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Advancements in Urban Street Microclimate Research Based on Citespace

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Abstract

Urban streets are regarded as the "skeleton" and "arteries" of a city, underscoring their pivotal role in the urban landscape. Research on the microclimate of urban streets holds significant importance for understanding development patterns and cutting-edge topics in this field. Employing the CiteSpace literature analysis software, we visually analyzed 903 English-language articles from the Web of Science database, emphasizing basic features such as publication volume, authors, countries, and institutions, as well as exploring research hotspots and frontiers. Suggestions are presented in conjunction with current research characteristics and shortcomings, with the aim of providing guidance and reference for future studies.

Keywords

Urban streets; microclimate; CiteSpace analysis.

1. Introduction

The urban microclimate plays a crucial role in enhancing the quality of urban life and fostering urban development. Amidst the backdrop of global climate change, urban environmental issues are gaining prominence. Concurrently, with the rapid urbanization process, residents are encountering heightened environmental pressures, particularly the growing contradiction between the adverse effects of a deteriorating urban climate and the populace's pursuit of healthy and comfortable outdoor spaces. Enhancing the microclimate environment of urban landscape gardens emerges as a pivotal strategy to elevate the quality of the urban living environment [1]. Urban streets typically span over a quarter of the urban area, constituting a vital component of urban landscape space. They are also among the most frequently utilized outdoor public spaces by citizens, serving functions related to residents' transportation and daily life [2]. The microclimate environment of urban streets reflects the micro-scale characteristics of the urban climate. Analyzing and evaluating the microclimate of urban streets can offer guidance and reference for the planning and design of future healthy streets and green livable cities [3].

2. Research Methods and Data Sources

2.1. Research Methods

Currently, Citespace stands as the predominant tool in the academic community for generating scientific knowledge maps. Utilizing statistical methods, it visually presents literature carriers and knowledge, showcasing specific research hotspots and dynamic frontiers. Citespace analyzes and constructs connections between knowledge, offering robust technical support for related research areas. This paper integrates the analysis results of CiteSpace software and the statistical analysis outcomes of Excel software, based on a literature review, to organize and analyze relevant literature on the microclimate of urban streets.

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2.2. Data Sources

The retrieval of relevant research data in this paper is grounded in the Web of Science core collection database. To ensure comprehensive coverage of street microclimate studies, search terms such as "street canyon" and "microclimate OR temperature OR humidity OR particulate matter OR radiation OR wind environment OR thermal environment OR thermal comfort" were employed. The language was set to English, and the time span encompassed all years. Research papers and reviews were refined, with irrelevant entries manually removed. Ultimately, through the deduplication process of CiteSpace, an effective data sample of 903 articles was obtained.

3. Basic Statistical Analysis

3.1. Overview of Literature Analysis

Publication volume serves as a direct reflection of changes in research within an academic field, allowing scholars to comprehend the development of the discipline comprehensively. It also facilitates the prediction of future trends based on the current state of development. Examining the annual publication volume statistical chart (Figure 1), the initiation of research related to the microclimate of urban streets dates back to 1991. From 1991 to before 2005, the annual publication volume remained relatively low, indicating an embryonic stage of development. However, from 2005 to 2019, a significant surge in academic interest is observed, marking a phase of rapid development. From 2019 onwards, the field entered an in-depth development stage, with a sustained, relatively high annual publication volume (around 100 papers). Despite an abnormal sharp decline due to the data cutoff date in June 2022, it is anticipated that future related research will continue on a stable upward trajectory.

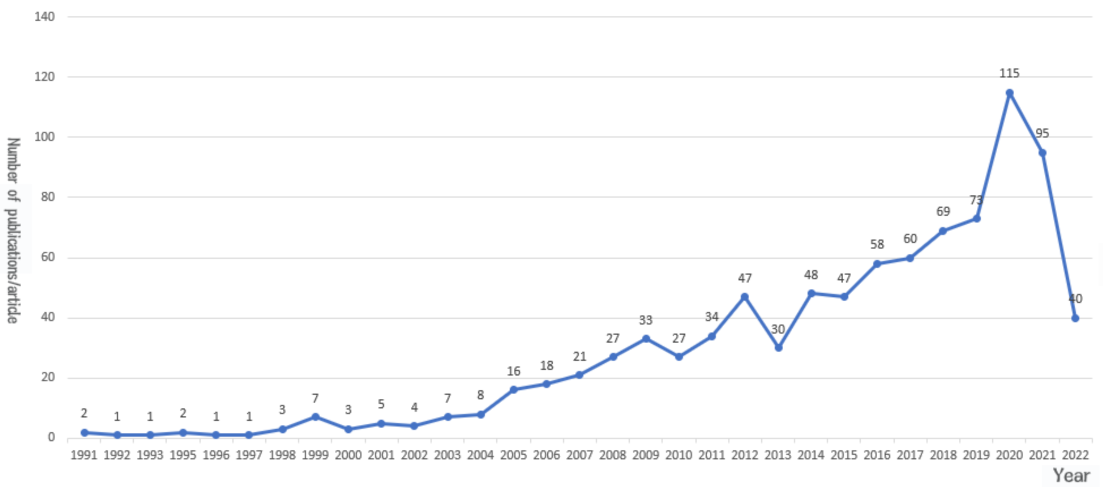

Figure1 Annual publication statistics of microclimate research in streets

3.2. Authorship, Country, and Institution Analysis

Interpreting the collaborative network map of authors and countries in street microclimate research (Figure 2), the top contributors are Leslie Norford (19 papers) and Jan Carmeliet (17 papers). Their research focuses on urban street wind-thermal environment and outdoor thermal comfort simulation[4-7], and heat transfer and fluid flow in street canyon environments[8], respectively. Leading collaborative groups are from the United States, the United Kingdom, Switzerland, and Finland. The top countries in street microclimate research include the United States, the United Kingdom, Germany, Italy, and Australia(Figure 3), with notable institutions such as Hong Kong Polytechnic University, University of Hong Kong, MIT,

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University of Birmingham, National University of Singapore, and University of Surrey (Figure 4).

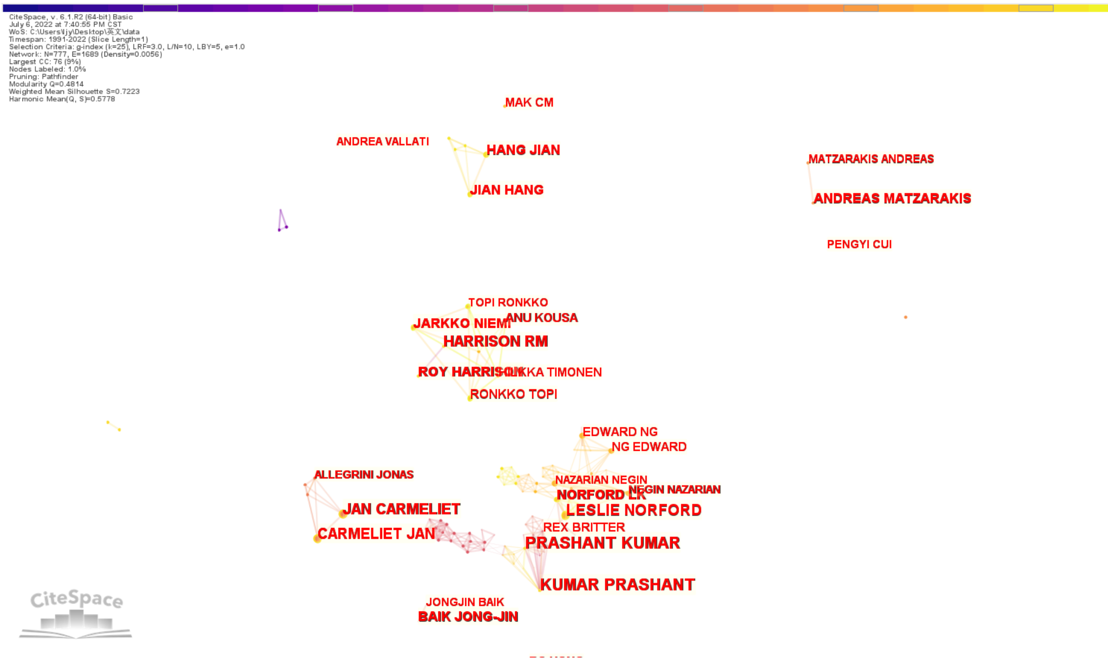

Figure 2 Network graph of author collaboration on microclimate research in streets

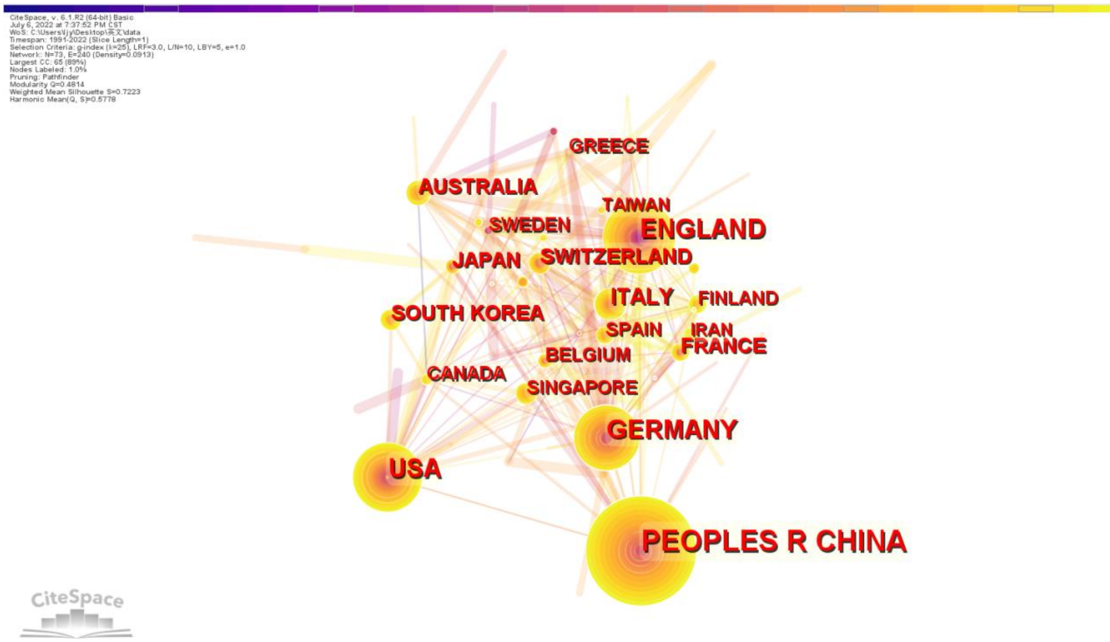

Figure 3 National Cooperation Network Map for Street Microclimate Research

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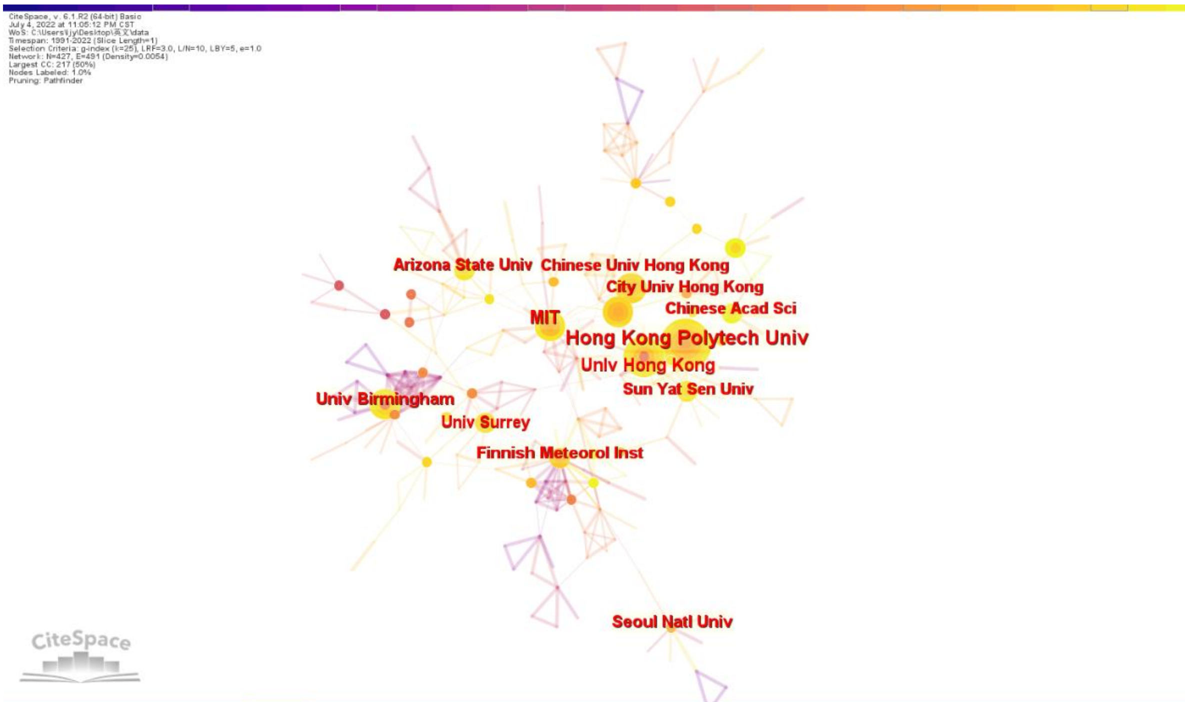

Figure 4 Collaborative Network Map of Street Microclimate Research Institutions

3.3. Citation Network Analysis

"Cocitation" reflects the knowledge foundation of a research field, with nodes of high intermediary centrality considered key drivers of field transformation. The citation network of literature in the study of street microclimates (Figure 5) is accompanied by Table 1, compiling the top six highly cited articles based on intermediary centrality. Notable journals include "Atmospheric Environment" and "Journal of Wind Engineering and Industrial Aerodynamics." The articles predominantly focus on wind-thermal environment, air quality, and spatial morphology of street canyons, with one review article and five research articles (Table 2).

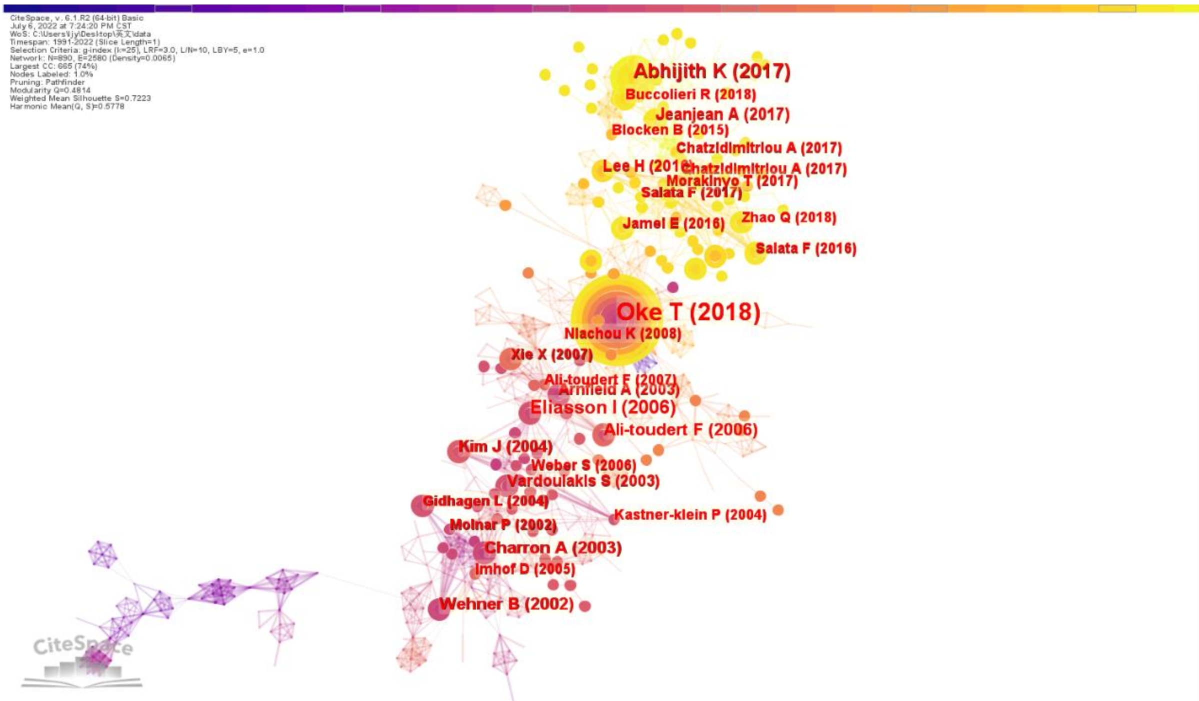

Figure 5 Co citation network of research literature on microclimate in streets

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Table 1 High cited literature on microclimate research in streets

Betweenness centrality	Publication time	Lead author	Article Title
0.39	2003	Charron A	Primary particle formation from vehicle emissions during exhaust dilution in the roadside atmosphere
0.34	2008	Niachou K	Experimental study of temperature and airflow distribution inside an urban street canyon during hot summer weather conditions - Part I: Air and surface temperatures
0.28	2011	Cheng W	Large-eddy simulation of turbulent transports in urban street canyons in different thermal stabilities
0.27	2006	Georgakis C	Modelling air quality in street canyons: A review.
0.26	2012	Allegrini J	Analysis of convective heat transfer at building facades in street canyons and its influence on the predictions of space cooling demand in buildings
0.21	2002	Wehner B	Particle number size distributions in a street canyon and their transformation into the urban-air background: Measurements and a simple model study

Table 2 High cited research articles on microclimate in streets

Author	Overview of Main Research Content
Charron A(2003)	Through the measurement of particle size distribution within the 11–452 nm range on one side of Marylebone Road in central London, an analysis was undertaken to investigate its correlation with traffic volume. The results indicate that cumulative mode particles are linked to emissions from heavy-duty traffic, predominantly diesel vehicles, while particles within the 30-60 nm range show a more robust correlation with light-duty traffic.
Niachou K(2008)	The study centers on examining the vertical distribution of air temperature and surface temperature under diverse weather conditions, alongside analyzing the temperature profiles at the center of the canyon. The primary objective is to investigate the influence of the urban environment on the potential for both natural and mixed ventilation.
Cheng W(2011)	Utilizing five sets of Large Eddy Simulation (LES), this study delves into the characteristics of flow and pollutant dispersion, with a specific focus on thermal stratification. The investigation is conducted within two-dimensional (2D) urban street canyons, considering varying building height-to-street width ratios under neutral, unstable, and stable atmospheric conditions.
Allegrini J(2012)	This study centers on the analysis of convective heat exchange on building facades within street canyons and its implications for predicting the cooling demand in building spaces. The goal is to quantitatively assess the influences of urban radiative balance, the urban heat island effect, and the Convective Heat Transfer Coefficient (CHTC) on spatial cooling demands.
Wehner B(2002)	Conducting measurements and investigations on the particle size distribution within street canyons, while simultaneously exploring its transition relationship to the urban air background using a simplified model.

4. Research Topic Evolution, Hotspots, and Trends Analysis

4.1. Analysis of Research Topic Evolution

The keyword timeline and burst detection map generated by Citespace provide an intuitive overview of the developmental trajectory and evolutionary trends in the research field, aiding in a deeper understanding. Combining Figures 6 and 7 reveals that in the embryonic phase of street microclimate research before 2005, early highlighted research topics included outdoor thermal comfort, urban heat island, and particulate matter. Key terms comprised temperature, street canyon, and models. In the later period of this nascent stage, while the publication volume remained relatively low, there was a noticeable upward trend in relevant research hotspots. Academic attention significantly increased, expanding research directions to include inhalable particles and pollutant dispersion. Post-2005, primary research directions exhibited

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further diversification and interdisciplinary development, with existing research directions flourishing, and new hotspots emerging such as indoor and outdoor air quality, layout patterns, and model gradients.

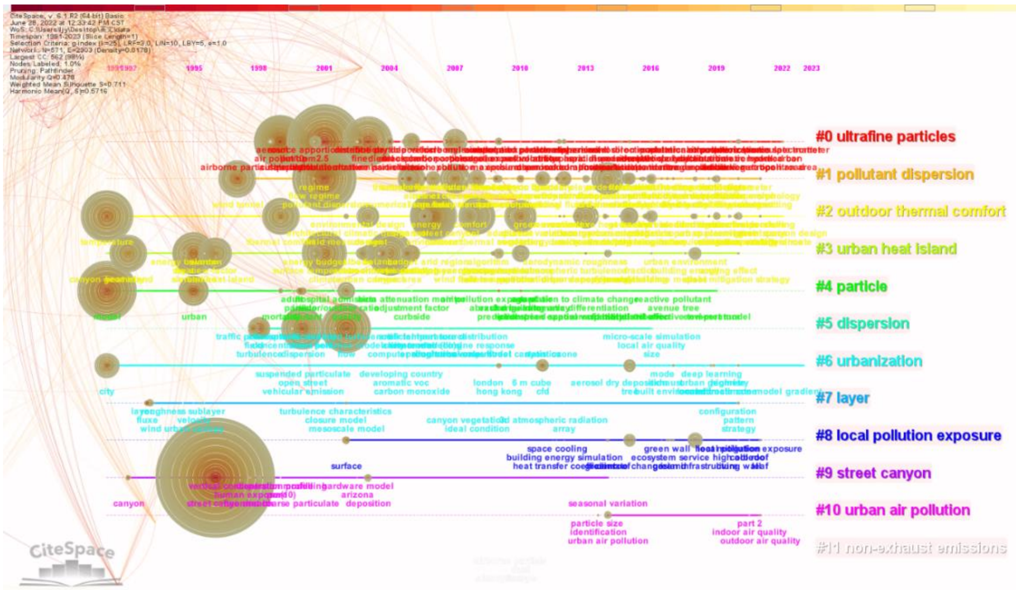

Figure 6 Timeline Map of Key Words in Street Microclimate Research

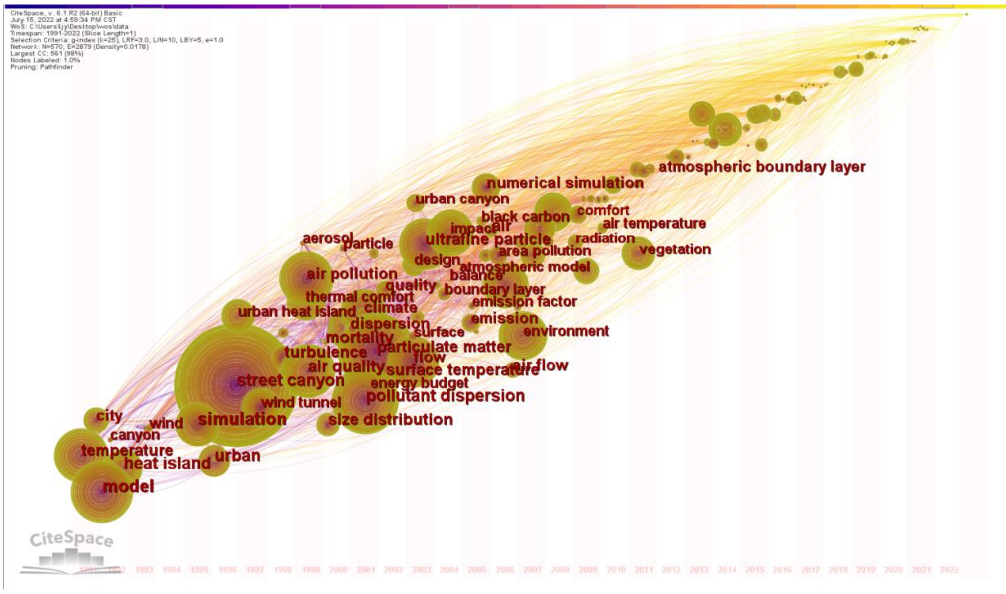

Figure 7 Time Zone Map of Key Words in Street Microclimate Research

4.2. Analysis of Research Hotspots

Conducting keyword co-occurrence and clustering analysis of literature data from the earliest year in relevant literature helps capture the evolving research hotspots. The keyword co-occurrence map incorporates frequency and intermediary centrality, representing occurrences and importance in the network. Prominent keywords from the analysis (Figure 8) include numerical simulation, pollutant dispersion, air quality, outdoor thermal comfort, temperature, and inhalable particles. Extracting the top 10 keywords by co-occurrence frequency (Table 3) reveals that keywords with intermediary centrality greater than 0.1 include "model," "street canyon," "simulation," "city," and "air." Research hotspots predominantly focus on numerical simulation, air quality, pollutant dispersion, theoretical models, and urban design.Additionally, 11 clusters emerge from the keyword co-occurrence (Figure 9), focusing on various aspects such as inhalable particles, pollutant dispersion, outdoor thermal comfort, urban heat island,

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particulate matter, dispersion, urbanization, hierarchy, local pollution exposure, street canyon, urban air pollution, and incomplete emissions. In conclusion, primary research directions encompass air pollution, inhalable particles, outdoor thermal comfort, model simulation, with hotspots revolving around numerical simulation, air quality, pollutant dispersion, theoretical models, and urban design.

(1) Pollutant Dispersion

Research on street pollutant dispersion has a long history with a solid foundation, involving disciplines such as environmental science, atmospheric science, civil engineering, architectural technology, environmental engineering, and mechanics. The research mainly focuses on model validation, street canyon spatial morphology, particle deposition, air detection, and turbulent simulation. Singh, Abhishek Pratap et al. utilized Computational Fluid Dynamics (CFD) technology to study the impact of Elevated Mass Rapid Transit (EMRT) on pollutant dispersion. The study indicated that pollutant concentrations at different locations in street canyons were significantly influenced by the introduction of elevated subway tracks. Compared to street canyons without elevated subway tracks, the pollutant concentration increased in the lower regions of the street canyon and decreased in the upper regions [9]. Jimenez-Hornero, Francisco J et al. employed an isothermal two-dimensional lattice model coupled with the Smagorinsky subgrid model to describe pollutant dispersion in street canyons [10]. Kang, Yoon-So et al. investigated how the flow and active pollutant dispersion in street canyons with a canyon aspect ratio of 1 varied with the heating intensity at the bottom of the street [11]. Hofman, Jelle et al. studied the usefulness of biogenic magnetic leaf monitoring of particle deposition in street canyon tree canopies in Ghent, Belgium, to assess the spatial distribution of particles in individual tree canopies and street canyon [12]. Kim, Minjoong et al. developed a coupled Computational Fluid Dynamics-Chemical model to study the transport and chemical transformation of reactive aerosols on urban streets. They used the model to investigate the daily variations and spatial distribution of PM1 and its components in street canyons [13].

(2) Thermal Environment

Research on the thermal environment of street canyons primarily focuses on heat effects, temperature, thermal comfort, and building thermal energy. Takebayashi, Hideki et al. found that mean radiant temperature (MRT) had a more significant impact on the distribution of the standard new effective temperature (SET*) in typical summer street canyons in Kobe City than wind speed. Shading of solar radiation was more effective in suppressing the daytime rise of SET* than improving land cover [14]. Niachou, K. conducted experimental studies on the thermal characteristics of a typical street canyon in the ESE-WNW direction under hot weather conditions. The aim was to investigate the impact of urban environment on the potential for natural ventilation and mixed ventilation [15].

(3) Model Validation and Numerical Simulation

Model validation and numerical simulation, as important research methods in street microclimate, are widely applied. Kim, Jae-Jin et al. used a Computational Fluid Dynamics (CFD) model to study the impact of bottom heating and rooftop heating on the flow in a three-dimensional street canyon [16]. Huang, H et al. developed a two-dimensional air quality numerical model based on the atmospheric convection diffusion equation and the kε turbulent model to predict the impact of vehicle emissions on air quality within urban street canyons [17]. Chan, Tat Leung et al. established a two-dimensional numerical model and used the FLUENT program to simulate fluid flow development and pollutant dispersion in an isolated street canyon. They found that wider streets and lower building heights favor the dilution of pollutants within the street canyon [18].

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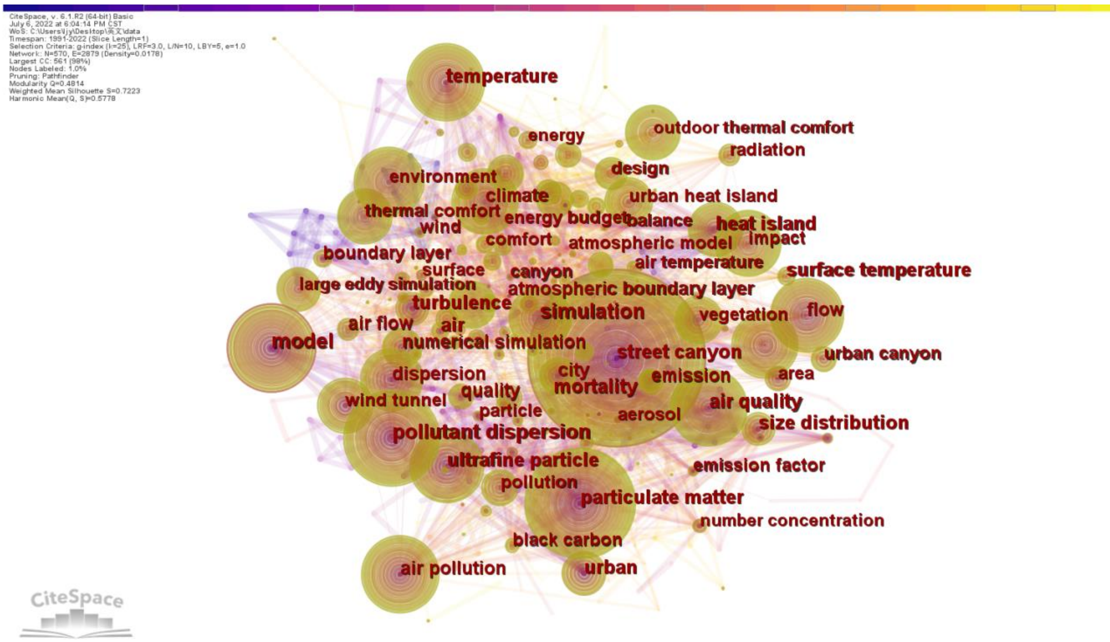

Figure 8 Keyword co-occurrence map of microclimate research in streets

Table 3 High frequency keywords of microclimate in streets

Serial Number	frequency	betweenness centrality	keyword
1	498	0.1	street canyon
2	163	0.06	particulate matter
3	135	0.09	pollutant dispersion
4	129	0.06	air quality
5	127	0.11	model
6	126	0.06	temperature
7	120	0.07	air pollution
8	119	0.03	impact
9	117	0.06	flow
10	102	0.1	simulation

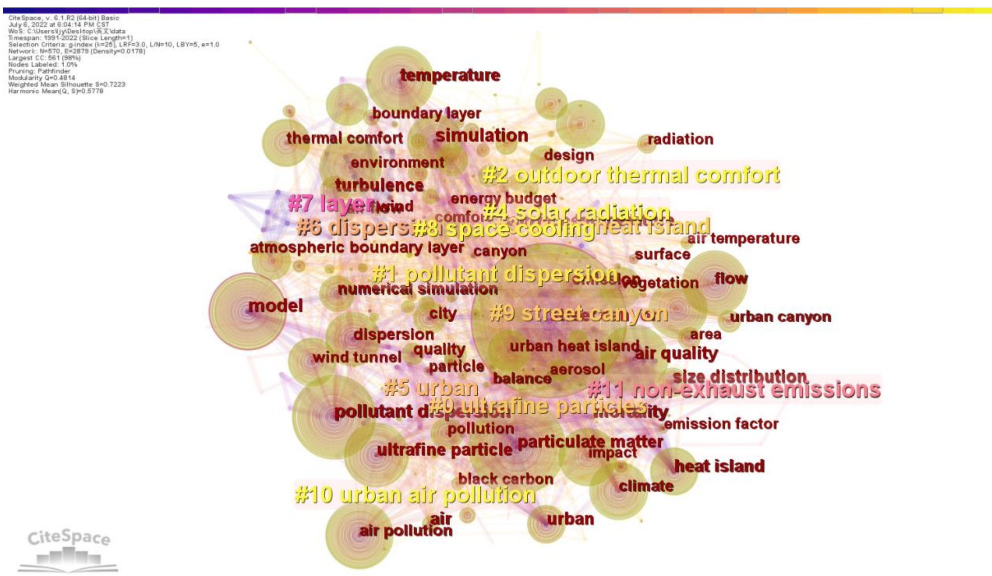

Figure 9 Keyword clustering map of microclimate research in streets

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4.3. Trend Analysis

The emergence of keywords depicts the explosive growth of specific terms during different periods, reflecting research hotspots and trends. We analyzed 15 emergent words (Figure 10). "Urban" emerged as the earliest keyword with explosive growth, sustained for approximately ten years. "Number concentration" emerged between 2007 and 2015, while "air pollution" had the shortest emergence time. Post-2005, the number of hotspot keywords significantly increased, aligning with document analysis results. Current hotspots include ventilation systems, aspect ratio, sky view factor, green infrastructure, and roadside trees, indicating recent research frontiers and future trends that started around 2019.

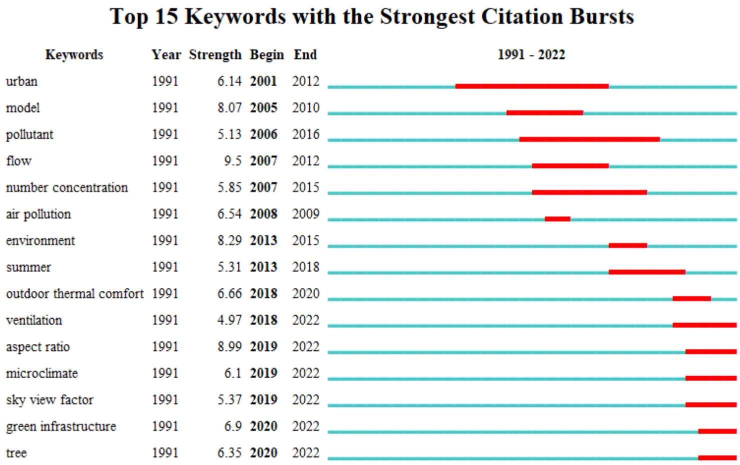

Figure 10 Keyword Emergence Map of Street Microclimate Research

5. Conclusion and Outlook

This study leveraged the Citespace visualization tool for a comprehensive analysis of the development overview, frontier hotspots, and research trends in the field of street microclimate. The following conclusions can be drawn: In terms of literature quantity, research interest in this field has exhibited a continuous upward trend, traversing three distinct development stages: initial, rapid, and stable. The early initiation of research progressed swiftly, indicating a high level of academic sensitivity. Regarding authors of the literature, individual researchers in this field have yielded substantial research outcomes, underscoring a robust research foundation and the formation of numerous collaborative relationships. While research institutions demonstrate relatively close collaboration, cross-regional cooperation appears somewhat limited. Besides Chinese universities, the core strength in this research area lies with academic institutions in the United States, the United Kingdom, Singapore, and other countries. Concerning research content, the prevailing focus revolves around pollutant dispersion, thermal environments, and comfort studies. Core research directions can be broadly summarized as air quality, pollutant exposure, and thermal environments. The research output and depth have attained high standards, encompassing diverse interdisciplinary areas. The practical methods employed in this research hold substantial reference value. However, there remains considerable room for improvement in street microclimate research. Efforts should be directed towards strengthening research perspectives, content, and methodologies. Emphasizing interdisciplinary research is crucial, given the rich and diverse content within street microclimate research, characterized by strong interdisciplinary and expandable attributes. Expanding into the foundational theories and research methods of multiple disciplines would enhance interdisciplinary integration and bolster research outputs.

Additionally, a focus on cross-regional and cross-institutional collaborative research is imperative to augment cooperation among research teams and individual scholars. Both the

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depth and breadth of relevant research necessitate enhancement. Considering the intricate and diverse urban street morphology, broadening the research scope is essential to effectively overcome current research limitations.

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