Knowledge Visualization in Outdoor Thermal Environment Studies: A Comprehensive Review and International Comparison

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Abstracts: This review highlights the escalating challenges of outdoor thermal discomfort and urban heat islands due to urbanization and climate change, impacting sustainability and health. Analyzing global research trends, it reveals methodological differences between Chinese and Western scholars, with the former focusing more on quantitative analysis and the latter on diverse approaches including adaptation strategies. It underscores the importance of using emerging technologies like GIS, AI, and remote sensing for precise mapping, scenario modeling, and environmental monitoring. These tools offer innovative, data-driven solutions for urban planning, essential for addressing thermal impacts. The paper calls for enhanced Sino-Western cooperation and interdisciplinary research to develop context-specific, sustainable strategies for improving urban thermal environments.

1 Introduction

In recent years, the investigation of outdoor thermal environments has garnered considerable interest among scholars and urban planning practitioners. The data used for analysis are retrieved from two databases of China National Knowledge Infrastructure (CNKI) and Web of Science (WOS).The present study endeavors to furnish a comprehensive synthesis of the domain, juxtaposing global and mainland research outlooks.It delves into the challenges posed by rapid urbanization and climate change, such as escalating urban heat islands (UHIs) and their health impacts. By examining a variety of research methods, from literature reviews to advanced GIS technology, These approaches prioritize green infrastructure, urban forestry, and reflective building materials to improve thermal comfort with rapid urbanization, using GIS and urban morphology analysis to explore the impact of urban planning and design on heat islands[1]. They emphasize the integration of vegetation, water bodies, and the use of traditional architecture to enhance natural ventilation and shading.

2 Data Sources and Research Methods

The study delves into the urban outdoor thermal environment through a precise lens, emphasizing urban sustainability and climate resilience[2]. By analyzing publications from 1991 to 2023 with a focus on "Urban Heat Island," "microclimate," and "outdoor thermal comfort," it identifies critical literature using CNKI and WOS data-bases (Fig.1). The research employs bi-bliometric tools like VOSviewer and Bibliometrix for a data-driven analysis, pinpointing key themes and influential works.

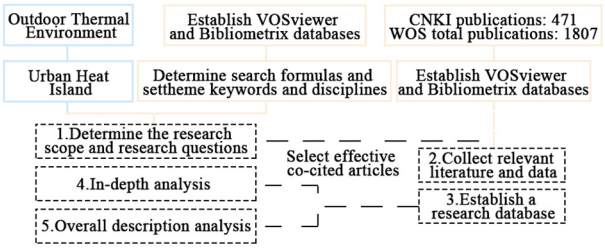

Fig. 1. Schematic diagram of document schedule

3 Results

The analysis of outdoor thermal environment research from 1991 to 2024 reveals a 4.63% annual increase in publications (Table.1), high-lighting sustained interest despite fluctuating citation impacts, with an average of 22.25 per- paper. This field's dynamic nature is underscored by the involvement of 5568 authors and a 31.49% international collaboration rate, suggesting a global effort in addressing thermal issues. The variability in citation rates, espec-ially the peak between 2009 and 2011 followed by a decline, reflects shifting research priorities and methodologies (Fig.2).

Table 1. The evolutionary process of literature

Main Information About Data	
Time-span	1991:2024
Annual Growth Rate %	4.63
Document Average Age	5.08
Average citations per doc	22.25

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Author's Keywords (DE)	5568
International co-authorships %	31.49

China leads in both volume and collaborative efforts, with a remarkable 30.3% of its research involving international cooperation, indicating a proactive stance towards global scientific engagement. The United States follows (Fig.3), showcasing substantial output and a 26.5% collaboration rate, while Australia stands out for its highest willingness to collaborate at 40.8%, despite fewer publications. This data essential for addressing the complex, cross-border nature of urban thermal challenges. (Fig.4).

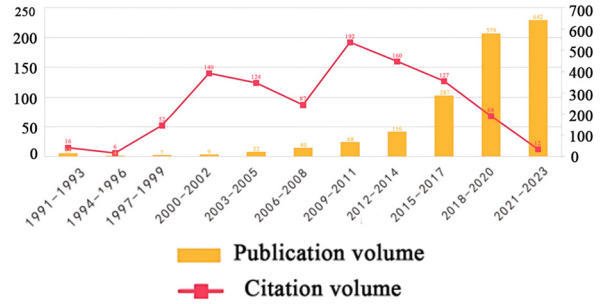

Fig 2. The historical changes of academic influence

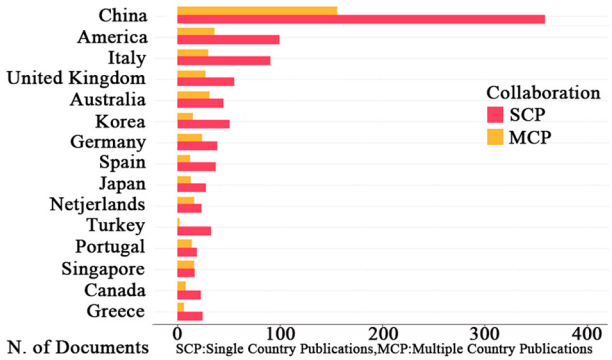

Fig. 3. Universities around the world research

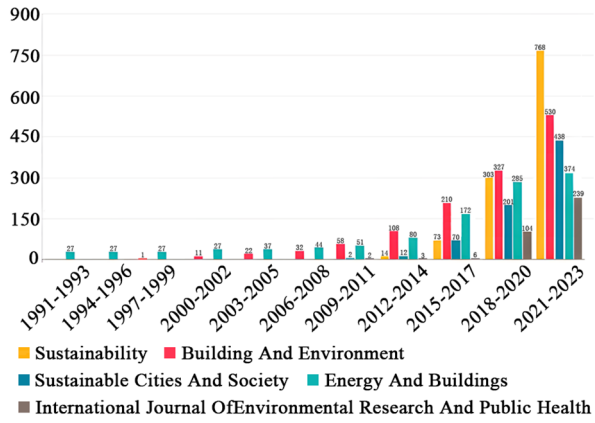

Fig. 4. Sustainability research in core journals

The evolution of major journals—Sustainability, Building and Environment, and others—reflects a growing academic focus on sustainability and urban planning. The surge in publications from 2018 to 2023 underscores the escalating importance of research on environmental sustainability[3]. The inclusion of newer journals like Urban Climate and Remote Sensing since 2010 signals an expanding research frontier (Table.2) emphasizing the need for comprehensive approaches to urban thermal management (Table.3).

Table 2. Ranking of academic activity in this research

Description	Country	Articles
The Chinese University of Hong Kong	China	61
The University of Hong Kong		53
Arizona State University	United States	51
National University of Singapore	Singapore	46
Seoul National University	South Korea	28
Griffith University	Australia	26

Table 3. Ranking of academic activity in this research

Year	Urban Climate	Buildings	Journal of Cleaner Production	Science of the Total Environment	Remote Sensing
2012 - 2014	0	0	8	4	1
2015 - 2017	3	0	34	10	6
2018 - 2020	47	22	81	60	37
2021 - 2023	165	122	144	127	105

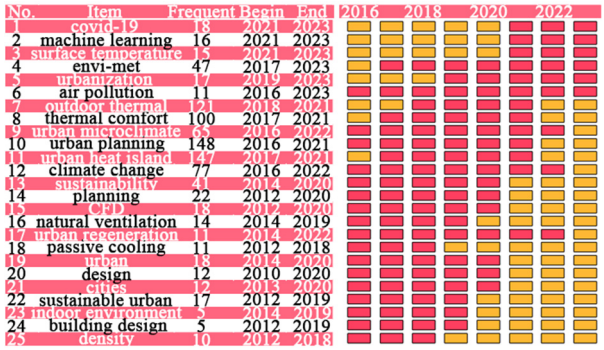

Fig. 5. Spatiotemporal characteristics of knowledge

Keyword analysis reveals a move towards sustainable urban planning and technology-driven methods, such as "envi-met" simulations and machine learning(Fig.5)

In this study, we explored the keywords in the author's papers before 2010 through cluster analysis to better understand the research trends in the outdoor thermal environment field, as shown (Fig.6). Based on the analysis of the upper-right quadrant, we found that urban planning, urban heat island, and urban design are key and highly developed themes in this field, playing a core role in their connections with other fields[4]. Research on "heat islands" and "outdoor thermal environments" are relatively "mature" areas of study within "urban climate" research. However, these established topics have fairly "weak connections" to research in other related disciplines and fields. This means research on urban heat and outdoor thermal conditions tend to be somewhat "siloed".

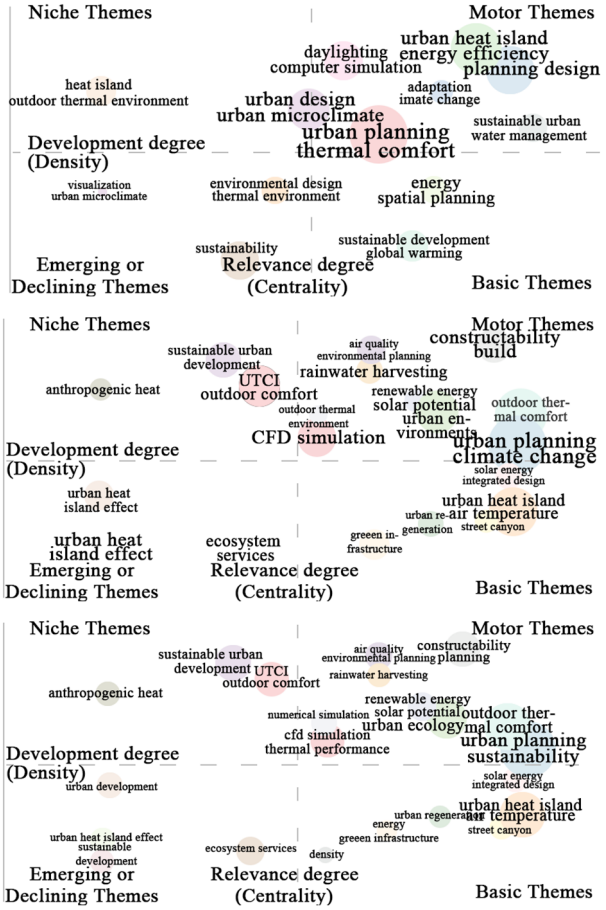

Fig. 6. Influences from Before 2010 to 2016

Initially, studies concentrated on foundational aspects like urban planning and thermal comfort. Between 2010 and 2016, this focus expanded to include climate change and sustainability, signaling a maturation phase. The integration of digital technologies, especially GIS, significantly enhanced analytical depth, enabling nuanced examinations of urban morphology and environmental impacts.

Post-2016 analysis reveals an emerging interest in circular economy and spatial planning, yet these areas remain underdeveloped compared to established topics. A comparative analysis of keyword clusters from different periods highlights a strategic pivot in research priorities—from a narrow focus on immediate urban planning and micro-environmental factors to a broader consideration of sustainability and climate resilience[5].

4. Analysis of Landmark Literature

Table 4. Technological methods to improve

Topic description	Summary
Urban thermal environment and adaptive design under the background of climate change	These articles mainly studied the urban heat island effect, green infrastructure, passive cooling design, and the impact of urban form and thermal performance on human thermal comfort. The research methods included numerical simulation, field measurement, geographic information system (GIS) analysis and evaluation methods. The articles focused on urban planning and design strategies in different climatic and urban contexts, such as vegetation, green roofs, green walls, water sensitive urban design.
Study the influencing factors of urban microclimate and thermal comfort	
Urban ventilation and thermal environment assessment methods	

This analysis contrasts urban microclimate research focuses between China and internationally. Chinese studies emphasize urban greening's impact on microclimates, leveraging urban planning to enhance thermal comfort through increased green spaces. These approaches typically correlate greenery with lower peak temperatures and reduced urban heat island (UHI) effects, reflecting a preference for qualitative and theoretical frameworks. (Table.4)

Conversely, international research adopts a quantitative stance, utilizing Computational Fluid Dynamics (CFD) simulations to examine urban design's influence on thermal comfort, with a strong emphasis on technological innovations such as lightweight insulated concrete(Table.5).This methodological diver-gence underscores the need for an integrated approach that combines theoretical insights and empirical methodologies, aiming to foster a holistic understanding of urban thermal dynamics and develop effective UHI mitigation strategies.

Table 5. International technological methods

Example analysis	Summary
The influence of urban green space and tree planting measures	These 20 articles mainly focus on thermal comfort and urban heat island issues in the urban environment. The research methods include urban morphology and thermal performance analysis, passive cooling design, water sensitive urban design, biometeorological assessment, ecosystem services assessment, simulation and optimization methods. In general, these articles emphasize the importance of urban greening, natural ventilation, green infrastructure, green roofs, passive cooling design and water sensitive urban design in improving urban thermal comfort and reducing urban heat island effect.
The formation mechanism of urban heat island effect is analyzed, and mitigation using green infrastructure are proposed	
Discuss how to improve urban thermal adaptability through urban design	

Research on urban thermal environments diverges sharply between mainland China and the international community[6]. Chinese studies concentrate on urban heat island (UHI) effects using quantitative methods like remote sensing emphasizing empirical analysis of UHI dynamics. In contrast, international research broadens to include Computational Fluid Dynamics (CFD) simulations, focusing on urban design's impact on thermal conditions and exploring innovative materials like lightweight insulated concrete for thermal mitigation[7]. There's a significant international tilt towards addressing climate change impacts, integrating adaptive strategies, and considering the social dimensions of thermal comfort (Fig.7). This reflects a shift from purely technical solutions to a holistic approach that balances technological innovations with environmental and human well-being considerations[8]. While China provides a solid base

through technical exploration of UHIs, global research advocates for a more integrated methodology, emphasizing sustainability and the quality of human life in urban thermal management.

Fig. 7 Hot Word Trends in Urban Outdoor Research

5. Discussion

This analysis refines the exploration of outdoor thermal environments by emphasizing data-driven insights and targeted findings. It focuses on the integration of GIS, remote sensing, and statistical methods to map and model urban heat dynamics, revealing precise patterns and causative factors[9]. Notably, it contrasts the research orientations of Chinese and international scholars. Chinese research is characterized by detailed empirical studies aiming at urban heat island mitigation, heavily relying on field observations and thermal remote sensing data[10]. In contrast, international research spans broader themes, connecting thermal comfort to climate change adaptation, health implications, and urban sustainability, employing diverse methodologies like urban climatology and agent-based modeling.

References

1. Ali-Toudert, F., and H. Mayer. 2006. “Numeri cal Study on the Effects of Aspect Ratio and Orientation of an Urban Street Canyon on Out door Thermal Comfort in Hot and Dry climat e[J].” Building and Environment 41 (2): 94–10 8. doi:10.1016/j.buildenv.2005.01.013.
2. Chen, X., P. Xue, L. Liu, L. Gao, and J. Liu. 2018. “Outdoor Thermal Comfort and Adapta tion in Severe Cold Area: A Longitudinal Sur vey in Harbin, China[J]”. Building and Enviro nment 143: 548–560. doi:10.1016/j. buildenv.2 018.07.041.
3. Hwang, R. L., T. P. Lin, and A. Matzarakis. 2011. “Seasonal Effects of Urban Street Shadi ng on Long-term Outdoor Thermal comfort[J].” Building and Environment 46 (4): 863–870. doi:10.1016/j.buildenv.2010.10.017.
4. Johansson, E. 2006. “Influence of Urban Geo metry on Outdoor Thermal Comfort in a Hot Dry Climate: A Study in Fez, Morocco[J].” B uilding and Environment 41 (10): 1326–1338. doi:10.1016/j. buildenv.2005.05.022.
5. Etheridge, D.2011 .“Natural Ventilation of Bu ildings TheoryMeasurement and Design.”Inte rnational Journal ofVentilation10 (4): 405–40 6. doi:10.1080/14733315.2012.11683965.
6. Franke, J.2006 .“Recommendations of the COS T Action C14 onthe Use of CFD in Predictin g Pedestrian Wind Environment.”The fourth in ternational symposium on computationalwind e ngineering, Yokohama, Japan, 529–532.
7. Gautam,K.R.,L.Rong,G.Zhang,andM.Abkar.2019. “Comparison of Analysis Methods for Wind-dr ivenCross Ventilation through Large Openings.” Buildingand Environment154: 375–388. doi:10.1016/j.buildenv.2019.02.009.
8. Hien, W. N., and D. Istiadji.2003.“Effects of External ShadingDevices on Daylighting an d Natural Ventilation.”Proceedings of the 8th International IBPSA Conference,Eindhoven, N etherlands, 475–482.
9. Kurabuchi, T., M. Ohba, T. Endo, Y. Akamine, andF. Nakayama.2004.“Local Dynamic Similar ity Model ofCross-ventilation Part 1-theoretical Framework.”International Journal of Ventilation 2 (4): 371–382.doi:10.1080/14733315.2004.1168 3679.
10. Lee, D. S., S. J. Kim, Y. H. Cho, and J. H. Jo.2015.“ExperimentalStudy for Wind Pressure Loss Rate through ExteriorVenetian Blind in C ross Ventilation.”Energy and Buildings107: 123 –130.doi:10.1016/j.enbuild.2015.08.018.