

# Analysis of ENVI-met Research Progress based on Citespace Knowledge Graphs

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## ABSTRACT

ENVI-met is of great value to the study of human habitat and has attracted much attention from scholars in recent years. The article searches in Web of Science with “ENVI-met” as the subject term, takes the relevant literature as the research object, visualizes and analyzes the authors and institutions, keyword clustering, hot research trends, etc. based on Citespace, and combs through the development trends and hot topics of the ENVI-met research, in order to provide reference and reference for subsequent research. We analyze the development trend and hot topics of ENVI-met research based on Citespace, in order to provide reference and reference for the subsequent research.

## KEYWORDS

Citespace; ENVI-met; Numerical Simulation; Research Hotspots and Trends.

## 1. INTRODUCTORY

As urbanization continues to accelerate, environmental problems such as air pollution and urban heat islands occur frequently. Deteriorating Habitat Prompts Landscape Architects to Find More Effective Ways to Solve Problems. Current academic research on microclimate and air pollutants in human environments is mainly based on actual measurements and numerical modeling. The actual measurement method is time-consuming and labor-intensive, limited by the actual conditions of the research object, and has many interfering factors. The numerical simulation method saves a lot of time and cost, is controllable, and can directly derive the role of scenarios under different conditions. It is worth noting that the numerical simulation software ENVI-met is able to comprehensively take into account a variety of factors such as urban form, landscape type, building density, vegetation cover, etc., which is of indispensable value in the study of microclimate and air pollutants. This study takes ENVI-met related papers as the data source, analyzes ENVI-met's research objects and indicators through the scientific bibliometric tool Citespace, and derives the research hotspots and emerging trends through the keyword co-occurrence analysis method, so as to provide guidance for the idea and methodology for the subsequent research in the field of microclimate and air pollutants.

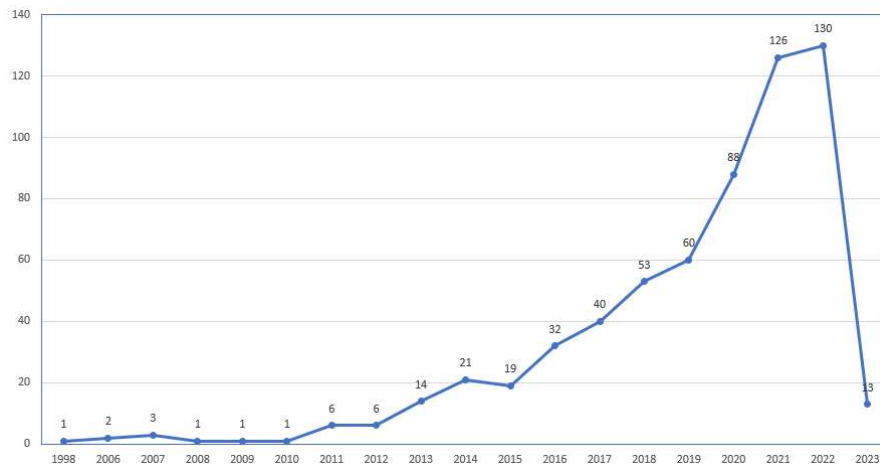
## 2. RESEARCH SUBJECTS AND RESEARCH METHODS

### 2.1. Object of Study

The ENVI-met model, developed in 1998 by Bruse et al. at the Institute of Geography of the University of Bochum, Germany, is a high-resolution, three-dimensional urban microclimate model based on hydrodynamics (CFD) and non-hydrostatics (Fig. 1), which is capable of calculating wind



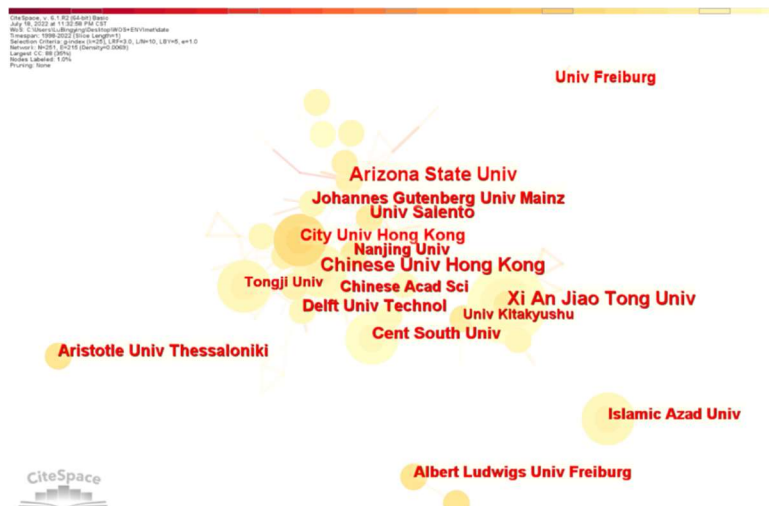
trend in 2023 is due to the fact that the literature data for that year are incomplete as of the time of the data statistics.



**Fig. 2** Statistics on the number of articles published in ENVI-met studies

### 3.2. Analysis of Authors, Countries and Institutional Cooperation Networks

A mapping of the collaborative network of authors, countries and institutions of the ENVI-met study. According to Fig. 3, the scholars with the largest number of publications are MORAKINYO TE, WANG YUPENG, YUPENG WANG, TOBI MORAKINYO, etc. The largest number of publications is MORAKINYO TE, with 17 publications. Meanwhile, authors such as BUCCOLIERI RICCARDO, ANDREAS MATZARAKIS, HYUNJUNG LEE, YUN LAM, and ARIANE MIDDEL, who are also the core strength of the field, have all produced emergent points in the map, and there is not much difference in the number of papers they have published among themselves. Based on the information in the figure, it can be seen that the whole research field has formed a research group centered on MORAKINYO TE, WANG YUPENG, JIA YU LI, etc., in which MORAKINYO TE's team mainly researches on the impacts of green infrastructures on the urban microclimate and particulate matter, pollutants in the street canyon, and so on; Wang YP's team focuses on urban morphology and urban microclimate effects, urban heat island effect mitigation, etc.; Matzarakis A's team focuses on urban thermal environment simulation, urban planning and urban heat island effect, etc.; The ENVI-met research team in general is characterized by “large dispersion and small aggregation”



**Fig. 3** Mapping of the ENVI-met study author collaboration network

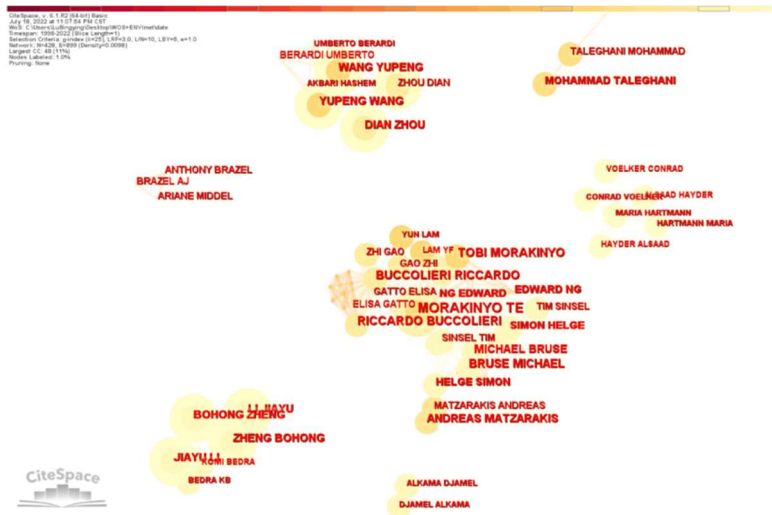


Fig. 4 Mapping of the ENVI-met research organization collaboration network

Fig. 4 shows the network analysis of ENVI-met research institutions. Table 1 reflects the number of articles published by each institution, and it can be clearly seen that Xi An Jiao Tong Univ, Arizona State Univ, Chinese Univ Hong Kong, City Univ Hong Kong, and Univ Freiburg, Johannes Gutenberg Univ Mainz, Albert Ludwigs Univ Freiburg, and Cent South Univ are the backbone of research in this field. The degree of research collaboration in this field is relatively high. The most frequent institutions are Arizona State Univ, Xi An Jiao Tong Univ, Chinese Univ Hong Kong, Cent South Univ, and City Univ Hong Kong, and all of these institutions have a certain degree of cooperation.

Table 1. Statistics on the number of articles published by ENVI-met research organizations

serial number	organization	volume of publications
1	XI AN JIAOTONG UNIVERSITY	16
2	ARIZONA STATE UNIVERSITY	14
3	ARIZONA STATE UNIVERSITY TEMPE	14
4	UNIVERSITY OF FREIBURG	14
5	CHINESE UNIVERSITY OF HONG KONG	13
6	JOHANNES GUTENBERG UNIVERSITY OF MAINZ	12
7	CENTRAL SOUTH UNIVERSITY	11
8	CITY UNIVERSITY OF HONG KONG	11
9	SOUTH CHINA UNIVERSITY OF TECHNOLOGY	10
10	CHINESE ACADEMY OF SCIENCES	9

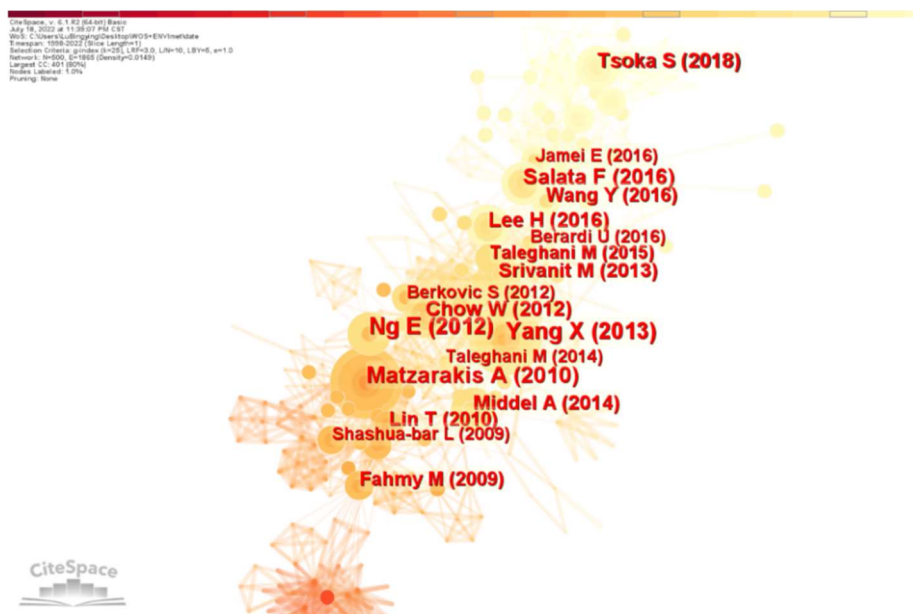
### 3.3. Literature Co-Citation Analysis

The citation relationship between literature reflects the similarity of literature in terms of content or theme, and to a large extent, it can indicate the academic value of the cited literature and its impact on other academic research. “Co-citation”, i.e., two articles being cited together by one article, can reflect the knowledge base of a research field, and nodes with high centrality of intermediaries can be regarded as key nodes to promote the transformation of a research field from one perspective to

another. Table 2 summarizes the top 6 highly cited documents of ENVI-met research intermediary centrality, and Figure 5 shows that the most frequently cited document is Evaluation of a microclimate model for predicting the thermal behavior of different ground surfaces, which was published by Yang x in 2013. different ground surfaces. The paper evaluated the microclimate model ENVI-met with field data, and confirmed that the ENVI-met model is able to reasonably simulate the diurnal thermal behavior of different surfaces and its effects on local air temperature and humidity[1]. Other highly cited literature, such as Ng, E et al. (2012) used the ENVI-met numerical model to parameterize the preferred location, amount and type of vegetation in urban planning, the study enabled urban planners to more accurately determine the greening principles, amount and policies needed to improve the urban living environment in high density cities[2]. Salata, F et al. (2016) focused on the evaluation of input parameters based on the ENVI-met solving equations, and also demonstrated the ability of the software to predict air and mean radiant temperatures[3]. Chow, WTL et al. (2012) used ENVI-met to generate drought scenarios in two residential areas with different surface vegetation cover (mesic vs. dry), and investigated the effects of dryland film on near-surface temperature and outdoor thermal comfort at different spatial scales and time periods[4].

**Table 2.** Statistics of highly cited literature of ENVI-met study

Centrality	Publication Date	First authors	Article Title
0.07	2013	Yang, Xs	Evaluation of a microclimate model for predicting the thermal behavior of different ground surfaces
0.14	2012	Ng, E	A study on the cooling effects of greening in a high-density city: An experience from Hong Kong
0.06	2010	Matzarakis, A	Modelling radiation fluxes in simple and complex environments: basics of the RayMan model
0.12	2016	Salata, F	Urban microclimate and outdoor thermal comfort. A proper procedure to fit ENV-met simulation outputs to experimental data
0.08	2016	Lee, H	Contribution of trees and grasslands to the mitigation of human heat stress in a residential district of Freiburg, Southwest Germany
0.11	2012	Chow, WTL	Assessing xeriscaping as a sustainable heat island mitigation approach for a desert city



**Fig. 5** ENVI-met research literature co-citation network discovery



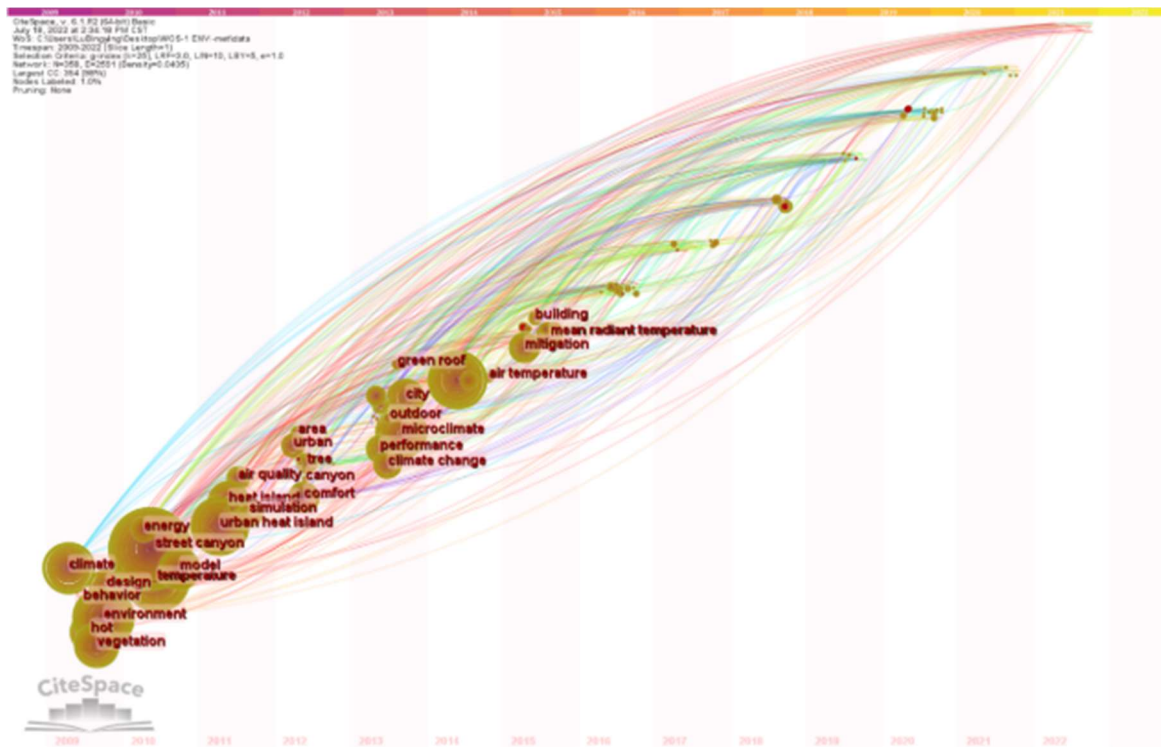


Fig. 7 ENVI-met keyword time zone mapping

## 4.2. Frontier Analysis of ENVI-met Research

The keyword emergence map can clearly reflect the research frontiers and evolution trends in the research years, and the degree of emergence reflects the heat of research. As can be seen from Fig. 8, there are 25 keywords in the ENVI-met keyword analysis, among which, the top 5 keywords in terms of salience are: land use, fluxe, energy use, hot summer, strategy. These keywords have a high degree of prominence and are the most representative topics of research in this field. The figure also shows that the hot words that are still active in the current research are hot summer, orientation, urban morphology, and ventilation. The starting year of these words is in 2020, which can be used to illustrate the research frontiers in recent years and the future research trends.

Top 25 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End	2009 - 2022
ultrafine particle	2009	2.42	2011	2016	
colombo	2009	2.8	2012	2014	
index	2009	2.08	2013	2014	
land use	2009	3.48	2014	2016	
fluxe	2009	3.47	2014	2015	
environment	2009	2.34	2014	2015	
urban design	2009	2.08	2014	2016	
model	2009	2.07	2014	2015	
energy use	2009	3.11	2015	2016	
phoenix	2009	2.7	2015	2018	
biometeorological assessment	2009	2.42	2015	2018	
air quality	2009	2.02	2015	2016	
park cool island	2009	2.19	2016	2017	
validation	2009	2.13	2016	2018	
numerical simulation	2009	2.07	2016	2018	
heat mitigation strategy	2009	2.83	2017	2018	
mitigation	2009	2.25	2017	2018	
outdoor thermal environment	2009	2.1	2017	2018	
strategy	2009	2.84	2018	2019	
land surface temperature	2009	2.32	2018	2019	
urban form	2009	2.77	2019	2020	
hot summer	2009	2.98	2020	2022	
orientation	2009	2.71	2020	2022	
urban morphology	2009	2.17	2020	2022	
ventilation	2009	2.17	2020	2022	

Fig. 8 ENVI-met keyword emergence map

### 4.3. Analysis of ENVI-met Research Hotspots

Keywords are the concentration and refinement of the core content of the literature, and the high-frequency keywords can reflect the hot content of the research field. Using CiteSpace to visualize the keywords in the literature, we obtained the keyword co-occurrence map (Fig. 9), and found that the keywords with the highest frequency of occurrence are: Impact, Thermal comfort, Temperature, Urban heat island, Outdoor thermal comfort, Microclimate, Vegetation, Environment, Climate, Model, Design, etc. The keywords with the highest frequency of occurrence are: Microclimate, Vegetation, Environment, Climate, Model, and Design, Microclimate, Vegetation, Environment, Climate, Model, Design and so on., Table 3 shows that the keywords with mediocentricity > 0.06 include Temperature, Climate, Vegetation, Microclimate, Design, which have higher mediocentricity than the other keywords, reflecting the hot areas of ENVI-met in the related research.

At the same time, in order to further investigate the knowledge structure of “ENVI-met” related studies, the log-likelihood algorithm was used to cluster the high-frequency keywords, and the parameters were adjusted to obtain a clearer keyword clustering map (Fig. 10), and it was found that the hotspots of the studies were mainly concentrated in the following areas: mean radiant It is found that the research hotspots are mainly concentrated in mean radiant temperature, urban heat island, hot and humid climate, particulate matter, urban microclimate, pedestrian-level thermal comfort, thermal environment, urban planning, and street canyon.

As a result of the comprehensive analysis, the ENVI-met research hotspots are mainly centered on the following six aspects.

#### (1) Thermal environment

Research on thermal aspects based on ENVI-met started earlier, and the key words are mainly reflected in the thermal environment, average radiation temperature, hot and humid climate, and so on. The research on thermal environment mainly focuses on thermal environment simulation, cooling effect and thermal mitigation strategy. In terms of research objects, more attention has been paid to urban morphology, green roofs, new materials, urban blue-green spaces, etc. For example, M.F. Shahidan (2012) used ENVI-met to achieve the cooling effect by adjusting the paving materials[5]. Fabbri, K (2020) found that the color of the building facade affects the temperature within 1°C[6]. Sinsel, T (2021) Simulated surface temperatures of roofs utilizing a new cooling material are found to remain around 6K below ambient air temperature using ENVI-met[7]. Middel et al. studied the cooling strategy of the residential area in Phoenix, USA, and found that there was a linear relationship between the canopy cover and the cooling effect, and every 1% increase in canopy cover could reduce the air temperature by 0.14 °C[8] ; Ng et al. simulated 33 scenarios in which buildings and green coverage in Hong Kong neighborhoods changed together, and found that 33% of urban green coverage could reduce air temperature by 1 °C[9];

#### (2) Thermal comfort

Thermal comfort has been studied in a wide range of areas, mainly focusing on characteristic areas, various types of urban spaces, plants and so on. Comprehensive research has found that thermal comfort is one of the main factors affecting the health of pedestrians, and most scholars believe that the factors affecting thermal comfort mainly include shadows (trees, buildings), the direction and geometry of the urban form, vegetation, solar reflective materials, and bodies of water, etc., which are the most effective ways to improve the outdoor thermal comfort. Meanwhile, the most important climatic factors affecting outdoor thermal comfort are the average radiant temperature, wind speed and wind direction in microclimate, and the best heat dissipation strategy to improve thermal comfort is vegetation, especially trees, because of their obvious shading effect, so the research on thermal comfort for plants is an important hot topic. For example, Wang YP (2022) explored the degree and scope of the influence of centralized green space on outdoor thermal comfort in summer, and used ENVI-met to analyze the influence of three green spaces on the thermal comfort of three types of

residential buildings under different planting patterns, and the study showed that residential gardens most obviously improved the thermal comfort of residential areas in various forms of green space[10]. Green and blue urban infrastructure (GBI) has also been recognized as an effective tool for mitigating urban thermal environments and improving human thermal comfort. Many studies have investigated the thermal effects of major blue and green infrastructures, including the physical characteristics of elements such as trees, green roofs, vertical greening, and water bodies, and examined their potential thermal comfort effects in relation to the characteristics of the surrounding urban fabric.

### (3) Particulate matter

The study of particulate matter mainly focuses on the neighborhood scale, including urban roads, roadway greening, and urban street valleys. The effects of different spatial models on the reduction of urban particulate matter are further explored based on the use of ENVI-met. For example, Deng, SX (2019) and others investigated the effects of different urban green space structures and configurations on PM through ENVI-met, and further confirmed that the ENVI-met model can well reflect the differences in PM concentrations among different green spaces and the effects of green spaces on PM[11]. Pugh (2012) used ENVI-met to show that road plants can clean 5% of the air and reduce 40% of nitrogen dioxide and 60% of PM10[12]. Wania (2012) found that an increase in street aspect ratio increased the ability to trap airborne particulate matter by setting different ratios of street aspect ratio[13]. Morakinyo (2016) Proposed Distance of Action and Related Parameters of Plant Barrier to Retard Airborne Particulate Matter through ENVI-met[14]. Urban green infrastructure provides a nature-based solution to urban PM pollution and is becoming a hot research topic.

### (4) Urban heat island

Research at the regional level has focused on mitigating the urban heat island effect and optimizing the urban morphological pattern, etc. In recent years, research on urban heat mitigation has been growing, and many studies have focused on green infrastructure (GI) as a strategy for mitigating the adverse effects of the urban heat island (UHI). Studies have shown that cooling intensity is the main way to measure the urban green space to mitigate the urban heat island effect, and the commonly used cooling observation indexes include air temperature, surface temperature, radiation temperature, etc. In this kind of research, most scholars discuss the influence of different urban spatial patterns and the layout of landscape elements of various types of green space as well as the morphology characteristics on the mitigation of the urban heat island effect. For example, Chen L (2012) utilized ENVI-met to establish a pilot group of architectural green space to study the mitigation of heat island under the situation of urban land tension[15]. Herath (2018) studied the impact of urban green infrastructure on enhanced microclimate conditions from a tropical city perspective[16].

### (5) Street Canyon

With the increase in climate change issues, street canyons are receiving increasing attention. As the main element of urban environment, urban street canyon is the most frequently used external space in citizens' daily life, and plays an important role in improving urban environment and public health. The current research mainly focuses on two aspects: on the one hand, it studies the parameters related to outdoor thermal comfort such as urban street air temperature, wind speed, sky visibility factor, average radiation temperature and physiological equivalent temperature, and conducts simulation research on the geometry of street canyons, meteorological conditions and vegetation characteristics, and some scholars study the influence of regional tree species and street orientation to improve the local thermal comfort conditions in the city. For example, the ENVI-met microclimate model was used for numerical simulation to study the influence of different street canyon landscape patterns on their thermal environments and the correlation between SVF and the thermal environment of street canyons. On the other hand, the studies mainly focused on the effects of the height-to-width ratio of street canyons, plant species and different configurations on the distribution and dispersion of pollutants, as well as the effects of other factors on the airflow and pollutant dispersion in urban street

canyons. Bruse M (2012) et al. used the three-dimensional microclimate model ENVI-met to evaluate the height-to-width ratio of the streets on both sides of a building and the vertical and horizontal densities of street vegetation, revealing the impacts, revealing the effects of vegetation on particle dispersion, including the effect of vegetation on street ventilation[17]. Morakinyo TE (2016) and others found that concentration levels were increased in street canyons with trees, especially within the pedestrian level, compared to street canyons without trees[18].

#### (6) Urban planning

In the context of global climate change, urban planning is closely related to thermal comfort, and the study of the relationship between urban planning and microclimate can contribute to the sustainable development of cities. Changes in urban form can lead to varying degrees of thermal comfort, and inappropriate urban planning can exacerbate the emergence of extreme hot weather in cities. Urban planning has a direct impact on thermal comfort by influencing solar radiation, mean radiation temperature, wind speed, etc. In addition, in high-density cities, the thermal comfort can be reduced by the use of a combination of the following factors. In addition, in high-density urban areas, large amounts of energy are consumed to meet indoor and outdoor thermal comfort needs, which increases anthropogenic heat emissions and affects thermal comfort. Therefore, the improvement of urban thermal comfort from the perspective of urban morphology has become a key issue in urban planning and climate research. In general, with the increasing depth of computer science, ecology, chemistry and other disciplines, future research will shift to focus on thermal emissions, energy consumption, air pollution, etc., and new research tools will be needed to support the research. In addition to building scale and block scale morphology, urban scale morphology and green infrastructure will also be the focus in the future. Taleghani M (2015) and others have shown that the duration of direct sunlight and average radiant temperature as influenced by urban morphology play the most important role in thermal comfort, and courtyards provide the most comfortable microclimate in the month of June as compared to the other studied urban morphologies[19].

**Table 3.** Statistics of high-frequency keywords in domestic ENVI-met studies

year	frequency	intermediary centrality	keywords
2010	223	0.01	Thermal comfort
2014	148	0.01	Impact
2011	128	0.05	Urban heat island
2010	126	0.09	Temperature
2013	112	0.06	Microclimate
2009	101	0.04	Environment
2009	89	0.11	Climate
2009	86	0.06	Vegetation
2009	69	0.06	Design
2010	66	0.04	Model

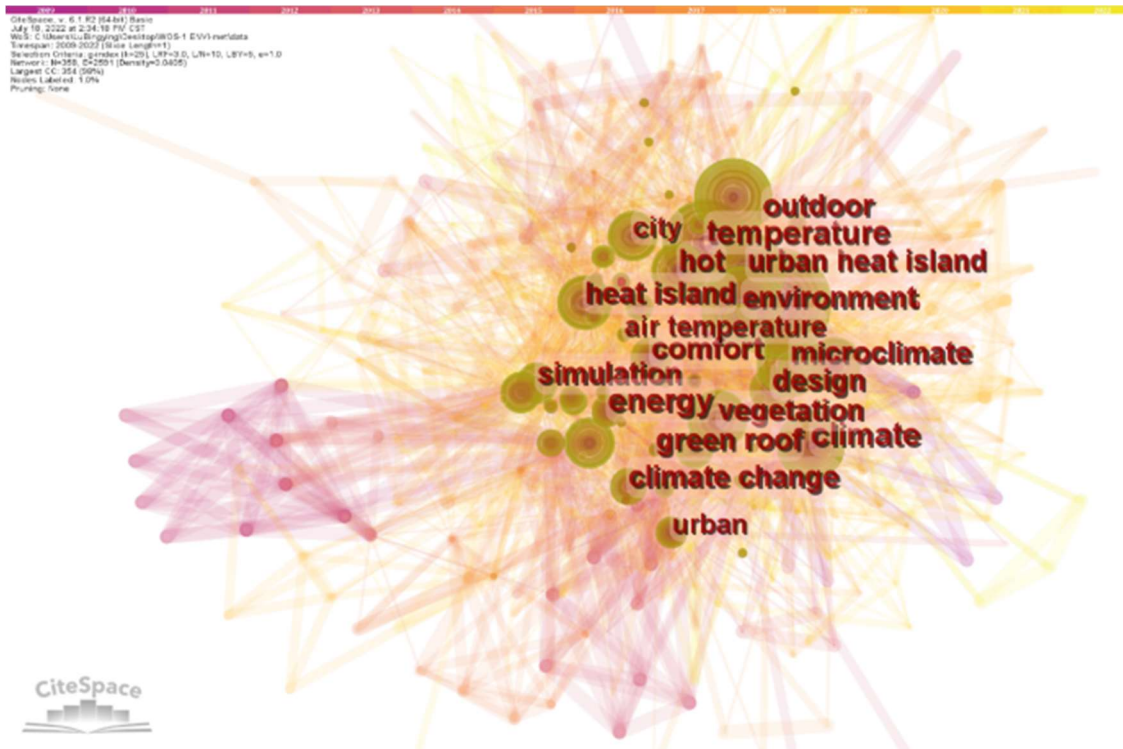


Fig. 9 ENVI-met keyword co-occurrence mapping



Fig. 10 ENVI-met keyword clustering map

## 5. CONCLUSION AND OUTLOOK

As the most widely used microclimate modeling tool, ENVI-met is of great significance in promoting the development of urban microclimate research. In this study, the literature related to ENVI-met was visualized and analyzed with the help of the metrological software CiteSpace. It is found that, in terms of the number of publications, ENVI-met research has shown a growing trend in recent years, and the enthusiasm of ENVI-met research field has been high, and the number of publications has continued to rise; in terms of research institutions, universities are the main ones, and some of the institutions

have close cooperation relationships and formed many cooperative groups; in terms of research authors, many cooperative groups have been formed, and authors who have published more publications come from China, Germany, the United States, and so on, Germany, the United States and so on. In terms of research content, there is a diversified trend, mainly focusing on urban spatial morphology, heat island effect, thermal mitigation strategies, particulate matter abatement, etc., but also includes the evaluation of different human environment climate indicators, such as wind and heat environment, human thermal comfort, climate adaptation, etc. Nowadays, microclimate modeling and particulate matter abatement are the most important research hotspots, mostly focusing on large-scale spatial environments, and particulate matter abatement is also becoming a common research hot topic.

As far as the ENVI-met software is concerned, ENVI-met is an important vehicle for the study of microclimate and air pollutants, and the research related to ENVI-met should be promoted in the future. However, most of the existing research objects have different focuses, and most of them only involve individual indicators of microclimate or air pollutants, so the improvement of the existing research indicators is also one of the directions for future work; the construction of simulation scenarios of ENVI-met software is affected by a number of factors, but compared with the actual scenarios, the software to a certain extent ignores the complexity of the environmental factors and their interactions, and the software should be set up with more detailed components. ENVI-met software simulation needs to be supported by actual conditions, but the actual measurement method is time-consuming and labor-intensive, so the development of new technology to facilitate researchers to obtain real-time data to match ENVI-met is also one of the future trends.

There are some limitations in this study, and future research can further track the development of this field by focusing on more related literature, with the aim of promoting the academic community to pay attention to ENVI-met in the field of microclimate research, continue to expand and deepen the research scope and research topics, and form more research results. Generally speaking, ENVI-met-related research frontiers are emerging continuously, which is reflected in the diversification of multidisciplinary integration and characterization. There is still much room for the development of ENVI-met in terms of research vision, research method and research quantity. Subsequent research should further strengthen the research vision, content and methodology, and emphasize interdisciplinary cross-study to enhance the integration of disciplines so as to strengthen the research output. At the same time, we should emphasize joint research across regions and units, strengthen the cooperation between research teams and individual scholars, and form a virtuous cycle of development trends, so as to further expand the field of research and better serve the improvement of the human environment in the future.

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