buildings

Review

A Literature Survey of Local Climate Zone Classification: Status, Application, and Prospect

Wenyun Feng and Jianjun Liu *

Department of Landscape Architecture, College of Landscape Architecture and Arts, Northwest A&F University, Yangling 712100, China
* Correspondence: ljj@nwsuaf.edu.cn

Abstract: Rapid urban expansion and climate change have prompted further investigations into urban thermal climates and the development of local climate zone (LCZ) classification systems. LCZs, proposed 10 years ago, comprise a new and systematic classification of field sites for heat island studies to provide a reference for future LCZ research, so that scholars can understand what research has been done and identify future research trends. We analyzed LCZ studies in a database from 2012 to the present, and identified recurring themes using VOSviewer software, including LCZ mapping, measurement methods, thermal environments, and outdoor thermal comfort, among others. A systematic evaluation was performed using bibliometric analysis in the PRISMA framework—190 relevant studies were selected for subsequent analysis. Descriptive analysis showed that LCZ research has received increasing attention, particularly in China, where more than 60% of the LCZ studies were conducted. The results showed that the maximum number of articles on all themes was 57 articles on LCZ mapping, followed by studies of the thermal environment (UHI/SLT). It is hoped that this article will provide scholars in this area with an understanding of the research that has been conducted and the methods used, and provide insight into future research directions.

Keywords: local climate zone; urban heat island; urban thermal climate; measurement method; outdoor thermal comfort

check for updates

Citation: Feng, W.; Liu, J. A Literature Survey of Local Climate Zone Classification: Status, Application, and Prospect. *Buildings* **2022**, *12*, 1693. https://doi.org/10.3390/buildings12101693

Academic Editor: Rafik Belarbi

Received: 6 September 2022
Accepted: 11 October 2022
Published: 14 October 2022

1. Introduction

During the 20th century and since, urban population growth has been accelerating, resulting in rapid urban development, industrialization, overall population growth, and densification. Natural landscapes are being replaced by a large number of artificial surfaces, buildings, and roads, significantly changing the urban space and the urban climate [1,2]. The urban heat island (UHI) effect is accelerating due to rapid urbanization and land cover change [3].

The UHI is the phenomenon where the ambient temperature in a city is higher than that in adjacent rural areas [4]. This is caused by cushion surface changes, climate condition changes, and artificial temperature releases in the process of urban expansion under different regional climate backgrounds [5]. In addition, automobile exhaust, air conditioning, and other artificial heat sources have an important impact on the thermal environment in cities. These artificial heat sources enhance the convection and turbulence in the air and strengthen UHI effects [6].

Before the emergence of "local climate zone" (LCZ) algorithms, most studies used the temperature difference between the urban core and the suburbs to obtain the urban heat island intensity (UHII), one of the most commonly used indicators to characterize UHIs [7]. With the process of urbanization and expansion, the boundary between "urban" and "rural" becomes blurred, and the suburban comparison method is too simple, such that is impossible to accurately describe the UHI. This provides no way to accurately describe the spatial heterogeneity of the near-surface temperature caused by the urban underlying land cover described by Stewart (2011). For this reason, Stewart and Oke (2012) introduced the LCZ concept to classify "urban" and "rural" land cover more objectively, using development effects on local temperatures, and proposed the use of LCZ X – LCZ D to represent the UHI (temperature of UHI = the temperature of any LCZ (LCZ X) minus the temperature of LCZ D) [7].

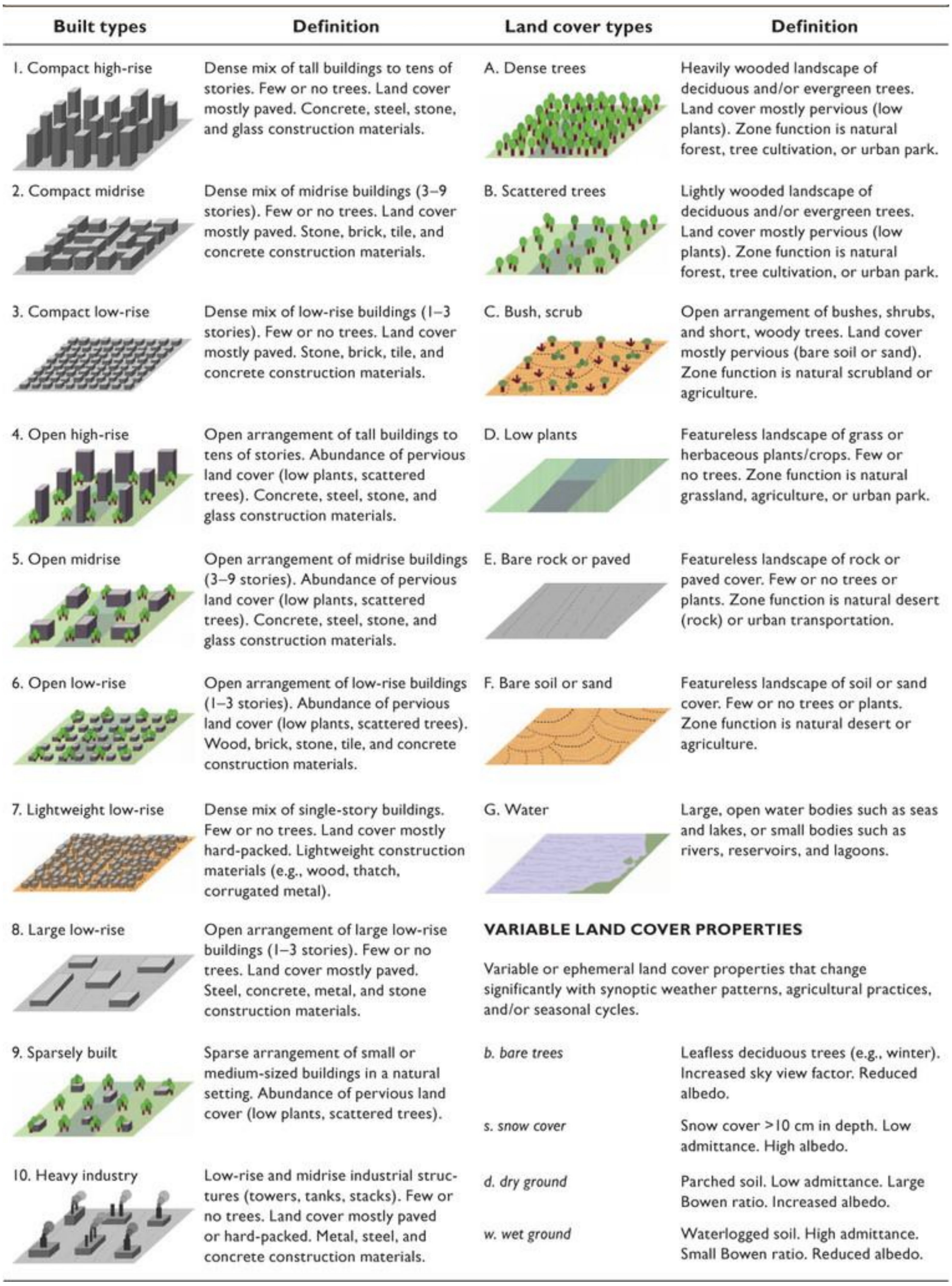
In recent years, there have been increasing studies on LCZs, globally dominated by research in China [8] and the United States [9]. Other countries and regions have also carried out empirical research combined with LCZ. Although the first proposed LCZ was intended for the field site classification in UHI studies [10], it is now being used in a variety of applications. In its first decade, we reviewed LCZ applications and summarized the range of represented research topics with the help of biometric tools, identifying future trends for LCZ applications in urban research.

Oke (2006) proposed the standard "Urban Climate Zone (UCZ)" at the 13th Committee of Instruments and Methods of Observation (CIMO) conference. In 2012, he divided this type of area into different, uniform sections based on characteristics previously identified, naming this classification "Local Climate Zone (LCZ)" with Stewart [11].

The primary goal of the LCZ is to identify a standard selection of urban measurement points with a recording of UHI intensity [11]. This study shows that thermal contrasts exist across all LCZ categories, which are largely determined by building height and spacing, impervious surface fraction, tree density, and soil moisture [10]. The LCZ program aims to expand and improve on previous work on the UCZ classification, increasing the number of land categories to 17, including 10 "Built Types" categories and seven "Land Cover Types" categories. The standard grade comprises 10 building types (compact high-rise, compact mid-rise, compact low-rise, open high-rise, open mid-rise, open low-rise, lightweight low-rise, large low-rise, sparsely built, and heavy industry) and seven land cover types (dense trees, scattered trees, bush/scrub, low plants, bare rock or paved, bare soil or sand, and water), with different microclimate conditions (Figure 1). The range is defined as a region crossing hundreds of meters to 200 m, with similar physical surface properties that can affect the local climate, including sky view factor (SVF), building surface fraction, aspect ratio, impervious surface fraction, terrain roughness grade, and height of roughness elements. The index provides a general framework for UHI research, which uses the temperature difference between LCZ (ΔT = LCZ X − LCZ D) to facilitate the quantification of UHI intensity. Following the LCZ's original development, there have also been occasional efforts to demonstrate its applicability [12].

The purpose of this work was to search for and synthesize all of the available literature on LCZ in urban environments and to examine how these LCZ methods were used in the research. For this purpose, three main objectives were identified:

- Summarize the last ten years of LCZ-related literature for summary analysis.
- Analyze the main LCZ application themes.
- Forecast the future LCZ research directions.



Built types	Definition	Land cover types	Definition
1. Compact high-rise	Dense mix of tall buildings to tens of stories. Few or no trees. Land cover mostly paved. Concrete, steel, stone, and glass construction materials.	A. Dense trees	Heavily wooded landscape of deciduous and/or evergreen trees. Land cover mostly pervious (low plants). Zone function is natural forest, tree cultivation, or urban park.
2. Compact midrise	Dense mix of midrise buildings (3–9 stories). Few or no trees. Land cover mostly paved. Stone, brick, tile, and concrete construction materials.	B. Scattered trees	Lightly wooded landscape of deciduous and/or evergreen trees. Land cover mostly pervious (low plants). Zone function is natural forest, tree cultivation, or urban park.
3. Compact low-rise	Dense mix of low-rise buildings (1–3 stories). Few or no trees. Land cover mostly paved. Stone, brick, tile, and concrete construction materials.	C. Bush, scrub	Open arrangement of bushes, shrubs, and short, woody trees. Land cover mostly pervious (bare soil or sand). Zone function is natural scrubland or agriculture.
4. Open high-rise	Open arrangement of tall buildings to tens of stories. Abundance of pervious land cover (low plants, scattered trees). Concrete, steel, stone, and glass construction materials.	D. Low plants	Featureless landscape of grass or herbaceous plants/crops. Few or no trees. Zone function is natural grassland, agriculture, or urban park.
5. Open midrise	Open arrangement of midrise buildings (3–9 stories). Abundance of pervious land cover (low plants, scattered trees). Concrete, steel, stone, and glass construction materials.	E. Bare rock or paved	Featureless landscape of rock or paved cover. Few or no trees or plants. Zone function is natural desert (rock) or urban transportation.
6. Open low-rise	Open arrangement of low-rise buildings (1–3 stories). Abundance of pervious land cover (low plants, scattered trees). Wood, brick, stone, tile, and concrete construction materials.	F. Bare soil or sand	Featureless landscape of soil or sand cover. Few or no trees or plants. Zone function is natural desert or agriculture.
7. Lightweight low-rise	Dense mix of single-story buildings. Few or no trees. Land cover mostly hard-packed. Lightweight construction materials (e.g., wood, thatch, corrugated metal).	G. Water	Large, open water bodies such as seas and lakes, or small bodies such as rivers, reservoirs, and lagoons.
8. Large low-rise	Open arrangement of large low-rise buildings (1–3 stories). Few or no trees. Land cover mostly paved. Steel, concrete, metal, and stone construction materials.	**VARIABLE LAND COVER PROPERTIES** Variable or ephemeral land cover properties that change significantly with synoptic weather patterns, agricultural practices, and/or seasonal cycles.	
9. Sparsely built	Sparse arrangement of small or medium-sized buildings in a natural setting. Abundance of pervious land cover (low plants, scattered trees).	*b. bare trees*	Leafless deciduous trees (e.g., winter). Increased sky view factor. Reduced albedo.
		s. snow cover	Snow cover >10 cm in depth. Low admittance. High albedo.
10. Heavy industry	Low-rise and midrise industrial structures (towers, tanks, stacks). Few or no trees. Land cover mostly paved or hard-packed. Metal, steel, and concrete construction materials.	*d. dry ground*	Parched soil. Low admittance. Large Bowen ratio. Increased albedo.
		w. wet ground	Waterlogged soil. High admittance. Small Bowen ratio. Reduced albedo.

Figure 1. Building and land cover types in the local climate zone (LCZ) classification system of Stewart and Oke [11].

2. Review Methods

We used the following three steps for the review analysis of LCZ.

2.1. Article Screening

The articles were systematically reviewed using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework [13]. Generally, systematic evaluations include the following five necessary steps: develop research issues and their scope, collect data and define sources, filter data and obtain relevant data, and finally summarize [14]. We chose "local climate zone" as the main keyword phrase in the "article title" field. Two academic research databases were selected to identify and extract the relevant scientific articles, namely, Web of Science (WoS) and Elsevier. Since the concept of "local climate zone" was proposed in 2012, our search selected all references of the literature for the period from 1 January 2012 to March 2022. The literature selection process consisted of five steps (Figure 2):

1. The query process, yielding many results for two databases: 170 articles from the WoS core collection and 94 articles from Elsevier, resulting in a total of 264 articles.
2. Screening alignment of the papers from the two databases, removing duplicates for further analysis, resulting in a total of 202 papers.
3. Filtering both databases to identify articles within the scope of this review. Filtering the types of articles, limiting the search to research and review articles only, while excluding social material, meeting, and comment, etc. After filtering, 195 articles were obtained.
4. Screening titles/abstracts/methods to identify studies that only mentioned LCZ and did not actually apply it.
5. Finally, 190 related articles on LCZ were obtained.

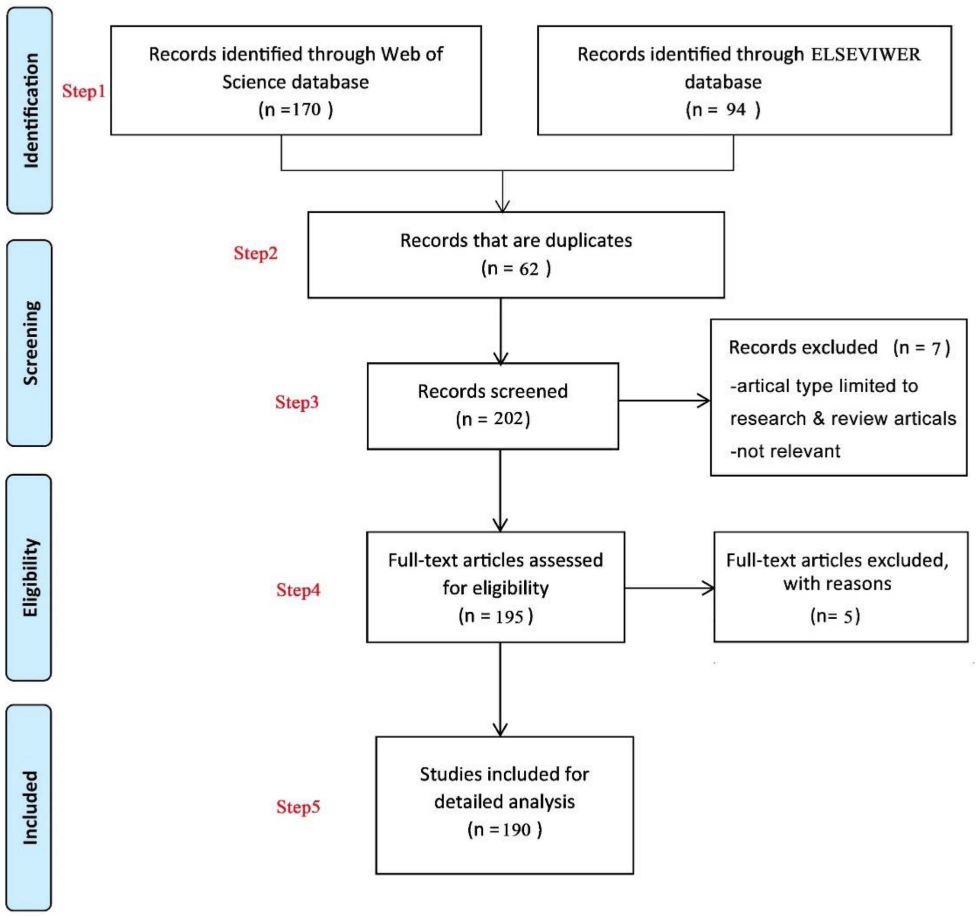


Figure 2. Flow chart of the literature selection and review process for the WoS and Elsevier databases using the initial keywords.

2.2. LCZ Overall Visualization Analysis

Several aspects of the LCZ study content related to this review were used in the analyses using VOSviewer software (1.6.18), which developed by Van Eck and Waltman of The Centre for Science and Technology Studies (CWTS) in the Netherlands in 2009 is a free software. This software supports the data retrieved from the WoS and Elsevier databases, but these data cannot be analyzed simultaneously, so each database was analyzed and visualized separately. In the analysis, the data were merged with matching terms. For instance, themes such as "local climate zone", "local climatic zones" and "LCZ" were merged with "local climate zone" to avoid confusion with more terms than actually occur.

The results were analyzed using the following criteria:

1. Keyword co-occurrence of the authors in the articles selected using WoS and Elsevier.
2. The most common sources of LCZ-related papers and the citation links between them are from WoS and Elsevier.
3. Top reference sources for LCZ-related papers and reference links in WoS and Elsevier.

2.3. LCZ Study Classification

The classification of the article contents based on the selected papers in step 1 primarily used the following scientific research fields: LCZ mapping, measurement methods, thermal environments, and outdoor thermal comfort, and others (Figure 3).

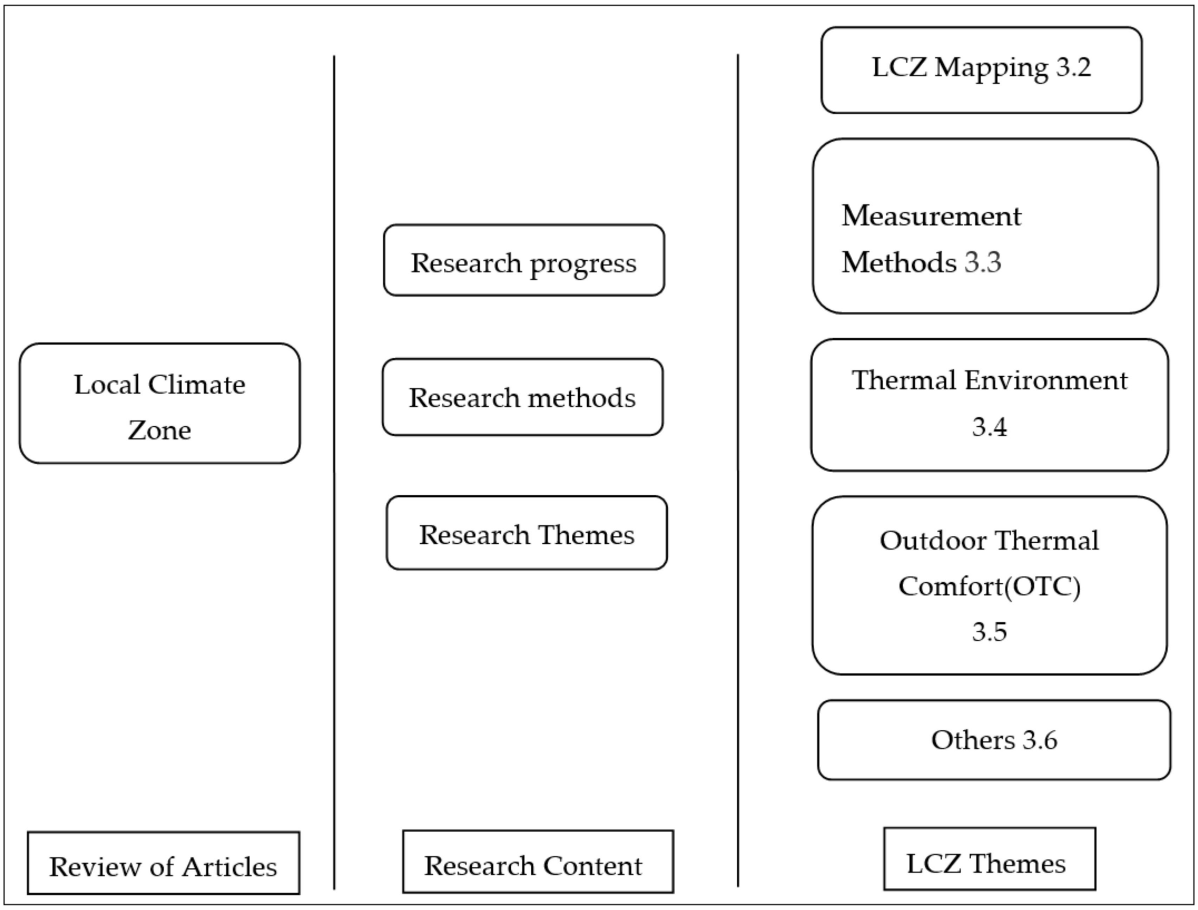


Figure 3. Research themes related to LCZ.

3. Results

3.1. Descriptive Analysis

3.1.1. Geographical Patterns

There is a concentration of LCZ studies in three countries (Figure 4). China has published up to 119 articles, followed by 33 in Germany, and 28 in the United States. Globally, China is the leading country in Asia, followed by 159 related articles published in 14 countries, including India and South Korea. European countries have since published many articles, including 113 studies from 12 different countries. In contrast, Africa and Oceania have published fewer relevant articles.

Figure 4. Geographic distribution of LCZ studies. The size indicates the number of articles originating from that country.

The statistics are only relevant to the study site (Figure 5). Some research compared LCZ among regions (e.g., [12,15]), while others were reviews that were not counted (e.g., [16]).

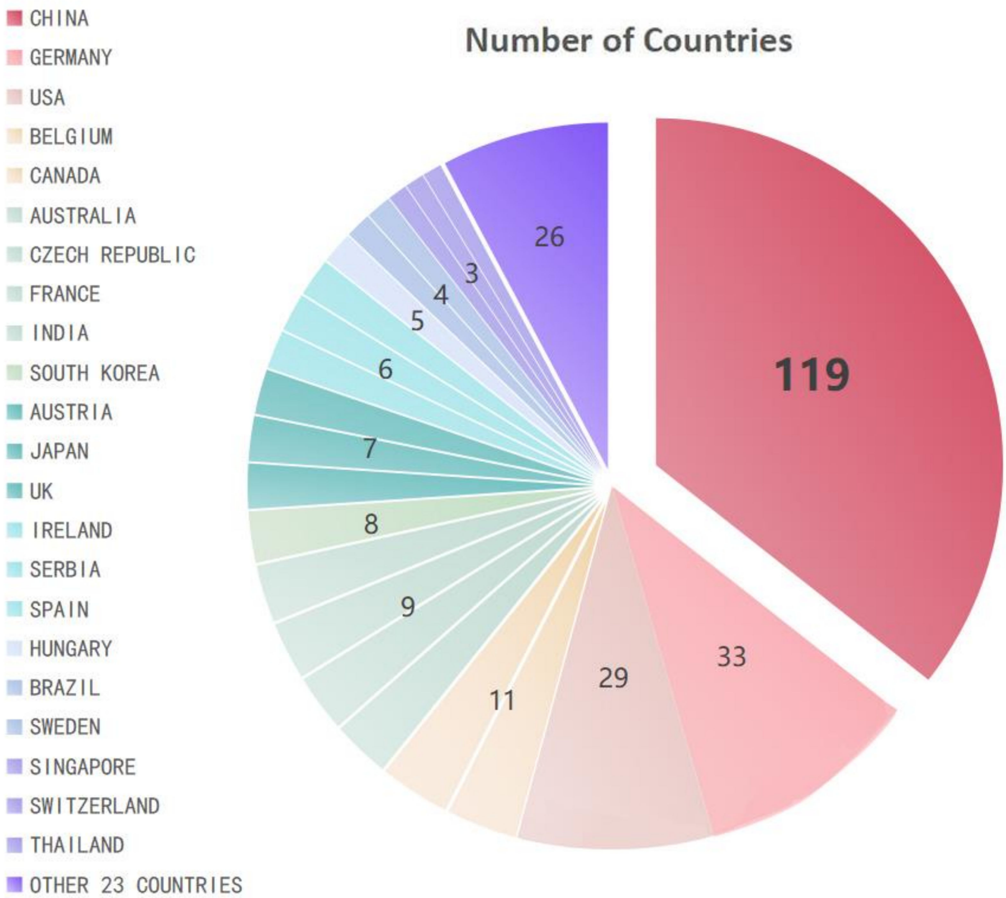


Figure 5. Number of published LCZ studies in each country.

3.1.2. Keywords

We identified 54 keywords in the LCZ literature and at least four simultaneously (Figure 6). The keyword "LCZ" is most commonly mentioned, together with "UHI" and "urban climate", followed by "WUDAPT", "urban morphology", and "LST".

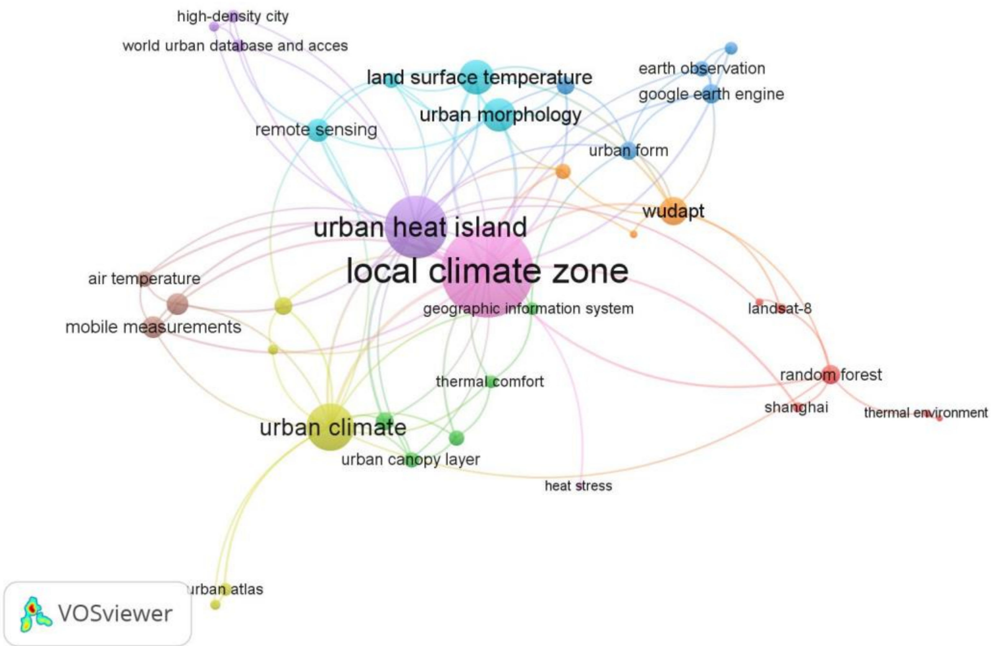


Figure 6. Author keyword co-occurrence analysis in selected articles.

3.1.3. Annual Distribution

The number of studies related to LCZ has increased dramatically, from 2 in 2012 to 57 in 2021, demonstrating an increasing global interest in LCZ (Figure 7).

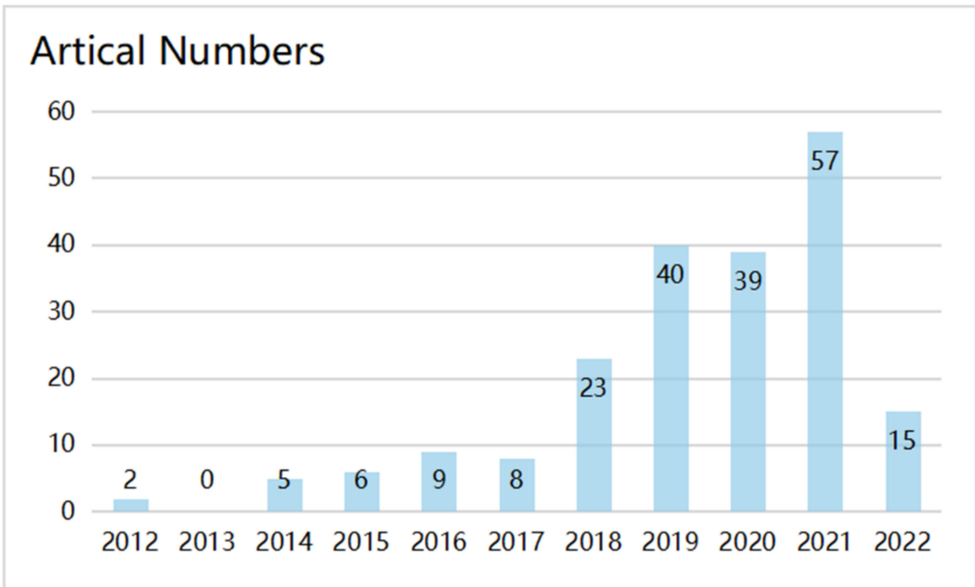


Figure 7. Annual distribution of the bibliographic data.

3.1.4. Contributing Journals

The journal *Urban Climate* had the most published articles (43), followed by *Building and Environment* and *Remote Sensing* ranked second and third, with 22 and 16 records, respectively (Table 1). These journals cover a wide scope of disciplines, for example, meteorology, environmental science, remote sensing technology, building science, and urban science.

Table 1. Publication journal ranking.

	Journal	Number
1	*Urban Climate*	43
2	*Building and Environment*	22
3	*Remote Sensing*	16
4	*IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*	10
5	*Sustainable Cities and Society*	9
6	*Sustainability*	7
7	*ISPRS Journal of Photogrammetry and Remote Sensing*	6
8	*International Journal of Applied Earth Observation and Geoinformation*	5
9	*Atmosphere*	5
10	*ISPRS International Journal of Geo Information*	3
11	*Climate Research*	3
12	*International Journal of Biometeorology*	3
13	*International Journal of Climatology*	3
14	*Journal of Geophysical Research Atmospheres*	3
15	*Landscape and Urban Planning*	3

3.1.5. Article Citation Frequency

The most-cited paper in the top 10 most-cited papers is the article entitled "Local climate zones for urban temperature studies" by Stewart and Oke (2012), which proposed the concept of LCZ to be the origin of LCZ (1441 citations as of March 2022) (Table 2).

Table 2. Top 10 most-cited papers identified in our literature search.

	Title	Number
1	Local climate zones for urban temperature studies [11]	1441
2	Impact of urban form and design on mid-afternoon microclimate in Phoenix Local Climate Zones [9]	308
3	Mapping local climate zones for a worldwide database of the form and function of cities [17]	268
4	Evaluation of the 'local climate zone' scheme using temperature observations and model simulations [10]	265
5	Using Local Climate Zone scheme for UHI assessment: Evaluation of the method using mobile measurements [18]	133
6	Classification of local climate zones based on multiple Earth observation data [19]	127
7	Local Climate Zone ventilation and urban land surface temperatures: Towards a performance-based and wind-sensitive planning proposal in megacities [8]	122
8	Design of an urban monitoring network based on Local Climate Zone mapping and temperature pattern modelling [20]	91
9	Employing an urban meteorological network to monitor air temperature conditions in the 'local climate zones' of Szeged, Hungary [21]	83
10	Land surface temperature differences within local climate zones, based on two central European cities [22]	75

3.2. LCZ Mapping

3.2.1. Simple Division of City Types Using the LCZ Classification

Generating urban LCZ maps is an important part of the related research. After reviewing all retrieved articles, 57 were related to LCZ mapping, some of which focused on the generation of LCZ classification maps in each city. There are three main methods of LCZ classification: field measurements, remote sensing (RS), and geographic information system (GIS). Among them, the method based on remote sensing images—World Urban

Database and Access Portal Tools (WUDAPT)—is most commonly used for the relative comparison of LCZ mapping research [17], which is a general method based on the Landsat database and the random forest (RF) classifier used in LCZ mapping, and is used in Hong Kong, China [23], Zimbabwe, Africa [24] and France [25]. The WUDAPT method was developed to promote the LCZ classification of urban climate studies at the city scale. Based on globally available satellite imagery from the Geological Survey and training samples from Google Earth (GE), the WUDAPT method can be processed in a standard workflow, applying machine learning using open-source software (System for Automated Geoscience Analysis, SAGA) to simulate human interpretations of the identification of LCZ classes [17].

A number of studies map urban LCZ using at least two of the above classification methods. Taking into account differences in urban microclimates within and between cities, the WUDAPT (Figure 8) has been developing an international database of global cities, using unanimous methodological and tool frameworks [26] (Table 3).

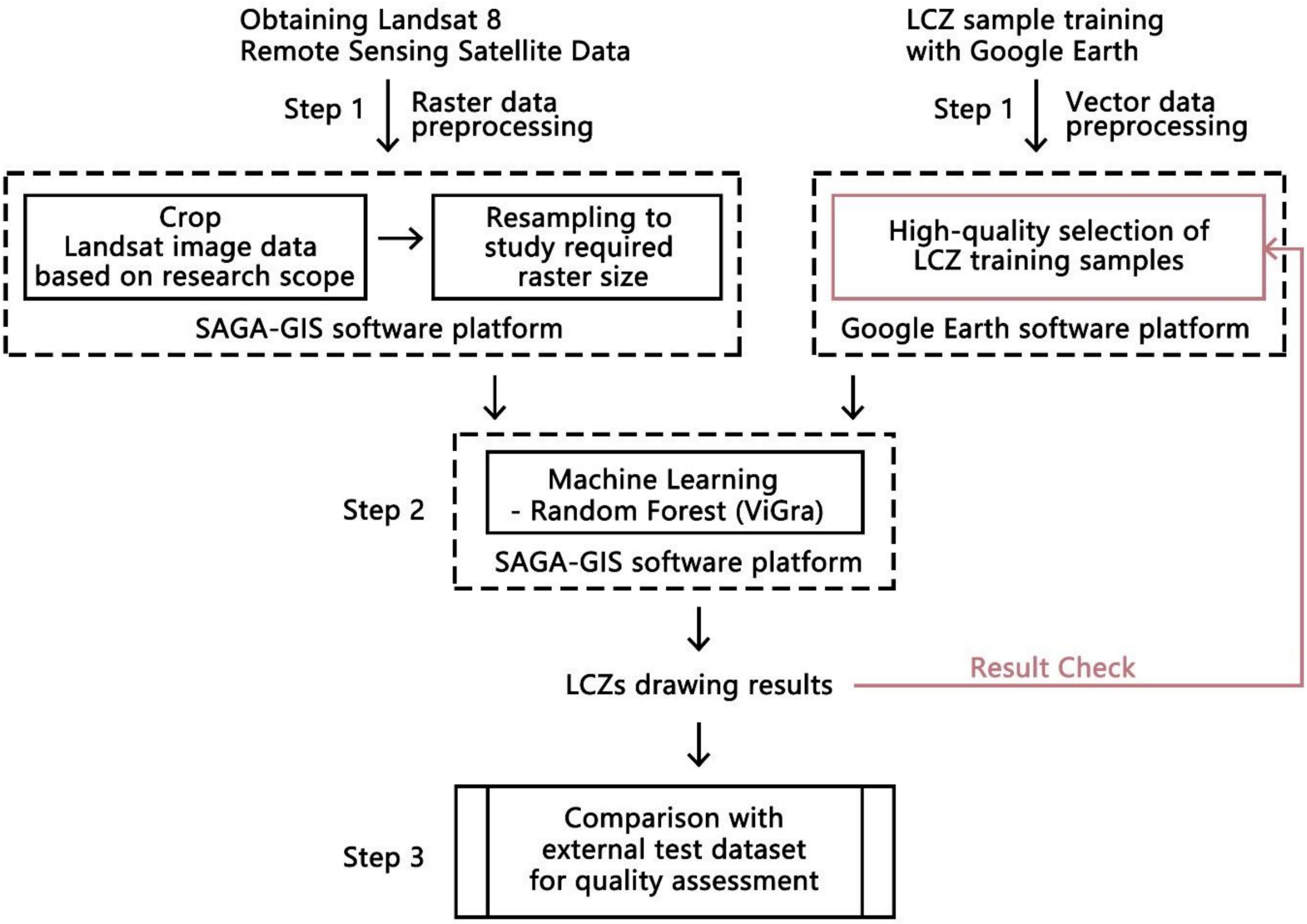


Figure 8. WUDAPT data collection process.

Table 3. Basic analytical methods used in LCZ mapping.

Method	Articles	Study Site	LCZ Types
WUDAPT	[26]	London, England	All types
	[25]	Sendai, Japan	LCZ 2, 24, 3, 42, 5, 6-10, A, B, D-G
	[27]	Kyiv and Lviv, Ukraine	All types
	[28]	Madrid, Spain	All types
	[29]	Bavaria, Germany	LCZ 2, 5, 6, 8, A, B, D, G, E
	[30]	15 European cities	All types
	[31]	20 individual cities and three major economic regions in China	All types
GIS-based and WUDAPT	[32]	Hong Kong, China	All types
GIS-based	[23]	Hong Kong, China	LCZ 1-6, 9, A, C, D-G, W
	[20]	Szeged, Hungary	LCZ 2, 3, 5, 6, 8, 9
	[33]	Szeged, Hungary	Six built LCZ types
	[34]	Brno, Hradec Králové, and Olomouc, Czech Republic	LCZ 1-6, 8-10, A-G
Earth observation (EO) datasets and classifiers seemed	[19]	Hamburg, Germany	All types
Sentinel-2 data	[35]	13 cities across the world	All types
	[36]	Munich and Berlin, Germany	All types
	[37]	Shenzhen, China	All types
ECOSTRESS data	[38]	Xi'an, China	LCZ 1-6, B
Sentinel-1 Dual-Pol data	[39]	29 cities across the world	All types

3.2.2. Optimizing LCZ Classification

In the traditional deep learning methods such as RS and GIS, the accuracy in the urban-type LCZ (LCZ1-10) remains relatively low because RS datasets cannot provide vertical or horizontal building components in detail [40]. Building information is typically obtained from the National Geospatial Information Agency or OpenStreetMap (OSM) building footprint data [27,41]. Some novel methods can improve this issue [42–44]. GIS-based building datasets can be used as a primary source for LCZ classification, but their use as input data for convolutional neural networks (CNNs) is limited due to their incompleteness [32,45]. Some recent studies have applied deep learning methods to further improve LCZ classification accuracy using RS data, which makes CNNs important [35,46].

There have been many studies improving the accuracy of LCZ mapping methods, most of which have proposed an upgraded version of the WUDAPT method or have compared WUDAPT L0 data, including a team at the University of Hong Kong and others to evaluate and refine the Chinese LCZ map [31,47,48]. In Colombo, Sri Lanka, using WUDAPT to make LCZ maps for initial classification, a large number of LCZs were subdivided to better represent the local conditions of this high-density tropical city [49].

Other studies differ from the WUDAPT methods and have considered it to be insufficient in accuracy, proposing further research to improve the methods of mapping LCZ. For example, a study introduced grid-based mapping methods using 1 km, 500 m, and 250 m for LCZ identification and mapping [50]. Scholar Hidalgo proposed that although the average building height standard in France corresponds to the LCZ classification, the boundary between the open and sparsely built areas was determined using the k-means statistical method [51] (Table 4).

Table 4. LCZ mapping improvement method.

Method	Articles	Study Site	Improved
WUDAPT	[30]	24 cities in Europe	Presents two strategies to expand LCZ coverage rapidly
	[35]	13 cities around the world	Proposes a multi-task learning (MTL) framework and develops an end-to-end convolutional neural network (CNN)
	[42]	Hamburg, Germany	WUDAPT + OpenStreetMap (OSM)
	[52]	15 cities that cross a series of climates	Google Earth Engine (EE) is a viable alternative approach compared to WUDAPT method
	[53]	New York, USA Nantes, France	The Delaunay triangulation versus a skeletonization
	[54]	Guangzhou, China	A block-based LCZs classification
	[55]	St. Petersburg, Russia Bamako, Mali Havana, Cuba	Simplified WUDAPT (the LCZ Generator described here further simplifies this process)
	[56]	Three cities in Belgium: Antwerp, Brussels, and Ghent	Due to the high degree of heterogeneity, neighborhood information on the LCZ mapping overcomes the difficulties of the WUDAPT community
	[57]	Manhattan, New York, USA; Atlanta, USA; Tokyo, Japan;	A fine-grained and 3D approach
	[58]	Vienna, Austria	GIS-based and WUDAPT
	[59]	Berlin, Germany; São Paulo, Brazil; Paris, France	A self-training classification framework (SCSF) based on spatial context information is proposed to address the lack of a unified framework for classification and spatial smoothing
	[60]	Xi'an, China	This method couples the World Urban Database and Access Portal Tools method
	[61]	Khartoum, Sudan	The methodology uses synthetic aperture radar (SAR) data
	[62]	Guangzhou and Wuhan, China	Combining Landsat and ASTER data to improve the LCZ mapping results
Others	[40]	Berlin, Germany; Seoul, South Korea	Provides novel methods using S2 images and incomplete building data based on a CNN classifier to classify LCZ
	[44]	11 cities around the world	This paper uses OpenStreetMap (OSM) data and multi-temporal, multispectral satellite images for the classification of LCZs
	[46]	Eight German cities	Proposes a workflow to generate LCZs using multi-temporal Sentinel-2 (S2) composites and supervised CNNs
	[48]	Guangzhou, China	Simplified LCZ method
	[49]	Colombo, Sri Lanka	Simplified LCZ method
	[50]	Nagpur, India	"Reduction-based GIS method" and "algorithm-based remote sensing" approach
	[51]	Nantes, Toulouse, and Paris, France	This paper uses GIS using administrative and 2.5 D building databases to generate the LCZs
	[53]	New York, USA; Nantes, France	Tries to translate this classification to a fine-grained level of detail
	[63]	Busan, Daegu, Daejeon, Gwangju, Incheon, and Seoul, South Korea	The study uses a multi-scale, multi-level attention network (MSMLA-Net) for LCZ classification
	[64]	Beijing, China	This paper proposes an enhanced GIS-based workflow to enable the hierarchical classification of LCZs with fewer indicators, but higher accuracies

Table 4. *Cont.*

Method	Articles	Study Site	Improved
	[65]	Wuhan, China	This paper combines neural networks and two graph convolutional networks (GCNs) into and directly using original image-generated LCZs
	[66]	Wuhan, China	This paper uses multi-source-generated LCZs
	[67]	Bandung, Indonesia	The result shows that the object-based image analysis (OBIA) provides higher accuracy in LCZ
	[68]	Basel, Switzerland	A method is proposed to bridge the gap between the classical land use/land cover (LULC) classification and the LCZ scheme
	[69]	Sydney, Australia	Examines the quality of the classification by analyzing the LST variability between LCZs using high-resolution airborne remote sensing data
	[70]	Eight metropolitan areas in the USA	Random forests and ResNets are applied for LCZ classification
	[71]	Beijing, Tianjin, and Wuhan, China	Uses freely available Sentinel-1 SAR and Sentinel-2 multispectral imagery to generated LCZs
	[72]	Shanghai, China	Provides a promising option for LCZ mapping

In the traditional deep learning methods, the accuracy in the urban-type LCZ (LCZ 1-10) remains relatively low because a remote sensing dataset cannot provide vertical or horizontal building components in detail. Some novel methods can improve this issue.

3.3. Measurement Methods

In addition to the LCZ studies using satellite data (in Section 3.2), there are other measurement methods, including both stationary and mobile measurements, as well as studies of LCZs using models.

3.3.1. Fixed-Point Observations

In most studies, placing measurement instruments in a fixed position for data collection and subsequent statistical analysis is a common research approach. Yang et al. simultaneously collected temperature and humidity data from 14 different LCZs in Nanjing using a fixed-point measurement method within 401 days [73,74]. LCZ air temperature data were collected at Parana using air temperature sensors with 10 built-in data loggers from 27 August to 15 December 2018 [75]. These data complemented the temperature data from five Spanish State Meteorological Agency (AEMET). The results showed that a relatively high UHI intensity has been observed in Madrid, reaching above 5 °C [76].

There have also been LCZ studies using data from local climate stations. One was located in Novi Sad, Serbia, to study the spatiotemporal dynamics of the official weather stations of the Hydrometeorological Service of the Republic of Serbia (RHMZ) and the relationship between air temperature and five air humidity variables (relative humidity, water vapor pressure, absolute humidity, specific humidity, and water vapor pressure deficit), based on two-year data [77].

In Berlin, Germany, they analyzed a 2015 annual dataset of near-surface air temperatures (AT) from the Cyber Movement Citizen Weather Station (CWS) and the surrounding environment. The data, combined with the concept of the LCZ, showed the applicability of a new dataset for urban climate research [78].

3.3.2. Mobile Measurements

Mobile measurement methods have been widely used in UHI or urban climate studies. Contrary to fixed-point observations, mobile measurement is a more cost-effective approach in investigating urban environments [79] (Table 5).

Table 5. Mobile measurements used in LCZ studies.

City	Articles	Mobile Measurements	Equipment
Nancy (France)	[18]	Instrumented vehicle	PT100 probe
Nancy (France)	[80]	Instrumented vehicle	PT100 probe
Chongqing (China)	[81]	/	/
Dijon (Eastern France)	[82]	Cargo bike	HOBO U23 v2 sensor located in an M-RSA solar radiation shield and attached to a data logger
Hong Kong (China)	[83]	Light-colored Toyota bB mini MPV vehicle	TESTO™ 480 Thermometers Garmin™ GPS Map 62 s Handheld Navigator Wide-angle video camera

The summer air temperature was recorded in the 13 LCZs in Nancy, France, in 2013 and 2015, with recordings made every three meters in a moving vehicle. To study the effect of speed on temperature, a sensitivity test was performed and the results showed that the average temperature value was little affected by vehicle speed [18,80]. In Chongqing, the authors used an instrumented vehicle for automatic loading temperature and humidity data loggers (HIOKI 3641) and a GPS data logger (GlobalSat DG-100). Five types of LCZ were measured [81]. In Dijon (eastern France), urban temperatures were analyzed using bicycle mobility measurements to quantify the effect of urban morphology on microscale variations in temperature [82]. An evaluation was made on the local climate zone classification in high-density heterogeneous urban environments using mobile measurements [83].

Fixed-point observations can acquire more data at the same LCZ location, and in contrast, mobile measurements can acquire data from more locations with fewer instruments; thus, to classify many types, research requires more instruments for which this measurement is suitable. Scholars can choose different measurement methods according to the needs and purposes of the data within the same LCZ type.

3.3.3. Urban Climate Models

Urban climate models are most commonly used as an LCZ research method (Table 6). Ariane Middel used model research as early as 2014, and it was also the second most-cited research article. The author used a three-dimensional microclimate model, ENVI-met, to simulate five LCZ types in Phoenix [9]. Alexander proposed that, although in recent years there have been models to describe urban surfaces and to simulate their climate effects, there is no solution to the data processing requirements of more complex urban models. Thus, they used the running Surface Urban Energy and Water Balance (SUEWS) energy balance model combined with LCZ as a solution [84]. In 2020, Liu proposed an application of the LCZ concept to quantify urban blocks, and developed the urban canopy layer (UCL) model to propose a visualization-based spatial form optimization strategy for local-scale urban blocks, developed and validated using Dynamic Local Energy Balance Model—V1.0 software [85].

Table 6. Models frequently used in LCZ studies.

Models	Number of Studies	Articles
Weather Research and Forecasting Model (WRF)	4	[86–89]
Solar and LongWave Environmental Irradiance Geometry-model (SOLWEIG)	4	[90–93]
MUKLIMO	2	[94,95]
Three-dimensional Microclimate Model	1	[9]
Urban energy Balance Calculation Model (UDC model)	1	[54]
SUEWS	1	[84].
Urban Canopy Layer (UCL) Model	1	[85]
Digital Surface Model (DSM) and normalized Digital Surface Model (nDSM)	1	[96]
Ozone Chemical Transport Model	1	[97]
Surface Energy Balance over Land (SEBAL) model	1	[98]
UrbClim model	1	[99]

3.4. Thermal Environment

Since LCZ was first proposed to facilitate further research on UHI, the number of articles in this field is the largest in all research fields.

3.4.1. Urban Heat Islands (UHIs)

UHIs refer to a higher temperature in urban areas compared to that of the surrounding environment. This temperature difference is generally larger during the day [100], and is closely related to an assessment of the thermal environment in urban areas [101]. In 2012, Oke proposed the use of the equation $\Delta T = LCZx - LCZD$ to describe and calculate urban heat island intensity. This method has already been used in a number of cities around the world. For example, Benjamin Bechtel, from Ruhr-Universität Bochum in Germany, analyzed and compared the surface urban heat islands (SUHI) of LCZs in 50 cities around the world [12]. During a period of 401 days, Yang et al. used fixed-point measurement to simultaneously collect the temperature data of 14 different LCZs in Nanjing to evaluate the Nanjing UHI [73]. However, using RS datasets on the LCZs to study the UHI is not enough, so many scholars have used other data to research the study area of UHI. Zhou analyzed Sendai's UHI in Japan based on 12 GIS-derived LCZ classifications with geometric and land cover properties, and proposed two specific UHI mitigation strategies for Sendai [102]. In Dublin, Ireland, the LCZ air temperature was obtained using metadata from six fixed weather stations, and the LCZ was derived as Dublin's UHI [103]. These results suggest that under conditions favorable for the development of UHIs, on average, an LCZ with high impermeability/building coverage is >4 °C higher than an LCZ with high permeability/vegetation coverage at night.

3.4.2. Land Surface Temperature (LST)

Understanding temporal and spatial variation in land surface temperature (LST) and the thermal impact of varying urban landscapes is critical for developing strategies to improve urban thermal conditions. The spatial distribution of heat in urban areas is primarily assessed via site air temperature or satellite-based LST measurements [18]. There are many studies in China exploring the relationship between LCZ and LST. For example, high-resolution remote sensing was used in Xi'an to explore the relationship between the LCZ-based 2D/3D urban form and LST inter-seasonal spatial changes in image and vector building data [38,104]. They also used MODIS to explore the urban surface thermal performance of the LSTs of three urban areas in China [105].

There have also been some related studies in the Czech Republic. In Prague and Brno, the two largest cities in the Czech Republic, a new GIS-based approach to LCZ demarcation was employed, using both LSTs from land and satellite data to explore how well LCZ categories differentiate LSTs [22]. Another paper attempts to combine LCZ and LSTs using a complex approach derived from a case study in Hradec Kralove, the Czech Republic [106].

3.5. Outdoor Thermal Comfort

Thermal comfort is a subjective evaluation of human satisfaction with the surrounding thermal environment (ISO 7730). Outdoor thermal comfort is closely related to the surrounding climate and environment, and the research in this field has been relatively rich, including such elements as heat comfort in cold areas [107–110], outdoor thermal comfort for special population groups [111,112], heat and comfort at tourist attractions [113], heat experiences in different populations and their effect on outdoor heat comfort [114], thermal comfort among outdoor plants [115,116], and the general impact of thermal comfort [117], but this article explores the articles combining OTC and LCZ to explore people's comfort index, which aims to improve the quality of the thermal environment.

Part of the study on thermal comfort used a field measurement and a survey questionnaire to evaluate the relationship between LCZ and outdoor thermal comfort. For example, in 2014, the author Villadiego performed an OTC study in the hot and humid climate of Barranquilla, Colombia [118]. Five LCZ types were selected for physical measurements and they used the ASHRAE sensorial scale of seven symmetrical points to assess people's subjective thermal sensation and thermal comfort among LCZs [118]. In Hong Kong (2019), Lau et al. evaluated the microclimate conditions and the subjective perception of the thermal environment in eight LCZs in sub-tropical high-density cities, including Hong Kong [119], among others.

Some research has also used models to describe LCZs. For example, Salal Rajan and Amirtham measured it at the three LCZs of Chennai, and used an "ENVI-met" model simulation to estimate the thermal comfort index (Tmrt + PET) [120]. Geletic used the MUKLIMO_3 (Mikroskaliges Urbanes KLImaMOdell in 3-Dimensionen) urban climate model in Germany to analyze outdoor thermal comfort conditions by HUMIDEX during the summer of 2015 (4–14 August), using meteorological data from 14 sites [95]. In Zhengzhou, Ren et al. used predicted mean vote (PMV) to calculate the OTC based on LCZs, and studied the correlation between LST and the vegetation-type effects of LCZ [121].

In addition, LCZ and thermal comfort were quantified by Lin Liu et al. First, nine typical urban LCZs were selected for a field survey. Outdoor thermal comfort levels with different urban spatial characteristics were assessed using a statistical method based on the fuzzy-AHP method "Quantitative". Through physical meteorological measurements and a subjective questionnaire, the thermal "neutral" value ranges were found for the three thermal comfort indicators, (TCI)-PET, OUT-SET*, and UTCI; linear, logarithmic, and cubic models were applied, and Fi (a parameter that describes/relates to thermal comfort indicators) and TCI values were calculated for the nine LCZs. The quantitative equation between Fi and TCI is expressed in their work [122].

Another data source for a study of thermal comfort and LCZ is the Hungarian Meteorological Service (HMS). This study found that the most pleasant areas during the day were those with fewer buildings, but the opposite was true at night. This work was applied at the urban scale, thus breaking the previous limitations of LCZ in OTC, which were at the micro scale [123].

Articles on thermal comfort tended to be based on small-scale research, regardless of the method used. Several typical LCZ types were selected to use different thermal comfort indexes for outdoor thermal comfort research (Table 7).

Table 7. Research on LCZ and thermal comfort.

Method	Articles	Type	City, Country	LCZ Types	Thermal Comfort Index
Simulation	[91]	SOLWEIG	Vancouver, Canada	6 LCZs	Tmrt
	[93]	LongWave Environmental Irradiance Geometry (SOLWEIG)	Brazil	LCZ 1 and 3	Mean Radiant Temperature (Tmrt)
	[95]	MUKLIMO_3 urban climate model	Brno, Czech Republic	LCZ 2-10, A-E, G	HUMIDEX
	[120]	ENVI-met	Chennai, India	LCZ 2. 3. 5. 6	Physiological Equivalent Temperature (PET)
	[121]	ENVI-met	Zhengzhou, China	All types	Predicted Mean Vote (PMV)
	[124]	BioKlima 2.6 model	Shenzhen, China	11 LCZ samples	Universal Thermal Climate Index (UTCI)
Questionnaire	[118]	Seven-point ASHRAE scale	Barranquilla, Colombia	5 LCZs	Mean Thermal Sensation Votes (MTSV)
	[119]	Seven-point ASHRAE scale	Hong Kong, China	LCZ 1-6, LCZ D, E	PET
	[122]	Seven-point ASHRAE scale	Shenzhen, China	9 LCZs	PET, OUT-SET* and UTCI
Weather station	[123]	Hungarian Meteorological Service (HMS)	Szeged, Hungary	6 LCZs	PET

3.6. Urban Planning and the Urban Environment

3.6.1. Urban Planning

Urbanization is determined by geographic location, local policies, and local circumstances. City managers most urgently need to fully consider climate adaptation issues in land use planning and implementation to improve climate resilience [125]. Therefore, many researchers combine LCZ with local policies with the purpose of enabling decision makers to propose better urban planning solutions and to improve the wellbeing of residents. Urbanization is one of the major drivers of global thermal environmental change and is changing rapidly and on a large scale, especially in China [126]. Kunming (China) [127] provides a simple framework to monitor rapid urban expansion and changes in urban form, and transfer/transform it to urban practitioners, enabling them to formulate sound urban planning strategies for sustainable urban development. Comparing the two high-density cities of Hong Kong and Guangzhou (China), this research provided a fast and effective way to understand the thermal environment within high-density cities and will help to better plan to improve urban thermal conditions and ensure more sustainable development [128].

The primary task of mapping LCZs in Indian cities has been shown to be very challenging without properly implemented spatial development plans, an understanding of complex urban morphology, and the issue of insufficient data. This information would provide city planners with the correct configuration of LCZ maps to understand how to concentrate on developing areas for UHI mitigation [129]. According to Perera and Emmanuel (2018), in Colombo (Sri Lanka), current planning regimes cannot address the challenges posed by individual local, regional, and global warming, and a simpler approach is proposed that uses the LCZ system for the environmental analysis of data-poor developing cities [59].

3.6.2. Urban Environments

Populations continue to move into cities, accelerating the process of urbanization. Environmental issues are the key to comfort solutions in urbanization. Numerous studies highlight the impact of respiratory particulate matter on human health [130]. A study in the English Bazar Municipality [131] attempted to correlate respiratory particulate matter (RPM) and LST in each LCZ to determine the effect of RPM on LST. Nine LCZs were identified in this study area. The results showed that LCZ3, LCZ5, LCZ6, LCZ7, and LCZD had relatively high LSTs and RPM, with important spatial seasonal variation. Particulate matter <2.5 µm in aerodynamic diameter (PM2.5) has been recognized as one of the major pollutants that reduce urban air quality [132]. Yuan Shi et al. investigated the effects of land use and landscape patterns on the spatial variation of PM2.5 in Hong Kong (China), particularly to determine the impact of regulating PM2.5 concentration levels on the types of landscapes affected.

A study in Shanghai aimed to provide a standard framework for estimating building carbon emissions within LCZs to better predict carbon emission patterns from buildings within other LCZs and to assist in energy management in different LCZs [133].

3.6.3. Others

In addition to the above-mentioned research types on LCZ, LCZ has also been increasing in popularity in other fields. Although LCZ was proposed to describe UHIs, there are also studies using LCZ on health issues, urban ventilation performance, and energy consumption. Oscar Brousse et al. were the first researchers who attempted to use WUDAPT and generate the LCZ in tropical sub-Saharan Africa, and they linked the framework of the LCZ as a tool to improve urban health with a malaria spread risk model [134,135]. A study in Shenyang (China) analyzed the wind information from 16 weather stations to demonstrate the suitability for the use of an LCZ classification scheme to represent local-scale urban ventilation performance [136].

Several articles have also appeared on energy consumption in buildings. Using three different methods to investigate the energy consumption patterns of two different building types in the LCZ in Nagpur, India, it has been shown that the recommendations of the LCZ are critical for building energy policy making [137]. Using the building energy simulations (BES) and as input to the EnergyPlus simulations, the yearly, monthly, and hourly cooling and heating energy demands (LCZ 8) were investigated and compared across all six LCZ sites. The method is used to reasonably evaluate the influence of the heat island effect on the building energy performance at the neighborhood scale [138].

4. Challenges and Future Direction

Oke suggested that the LCZ is a relatively new classification and framework [11]. The LCZ classification was proposed to facilitate the quantification of UHI, but now, researchers are primarily using it for LCZ mapping research that can be seen from Section 3.2. Indeed, UHI can be further explored, although there have been many of these studies conducted in recent years. We summarize five avenues for improvement.

First, there are two key problems in the actual implementation of LCZ mapping: a lack of data and a lack of method specification. From Section 3.1, it can be analyzed that most of the research sites are in China; therefore, additional studies on LCZ mapping in other areas that have not been studied are needed and can further increase the possibility of standardization. While numerous accuracy assessments and precision improvements have been made for LCZ classification, there is still a need to improve cartographic accuracy and to develop a unified/standard method for generating LCZ maps.

Second, improvements in LCZ mapping methods are required. There have been many methods used in LCZ applications, with most studies focusing on the use of WUDAPT and GIS to classify LCZ type. Section 3.2.2 discusses many studies that use different methods to improve the accuracy of LCZ mapping. Most of them use different deep learning or machine learning methods, including CNN (traditional and novel), GCNs, and RF. LCZs represent a generic climate study description applicable to land cover (LULC). A key point is that LCZs are universal in their application and they can be linked to measurable urban parameters of urban form and function. There have been many articles dedicated to improving the accuracy of LCZ mapping, but there is not yet a universal method. Instead of requiring more research to further improve the methodology to increase its accuracy, LCZ maps can be generated for the entire globe.

Third, the application of LCZ is becoming more extensive. It is not only used in urban planning, climatology, UHI, and other fields, but also in many new fields such as diseases and building energy. According to the statistics of this paper, LCZ mapping-related literature is the most numerous, followed by urban thermal environment (including UHI and LST), and although LST can reflect UHI to a certain degree, few articles simply discuss UHI. Since LCZ was first proposed to describe UHI, most scholars still focus on LCZ mapping innovation, in addition to the LCZ mapping standardization based on the second point noted earlier. Thus, the future research direction should increase the main research on the pure UHI theme. New breakthroughs have also been made. Therefore, innovations can be made using combined data sources. This also suggests that other fields could be developed in conjunction with LCZ to discover novel research directions.

Fourth, modeling is most frequently used as a research method. In other fields except LCZ mapping, modeling is used the most frequently. It is recommended that other research methods are used to increase the actual research in this area.

Finally, from the perspective of urban policymakers, there are policy-making aspects that need to be considered. LCZ can help to show the distribution of the thermal environment in a city, which can guide city planners to formulate corresponding urban development plans, provide a basis for urban future planning, improve the implementation of policies, and provide a more comfortable living environment for urban residents.

5. Conclusions

A total of 190 LCZ studies were collected and analyzed in our review. This research used bibliometric and thematic analyses to systematically review the local climate zones. Over the past decade, the number of studies related to LCZs has increased, demonstrating its importance in urban climate research. Overall, the results show that more than half of the published studies on LCZ are in Chinese cities. Due to its close relationship with the urban heat island effect, the local climate zone is an important way to solve the problem of climate change. Systematic reviews reveal a wealth of data sources, methodologies, and analyses used to generate and use maps of local climate zones. The most common topics that appear in the LCZ literature include LCZ mapping, measurement methods, thermal environments, and outdoor thermal comfort. Among them, LCZ mapping has the largest number of articles, followed by thermal environment. Regarding the study of LCZs, scholars focus on discussing the method of LCZ mapping, from the basic RS images and GIS methods used, and then further improve the accuracy, ignoring the fact that LCZ was proposed to describe the UHI. A discussion of UHI and research using other research methods other than modeling is encouraged for LCZ. At the same time, a further standardization of the LCZ mapping method and improvements to the accuracy of LCZ mapping will allow effective preliminary analysis for the field of urban planning, and guide policies to improve the urban thermal environment. The study of LCZ in urban areas improves the urban environment, relieves thermal stress, helps urban decision makers to enhance urban planning solutions, improves the outdoor thermal comfort of urban residents, and helps promote urban sustainability.

Author Contributions: Conceptualization, W.F. and J.L.; methodology, J.L.; software, W.F.; validation, W.F. and J.L.; formal analysis, W.F.; investigation, W.F.; resources, W.F.; data curation, W.F.; writing—original draft preparation, W.F.; writing—review and editing, W.F.; visualization, W.F.; supervision, W.F.; project administration, W.F.; funding acquisition, J.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by [Ministry of Education in China Project of Humanities and Social Science] grant number [No. 17YJCZH166].

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

CIMO	Committee of instruments and methods of observation
CNN	Convolutional neural network
CWS	Citizen weather stations
CWTS	The Centre for Science and Technology Studies
DSM	Digital surface model
EO	Earth observation
EE	Google Earth Engine
GIS	Geographic information system
HMS	Hungarian Meteorological Service
LCZ	Local climate zone
LST	Land surface temperature
MTL	Multi-task learning
MTSV	Mean thermal sensation votes
nDSM	normalized digital surface model
OTC	Outdoor thermal comfort
OSM	Open Street Map
PET	Physiological equivalent temperature
PMV	Predicted mean vote
PRISMA	Preferred reporting items for systematic reviews and meta-analyses
PM2.5	Particulate matter <2.5 μm in aerodynamic diameter
RPM	Respiratory particulate matter
RS	Remote sensing
RHMZ	Republic hydrometeorological service of Serbia
SUEWS	Surface urban energy and water balance model
SAR	Synthetic aperture radar
SAGA	System for automated geoscientific analyses
SCSF	Spatial-contextual information-based self-training classification framework
SVF	Sky view factor
SOLWEIG	Long-wave environmental irradiance geometry
SUHI	Surface urban heat island
Tmrt	Mean radiant temperature
TCI	Thermal comfort indicators
TLCZ	Temperature of LCZ
UHI	Urban heat island
UTCI	Universal thermal climate index
UCL	Urban canopy layer
UDC	Urban energy balance calculation model
UHII	Urban heat island intensity
WUDAPT	Word Urban Database and Access Portal Tools
WoS	Web of Science
WRF	Weather research and forecasting model

References

1. Taha, H. Urban climates and heat islands: Albedo, evapotranspiration, and anthropogenic heat. *Energy Build.* **1997**, *25*, 99–103. [CrossRef]
2. Zhao, L.; Lee, X.; Smith, R.B.; Oleson, K. Strong contributions of local background climate to urban heat islands. *Nature* **2014**, *511*, 216–219. [CrossRef] [PubMed]
3. Ruiz, M.A.; Correa, E.N. Adaptive model for outdoor thermal comfort assessment in an Oasis city of arid climate. *Build. Environ.* **2015**, *85*, 40–51. [CrossRef]
4. Memon, R.A.; Leung, D.Y.; Chunho, L. A review on the generation, determination and mitigation of urban heat island. *J. Environ. Sci.* **2008**, *20*, 120–128. [CrossRef]
5. Santamouris, M. Cooling the cities—A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. *Sol. Energy* **2014**, *103*, 682–703. [CrossRef]

6. Li, J.; Song, C.; Cao, L.; Zhu, F.; Meng, X.; Wu, J. Impacts of landscape structure on surface urban heat islands: A case study of Shanghai, China. *Remote Sens. Environ.* **2011**, *115*, 3249–3263. [CrossRef]
7. Estoque, R.C.; Murayama, Y.; Myint, S.W. Effects of landscape composition and pattern on land surface temperature: An urban heat island study in the megacities of Southeast Asia. *Sci. Total Environ.* **2017**, *577*, 349–359. [CrossRef]
8. Yang, J.; Jin, S.; Xiao, X.; Jin, C.; Xia, J.C.; Li, X.; Wang, S. Local climate zone ventilation and urban land surface temperatures: Towards a performance-based and wind-sensitive planning proposal in megacities. *Sust. Cities Soc.* **2019**, *47*, 101487. [CrossRef]
9. Middel, A.; Häb, K.; Brazel, A.J.; Martin, C.A.; Guhathakurta, S. Impact of urban form and design on mid-afternoon microclimate in Phoenix Local Climate Zones. *Landsc. Urban Plan.* **2014**, *122*, 16–28. [CrossRef]
10. Stewart, I.D.; Oke, T.R.; Krayenhoff, E.S. Evaluation of the 'local climate zone' scheme using temperature observations and model simulations. *Int. J. Climatol.* **2014**, *34*, 1062–1080. [CrossRef]
11. Stewart, I.D.; Oke, T.R. Local Climate Zones for Urban Temperature Studies. *Bull. Amer. Meteorol. Soc.* **2012**, *93*, 1879–1900. [CrossRef]
12. Bechtel, B.; Demuzere, M.; Mills, G.; Zhan, W.; Sismanidis, P.; Small, C.; Voogt, J. SUHI analysis using Local Climate Zones—A comparison of 50 cities. *Urban Clim.* **2019**, *28*, 100451. [CrossRef]
13. Liberati, A.; Altman, D.G.; Tetzlaff, J.; Mulrow, C.; Gøtzsche, P.C.; Ioannidis, J.P.A.; Clarke, M.; Devereaux, P.J.; Kleijnen, J.; Moher, D. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: Explanation and elaboration. *J. Clin. Epidemiol.* **2009**, *62*, e1–e34. [CrossRef]
14. Armstrong, R.; Hall, B.J.; Doyle, J.; Waters, E. 'Scoping the scope' of a cochrane review. *J. Public Health* **2011**, *33*, 147–150. [CrossRef]
15. Eldesoky, A.H.M.; Gil, J.; Pont, M.B. The suitability of the urban local climate zone classification scheme for surface temperature studies in distinct macroclimate regions. *Urban Clim.* **2021**, *37*, 100823. [CrossRef]
16. Lehnert, M.; Savić, S.; Milošević, D.; Dunjić, J.; Geletič, J. Mapping Local Climate Zones and Their Applications in European Urban Environments: A Systematic Literature Review and Future Development Trends. *Isprs Int. J. Geo-Inf.* **2021**, *10*, 260. [CrossRef]
17. Bechtel, B.; Alexander, P.; Böhner, J.; Ching, J.; Conrad, O.; Feddema, J.; Mills, G.; See, L.; Stewart, I. Mapping Local Climate Zones for a Worldwide Database of the Form and Function of Cities. *Isprs Int. J. Geo-Inf.* **2015**, *4*, 199–219. [CrossRef]
18. Leconte, F.; Bouyer, J.; Claverie, R.; Pétrissans, M. Using Local Climate Zone scheme for UHI assessment: Evaluation of the method using mobile measurements. *Build. Environ.* **2015**, *83*, 39–49. [CrossRef]
19. Bechtel, B.; Daneke, C. Classification of Local Climate Zones Based on Multiple Earth Observation Data. *IEEE J. Sel. Top. Appl. Earth Observ. Remote Sens.* **2012**, *5*, 1191–1202. [CrossRef]
20. Lelovics, E.; Unger, J.; Gál, T.; Gál, C.V. Designation of an urban monitoring network based on Local Climate Zone mapping and temperature pattern modelling. *Clim. Res.* **2014**, *60*, 51–62. [CrossRef]
21. Skarbit, N.; Stewart, I.D.; Unger, J.; Gál, T. Employing an urban meteorological network to monitor air temperature conditions in the 'local climate zones' of Szeged, Hungary. *Int. J. Climatol.* **2017**, *37*, 582–596. [CrossRef]
22. Geletič, J.; Lehnert, M.; Dobrovolný, P. Land Surface Temperature Differences within Local Climate Zones, Based on Two Central European Cities. *Remote Sens.* **2016**, *8*, 788. [CrossRef]
23. Zheng, Y.; Ren, C.; Xu, Y.; Wang, R.; Ho, J.; Lau, K.; Ng, E. GIS-based mapping of Local Climate Zone in the high-density city of Hong Kong. *Urban Clim.* **2018**, *24*, 419–448. [CrossRef]
24. Mushore, T.D.; Dube, T.; Manjowe, M.; Gumindoga, W.; Chemura, A.; Rousta, I.; Odindi, J.; Mutanga, O. Remotely sensed retrieval of Local Climate Zones and their linkages to land surface temperature in Harare metropolitan city, Zimbabwe. *Urban Clim.* **2019**, *27*, 259–271. [CrossRef]
25. Zhou, X.; Okaze, T.; Ren, C.; Cai, M.; Ishida, Y.; Mochida, A. Mapping local climate zones for a Japanese large city by an extended workflow of WUDAPT Level 0 method. *Urban Clim.* **2020**, *33*, 100660. [CrossRef]
26. Mouzourides, P.; Eleftheriou, A.; Kyprianou, A.; Ching, J.; Neophytou, M.K.A. Linking local-climate-zones mapping to multi-resolution-analysis to deduce associative relations at intra-urban scales through an example of Metropolitan London. *Urban Clim.* **2019**, *30*, 100505. [CrossRef]
27. Danylo, O.; See, L.; Bechtel, B.; Schepaschenko, D.; Fritz, S. Contributing to WUDAPT: A Local Climate Zone Classification of Two Cities in Ukraine. *IEEE J. Sel. Top. Appl. Earth Observ. Remote Sens.* **2016**, *9*, 1841–1853. [CrossRef]
28. Brousse, O.; Martilli, A.; Foley, M.; Mills, G.; Bechtel, B. WUDAPT, an efficient land use producing data tool for mesoscale models? Integration of urban LCZ in WRF over Madrid. *Urban Clim.* **2016**, *17*, 116–134. [CrossRef]
29. Beck, C.; Straub, A.; Breitner, S.; Cyrys, J.; Philipp, A.; Rathmann, J.; Schneider, A.; Wolf, K.; Jacobeit, J. Air temperature characteristics of local climate zones in the Augsburg urban area (Bavaria, southern Germany) under varying synoptic conditions. *Urban Clim.* **2018**, *25*, 152–166. [CrossRef]
30. Demuzere, M.; Bechtel, B.; Middel, A.; Mills, G. Mapping Europe into local climate zones. *PLoS ONE* **2019**, *14*, e214474. [CrossRef]
31. Ren, C.; Cai, M.; Li, X.; Zhang, L.; Wang, R.; Xu, Y.; Ng, E. Assessment of Local Climate Zone Classification Maps of Cities in China and Feasible Refinements. *Sci. Rep.* **2019**, *9*, 18848. [CrossRef] [PubMed]
32. Wang, R.; Ren, C.; Xu, Y.; Lau, K.K.; Shi, Y. Mapping the local climate zones of urban areas by GIS-based and WUDAPT methods: A case study of Hong Kong. *Urban Clim.* **2018**, *24*, 567–576. [CrossRef]
33. Unger, J.; Lelovics, E.; Gál, T. Local Climate Zone mapping using GIS methods in Szeged. *Hung. Geogr. Bull.* **2014**, *63*, 29–41. [CrossRef]

34. Geletič, J.; Lehnert, M. GIS-based delineation of local climate zones: The case of medium-sized Central European cities. *Morav. Geogr. Rep.* **2016**, *24*, 2–12. [CrossRef]
35. Qiu, C.; Liebel, L.; Hughes, L.H.; Schmitt, M.; Korner, M.; Zhu, X.X. Multitask Learning for Human Settlement Extent Regression and Local Climate Zone Classification. *IEEE Geosci. Remote Sens. Lett.* **2022**, *19*, 3037246. [CrossRef]
36. Ma, L.; Zhu, X.; Qiu, C.; Blaschke, T.; Li, M. Advances of Local Climate Zone Mapping and Its Practice Using Object-Based Image Analysis. *Atmosphere* **2021**, *12*, 1146. [CrossRef]
37. Zhou, Y.; Wei, T.; Zhu, X.; Collin, M. A Parcel-Based Deep-Learning Classification to Map Local Climate Zones From Sentinel-2 Images. *IEEE J. Sel. Top. Appl. Earth Observ. Remote Sens.* **2021**, *14*, 4194–4204. [CrossRef]
38. Chang, Y.; Xiao, J.; Li, X.; Middel, A.; Zhang, Y.; Gu, Z.; Wu, Y.; He, S. Exploring diurnal thermal variations in urban local climate zones with ECOSTRESS land surface temperature data. *Remote Sens. Environ.* **2021**, *263*, 112544. [CrossRef]
39. Hu, J.; Ghamisi, P.; Zhu, X. Feature Extraction and Selection of Sentinel-1 Dual-Pol Data for Global-Scale Local Climate Zone Classification. *Isprs Int. J. Geo-Inf.* **2018**, *7*, 379. [CrossRef]
40. Yoo, C.; Lee, Y.; Cho, D.; Im, J.; Han, D. Improving Local Climate Zone Classification Using Incomplete Building Data and Sentinel 2 Images Based on Convolutional Neural Networks. *Remote Sens.* **2020**, *12*, 3552. [CrossRef]
41. Fan, H.; Zipf, A.; Fu, Q.; Neis, P. Quality assessment for building footprints data on OpenStreetMap. *Int. J. Geogr. Inf.Sci. IJGIS* **2014**, *28*, 700–719. [CrossRef]
42. Fonte, C.C.; Lopes, P.; See, L.; Bechtel, B. Using OpenStreetMap (OSM) to enhance the classification of local climate zones in the framework of WUDAPT. *Urban Clim.* **2019**, *28*, 100456. [CrossRef]
43. Chen, F.; Tsou, J.Y. DRSNet: Novel architecture for small patch and low-resolution remote sensing image scene classification. *Int. J. Appl. Earth Obs. Geoinf.* **2021**, *104*, 102577. [CrossRef]
44. Zhang, G.; Ghamisi, P.; Zhu, X.X. Fusion of Heterogeneous Earth Observation Data for the Classification of Local Climate Zones. *IEEE Trans. Geosci. Remote Sensing* **2019**, *57*, 7623–7642. [CrossRef]
45. Yoo, C.; Han, D.; Im, J.; Bechtel, B. Comparison between convolutional neural networks and random forest for local climate zone classification in mega urban areas using Landsat images. *Isprs J. Photogramm. Remote Sens.* **2019**, *157*, 155–170. [CrossRef]
46. Rosentreter, J.; Hagensieker, R.; Waske, B. Towards large-scale mapping of local climate zones using multitemporal Sentinel 2 data and convolutional neural networks. *Remote Sens. Environ.* **2020**, *237*, 111472. [CrossRef]
47. Cai, M.; Ren, C.; Xu, Y.; Lau, K.K.; Wang, R. Investigating the relationship between local climate zone and land surface temperature using an improved WUDAPT methodology—A case study of Yangtze River Delta, China. *Urban Clim.* **2018**, *24*, 485–502. [CrossRef]
48. Cai, M.; Ren, C.; Xu, Y.; Dai, W.; Wang, X.M. Local Climate Zone Study for Sustainable Megacities Development by Using Improved WUDAPT Methodology—A Case Study in Guangzhou. *Procedia Environ. Sci.* **2016**, *36*, 82–89. [CrossRef]
49. Perera, N.G.R.; Emmanuel, R. A "Local Climate Zone" based approach to urban planning in Colombo, Sri Lanka. *Urban Clim.* **2018**, *23*, 188–203. [CrossRef]
50. Kotharkar, R.; Bagade, A. Local Climate Zone classification for Indian cities: A case study of Nagpur. *Urban Clim.* **2018**, *24*, 369–392. [CrossRef]
51. Hidalgo, J.; Dumas, G.; Masson, V.; Petit, G.; Bechtel, B.; Bocher, E.; Foley, M.; Schoetter, R.; Mills, G. Comparison between local climate zones maps derived from administrative datasets and satellite observations. *Urban Clim.* **2019**, *27*, 64–89. [CrossRef]
52. Demuzere, M.; Bechtel, B.; Mills, G. Global transferability of local climate zone models. *Urban Clim.* **2019**, *27*, 46–63. [CrossRef]
53. Rodler, A.; Leduc, T. Local climate zone approach on local and micro scales: Dividing the urban open space. *Urban Clim.* **2019**, *28*, 100457. [CrossRef]
54. Jin, L.; Pan, X.; Liu, L.; Liu, L.; Liu, J.; Gao, Y. Block-based local climate zone approach to urban climate maps using the UDC model. *Build. Environ.* **2020**, *186*, 107334. [CrossRef]
55. Demuzere, M.; Kittner, J.; Bechtel, B. LCZ Generator: A Web Application to Create Local Climate Zone Maps. *Front. Environ. Sci.* **2021**, *9*, 637455. [CrossRef]
56. Verdonck, M.; Okujeni, A.; van der Linden, S.; Demuzere, M.; De Wulf, R.; Van Coillie, F. Influence of neighbourhood information on 'Local Climate Zone' mapping in heterogeneous cities. *Int. J. Appl. Earth Obs. Geoinf.* **2017**, *62*, 102–113. [CrossRef]
57. Quan, S.J.; Dutt, F.; Woodworth, E.; Yamagata, Y.; Yang, P.P. Local Climate Zone Mapping for Energy Resilience: A Fine-grained and 3D Approach. *Energy Procedia* **2017**, *105*, 3777–3783. [CrossRef]
58. Hammerberg, K.; Brousse, O.; Martilli, A.; Mahdavi, A. Implications of employing detailed urban canopy parameters for mesoscale climate modelling: A comparison between WUDAPT and GIS databases over Vienna, Austria. *Int. J. Climatol.* **2018**, *38*, e1241–e1257. [CrossRef]
59. Zhao, N.; Ma, A.; Zhong, Y.; Zhao, J.; Cao, L. Self-Training Classification Framework with Spatial-Contextual Information for Local Climate Zones. *Remote Sens.* **2019**, *11*, 2828. [CrossRef]
60. He, S.; Zhang, Y.; Gu, Z.; Su, J. Local climate zone classification with different source data in Xi'an, China. *Indoor Built Environ.* **2018**, *28*, 1190–1199. [CrossRef]
61. Bechtel, B.; See, L.; Mills, G.; Foley, M. Classification of Local Climate Zones Using SAR and Multispectral Data in an Arid Environment. *IEEE J. Sel. Top. Appl. Earth Observ. Remote Sens.* **2016**, *9*, 3097–3105. [CrossRef]
62. Xu, Y.; Ren, C.; Cai, M.; Edward, N.Y.Y.; Wu, T. Classification of Local Climate Zones Using ASTER and Landsat Data for High-Density Cities. *IEEE J. Sel. Top. Appl. Earth Observ. Remote Sens.* **2017**, *10*, 3397–3405. [CrossRef]

63. Kim, M.; Jeong, D.; Kim, Y. Local climate zone classification using a multi-scale, multi-level attention network. *Isprs J. Photogramm. Remote Sens.* **2021**, *181*, 345–366. [CrossRef]
64. Quan, J. Enhanced geographic information system-based mapping of local climate zones in Beijing, China. *Sci. China Technol. Sci.* **2019**, *62*, 2243–2260. [CrossRef]
65. Yu, Y.; Li, J.; Yuan, Q.; Shi, Q.; Shen, H.; Zhang, L. Coupling Dual Graph Convolution Network and Residual Network for Local Climate Zone Mapping. *IEEE J. Sel. Top. Appl. Earth Observ. Remote Sens.* **2022**, *15*, 1221–1234. [CrossRef]
66. Shi, L.; Ling, F. Local Climate Zone Mapping Using Multi-Source Free Available Datasets on Google Earth Engine Platform. *Land* **2021**, *10*, 454. [CrossRef]
67. Simanjuntak, R.M.; Kuffer, M.; Reckien, D. Object-based image analysis to map local climate zones: The case of Bandung, Indonesia. *Appl. Geogr.* **2019**, *106*, 108–121. [CrossRef]
68. Wicki, A.; Parlow, E. Attribution of local climate zones using a multitemporal land use/land cover classification scheme. *J. Appl. Remote Sens.* **2017**, *11*, 26001. [CrossRef]
69. Bartesaghi Koc, C.; Osmond, P.; Peters, A.; Irger, M. Understanding Land Surface Temperature Differences of Local Climate Zones Based on Airborne Remote Sensing Data. *IEEE J. Sel. Top. Appl. Earth Observ. Remote Sens.* **2018**, *11*, 2724–2730. [CrossRef]
70. Xu, C.; Hystad, P.; Chen, R.; Van Den Hoek, J.; Hutchinson, R.A.; Hankey, S.; Kennedy, R. Application of training data affects success in broad-scale local climate zone mapping. *Int. J. Appl. Earth Obs. Geoinf.* **2021**, *103*, 102482. [CrossRef]
71. Zhou, L.; Shao, Z.; Wang, S.; Huang, X. Deep learning-based local climate zone classification using Sentinel-1 SAR and Sentinel-2 multispectral imagery. *Geo-Spat. Inf. Sci.* **2022**, *25*, 383–398. [CrossRef]
72. La, Y.; Bagan, H.; Yamagata, Y. Urban land cover mapping under the Local Climate Zone scheme using Sentinel-2 and PALSAR-2 data. *Urban Clim.* **2020**, *33*, 100661. [CrossRef]
73. Yang, X.; Yao, L.; Jin, T.; Peng, L.L.H.; Jiang, Z.; Hu, Z.; Ye, Y. Assessing the thermal behavior of different local climate zones in the Nanjing metropolis, China. *Build. Environ.* **2018**, *137*, 171–184. [CrossRef]
74. Yang, X.; Peng, L.L.H.; Chen, Y.; Yao, L.; Wang, Q. Air humidity characteristics of local climate zones: A three-year observational study in Nanjing. *Build. Environ.* **2020**, *171*, 106661. [CrossRef]
75. Anjos, M.; Targino, A.C.; Krecl, P.; Oukawa, G.Y.; Braga, R.F. Analysis of the urban heat island under different synoptic patterns using local climate zones. *Build. Environ.* **2020**, *185*, 107268. [CrossRef]
76. Núñez-Peiró, M.; Sánchez-Guevara Sánchez, C.; Neila González, F.J. Hourly evolution of intra-urban temperature variability across the local climate zones. The case of Madrid. *Urban Clim.* **2021**, *39*, 100921. [CrossRef]
77. Dunjić, J.; Milošević, D.; Kojić, M.; Savić, S.; Lužanin, Z.; Aećerov, I.; Arsenović, D. Air Humidity Characteristics in "Local Climate Zones" of Novi Sad (Serbia) Based on Long-Term Data. *Isprs Int. J. Geo-Inf.* **2021**, *10*, 810. [CrossRef]
78. Fenner, D.; Meier, F.; Bechtel, B.; Otto, M.; Scherer, D. Intra and inter 'local climate zone' variability of air temperature as observed by crowdsourced citizen weather stations in Berlin, Germany. *Meteorol. Z.* **2017**, *26*, 525–547. [CrossRef]
79. Peters, J.; Van Poppel, M.; Theunis, J. Air quality mapping in urban environments using mobile measurements. *Sens. A Chang. World* **2012**, *2012*, 1–9.
80. Leconte, F.; Bouyer, J.; Claverie, R. Nocturnal cooling in Local Climate Zone: Statistical approach using mobile measurements. *Urban Clim.* **2020**, *33*, 100629. [CrossRef]
81. Wang, Z.; Xing, W.; Huang, Y.; Xie, T. Studying the Urban Heat Island Usinga Local Climate Zone Scheme. *Pol. J. Environ. Stud.* **2016**, *25*, 2609–2616. [CrossRef]
82. Emery, J.; Pohl, B.; Crétat, J.; Richard, Y.; Pergaud, J.; Rega, M.; Zito, S.; Dudek, J.; Vairet, T.; Joly, D.; et al. How local climate zones influence urban air temperature: Measurements by bicycle in Dijon, France. *Urban Clim.* **2021**, *40*, 101017. [CrossRef]
83. Shi, Y.; Lau, K.K.; Ren, C.; Ng, E. Evaluating the local climate zone classification in high-density heterogeneous urban environment using mobile measurement. *Urban Clim.* **2018**, *25*, 167–186. [CrossRef]
84. Alexander, P.J.; Mills, G.; Fealy, R. Using LCZ data to run an urban energy balance model. *Urban Clim.* **2015**, *13*, 14–37. [CrossRef]
85. Liu, L.; Liu, J.; Jin, L.; Liu, L.; Gao, Y.; Pan, X. Climate-conscious spatial morphology optimization strategy using a method combining local climate zone parameterization concept and urban canopy layer model. *Build. Environ.* **2020**, *185*, 107301. [CrossRef]
86. Richard, Y.; Emery, J.; Dudek, J.; Pergaud, J.; Chateau-Smith, C.; Zito, S.; Rega, M.; Vairet, T.; Castel, T.; Thévenin, T.; et al. How relevant are local climate zones and urban climate zones for urban climate research? Dijon (France) as a case study. *Urban Clim.* **2018**, *26*, 258–274. [CrossRef]
87. Mughal, M.O.; Li, X.X.; Yin, T.; Martilli, A.; Brousse, O.; Dissegna, M.A.; Norford, L.K. High-Resolution, Multilayer Modeling of Singapore's Urban Climate Incorporating Local Climate Zones. *Journal of Geophysical Research: Atmospheres* **2019**, *124*, 7764–7785. [CrossRef]
88. Mu, Q.; Miao, S.; Wang, Y.; Li, Y.; He, X.; Yan, C. Evaluation of employing local climate zone classification for mesoscale modelling over Beijing metropolitan area. *Meteorol. Atmos. Phys.* **2020**, *132*, 315–326. [CrossRef]
89. Mughal, M.O.; Li, X.; Norford, L.K. Urban heat island mitigation in Singapore: Evaluation using WRF/multilayer urban canopy model and local climate zones. *Urban Clim.* **2020**, *34*, 100714. [CrossRef]
90. Yi, C.; Kwon, H.; Yang, H. Spatial temperature differences in local climate zones of Seoul metropolitan area during a heatwave. *Urban Clim.* **2022**, *41*, 101012. [CrossRef]

91. Aminipouri, M.; Rayner, D.; Lindberg, F.; Thorsson, S.; Knudby, A.J.; Zickfeld, K.; Middel, A.; Krayenhoff, E.S. Urban tree planting to maintain outdoor thermal comfort under climate change: The case of Vancouver's local climate zones. *Build. Environ.* **2019**, *158*, 226–236. [CrossRef]
92. Aminipouri, M.; Knudby, A.J.; Krayenhoff, E.S.; Zickfeld, K.; Middel, A. Modelling the impact of increased street tree cover on mean radiant temperature across Vancouver's local climate zones. *Urban For. Urban Green.* **2019**, *39*, 9–17. [CrossRef]
93. Pereira, C.T.; Masiero, É.; Bourscheidt, V. Socio-spatial inequality and its relationship to thermal (dis)comfort in two major Local Climate Zones in a tropical coastal city. *Int. J. Biometeorol.* **2021**, *65*, 1177–1187. [CrossRef] [PubMed]
94. Geletič, J.; Lehnert, M.; Dobrovolný, P.; Žuvela-Aloise, M. Spatial modelling of summer climate indices based on local climate zones: Expected changes in the future climate of Brno, Czech Republic. *Clim. Chang.* **2019**, *152*, 487–502. [CrossRef]
95. Geletič, J.; Lehnert, M.; Savić, S.; Milošević, D. Modelled spatiotemporal variability of outdoor thermal comfort in local climate zones of the city of Brno, Czech Republic. *Sci. Total Environ.* **2018**, *624*, 385–395. [CrossRef]
96. Du, P.; Chen, J.; Bai, X.; Han, W. Understanding the seasonal variations of land surface temperature in Nanjing urban area based on local climate zone. *Urban Clim.* **2020**, *33*, 100657. [CrossRef]
97. Pellegatti Franco, D.M.; Andrade, M.D.F.; Ynoue, R.Y.; Ching, J. Effect of Local Climate Zone (LCZ) classification on ozone chemical transport model simulations in Sao Paulo, Brazil. *Urban Clim.* **2019**, *27*, 293–313. [CrossRef]
98. Daramola, M.T.; Balogun, I.A. Local climate zone classification of surface energy flux distribution within an urban area of a hot-humid tropical city. *Urban Clim.* **2019**, *29*, 100504. [CrossRef]
99. Verdonck, M.; Demuzere, M.; Hooyberghs, H.; Beck, C.; Cyrys, J.; Schneider, A.; Dewulf, R.; Van Coillie, F. The potential of local climate zones maps as a heat stress assessment tool, supported by simulated air temperature data. *Landsc. Urban Plan.* **2018**, *178*, 183–197. [CrossRef]
100. Arnfield, A.J. Two decades of urban climate research: A review of turbulence, exchanges of energy and water, and the urban heat island. *Int. J. Climatol.* **2003**, *23*, 1–26. [CrossRef]
101. Li, X.; Zhou, Y.; Asrar, G.R.; Imhoff, M.; Li, X. The surface urban heat island response to urban expansion: A panel analysis for the conterminous United States. *Sci. Total Environ.* **2017**, *605–606*, 426–435. [CrossRef]
102. Zhou, X.; Okaze, T.; Ren, C.; Cai, M.; Ishida, Y.; Watanabe, H.; Mochida, A. Evaluation of urban heat islands using local climate zones and the influence of sea-land breeze. *Sust. Cities Soc.* **2020**, *55*, 102060. [CrossRef]
103. Alexander, P.; Mills, G. Local Climate Classification and Dublin's Urban Heat Island. *Atmosphere* **2014**, *5*, 755–774. [CrossRef]
104. Zhou, L.; Yuan, B.; Hu, F.; Wei, C.; Dang, X.; Sun, D. Understanding the effects of 2D/3D urban morphology on land surface temperature based on local climate zones. *Build. Environ.* **2022**, *208*, 108578. [CrossRef]
105. Li, N.; Yang, J.; Qiao, Z.; Wang, Y.; Miao, S. Urban Thermal Characteristics of Local Climate Zones and Their Mitigation Measures across Cities in Different Climate Zones of China. *Remote Sens.* **2021**, *13*, 1468. [CrossRef]
106. Středová, H.; Chuchma, F.; Rožnovský, J.; Středa, T. Local Climate Zones, Land Surface Temperature and Air Temperature Interactions: Case Study of Hradec Králové, the Czech Republic. *Isprs Int. J. Geo-Inf.* **2021**, *10*, 704. [CrossRef]
107. Xu, M.; Hong, B.; Jiang, R.; An, L.; Zhang, T. Outdoor thermal comfort of shaded spaces in an urban park in the cold region of China. *Build. Environ.* **2019**, *155*, 408–420. [CrossRef]
108. Mi, J.; Hong, B.; Zhang, T.; Huang, B.; Niu, J. Outdoor thermal benchmarks and their application to climate–responsive designs of residential open spaces in a cold region of China. *Build. Environ.* **2020**, *169*, 106592. [CrossRef]
109. An, L.; Hong, B.; Cui, X.; Geng, Y.; Ma, X. Outdoor thermal comfort during winter in China's cold regions: A comparative study. *Sci. Total Environ.* **2021**, *768*, 144464. [CrossRef]
110. Niu, J.; Hong, B.; Geng, Y.; Mi, J.; He, J. Summertime physiological and thermal responses among activity levels in campus outdoor spaces in a humid subtropical city. *Sci. Total Environ.* **2020**, *728*, 138757. [CrossRef]
111. Ma, X.; Tian, Y.; Du, M.; Hong, B.; Lin, B. How to design comfortable open spaces for the elderly? Implications of their thermal perceptions in an urban park. *Sci. Total Environ.* **2021**, *768*, 144985. [CrossRef]
112. Huang, B.; Hong, B.; Tian, Y.; Yuan, T.; Su, M. Outdoor thermal benchmarks and thermal safety for children: A study in China's cold region. *Sci. Total Environ.* **2021**, *787*, 147603. [CrossRef]
113. Tian, Y.; Hong, B.; Zhang, Z.; Wu, S.; Yuan, T. Factors influencing resident and tourist outdoor thermal comfort: A comparative study in China's cold region. *Sci. Total Environ.* **2022**, *808*, 152079. [CrossRef]
114. He, X.; An, L.; Hong, B.; Huang, B.; Cui, X. Cross-cultural differences in thermal comfort in campus open spaces: A longitudinal field survey in China's cold region. *Build. Environ.* **2020**, *172*, 106739. [CrossRef]
115. Zhang, T.; Hong, B.; Su, X.; Li, Y.; Song, L. Effects of tree seasonal characteristics on thermal-visual perception and thermal comfort. *Build. Environ.* **2022**, *212*, 108793. [CrossRef]
116. Zhang, T.; Su, M.; Hong, B.; Wang, C.; Li, K. Interaction of emotional regulation and outdoor thermal perception: A pilot study in a cold region of China. *Build. Environ.* **2021**, *198*, 107870. [CrossRef]
117. Geng, Y.; Hong, B.; Du, M.; Yuan, T.; Wang, Y. Combined effects of visual-acoustic-thermal comfort in campus open spaces: A pilot study in China's cold region. *Build. Environ.* **2022**, *209*, 108658. [CrossRef]
118. Villadiego, K.; Velay-Dabat, M.A. Outdoor thermal comfort in a hot and humid climate of Colombia: A field study in Barranquilla. *Build. Environ.* **2014**, *75*, 142–152. [CrossRef]
119. Lau, K.K.; Chung, S.C.; Ren, C. Outdoor thermal comfort in different urban settings of sub-tropical high-density cities: An approach of adopting local climate zone (LCZ) classification. *Build. Environ.* **2019**, *154*, 227–238. [CrossRef]

120. Salal Rajan, E.H.; Amirtham, L.R. Impact of building regulations on the perceived outdoor thermal comfort in the mixed-use neighbourhood of Chennai. *Front. Archit. Res.* **2021**, *10*, 148–163. [CrossRef]
121. Ren, J.; Yang, J.; Zhang, Y.; Xiao, X.; Xia, J.C.; Li, X.; Wang, S. Exploring thermal comfort of urban buildings based on local climate zones. *J. Clean Prod.* **2022**, *340*, 130744. [CrossRef]
122. Liu, L.; Lin, Y.; Xiao, Y.; Xue, P.; Shi, L.; Chen, X.; Liu, J. Quantitative effects of urban spatial characteristics on outdoor thermal comfort based on the LCZ scheme. *Build. Environ.* **2018**, *143*, 443–460. [CrossRef]
123. Unger, J.; Skarbit, N.; Gál, T. Evaluation of outdoor human thermal sensation of local climate zones based on long-term database. *Int. J. Biometeorol.* **2018**, *62*, 183–193. [CrossRef]
124. Wu, J.; Liu, C.; Wang, H. Analysis of Spatio-temporal patterns and related factors of thermal comfort in subtropical coastal cities based on local climate zones. *Build. Environ.* **2022**, *207*, 108568. [CrossRef]
125. Xu, L.; Cui, S.; Tang, J.; Nguyen, M.; Liu, J.; Zhao, Y. Assessing the adaptive capacity of urban form to climate stress: A case study on an urban heat island. *Environ. Res. Lett.* **2019**, *14*, 44013. [CrossRef]
126. Ng, E.; Ren, C. China's adaptation to climate & urban climatic changes: A critical review. *Urban Clim.* **2018**, *23*, 352–372. [CrossRef]
127. Vandamme, S.; Demuzere, M.; Verdonck, M.; Zhang, Z.; Coillie, F.V. Revealing Kunming's (China) Historical Urban Planning Policies Through Local Climate Zones. *Remote Sens.* **2019**, *11*, 1731. [CrossRef]
128. Chen, X.; Xu, Y.; Yang, J.; Wu, Z.; Zhu, H. Remote sensing of urban thermal environments within local climate zones: A case study of two high-density subtropical Chinese cities. *Urban Clim.* **2020**, *31*, 100568. [CrossRef]
129. Kotharkar, R.; Bagade, A. Evaluating urban heat island in the critical local climate zones of an Indian city. *Landsc. Urban Plan.* **2018**, *169*, 92–104. [CrossRef]
130. Hoon Leh, O.L.; Ahmad, S.; Aiyub, K.; Mohd Jani, Y. Urban air environmental health indicators: A preliminary set for city of kuala lumpur. *Plan. Malays. J.* **2016**, *9*. [CrossRef]
131. Ziaul, S.; Pal, S. Analyzing control of respiratory particulate matter on Land Surface Temperature in local climatic zones of English Bazar Municipality and Surroundings. *Urban Clim.* **2018**, *24*, 34–50. [CrossRef]
132. Shi, Y.; Ren, C.; Lau, K.K.; Ng, E. Investigating the influence of urban land use and landscape pattern on PM2.5 spatial variation using mobile monitoring and WUDAPT. *Landsc. Urban Plan.* **2019**, *189*, 15–26. [CrossRef]
133. Wu, Y.; Sharifi, A.; Yang, P.; Borjigin, H.; Murakami, D.; Yamagata, Y. Mapping building carbon emissions within local climate zones in Shanghai. *Energy Procedia* **2018**, *152*, 815–822. [CrossRef]
134. Brousse, O.; Georganos, S.; Demuzere, M.; Vanhuysse, S.; Wouters, H.; Wolff, E.; Linard, C.; van Lipzig, N.P.M.; Dujardin, S. Using Local Climate Zones in Sub-Saharan Africa to tackle urban health issues. *Urban Clim.* **2019**, *27*, 227–242. [CrossRef]
135. Brousse, O.; Georganos, S.; Demuzere, M.; Dujardin, S.; Lennert, M.; Linard, C.; Snow, R.W.; Thiery, W.; van Lipzig, N. Can we use local climate zones for predicting malaria prevalence across sub-Saharan African cities? *Environ. Res. Lett.* **2020**, *15*, 124051. [CrossRef]
136. Zhao, Z.; Shen, L.; Li, L.; Wang, H.; He, B. Local Climate Zone Classification Scheme Can Also Indicate Local-Scale Urban Ventilation Performance: An Evidence-Based Study. *Atmosphere* **2020**, *11*, 776. [CrossRef]
137. Kotharkar, R.; Ghosh, A.; Kapoor, S.; Reddy, D.G.K. Approach to local climate zone based energy consumption assessment in an Indian city. *Energy Build.* **2022**, *259*, 111835. [CrossRef]
138. Yang, X.; Yao, L.; Peng, L.L.H.; Jiang, Z.; Jin, T.; Zhao, L. Evaluation of a diagnostic equation for the daily maximum urban heat island intensity and its application to building energy simulations. *Energy Build.* **2019**, *193*, 160–173. [CrossRef]