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Mobile measurements with bicycles: a systematic review applied to the thermal environment of urban microclimates

Medições móveis com bicicletas: uma revisão sistemática aplicada ao ambiente térmico de microclimas urbanos

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Abstract

This study concerns in to collect, via a systematic review, papers from international academic researches that employed bicycles only to collect primary data on environmental variables for research on microclimatic thermal problems in urban contexts and others. Three international article search platforms were used. After reading the titles, abstracts, and entire works, 13 articles were chosen that employed bicycles in their mobile transects between 2011 and 2023. The analytical methodologies connected them to the thermal environment employed by the research, such as the primary characterizers of urban morphology, were visible from this. It is worth emphasizing that, while the platforms offer outstanding results in terms of article discovery, it is know that there are additional publications that employed similar technique but did not appear in the platforms' results. Six more items were discovered that were absent from the chosen search engines. It is significant to observe that, after looking over the 19 articles, the most part of them were only released in the past 25 years, with the oldest being found in 1998. Research has indicated that the use of bicycles to collect environmental data is related to the possibility that bicycles are more accessible than cars and more safety than walking along cities, moreover, this approach is less expensive. Apart from the several benefits that studies utilizing this methodology observed, it is believed that bicycles would be a more environmentally responsible and sustainable mode of transportation than alternatives. In this manner, it is hoped that additional research utilizing the effective mobile measurement technique with bicycles would be carried out in the future.

Keywords:
Urban Thermal Environment, Environmental Variables, Thermal Effects, Urban Microclimate, Urban Climate Methods.

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Resumo

O objetivo do estudo é reunir, por meio de uma revisão sistemática, artigos de pesquisas internacionais que utilizaram bicicletas para coletar dados ambientais em investigações sobre problemas térmicos microclimáticos em contextos urbanos. Foram utilizadas três plataformas de busca por artigos internacionais. Após analisar os títulos, resumos e textos completos, foram encontrados 13 artigos que usaram bicicletas em transectos móveis entre 2011 e 2023. As metodologias apresentaram quais os principais caracterizadores da morfologia urbana foram mais recorrentes. É importante observar que, embora as plataformas de pesquisa forneçam excelentes resultados na descoberta de artigos, há publicações adicionais que utilizaram técnicas semelhantes, mas não foram encontradas nessas plataformas. Seis artigos adicionais foram encontrados e estavam ausentes das buscas realizadas. A maioria dos 19 artigos foi publicada nos últimos 25 anos, com o mais antigo em 1998. A pesquisa indica que o uso de bicicletas para coleta de dados ambientais é vantajoso devido à acessibilidade das bicicletas em comparação aos carros e à segurança em relação à caminhada pelas cidades, além de ser uma opção mais econômica. Os estudos que utilizam essa metodologia observam diversos benefícios e acreditam que as bicicletas representam um modo de transporte mais responsável e sustentável. Espera-se que mais pesquisas utilizando a técnica de medição móvel com bicicletas sejam realizadas no futuro, contribuindo para uma melhor compreensão e gestão dos problemas térmicos urbanos.

Palavras-chave:
Ambiente Térmico Urbano, Variáveis Ambientais, Efeitos Térmicos, Microclima Urbano, Métodos Climáticos Urbanos.

I. INTRODUCTION

The rapid expansion of urban areas has induced substantial alterations in the environmental landscape, marked by a decline in green spaces juxtaposed with an upsurge in built structures. This confluence of urban form and function has intricated interplays with the atmosphere, often stemming from inadvertent human activities. Consequently, the resultant microclimatic ramifications arising from this nexus continue to pose a challenge (OKE, 1978). Living organisms, responding to atmospheric vagaries, undergo transformations that reciprocally impact the environment itself (AULICIEMS, 1998)

The quest for open spaces within urbanized settings has become conspicuously apparent, propelling research endeavors investigating the thermal dynamics within cities' constructed areas. This surge in studies underpins the burgeoning field of human bioclimatology (OKE, 1978; NIKOLOPOULOU, 2011), notably due to the heightened impact of climate change experienced within urban centers, marked by extreme meteorological events and abrupt air temperature (Ta) fluctuations (CROCE et al., 2022). Hence, the development of precise and effective methodologies for meteorological observations in outdoor urban environments becomes imperative (KIM et al., 2022).

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Fixed weather stations stationed at specific urban points may exhibit limitations in comprehensively delineating microclimate conditions, owing to constraints such as accuracy, time, and cost (GOBO et al., 2017). Consequently, they serve as adjuncts providing supporting references for research (KIM et al., 2022; WRITZL et al., 2022; PARSONS, 2014; RAJKOVICH et al., 2016). In this context, measurements of atmospheric and environmental variables via mobile transects, whether on foot or using vehicles (bicycles, motorcycles, or cars), offer a more nuanced portrayal of the built environment than official stations, especially when conducted via bicycles (CORREA; VALE, 2016; PFAUTSCH et al., 2023).

It is pertinent to note that recent researches have showcased the efficacy of mobile measurements using bicycles in comprehending urban microclimates, albeit this method remains relatively underutilized. Its simplicity of application and low maintenance costs present promising avenues, although the technology's widespread implementation remains limited. Nonetheless, it has already exhibited success in discerning climatic variations in diverse urban morphologies (WRITZL et al., 2022). Such studies hold the potential to unravel intricate Ta patterns within microclimates, encompassing aspects of Human Thermal Comfort (HTC), Urban Heat Islands (UHI) and Urban Cool Islands (UCI), (ROSSI et al., 2005; KRUGER et al., 2011; ROSSI et al., 2013).

In investigations delving into the urban thermal environment, a profound grasp of urban morphology assumes paramount importance in understanding how specific environmental qualities elicit varied human responses across different times of the day and seasons (VASILIKOU et al., 2020). The urban climatology sciences have introduced methodologies such as Local Climate Zones (LCZ), Sky View Factor (SVF), and Land Surface Temperature (LST) maps, facilitating this understanding (WRITZL et al., 2022; STEWART et al., 2012; OKE et al., 2017; MATZARAKIS et al., 2010; DEMUZERE et al., 2021).

In pursuit of innovative methodologies for deciphering the urban thermal landscape, the Systematic Review stands out as a research tool distinct from conventional methods, consolidating and disseminating scientific findings that enrich the repository of knowledge. Serving as a comprehensive platform for consolidating insights, the systematic review aids in refining and advancing specific approaches (STEWART, 2011; PAUL et al., 2020).

This paper was inspired by the effectiveness of mobile, bicycle-based research methods, their underutilization in environmental data collection in urban environments, their ecological, sustainable approach, and the possibility of using low-cost materials.

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Then, this study concerns in to collect, via a systematic review, papers from international academic researches that employed bicycles only to collect primary data on environmental variables for research on microclimatic thermal problems in urban contexts and others.

The main focus of the research, at the end, is to present the research that had applications in thermal conditions under the framework of microclimates, not for urban mobility or health/exercises.

II. Materials and Methods

The systematic review occurs in several stages, but it is up to each author to select the criteria that best reflect their study. Such procedures elevate this study to the same level as the research it reviews (STEWART, 2011).

There are four critical stages for a systematic review construction (STEWART, 2011): (1) strict eligibility criteria define the population, or "universe," of studies about which the review aims to generalize; (2) a representative sample of this universe is retrieved from the literature via a logical search strategy; (3) essential information from each eligible item is extracted, coded, and combined into statistical outcome measures; and (4) the methods, results, and theoretical implications of the analysis are reported and discussed.

Following the same rationale, a list of seven critical measures used throughout this systematic study (HIGGINS et al., 2011) (Figure 1). They are as follows: 1 - Question formulation, 2 - Study location and selection, 3 - Study critical assessment, 4 - Data collection, 5 - Data analysis and presentation, 6 - Data interpretation, and 7 - Review improvement and updating.

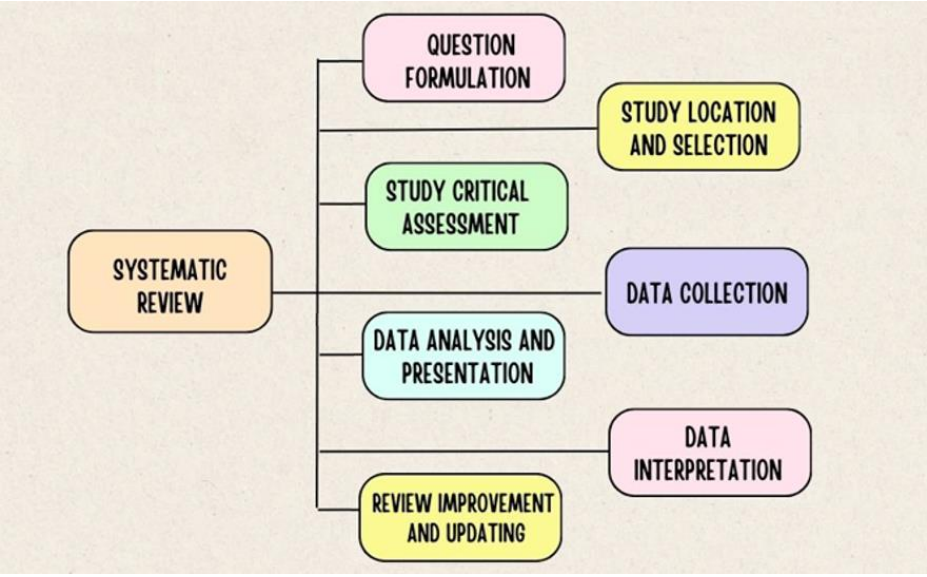

Figure 1- Diagram with the basis of the systematic process. Source: Authors (2024).

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The question was formulated in the first step. This stage was critical in carrying out the full study, since it needed to be well formulated and simple to grasp (SAMPAIO et al., 2007). In this regard, the issue is, "For what analysis methods are bicycles being adopted as a mobile measurement instrument for environmental variables in papers related to the urban thermal environment?" This allowed to the researchers to consider the keywords that led the research. The selection of keywords is an important search strategy for carrying out the second stage. The following keywords were used: "mobile measurements, bicycle, thermal effects, and microclimate".

For the second stage, studies were found and chosen, and the words were translated into English and added to the Connected Papers platform, which provides a general and visual overview of various academic fields as well as building a graph of similar articles with popular papers on the topic of interest (CONNECTED PAPERS, 2024). Science Direct (SCIENCE DIRECT, 2024) and Scopus (SCOPUS, 2024) were also used in addition to this platform. The search platforms chosen were chosen because they are well-regarded, with the belief that this stage is critical since it is the platform that will add to the available paper on the issue covered (HIGGINS et al., 2011), as well as research in urban climatology and human bioclimatology are, for the most part, published in journals indexed in these databases. The IEEE Xplore platform was not used because the research found in this database of scientific publications deals almost exclusively with urban mobility and health when the topic is the use of bicycles in research. Only one article with applicability to climate was found, but this was also found in the other databases previously mentioned.

The papers were then critically examined (step 3), with the titles first read. Titles that obviously departed from the notion of thermal effects were rejected, as were those that did not employ mobility measurements with a bicycle (cars or on foot were omitted) for other objectives. Some people utilized the bicycle to learn about air quality, which was not the goal of this study, as well as other issues that did not fit, which were also removed.

When reading the titles, those that could somehow fit into a research subject connected to the urban thermal environment and that either stated or indicated the usage of bicycles were taken into account.

The titles that were chosen were divided so that the abstracts could be read. The same selection and exclusion rationale was used for abstracts as it was for titles. It was already possible to identify papers that used bicycles for mobile measurements in, urban or not, thermal environment research by reading the abstracts; however, some still did not specify in the abstracts which methodology they had used for carrying out mobile measurements (car, motorcycles, bicycles, or walking), so these works were also selected alongside the others so that a complete reading could occur. After thoroughly reviewing the publications, it was possible to decisively

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pick those studies that employed bicycles to gather environmental data in order to analyze the urban thermal environment, which were used in this research.

Author and year, city/country, continent, local climate according to Köppen (KOTTEK et al., 2006), season, period of the day for mobile collection, number of collection days, and analysis methods for defining urban morphology based on specific objectives were obtained from the studies (step 4 and 5). The use of urban morphology descriptors in thermal research in urban environments helps to establish linkages between environmental variables and different microclimates.

Bicycles were used in other research to evaluate environmental elements in the urban thermal environment that were not detected using keyword searches. These works were found through previous research, studies carried out using alternative techniques, and, most crucially, by looking through references provided in studies that used the mobile measurements method with a bicycle. Regardless of the systematic review, a general conversation was held for each of the mentioned publications. Other considerations were equipment mounted on bicycles for mobile measurements, exposure to the air, and permanent stations.

III. Results and Discussions

Selected articles

After entering the keywords into the search platforms Connected Papers (CONNECTED PAPERS, 2024), Science Direct (SCIENCE DIRECT, 2024) and Scopus (SCOPUS, 2024), 414 papers were found in Connected Papers, 57 in Science Direct, and 7 in Scopus. In all, 478 items were discovered (Table 1).

Table 1- Articles found and selected in every platform

Research platform	Total articles in the first search	Selected Titles	Rejected titles
Connected Papers	414	167	247
Science Direct	57	19	38
Scopus	7	7	0
Total	478	193	286
Research platform	**Total Abstract evaluated**	**Selected Abstracts**	**Rejected Abstracts**
Connected Papers	167	149	18
Science Direct	19	2	17
Scopus	7	6	1
Total	193	157	36
Research platform	**Articles selected for full reading**	**% for full reading**	
Connected Papers	10	24,2%	
Science Direct	1	1,8%	
Scopus	2	28,6%	
Total	13		

Source: The authors (2024).

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According to Table 1, after reading all 478 titles (100.0%) identified, 193 (about 40.2%) were chosen to read the abstract and 286 (roughly 59.8%) were rejected because they did not satisfy expectations.

Most of these articles dealt with the use of bicycles as a new form of urban mobility, in addition to studies of leisure and physical activities, and these are not part of the criteria for this research.

After reading the abstracts, 157 (about 81.0%) were chosen for full reading, while 36 (about 19.0%) were rejected because they did not suit the theme. It is worth noting that just 13 (roughly 3.0%) of the 478 (100.0%) original titles were selected to continue the investigation.

To resume this information, the graph in the Figure 1 reveals that 77.0% (10) of the 13 papers chosen were located in Connected Papers, 15.0% (2) in Scopus, and just 8.0% (1) in Science Direct. Four papers were removed from the Scopus selection because they had already published on the Connected Papers platform.

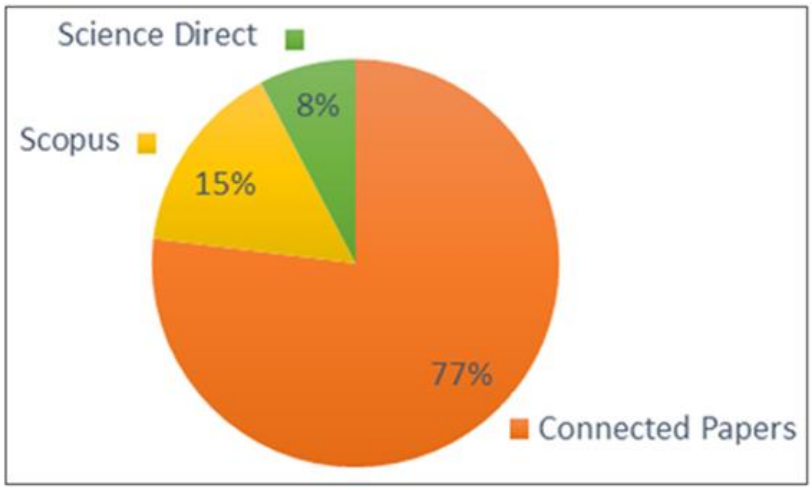

Figure 2- Percentual of articles selected on each platform. Source: Authors (2024).

Data collection

Following the selection of the 13 publications about thermal environment in microclimatic scale context, data such as author/year, city/country, continent, climate, major purpose, season, period of the day, collecting days with mobile measurements, and microclimate characterizers were gathered, as shown in table 2. Researches were organized from oldest to most recent.

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Table 2- Collection of main data from the 13 articles

Author / Year	Country	Continent	Climate	Objectives	Seasons	Day / Period	Collection / Days	Urban Climate Methods
Chow et al. (2011)	USA	America	BWh	UCI	Autumn	Day	1 day	ENVI-met SVF 3D SkyView
Drach et al. (2014)	Brazil	America	Am	HTC	Summer	Day	16 days	SVF ENVI-met
Klemm et al. (2015)	Netherlands	Europe	Cfb	HTC	Summer	Day and Night	2 days	Interview
Rajkovich et al. (2016)	USA	America	Dfa	Ta	Summer	Day	1 day	SVF
Nastos et al. (2017)	Greece	Europe	Csa	HTC	Summer	Day and Night	1 day	ENVI-met
Lenhert et al. (2018)	Czech Republic	Europe	Cfb	Ta	Autumn, Summer and Winter	Day and Night	16 days	LCZ
Alonso et al. (2020)	France	Europe	Cfb	Ta	Summer	Day	4 days	Many methods
Emery et al. (2021)	France	Europe	Cfb	Ta	Spring and Summer	Night	33 days	LCZ
Kim et al. (2022)	South Korea	Asia	Dwa	HTC	Autumn	Day	2 days	SKYEF
Writzl et al. (2022)	Brazil	America	Cfa	HTC	Summer	Day	2 days	SVF LCZ
Croce et al. (2022)	Italy	Europe	Dfb	UHI	Spring	Day	60 days	LoRaWAN gateway
May et al. (2023)	USA	America	Csc	UCI	Summer and Autumn	Day	90 days	Many methods
Viejira et al. (2023)	Belgian	Europe	Cfb	Ta	Summer	Night	2 days	Bodembedek Ekingskaart (BBK)

Source: Authors (2024).

According to the right collum in Table 2, Urban Climate Methods found were, the high-resolution 3D modeling program called ENVI-met can replicate intricate microclimatic processes (CHOW et al., 2011; DRACH et al., 2014; NASTOS et al., 2017). Urban canyon geometry is measured by the Sky View Factor (SVF), which counts the locations where trees or buildings block the sky (WRITZL et al., 2022; RAJKOVICH et al., 2016). To know the height of buildings and their spacing in urban canyons, sky view factors can be estimated using 3DSkyView, an extension of the GIS program ArcView 3.2 (CHOW et al., 2011).

The Local Climatic Zones (LCZ) attempt to characterize the urban environment by searching integrally for microscale physical phenomena (WRITZL et al., 2022; MICHAL et al., 2018; ALONSO et al., 2020). The Sky Exposure Factor (SkyEF) to represent the "geometric definition" of SVF, which differentiates itself clearly from the SVF (KIM et al., 2022). The LoRaWAN gateway serves as a collector/forwarder of data packets. the Bodembedekkingskaart (BBK) provides land cover data (VIEIJRA et al., 2023). Other papers talk about interview

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of pedestrians (KLEMM at al., 2015), artificial intelligence (ALONSO et al., 2020) collection of meteorological variables for UCI description (MAY et al., 2023).

Geographic location and climate classification

Figure 3 presents the geographic spatiality of the papers found that used mobile transects with bicycles. It is known that research, even if theoretical, on the use of bicycles was carried out in Germany, but remember again that only studies that used bicycles to collect environmental data for analyzing the urban thermal environment were included on the map, excluding exclusive studies of UHI/UCI and other topics not linked to climatology.

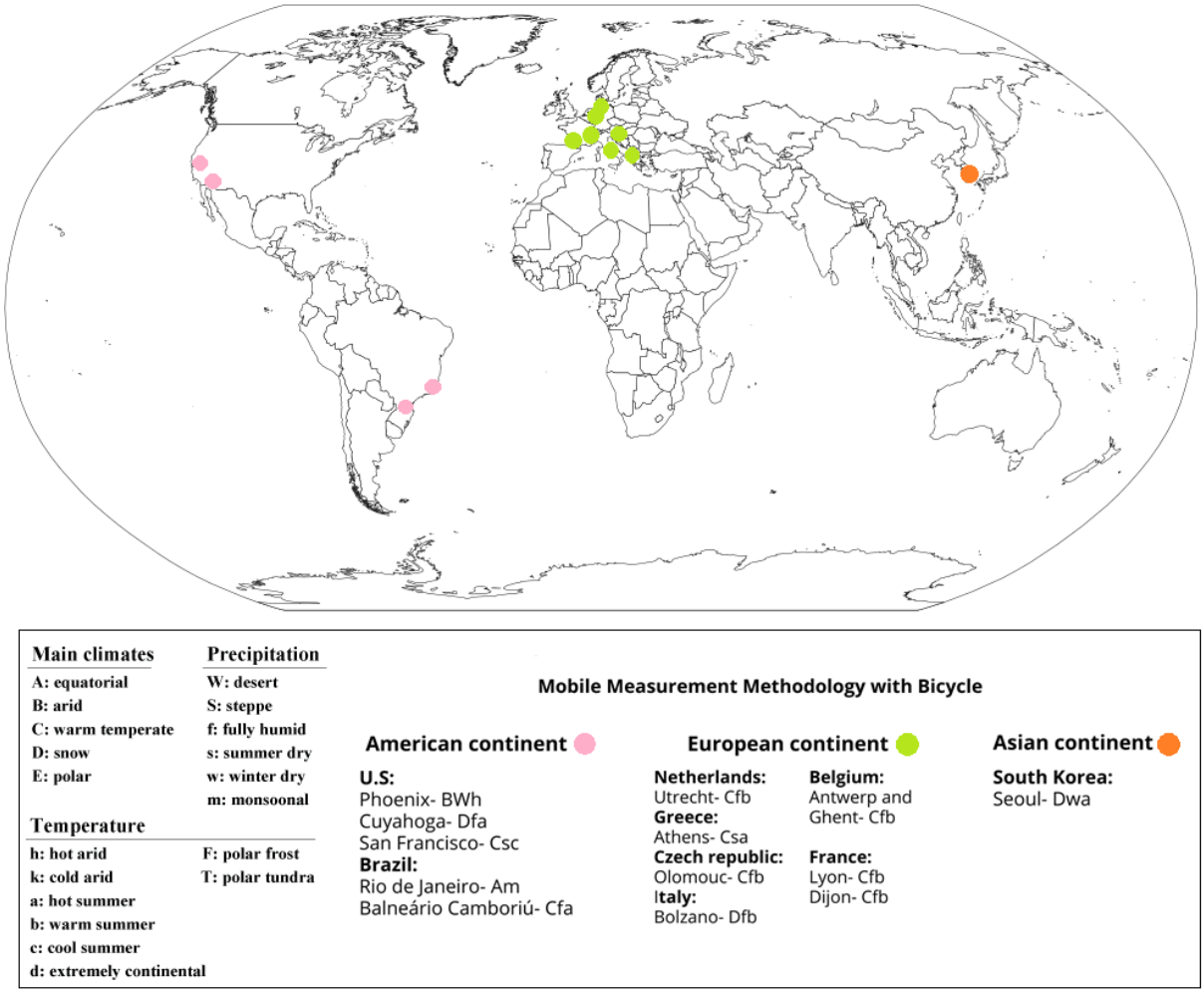

Figure 3 - Worldwide location of papers found according to climate. Source: Authors (2024).

The disparity between the Southern and Northern Hemispheres is evident in Figure 3, illustrating a pronounced concentration of papers in the Northern Hemisphere. Notably, the preponderance of these ones (7) emanated from various European nations, including Greece, Czech Republic, Italy, Netherlands, Belgium, and two studies from France. In North America, three studies were identified, all of which were conducted in the

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United States. Asia contributed only one study, situated in South Korea, while South America yielded two studies conducted in Brazil.

Regarding climatic classifications based on the Köppen system (KOTTEK et al., 2006), the research encompassed a diverse spectrum of climatic conditions. Mobile measurements were sourced from nine distinct climate types: Am, Bwh, Cfa, Cfb, Csa, Csc, Dfa, Dfb, Dwa. Notably, a predominant focus was observed in coastal cities, in maritime climate zones, notably with five studies centered on Cfb, while the remaining climate types were each represented in one study. Additionally, a separate investigation on thermal environments within densely populated metropolitan areas highlighted a similar emphasis on temperate climatic zones (group C) (WAI et al., 2022).

Researches found

Given the recent rise of urban centers, the demand for open spaces in urbanized regions is clear, stressing the need for even more study including the thermal environment (OKE, 1978; NIKOLOPOULOU, 2011). Although some studies had the primary goal of examining HTC (KIM et al., 2022; WRITZL et al., 2022; NASTOS et al., 2017), or UHI/UCI (CHOW et al., 2011; MAY et al., 2023), each research had its own unique characteristics.

To explore the impacts of canyons and urban environment on air temperature and exterior thermal comfort in a Seoul open plaza, another research using bicycle was used (KIM et al., 2022). To assess the accuracy of the mobile approach, data from mobile bicycle measures taken in October at 2pm and 3pm were compared to those from stationary measurements. The effects of the spatial parameters of the urban plaza and local street were investigated using Ta and Physiological Equivalent Temperature (PET).

During the summer, one bicycle was used to investigate the degree of human thermal (dis)comfort in connection to the various microclimates prevalent around the cycling lanes in Balneário Camboriú, Brazil (WRITZL et al., 2022). The Physiological Equivalent Temperature (PET) and Universal Thermal Climate Index (UTCI) indices were applied to measure outdoor thermal comfort, while the Local Climatic Zones (LCZ) and Sky View Factor (SVF) were employed to establish urban form. During the summer, data on environmental variables such as air temperature, relative humidity, and global temperature collected by mobile transects on bicycles are integrated with data from permanent stations in the city.

Measurements in the urban microclimate and details of a hardware and software components application as a methodology for one research was employed to build a mobile transect (CROCE et al., 2022). The approaches were evaluated in the Italian city of Bolzano, confirming their applicability for recognizing the

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geographical variability of the microclimate in connection to urban morphology, as well as emphasizing the presence and assessing the severity of the urban heat island (RIBEIRO et al., 2018).

A study in Ohio, USA, validated a bicycle for use in mobile measurements, allowing mobility within the city to analyze physical and thermal qualities (RAJKOVICH et al., 2016). Microclimatic data were gathered during the warmest portion of the day to evaluate how physical factors (solar radiation, albedo, SVF, vegetation) influenced local changes in soil and Ta (ALBUQUERQUE; LOPES, 2016). The kinds of land surface temperature and land cover explained the variance in air temperatures, while solar radiation and albedo helped to explaining the variation in LST throughout the transect.

The impact of horizontal and vertical nighttime cooling of a small park with irrigated grass and dry surfaces on a university campus in the Phoenix metropolitan region was investigated (CHOW et al., 2011). Ta data collected on a bicycle mobile transect was integrated with spatial Ta data modeled in ENVI-met 3.1. Variations in the thermal characteristics of the surface, urban geometry, building orientation, and soil humidity were all important for determining the distinct urban and non-urban temperatures near to the surface.

A study conducted in Rio de Janeiro, Brazil, was discovered (DRACH et al., 2014). The primary goal was to investigate the overall human reaction of the local population to the climatic peculiarities of Rio de Janeiro, as well as to identify certain intervention options in urban morphology that may lead to greater environmental comfort.

There was also a comparison of Ta conditions and park spatial characteristics (size, tree canopy, and plant protection against wind). To establish distinctions, air temperature (Ta), and mean radiant temperature (Tmrt), were measured during the day in urban parks, the city center, and open fields outside the city on hot summer days, to carry out the Physiological Equivalent Temperature (PET) (KLEMM et al., 2015).

Another research using bicycles to conduct mobile assessments of thermal comfort in the Athens metropolitan region (NASTOS et al., 2017). The transects were completed in a single day, at midday and at night. The ENVI-met model was used to simulate surface, plant, and air interactions in an urban context. Air temperature, relative humidity, wind speed, global temperature, and global solar radiation were all measured. For the analyses, the PET index was employed.

A bicycle for mobile measurements in the city of Olomouc was employed to look for hot and cold places by analyzing air temperature in distinct Local Climatic Zones (LCZs) throughout the summer, autumn, and winter. The findings revealed that the microclimate and local climate had a considerable impact on temperature (MICHAL et al., 2018).

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Exploring the contribution of factors is critical for air temperature modeling studies, as is accounting for measurement errors, mentioning data collection methods, and statistical processes for urban climate studies, thermal comfort, and primary data collection (ALONSO et al., 2020). Furthermore, scientific study of this kind should constantly try to enhance urban design in the context of climate change in order to reduce urban heat islands.

Research in Dijon, Eastern France, using mobile measurements on a bicycle equipped with environmental variables equipment to quantify the effect of urban design on microscale air temperature fluctuation (EMERY et al., 2021). The trek was completed over the course of 33 spring and summer evenings. Based on analysis of variance, the influence of urban design and land cover on air temperatures was evaluated using land cover and LCZs.

Mobile bicycle transects were done in Golden Gate Park and neighboring residential districts in San Francisco, CA, from July to October 2012, when temperatures were at their highest (MAY et al., 2023). Ta, relative humidity, sun radiation, and radiometric surface temperature were all measured.

The goal was to assess the spatial variability in near-surface temperature profiles at these places and on neighboring surfaces. The magnitude of so-called "park cool islands" (PCI) was studied for various types of park land use, at different times of day, during different regional-scale weather conditions, and across the entire range of heights that a human body can experience, as well as humidity differences and the likely drivers of PCI in the urban park.

More comprehensive temperature drop correction approach for mobile readings was researched and tested using bicycle (VIEIJRA et al., 2023). Temperature evolution may be greatly influenced by the environment, and the link between land cover and temperature was taken into consideration during the period of bicycling readings in two Belgian towns.

Studies in the Thermal Environment

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As indicated in graph of Figure 4, the major goals of the researches that employed the bicycle for mobile measurements in urban thermal settings (from the universe of thirteen papers selected) were to explore thermal comfort with 38.0% (5) and temperature with 38.0% (5), urban cooler island 15.0% (2) and urban heat island 8.0% (1).

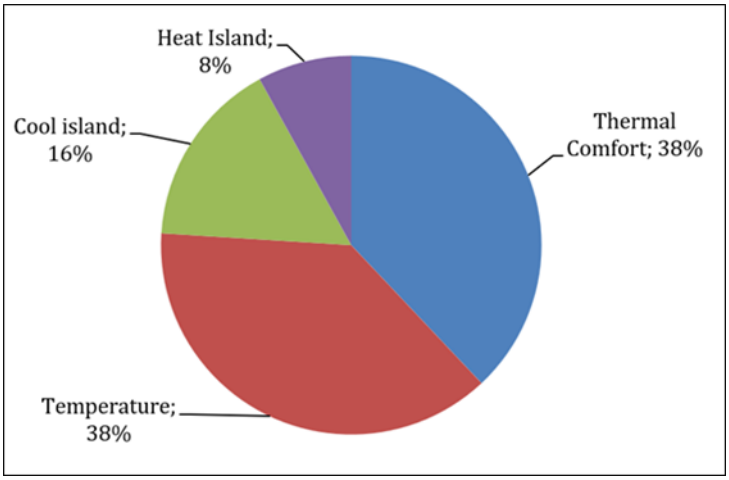

Figure 4 - Main study objectives of the 13 papers selected. Source: Authors (2024).

Graph in Figure 5 demonstrates that the majority of mobile measurements happened solely during the day, with 62.0% (8) occurring during the day, 15.0% (2) occurring at night, and 23.0% (3) occurring both during the day and at night.

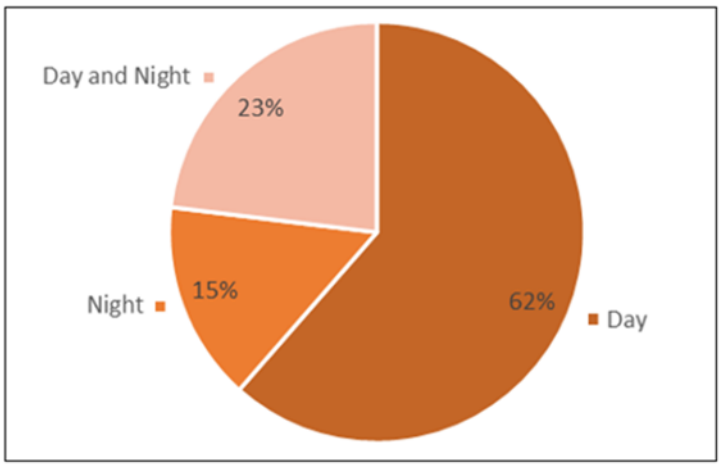

Figure 5 - Period of the day when collection occurred in the 13 papers selected. Source: Authors (2024).

In terms of the hour of daytime when the measurements are taken, it is worth mentioning that the majority of the studies were conducted during the day but not mentioning a specific hour. Table 2 demonstrated that the selection of the collection period did not follow a consistent trend.

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In terms of season, it is easy to see that 54.0% (7), or more than half of the papers, decided to conduct out collections in the summer, with autumn following closely after with 15.0% (2) and just 8.0% (1) of the papers presenting the other seasons (Figure 6).

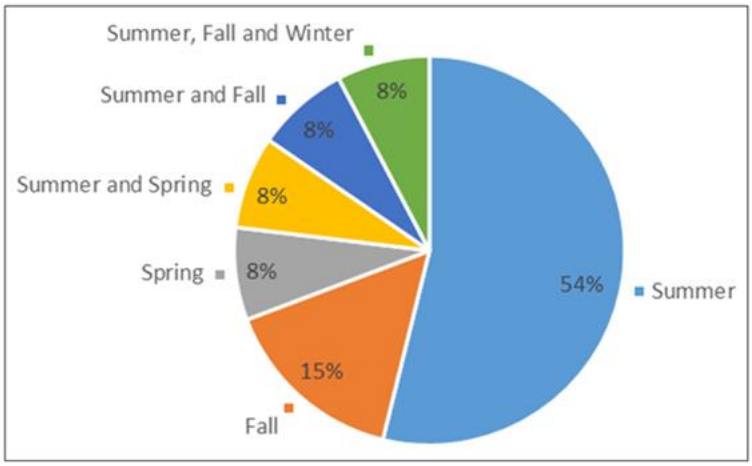

Figure 6 - Seasons of researches occurrence in the 13 papers selected. Source: Authors (2024).

The most popular urban morphology characterizer was the Sky View Factor (SVF), which was used in four surveys. This was followed by ENVI-met, which was used in three surveys, and Local Climatic Zones (LCZ), which were also used in three. The others only appeared once. Urban canyon geometry is measured by the Sky View Factor (SVF), which counts the locations where trees or buildings block the sky. The Local Climatic Zones (LCZ) attempt to characterize the urban environment by searching integrally for microscale physical phenomena (CROCE et al., 2022; RAJKOVICH et al., 2016). The high-resolution 3D modeling program called ENVI-met can faithfully replicate intricate microclimatic processes (CHOW et al., 2011).

Other important studies using bicycle

During the investigation, a significant number of papers was discovered. There were researched that used the bicycle as a means of measuring environmental variables in the urban thermal environment, but they were not found based on the keywords defined in this systematic review methodology, so the need to present them arose due to the importance and relevance of their results. It is worth emphasizing here that there may be a constraint encountered while carrying out the measures that were taken.

The bicycle was employed in a 1998 study in two cities with differing summer climates: Vancouver (BC) Canada, and Sacramento (CA) United States of America. Although it was not the sole way of carrying out mobile measurements in this investigation. The temperature regime of urban parks was investigated. To quantify the amount of park-related coolness, surface and air temperatures were remotely measured from permanent stations as well as movable automobile and bicycle crossings. The bicycle was employed in certain study in

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Vancouver because it allowed access to the interiors of parks and some roadways. A sensor put on the front of the bicycle was used to monitor air temperature (SPRONKEN-SMITH et al., 1998).

A study in 2014 in which meteorological data were taken on a bicycle in Rotterdam to examine the regional change of temperature throughout a tropical day (HEUSINKVELD et al., 2014) The researchers assessed Urban Heat Islands and their geographic variability in urban canyons, linking them to urban form. A multiple linear regression model was built using cross sectional observation data and verified with 3-year summer UHI statistics taken from four fixed urban and two fixed rural weather sites.

Research to evaluated the frequency of use of mode of transport by cyclists classed as both commuting and leisure riders under particular atmospheric settings in the city of Vienna, Austria was conducted (BRANDENBURG et al., 2004). Statistical approaches and the PET index were used, which revealed that leisure cyclists are more susceptible to weather than commuters/commuters.

Between March 2006 and January 2009, mobile temperature and humidity measurements were taken along a bicycle transect in the Dutch city of Utrecht. To explain the mean intensity profiles and maximum nighttime Urban Heat Island (UHI) of the city in relation to the Sky View Factor, two multiple linear regression models were developed (BRANDSMA et al., 2012). The midday cooling impact of Utrecht's green areas was investigated in order to uncover physical evidence to support the experience of HTC (LOBATO et al., 2016). The bicycle was outfitted with micrometeorological sensors, and the Ta conditions in thirteen parks were compared to those in the city center and open pastures outside the city.

To attempted to assess the thermal comfort of spectators along a Tokyo Olympic marathon course in 2019 (VANOS et al., 2019). The study demonstrated how numerous environmental elements might influence human thermal comfort. It was feasible to determine air and surface temperature, solar radiation, humidity, and wind speed using mobile measurements taken with a bicycle along the marathon course over 15 days in the summer of 2016, in conjunction with the usage of the Sky View Factor (SVF).

Mobile measurements on a bicycle to assess the interplay of canopy cover and impervious surface cover on daytime urban air temperature throughout the summer were made (ZITER et al., 2019). In a medium-sized setting in a city in the Upper Midwest of the United States, ten transects were carried out with measurements every 5 meters encompassing a range of impervious cover and canopy.

In order to facilitate climate stress testing, a standardized physical equivalent temperature (PET) urban heat map with 1 m spatial resolution was created in the Netherlands. Several meteorological data sets were

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used to create an empirical regression model for PET. By using a bicycle to conduct mobile measurements, the proposed method was verified (KOOPMANS et al., 2020).

Bicycle Measurements: Overview

The first article found was published in 1998, the second article using bicycles in its tooling occurred in 2004, and the third in 2011.

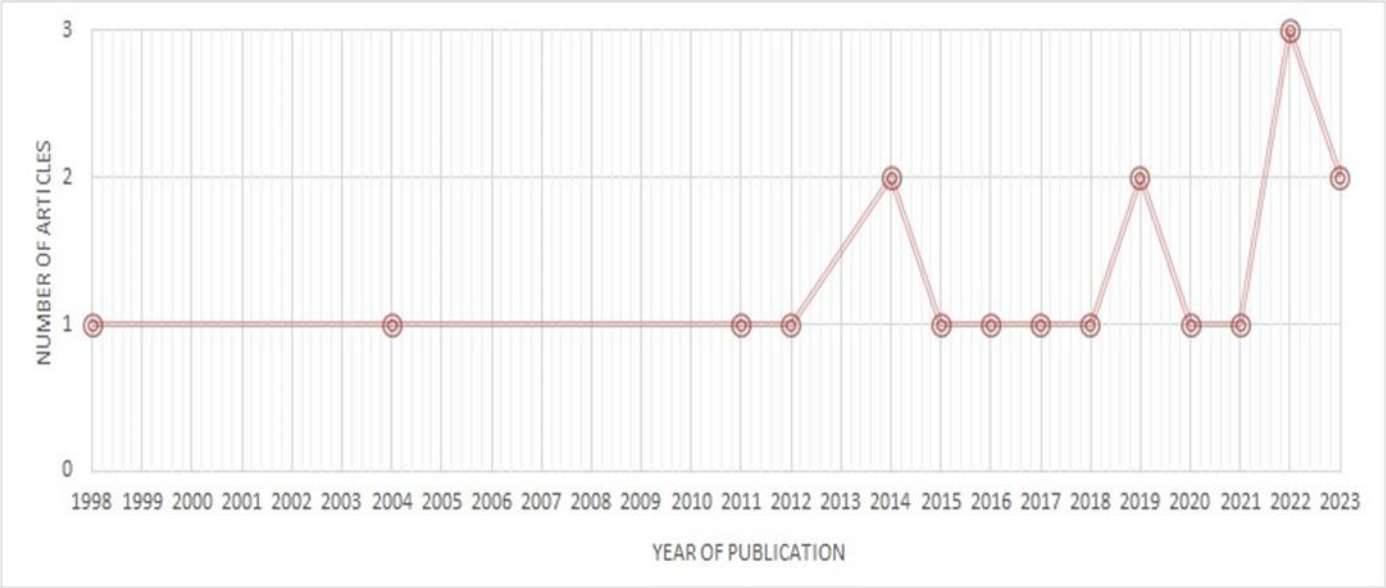

Figure 7 - Number of studies selected by year of publication since 1998, when the first article was found using bicycle in studies. Source: Authors (2024).

The graph illustrates a notable trend indicating an increase in the publication of papers utilizing bicycle-based approaches for mobile measurements over time. Until 2014, the annual output remained consistently low. After 2014, only in 2019 were there two articles published again in the year and in 2023 there was a significant surge in publications, surpassing the previous decade's numbers with 3 articles published in the year.

This trend clearly indicates that despite being a relatively new approach, its utilization has been historically limited, clearly the graph shows the gaps that exist between 1998 (date of the first article) until 2011 (when the gaps decrease), with no articles published in many years using the mobile bicycle measurement approach.

The rising number of articles produced annually following 2021 suggests a potential shift towards increased adoption and exploration of this methodology. If this trajectory continues, it implies a growing interest and potential for further development and application of bicycle-based mobile measurements in research related to the urban thermal environment on an international scale in the forthcoming years.

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Furthermore, in order to meet the impending standards for net zero emissions, communities must prioritize promoting bicycle transportation both inside and between cities. This is a topic that gets more important every day (EGUILUZ et al., 2022).

In this way, one argument made in support of the use of bicycles in research was that they would be a more environmentally friendly and sustainable method of transportation than other approaches. In addition, research endeavors may be impeded by the increased traffic associated with methods that use vehicles (WRITZL et al., 2022).

The grounds for utilizing the bicycle to assess environmental factors were the low cost of the supplies, as well as the bicycle's ability to reach locations that other forms of vehicles could no longer access (ZITER et al., 2019).

Several studies cited that their objectives were to validate measurement with the bicycle (KIM et al., 2022; WRITZL et al., 2022; RAJKOVICH et al., 2016), this may occur due to the fact that no work of this kind could have been carried out in their locality, as well as no work that used bicycles for this purpose could have been found.

The detailing of information on equipment, software, and atmospheric weather choices for carrying out mobile measurements differed according to the core purpose of each study discovered, with some offering more detail than others.

Furthermore, depending on the primary goal of the investigations, the equipment linked to bicycles in study differ substantially (Figure 8). In the urban thermal environment, research is often conducted using specified criteria for each approach, with measuring instruments varied.

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Figure 8 - Equipment attached to bicycles for mobile measurements found in some of the selected articles.
A) (RAJKOVICH et al, 2016), B) (EMERY et al, 2021), C) (MICHAL et al, 2018), D) (WRITZL et al, 2022). Source: Authors (2024).

Some studies showed photographs of bicycles with equipment mounted, however each research was unique based on the instruments used for measurements. Several tests revealed that the equipment should be higher than 1.14-2.00 meters above ground level to minimize interference from the ground and the pilot (CROCE et al., 2022; WRITZL et al., 2022; RAJKOVICH et al., 2016; NASTOS et al., 2017).

Furthermore, studies documented the use of stationary meteorological stations, in addition to mobile readings, to quantify the average temperature environment, as well as minimizing potential inaccuracies

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through comparisons of the accuracy of equipment mounted to bicycles with official weather stations (CROCE et al., 2022; WRITZL et al., 2022; NASTOS et al., 2017; HEUSINKVELD et al., 2014).

In terms of the atmospheric environment, some researchers choose to schedule mobile measurements that take sun radiation into consideration because it is a key component of the study (WRITZL et al., 2022; RAJKOVICH et al., 2016; MICHAL et al., 2018). Others reported picking days with no precipitation for observations (MICHAL et al., 2018), calibration of dataloggers, and wind speed readings corrected for cycling speed were also taken into account (WRITZL et al., 2022; KLEMM et al., 2015).

The use of bicycles as an additional tool for climatology study

The use of bicycles as a collection method was observed in research types other than those that sought to study the urban thermal environment in climatology during the systematic review and the overall execution of this work. For this reason, they are considered important for scientific knowledge, and therefore, they will be cited here. The purpose of mentioning these works here is to highlight those that have evolved through research and systematic review, rather than to include all previous works that have chosen to employ the bicycle as a measurement tool in climatology-related tasks.

For the city of Bilbao, Spain, a project proposal was produced (EGUILUZ et al., 2022) that involved the creation of an open-source urban mobility web service based on data on bicycle mobility and environmental quality. One component of this project was a system that, when mounted on any bicycle, gathers data on environmental quality and movement.

The systematic study revealed a considerable increase in the use of bicycles for air quality measurement. One of the more obvious studies involved mounting a series of sensors on an electric bike and using mobile CO, NO_2, and SO_2 measurements on a road in the heart of Shaoxing, China, to track the exposure of air pollutants associated with motor vehicle traffic (ZHAO et al., 2023).

Bicycles have also been used in research on human exposure to air pollution with the goal of assessing and quantifying the levels of human exposure to particulate matter in real-time in transport microenvironments, such as cars, buses, bicycles, and pedestrians (KUMAR et al., 2018). In this way, one tool utilized in Guildford, UK, to conduct these kinds of measurements was the bicycle. Research on bikers' exposure to air pollution was also conducted in Münster, northwest Germany, using a cargo bike for transportable measurements (CARRERAS et al., 2020).

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IV. CONCLUSIONS

The number of studies that used bicycles for mobile measurements in research involving the urban thermal environment has grown considerably in recent years, especially since 2011, appearing more frequently in systematic review tools.

The main objectives of the research that used the bicycle for mobile measurements in urban thermal environments was to explore HTC, Ta, and the occurrence of UHI and UCI, and in this sense, it was realized that the characterization of morphology urban thermal environment was very important for carrying out assessments related to the urban thermal environment, where SVF, ENVI-met, and LCZ were highlighted.

Furthermore, most of the research was carried out in the Northern Hemisphere, with an emphasis on coastal cities and climates of the Cfb type, a climate that is mostly found in Europe, followed by North America, South America and Asia.

In relation to the objectives of this research, the systematic review made it possible to validate the methodology of mobile transects for measuring environmental factors using a bicycle as an important tool that combines practicality and low cost, proving to be efficient according to what was presented in the results of each paper read.

Not only with a climate bias, but also applications to human exposure to urban pollutants and mobility in cities, the bicycle was used in research of different types. Therefore, it is expected that this systematic review will serve as a guide for readers and enthusiasts in this field of scientific knowledge, presenting and concatenating the results of the last thirteen years.

From 2022 onwards, there has been even more significant growth compared to previous years in research using bicycles, and the tendency is for this number to grow even more in the coming years due to the ease, cost-benefit and increase in use in relation to the sustainability that involves its use.

Certainly, the number of studies that used bicycles as a collection tool must be much greater than that presented in this research, as it is known that many of these results were published in the form of master's dissertations, doctoral theses and articles from event annals, which are not collected by research carried out in the three databases consulted in this work.

It was chosen not to search for these publications (grey bibliography), as it is known that publications in journals have greater scientific rigor, as they were evaluated in several phases, in many of them by blind peers, guaranteeing this research great methodological rigor and high performance in applications to other areas.

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Lastly, the authors acknowledge that a systematic review cannot be completed with just 13 articles, but this case is notable because, aside from studies on bicycle use in urban mobility, a total of 478 articles (spanning three research platforms) address the use of bicycles in climate research. The main focus of the research that will be presented here is the thirteen that had applications in thermal conditions under the framework of microclimates.

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