35] J. Wei, J. Li, J. Zhao, and X. Wang, "Hot Topics and Trends in Zero-Energy Building Research—A Bibliometrical Analysis Based on CiteSpace," Buildings, vol. 13, no. 2, 2023. https://doi.org/10.3390/buildings13020479.

[36] D. Scala, Á. I. Aguilar Cuesta, M. Á. Rodríguez-Domenech, and M. del C. Cañizares Ruiz, "Bibliometric Study on the Conceptualisation of Smart City and Education," Smart Cities, vol. 7, no. 1, pp. 597–614, 2024. https://doi.org/10.3390/smartcities7010024.

[37] D. Lai et al., "A comprehensive review of thermal comfort studies in urban open spaces," Sci. Total Environ., vol. 742, p. 140092, 2020. https://doi.org/10.1016/j.scitotenv.2020.140092.

[38] D. Serghides, S. Dimitriou, I. Kyprianou, and C. Papanicolas, "The Adaptive Comfort Factor in Evaluating the Energy Performance of Office Buildings in the Mediterranean Coastal Cities," in Energy Procedia, vol. 134, pp. 683–691, 2017. https://doi.org/10.1016/j.egypro.2017.09.588.

[39] N. Gao, W. Shao, M. S. Rahaman, J. Zhai, K. David, and F. D. Salim, "Transfer learning for thermal comfort prediction in multiple cities," Build. Environ., vol. 195, p. 107725, May 2021. https://doi.org/10.1016/j.buildenv.2021.107725.

[40] W. Zhang, F. Liu, and R. Fan, "Improved thermal comfort modeling for smart buildings: A data analytics study," Int. J. Electr. Power Energy Syst., vol. 103, pp. 634–643, 2018. https://doi.org/10.1016/j.ijepes.2018.06.026.

[41] Y. Boutahri and A. Tilioua, "Machine learning-based predictive model for thermal comfort and energy optimization in smart buildings," Results Eng., vol. 22, p. 102148, 2024. https://doi.org/10.1016/j.rineng.2024.102148.

[42] M. Charai, H. Sghiouri, A. Mezrhab, and M. Karkri, "Bioclimatic Building Design Analysis.

Case Study: Oujda, Morocco," in 2019 IEEE International Renewable and Sustainable Energy Conference (IRSEC), 2019. https://doi.org/10.1109/IRSEC48032.2019.9078176.

[43] A. Banjac, H. Novak, and M. Vasak, "Implementation of model predictive indoor climate control for hierarchical building energy management," Control Eng. Pract., vol. 136, 2023. https://doi.org/10.1016/j.conengprac.2023.105536.

[44] M. V. Tabib, A. Rasheed, and T. P. Uteng, "Methodology for assessing cycling comfort during a smart city development," in CISBAT 2017 International Conference Future Buildings & Districts - Energy Efficiency from Nano to Urban Scale, vol. 122, pp. 361–366, 2017. https://doi.org/10.1016/j.egypro.2017.07.286.

[45] I. Lahmar, N. Zemmouri, A. Cannavale, and F. Martellotta, "Investigating the impact of electrochromic glazing on energy performance in hot arid climate using parametric design," IOP Conf. Ser. Mater. Sci. Eng., vol. 609, no. 6, 2019. https://doi.org/10.1088/1757-899X/609/6/062027.

[46] G. Mutani and V. Todeschi, "Roof-integrated green technologies, energy saving and outdoor thermal comfort: Insights from a case study in urban environment," Int. J. Sustain. Dev. Plan., vol. 16, no. 1, pp. 13–23, 2021. https://doi.org/10.18280/ijsdp.160102.

[47] S. Dorahaki, M. Rashidinejad, M. MollahassaniPour, M. Pourakbari Kasmaei, and P. Afzali, "A sharing economy model for a sustainable community energy storage considering end-user comfort," Sustain. Cities Soc., vol. 97, 2023. https://doi.org/10.1016/j.scs.2023.104786.

[48] W. Zhang, W. Hu, and Y. Wen, "Thermal comfort modeling for smart buildings: A fine-grained deep learning approach," IEEE Internet Things J., vol. 6, no. 2, pp. 2540–2549, 2019. https://doi.org/10.1109/JIOT.2018.2871461.

[49] R. Ashrafi, M. Azarbayjani, and H. Tabkhi, "Machine Learning-Based Automated Thermal Comfort Prediction: Integration of Low-Cost Thermal and Visual Cameras for Higher Accuracy," 2022. [Online]. Available: http://arxiv.org/abs/2204.08463