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Review

A Systematic Review of Outdoor Thermal Comfort Studies for the Urban (Re)Design of City Squares

Lazar Mandić, Aleksandra Đukić, Jelena Marić * and Biserka Mitrović

Faculty of Architecture, University of Belgrade, Bul. Kralja Aleksandra 73/2, 11000 Belgrade, Serbia; archlazarmandic@gmail.com (L.M.); adjukic@afrodita.rcub.bg.ac.rs (A.Đ.); biserka@arh.bg.ac.rs (B.M.)
* Correspondence: jelena.maric@arh.bg.ac.rs; Tel.: +381-600313155

Abstract: In the upcoming period, city squares' urban redesign will be crucial in achieving sustainable development goals. This study presents a systematic review of OTC-related studies for the urban design of city squares using the PRISMA 2020 methodology. A review included a total of 173 papers from 2001 to 2023. The results identified five study types—clusters based on four pre-defined criteria: study approach, data collection methods, time duration, and primary objectives. The clusters indicate that more than half of all studies are related to the comparison of thermal comfort and heat mitigation measures. Most of the case studies were located in one of three climate zones: temperate oceanic (Cfb) (58 studies), hot summer Mediterranean (Csa) (40 studies), or humid subtropical (Cfa) (28 studies). The most common geometry of the analyzed urban square is medium-sized, is rectangular, and has dominant axel orientation south–north. Also, based on all five clusters, several research gaps were identified, appropriate for future research: the majority of studies related to the traditionally considered climate areas, no typology of urban square geometry configuration based on OTC assessment, and the lack of a local design model for assessing and improving the thermal comfort of city squares.

Keywords: city square; urban (re)design; outdoor thermal comfort; quality of city space; mitigation strategies; research methodology

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1. Introduction

In the coming period, the urban redesign and retrofit of city squares will be significant for achieving sustainable development goals [1], thus improving the lives of different users in cities worldwide, mainly due to global climate change, extreme meteorological phenomena, and heat island effects. There is high agreement that the role of urban design in local adaptation is essential and plays a central role in the adaptive response to climate change [2].

Outdoor thermal comfort (OTC) directly affects the quality of city squares in terms of duration, frequency, and outdoor activity patterns for users. The urban design of city squares impacts the OTC. If the OTC of the city square is of good quality, it increases the overall quality of time spent in this type of open space and, therefore, the health and well-being of city residents, further improving tourism and the city's economy [3–11].

This systematic review paper was prepared due to the recognized need for an up-to-date overview of the various approaches to the research methodology of OTC studies in the context of the urban design of city squares. Regarding the novelty of the research, this systematic review aims to fill the currently identified gap in the OTC-related urban design literature by providing a comprehensive analysis of these studies that are specifically related to the redesign of city squares. While individual studies have addressed various aspects of thermal comfort in urban environments, no prior review has synthesized these findings to offer actionable insights. The novelty of this paper lies in its multi-dimensional and complex methodological process, examining the study approach, data collection methods, time duration, and primary objectives.

It is usual to have an uneven representation of the parameters of the square geometry in OTC studies for city squares, which is why in this paper, a separate analysis of the climate zone, size, shape, predominant orientation, and dimension of the square was performed for each square with a tabular representation.

The main aim of the study is to systematize the extensive literature regarding OTC-related studies and to deepen the knowledge of the diversity of possible methodological approaches in selected OTC studies, which are mainly focused on the urban design of open public spaces and, more precisely, the urban design of city squares. The particular aim is to divide the existing studies into clusters based on similar characteristics. These characteristics are described in detail in the following section and defined according to the preselected set of criteria personalized for OTC-related studies. The additional aim is to compare the aforementioned clusters in order to establish a better insight into the research methodology and, therefore, assist future scientific research studies in the domain of OTC and the urban design of city squares. Also, the specific contribution of this systematic review lies in the fact that it can be used by urban environment researchers and urban design professionals involved in assessing and improving the overall OTC of city squares and dealing with climate-sensitive urban design.

The climate-sensitive urban design (CSUD) of public open spaces (POSs), city squares, urban parks, and streets has attracted the attention of researchers in the field of urban design in the last twenty years due to the possibility of using this approach to improve physical comfort in public spaces and to define measures to mitigate the effects of urban heat islands in cities [11–15]. Climate-sensitive urban design (CSUD) mitigates climate risks, reduces the use of resources and emissions, and extends the time different users spend in open spaces. It is a conscious effort to create a pleasant POS for users using available and adequate design tools [14]. CSUD implies that urban interventions related to mitigating and adapting to climate change are mainly related to warm periods, but cold periods are also considered. The urban design of city squares based on a climate-sensitive approach is vital for developing urban renewal strategies [16–19] as well as thermal-responsive strategies for mitigating the effects of urban heat islands (UHI) in cities, and OTC is one of the main characteristics of CSUD.

One of the first urban studies of city square qualities was conducted by Camillo Sitte, an Austrian architect, during the second part of the nineteenth century [20]. Sitte refers to the importance of comfort in the city square, relying on ancient thinkers in architecture (Vitruvius) and explains that the city square cannot be just a space in the city but an architecturally shaped public place under the open sky [20]. For Sitte, the essential of both a room in a house and a city square is the "quality of enclosed space" [20]. Contemporary research has become interesting after Bosselmann applied a bioclimatic analysis and developed a methodology for the San Francisco bioclimatic study in 1984 [21]. He first made field microclimate comparison measurements for a whole year to determine the comfort of public squares, and the results of this study were the main argument for new building regulations and planning.

In this review, we included not only studies in which it is explicitly stated that they are being carried out to improve the urban design of city squares from the aspect of thermal comfort but also studies that were carried out on the squares and that aimed to evaluate the effects of mitigation strategies to climate change, the improvement of microclimate-sensitive design methodology, the analysis of thermal comfort thresholds, and thermal stress in public spaces. Also, in order to prepare a representative systematic review, only studies from the last 20 years have been taken into account in the research. The main research questions were strictly connected with the characteristics of the OTC studies, such as the year of the publication and publishers and also the geographical location of the case studies and the climate regions; the specific methods used in the process of OTC measurements—the type of research method, research approach, time duration, and measured outcome; the primary geometric characteristics of urban squares chosen as case studies; and the statistics of other specific parameters used in studies.

One of the main reasons for the research was to identify the research gap, primarily based on the extensive literature review of similar previous studies. There is no record of previous systematic review research conducted specifically on OTC studies from the aspects of the urban design of city squares. A relatively small number of recent review papers on OTC, in general, include a limited number of studies on open public spaces and urban squares, which were focused on different review scopes and research methodologies than the ones presented in this paper. Previous reviews of OTC studies were focused on different climatic regions and behavioral aspects [22–24], human perceptions of OTC in various climates [25], well-being, and quality of life in general [26]. An essential overview of the methodology, techniques, and research procedures of OTC studies was performed by several researchers [27–29] and on the CFD analysis of urban microclimate [30]. Additionally, there are review papers published on different OTC and micro urban design heat mitigation measures and strategies [31–38] that are based on the impact of urban geometry and façade on OTC; the effective parameters, factors, and approaches; or modeling techniques, validation, and scenario simulations in the OTC studies. Review papers on OTC studies in public open spaces for specific regions or countries were written by Dunjić [39] regarding the urban areas of Central and Southeast Europe, Li and Liu [40] regarding China, Shooshtarian et al. [41] regarding Australia, or Khaire et al. [42] regarding India.

All these reviews of OTC studies include analysis studies for the urban design of city squares. However, many case studies have considered a rather limited number of studies, and significant OTC-related studies were left out of the scope.

2. Materials and Methods

The applied methodology for this systematic review was systematic, quantitative, and analytical by nature. A four-phase systematic study selection and review process (identification, screening, eligibility, and included for synthesis) was used using the PRISMA 2020 statement for reporting systematic reviews [43,44]. The research consisted of several phases. First, the overall topic, research gap, research questions, and aims were established, followed by the identification of keywords, database searches, the creation of review and summary tables, summarizing studies into different clusters based on predefined criteria for study research classification, study assessments, urban square geometry analysis using Google Earth tools, the statistical analysis of the main characteristics of research papers, and study comparisons.

The pyramid chart (Figure 1) presents the hierarchy of research topics across the thematic field mentioned earlier. The basic research on thermal comfort is at the bottom, the urban design research is on the second layer, the next layer is open public spaces research (especially research for city squares), and the quality of enclosed space research is on the narrowest layer.

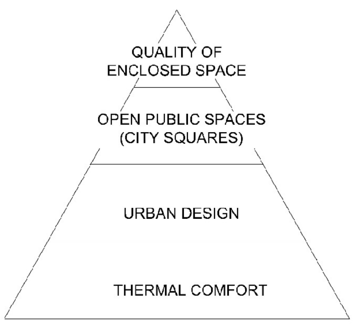

Figure 1. Pyramid chart—hierarchy of study research topics.

Information Sources, Search Strategy, and Selection Process

This review covered 173 peer-reviewed studies—data sources from 38 countries listed in WoS or Scopus databases. Studies were classified by type of papers published and included a total of 31 conference papers and 142 journal articles.

The literature selection process included several steps divided into identification and screening.

(1) Identification: For gathering relevant studies for this review paper, on 6 August 2023, two bibliographic databases were searched, SCOPUS and Web of Science (collections: WoS Core Collection, KCI-Korean Journal Database, Preprint Citation Index, ProQuest Dissertations & Theses Citation Index, SciELO Citation Index) through EBSCOhost platform. Two databases were chosen due to their extent and relevance of publication and according to a predefined list of journals, publishers, and subject areas.

A combination of keywords that accurately describe the research questions was selected after testing a combination of different search terms. Keywords “thermal comfort” and “square or piazza” were chosen as those that most often appear in studies relevant to the scope of the review paper. The applied search query for WoS was as follows: (((AB = (“thermal comfort”)) AND AB = (square or piazza)) OR ((TS = (“thermal comfort”)) AND TS = (square or piazza))) and applied search query for SCOPUS: TITLE-ABS (“thermal comfort”) AND TITLE-ABS (square OR piazza). A total of N_1 = 988 bibliographic records (WoS n = 583 and SCOPUS n = 405) were identified in the search from relevant databases. All bibliographic records were exported from databases and imported into Zotero 6.0 open-source reference management software. Duplicate records (n_1 = 287) were removed using the duplicate items option in Zotero, such as records marked as ineligible by automation tools: not in proper time reference 2001–2023 (n_{r1} = 22), not in eligible format (book, review, retraction, thesis) (n_{r2} = 19), and not written in the English language (n_{r3} = 41). Thus, the final collection for screening was made (N_2 = 701). Also, the research’s relevance and data availability in electronic databases were considered.

The selection of research studies was limited to works available in English, considering that most cited studies published on outdoor thermal comfort for assessing and improving the urban design of city squares were written in English [45]. Due to this criterion, the shortcoming of this overview research is the omission of some significant works in Chinese, German, Portuguese, Korean, Spanish, etc., which can be the subject of a separate study.

(2) Screening: Records issued for screening (N_2 = 701) were independently reviewed for title-end abstract eligibility by two authors and selected for further review. This was made using the Zotero open-source reference management software. For several studies, the decision for review selection was made by consensus after discussion between reviewers. The index of agreement between reviewers was K = 0.88, indicating a strong agreement. After screening, non-eligibility records were excluded (n_{r4} = 421), and reports for retrieval were selected (N_3 = 280). Four reports could not be found and downloaded (n_{r5} = 4), and finally, reports assessed for eligibility were defined (N_4 = 276).

(3) After screening, full-text studies were retrieved (N = 274), and a full-text eligibility assessment was undertaken. All reviewers retrieved reports according to the agreed distribution of the selected works. All retrieved reports were in PDF format, and after the reports’ detailed reading, a new selection was made with two criteria for exclusion: (a) not focused on OTC (studies focused on solar rights, solar insolation, UHI without human thermal comfort assessment, or climate-sensitive urban design) (n_{r5} = 103) and (b) not focused on urban design of city squares (n_{r6} = 56). After the whole process, the number of reports selected for analysis and review was (N_5 = 117).

(4) Further, data of interest were analyzed, collected, and extracted with insight into each study separately and by filling out a standard Excel table. Common tools for finding specific words, such as search options and marker tools for text highlighting in PDF texts, were used, and no automation tool was used. Reports included by citation were added (N_6 = 56) for systematic review. A search and identification of additional studies suitable for consideration by citation was carried out using the “snowballing” method [46]. Additional studies were eligible for further full-text review if they appeared in SCOPUS or the Web of Science database. Based on the process above (Figure 2), the search strategy identified a total of N = 173 relevant records for review synthesis. These studies were summarized and

divided into five different clusters, with an identified and explained variety of research methodological approaches in studies, and these clusters were later compared.

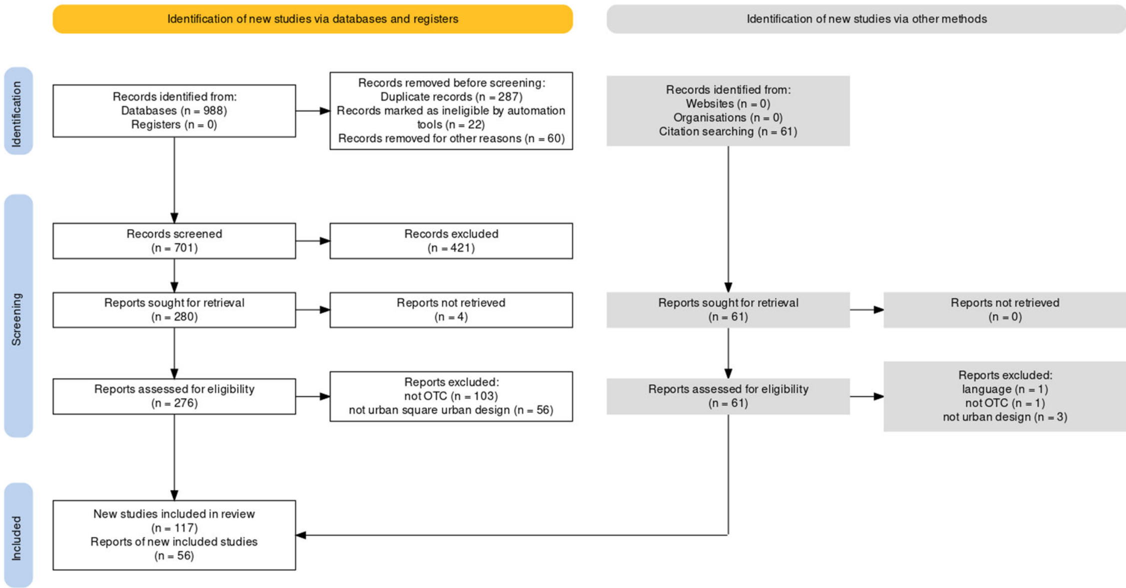

Figure 2. A flowchart of the literature selection process using PRISMA (WoS and SCOPUS) generated using An R package and the Shiny app for producing PRISMA 2020-compliant flow diagrams [47].

Based on classification and criteria by Creswell and Chadwick [48,49], five main clusters were identified that were used to analyze the OTC of urban design of city squares,

There were four main criteria for the classification of the OTC-related studies:

(1) The first criterion included the data collection methodology for selected research. This methodology was (a) quantitative, (b) qualitative, or (c) mixed research type. Quantitative methodology refers to in situ observation, photo taking, instrumental measurement, or data obtained from referent meteorological station for weather data variables—parameters (air temperature Ta, Surface temperature Tsurf, globe thermometer temperature Tg, wet bulb temperature, Façade temperature Tfac, relative humidity RH, soil relative humidity SH, short and long wave irradiance SW, SL, solar illumination Slux, Atmospheric pressure AP, wind speed Ws, wind direction Wd, cloud cover CC, pm particles PM). In situ observation for data of urban morphology and configuration parameters included building data (volume and object arrangement design VOA, object height/width aspect ratio H/W, sky view factor SVF), surface data (ground surface material, façade material, colour of urban structures, thermal capacity of the pavement material), and vegetation data (amount of vegetation, grass cover, number of trees, canopy/crown size, LAD, LAI, height, and distribution). In situ observation for data on human parameters included clothing level (Clo) and metabolism (Ma). (b) Qualitative methodology included data from a survey administered to selected public spaces users, questionnaire survey (actual comfort vote ACV, actual sensation vote ASV, thermal sensation vote TSV, humidity sensation vote HSV, sunshine sensation vote SSV, wind sensation vote WSV, an emotion about space EAS, overall comfort vote OCV, subjective loudness vote SLV, weather preference vote WPV, thermal preference vote TPV, humidity preference vote HPV, sunshine preference vote SPV, wind preference vote WPV, air pollution perception APP, noise pollution perception NPP). (c) Data were gathered from combined quantitative and qualitative forms for mixed methodology.

(2) The second criterion was the applied study approach in research design. Some of the review studies were (a) field research—surveys with non-experimental research design—while others are with (b) quasi-experimental research design—also called one group posttest-only design [50] with a lack of a control group, a lack of random assignment, and a lack of weather variable control to compare measured effects.

(3) The third criterion considered time duration and included (a) single cross-sectional study (one season's cross-sectional survey) and (b) multiple cross-sectional (two, three, or four seasons cross-sectional survey).

(4) The fourth criterion focused on the aim of the research studies, which considered research purposes (measured outcome) and included (a) exploration, (b) description, or (c) explanation. (a) Exploration research studies explore new methods and measurement techniques for thermal comfort measurements on urban squares. (b) Description research is characteristic of the qualitative approach. Observational evaluation research is an assessment of the correlation of subjective thermal comfort and city square urban design or mitigation strategy. This type of research was usually based on user activity, behavior, needs, habits, and cultural dimensions. Ethnographical and phenomenological interpretation were the standard methods of description research analysis. (c) Explanation or hypothesis testing research was characteristic of rational models and quantitative approaches. These studies explain the correlation of dependent and independent variables and usually contain logical construction "if-then". Many thermal comfort index comparison studies and explanations of their connection and correlation with urban square morphology, sun/shadow elements, sitting area, length of time users stayed in urban public spaces, and frequency of activities are in this category. Based on these four criteria, the main clusters or types of OTC-related studies and the summary of these selected studies are presented in the next section.

3. Results

A review process identified 173 papers from 2001 to 2023 that examined assessing and improving city squares' urban (re)design. Details of the 173 studies that examined assessing and improving the urban (re)design of city squares are given in Table A1 in Appendix A.

3.1. Specific Characteristics of OTC-Related Studies

Figure 3 shows the number of research studies published by year, starting in 2001. The increased number of papers from 2001 onwards may be associated with a strong interest in research in outdoor microclimates for public spaces. The development of new research methods, instruments, and approaches (computational simulation tools, cheap outdoor measurement instruments) has led to the rapid growth of OTC-related studies.

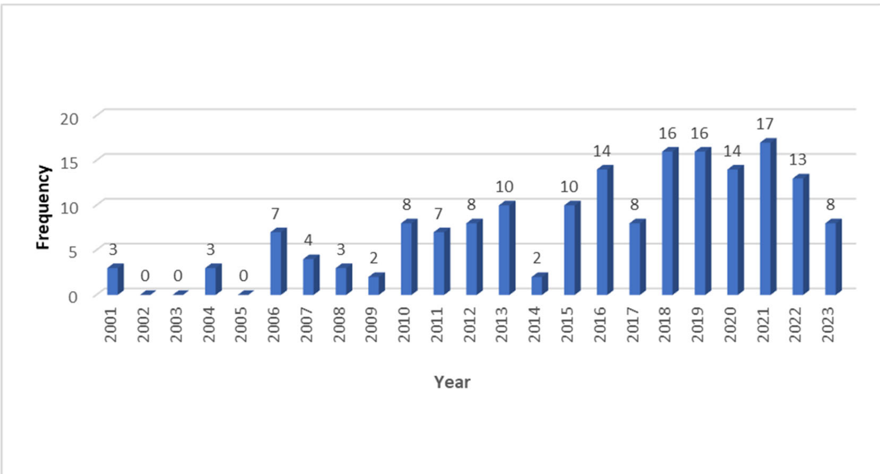

Figure 3. The yearly distribution of the reviewed journal papers and conferences on OTC studies for the urban (re)design of city squares.

The geographic distribution of studies shows that from 182 single-studied sites, research is mainly focused on three countries (Figures 4–6): Italy (11.41%), China (11.41%), and Greece (10.33%). If we compare city-based analyses, the most research was conducted in Athens (11), Rome (9), Esfahan (8), Eindhoven (6), Goteborg (6), Szeged (5), Thessaloniki (5), and Milan (5).

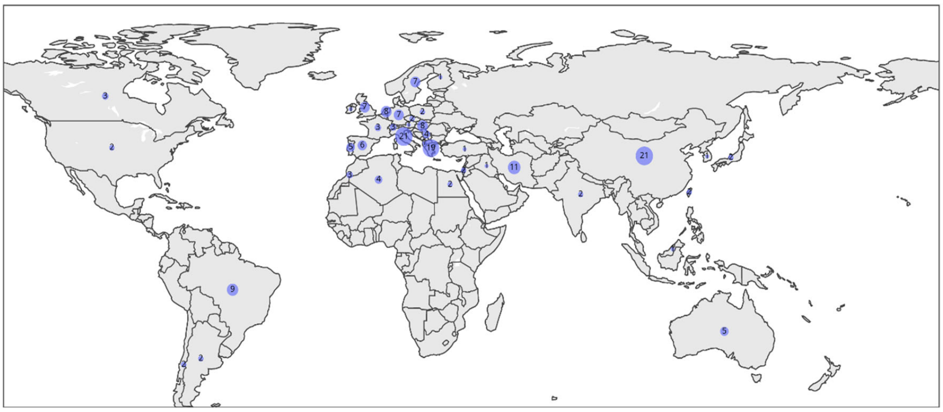

Figure 4. Geographical distribution of study sites—map of countries with a number of studies.

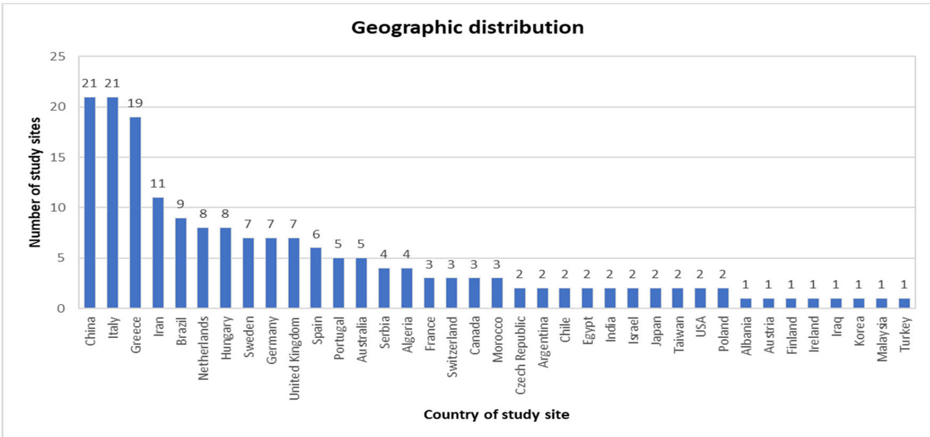

Figure 5. Geographic distribution of study sites—country of study site * (* some studies cover two or more countries).

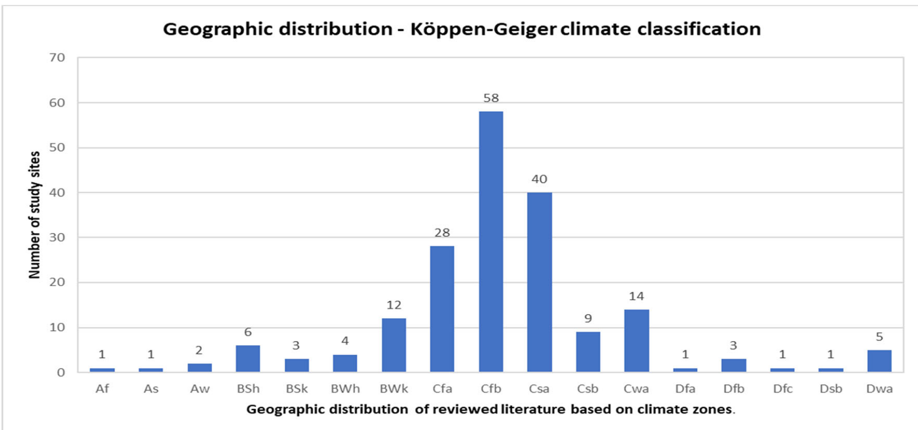

Figure 6. Geographic distribution of reviewed literature based on—Köppen–Geiger climate classification.

For climate classification, we used the updated Köppen–Geiger climate classification [51,52], and the most studied places were in temperate oceanic (Cfb) (58 studies), hot summer Mediterranean (Csa) (40 studies), humid subtropical (Cfa) (28 studies), humid subtropical climate with hot summers (Cwa) (14 studies), cold desert climate (BWk)

(12 studies), hot semi-arid climates (BSh) (6), and humid continental (Dwa) (5 studies); other climates are with less than three studies.

3.2. Identified Clusters of OTC-Related Study Types

Based on the classification process mentioned above and systematization, the five main clusters of OTC-related studies were established. The integral table of the synthesis of all the characteristics regarding the preselected OTC-related studies is available in the Supplementary Materials (Table S1: Data for study classification and Table S3: Studied parameters). OTC-related studies of urban squares design are classified according to the type of research method, research approach, time duration, and measured outcome in Table 1.

Table 1. Summary of OTC-related study types for the urban design of city squares.

CLUSTERS (Types of Research Design-Research Focus)	Quantitative—Qualitative Data Collection	Non Experimental—Quasi Experimental	Time—Duration	Primary Objectives Measured Outcome	Number of Studies
I Cluster—Human behavior and user activity for OTC urban redesign of city squares	Quantitative	Non-experimental	Cross-sectional Multiple cross-sectional—(seasons based)	Explanation	14
II Cluster—Psychological and cultural factors for OTC urban redesign of city squares	Qualitative	quasi-experimental research	Cross-sectional Multiple cross-sectional (seasons based)	Description	18
III Cluster—Thermal comfort and heat mitigation measures—comparison for OTC urban redesign of city squares	Mixed—Quantitative and Qualitative	quasi-experimental research	Cross-sectional Multiple cross-sectional (seasons based)	Explanation	94
IV Cluster—Outdoor thermal comfort perception comparison for OTC urban redesign of city squares	Mixed—Qualitative and Quantitative	quasi-experimental research	Cross-sectional Multiple cross-sectional (seasons based)	Description and Explanation	34
V Cluster measurement methods and techniques development for OTC urban redesign of city squares	Quantitative	quasi-experimental research	Cross-sectional	Exploration	13

Fourteen publications (8.09%) are classified as the research of human behavior—user activity. Eighteen research studies (10.4%) focused on psychological and cultural factors and adaptive behavior. A comparison of thermal comfort and heat mitigation measures accounts for ninety-four of all research studies (54.3%), outdoor thermal comfort perception comparison in thirty-four studies (19.65%), and measurement methods and technique development in thirteen studies (7.50%).

Some studies are in-between types—clusters—and the prevailing type and additional study types were identified. There were five subcategories for III Cluster—Thermal comfort and heat mitigation strategies or measures, depending on the compared factors: green-blue infrastructure, urban square morphology and geometry, surface materialization, small urban elements and wind, and design scenario evaluation. Additionally, there were three subcategories for the IV Cluster: Outdoor thermal comfort perceptional-based research: thermal perception research, neutral temperature perception thresholds, and special group analysis on thermal perception in urban squares.

I Cluster: Human behavior—user activity

This group of studies is based on the environmental–behavioral, non-obstructive observation methodological approach. In this type of study, researchers tried to explain how micrometeorological parameters and urban design influence people's usage of the square, the duration of the stay in urban public spaces, and the frequency of activities. They try to find a pattern matching how user groups use the urban square environment in different microclimate conditions. A time series analysis is a typical analytic technique used in this approach. Important aspects of these types of studies are general trends on the heat sensitivity of human activities on urban squares, the effects of thermal conditions on square usage, and applying such understandings in the design process of urban squares.

The main research issues in this cluster of studies are the relation of measured microclimatic conditions (time of day, ambient air temperature, presence or absence of sunlight, proportion of surface area in sunlight, and wind condition) and use levels, the length of the stay, and the types and frequencies of user activities on the urban square (number of standing, sitting, eating, or smoking individuals in the sun or in the shade).

All the studies use methods for studying people's behavior in their natural settings, such as field studies or non-obstructive observations in natural settings. These studies are rationally based, while qualitative, subjective perceptions of the thermal comfort and subjective preferences of participants in most studies were not taken into consideration.

William Whyte popularized behavioral case studies after realizing the "Street Life Project" in New York and publishing a book and film titled "The Social Life of Small Urban Spaces" [3]. His research lasted three years and included observing people's behavior in the city's streets, parks, and squares while using surveys and interviews. As part of the research, a time-lapse method was used for the first time, with a camera recording how the space was used.

These studies do not usually have scenario redesign comparisons; they are carried out through time series, such as different weather seasons or before and after the square reconstruction. Also, case studies usually cover multiple environmental conditions over daytime and season. Temporal patterns are significant for user behavior in urban squares. The main focus is understanding the causality and correlation of observable human behavior and external—micrometeorological stimuli in urban squares. Those are mainly correlational studies, where spatial statistics, behavior mapping methods, and techniques are used to illustrate data findings.

Used methods for research data gathering in the clusters studies are: a collection of microclimate data in the field (environmental monitoring); air temperature, air humidity, solar radiation, airspeed (wind direction); outdoor non-obstructive observation (human behavior monitoring); photographing and recording of user's activities; measurement of the length of the visitor's stay in the square depending on the basic microclimatic conditions, fish eye diagram; daily shading patterns; behavior mapping.

Zacharias, Stathopoulos, and Wu [7,53] were concerned with use levels (time presence) and activity types (standing, sitting, smoking) in city squares in downtown areas in Montreal and San Francisco as a function of measured microclimatic conditions (time of day, ambient air temperature, presence or absence of sunlight, proportion of surface area in sunlight and wind condition). Marialena and Lykoudis [54] researched different usage of urban squares by different age groups and genders during different seasons (winter, spring, summer, and autumn), people's reasons for visiting the squares, correlation of people's preferences for sunlight, which differ from season to season. De Castro [55] showed that the user's thermal comfort depends not only on microclimate parameters but also on the place's social aspects and historical importance. For example, the research results show that the most intensive use of Queen Square in Bath, UK, is during lunchtime because the square functions as a public space of historical importance and as a food court. In most cases, users look for benches on squares regardless of whether in the sun or shade, even on cold days. Karimina [56] also concluded that increasing thermal factors (Ta, Tmrt, and PET) during the summer season decreased the number of square visitors, and a strong correlation was confirmed between OTC and the usage of OPS. Martinelli and colleagues [57] used nonobtrusive observation and meteorological measurement, and as an innovative approach, they included daily shading patterns and "fish eye" diagrams for OTC analyses. For comparison, they registered different groups on the square (children, adults, and older adults). A significant connection between shading patterns and attendance on the square was identified. Also, the distribution of people in the square influenced by shading was documented. The low attendance corresponded well with a complete absence of sitting possibilities in the shade on the square's benches. Piaskowy and Krüger [58–60] carried out a non-invasive observational study on summer and winter days in Curitiba (Brazil) using two time-lapse digital cameras for the evaluation of "Japan" square attendance. They used observational methods to collect data on people's behavior—preferences for specific resting areas within an urban square surrounded by high-rise buildings. Each bench's shading profile, attendance, and residency (duration of stay) were evaluated. Length of stay is increased in shaded and partly shaded conditions. It is noticed that there is a trend in situations with long duration of stay on the square, where the person who is sitting chooses to move from initial bench to another, thereby tracking the sun/shadow for reducing heat stress by moving to more shade over time and opposite behavior when there was a drop in comfort range indices. Sharifi, Sivam, and Boland [61] used the observational method to examine the links between urban microclimates, thermal discomfort, and outdoor activity patterns in Adelaide, South Australia. They introduced special coding for location and frequency of activities, printed it on prepared field study maps, and after that, statistically analyzed. In this study, they supported the concept that urban microclimates influence public life by altering the typology, duration, and frequency of outdoor activities. Also, they reported on the correlations between heat-sensitive activities and urban greenery. Peng, Wang, and Li [62] have analyzed several correlation patterns of Market Square (Cambridge) users to pinpoint the affordance theory and inform relevant design strategies. Their innovative approach included spatial coupling results from agent-based modeling, on-site behavior snapshots, and thermal comfort zones. Samples were marked with the behavior category, location, and whether they stayed in the sun or shade, and the overall duration of the stay was measured based on activity. The turning point (thermal threshold) for sitting was 11.8 °C, for standing 10.4 °C, for strolling 10.5 °C, and for walking 9.6 °C. With a 4 °C increase, less comfortable areas appear acceptable for more than half of the observed groups. The results have shown a tendency toward occupying shady spaces in general. Boumaraf and Amireche [63] tried to verify the impact of microclimatic characteristics on variations in the frequency of usage and the duration of the stay in urban public spaces. They used naturalistic observations based on video recordings during the summer and winter to gather information on where people stay the longest. For this study, they developed a spatial coordination technique that is represented by nine divided sections (12 m × 15 m) for comparison. During the winter, people stayed longer, and during the summer, people stayed for less time. The study shows clear differences in the distributions of frequentation density for public spaces and the nature of user activities between the summer and the winter. Boeri and his team [64] focused on two squares located in Bologna's city center and collected information on urban dynamics and citizens' behaviors using human presence sensors and the results of microclimatic simulations. The conclusions of the OTC-related studies in this cluster, the activities, show that public events are the main deciding factor influencing square crowding, and the study confirms a direct correlation between outdoor climate, perceived thermal comfort (PET), and people's presence.

II Cluster: Psychological and cultural factor—adaptive behavior

In studies from this cluster, the primary methods used for research data gathering are questionaries and pedestrian-based interviews, a collection of microclimate data in the field (environmental monitoring), air temperature, air humidity, solar radiation, airspeed (wind direction), and observation of people activity and behavior. The main aim of these studies is to describe perception, emotions, subjective adaptation, human needs, space thermal comfort, and the overall quality of the urban design. It uses a single cross-sectional or multiple cross-sectional research design.

Essential for these urban studies is that thermal comfort assessment relies not only on microclimate weather parameters but also primarily on assessing user-specific social and cultural factors [9,65–73]. This group of studies is focused on evaluating and improving thermal comfort in urban squares, with the most significant attention on the subjective experiences, perceptions, and preferences of pedestrians (the quality approach). Different subjective thermal sensations are interpreted concerning users' social, cultural, and economic conditions.

In studies regarding the Dutch city squares, people were asked to draw cognitive microclimate maps of locations with microclimate characteristics and to express their emotions and impressions about materialization and the spatial configuration of the space. This led to recognising wind as a unique problem for Dutch squares, where people overestimate the wind factor [10,67,74]. Knez, Eliasson, and Thorson [65] analyzed subjective perceptions and preferences in Nordic city squares through structured interviews and compared them to the Japanese ones. The research scope and methodology were interdisciplinary and carried out in different public spaces during all four seasons. Studies further showed that good weather is more important for using city squares (increasing the number of people in the square) in Sweden than in Japan, which is attributed to cultural differences between the two countries. They also found a user correlation between the aesthetic appearance of waterfront plazas and standard squares and different wind speeds, air temperatures, and sky clearness in Nordic cities [65]. In front of waterfront plazas, people perceived places as more beautiful and warmer, with increased wind and a higher clear sky index. Attendance was increased by a temperature rise and with a higher clearness index.

In a different study on OTC for urban squares in temperate and dry climates, Kariminia and colleagues [75] recognized four groups concerning the reason they visited the square in Isfahan, Iran. The percentage of users who felt comfortable was largest among the visitors who were resting and sightseeing, followed by those who were shopping or engaging in social activities. The thermal sensation of the visitor exposed to different environment designs did not significantly differ in winter, unlike in various situations during the summer. Thermal sensation votes are correlated considerably in the summer but did not significantly correlate with microclimate variables in the winter. During the winter, thermal sensation votes were found to have a negative relationship with wind speed. The study aimed to compare OTC in different squares and other open spaces during summer and winter between Marrakech (Morocco) and Phoenix (Arizona, USA). Aljawabra and Nikolopoulou found a correlation between the effects of socioeconomic and cultural diversity on thermal comfort, behavior, and space usage [69]. Clothing was different during the summer period because of cultural differences. People in Marrakech even wear clothing that covers most of their bodies during summer. Most of the interviewed people in Marrakech live in non-air-conditioned spaces (75%), unlike those in Phoenix (25%). People with better education and better-paid jobs tend to stay for shorter periods in urban squares. However, when solar intensity decreases, time spent in outdoor squares increases.

A study by Kenawy and Elkadi [72] on outdoor thermal perception in Melbourne urban square found the effect of the users' cultural and climatic background on their thermal sensation votes. These parameters are crucial to take into consideration when designing urban places within multicultural communities. Similar findings were found in a study by [76] in the square of the university campus in Putra, Malaysia. There is a significant difference between local and international groups of students regarding the perception of weather conditions. A comparison between subjective assessment and objective measurement showed a high tolerance of local respondents to the thermal environment because of their climate adaptation and both their experience and expectations. Some studies found a correlation between the sense of place, the urban square, and individual thermal adaptation [70,77]. Zabetian and Kheyroddin found a direct correlation between a sense of place and individuals' thermal adaptation to achieve thermal comfort. Also, the results indicate that an individual's thermal comfort adaptation will increase with the increase in selective and social activities rather than compulsory activities.

III Cluster: Thermal comfort and heat mitigation measures—comparison

Studies in this cluster focus on user OTC comparison and mitigation measure comparison, with a focus on the physical factors of the urban environment. The study design approach is complex, with the usage of (a) qualitative (questionary, survey, analytical time series observation) and (b) quantitative data collection methods (in situ weather measurements, computer spatial analysis, modeling, and simulation scenario data output). Over time, an important difference in quantitative data collection is the gradual improvement of instruments' precision and techniques for data collection. Before 1990, there were few or no digital instruments for collecting meteorological data. After 2000, technological changes, automatization and digitalization, digital data loggers, wi-fi and internet-supported instruments, computer-supported analyses, and new indices were introduced.

Many studies assess the effects before and after an urban square redesign or with comparisons of conceptual urban redesign scenarios. Some of the studies of the urban redesign process consider mitigation measures (a) one by one and (b) with the composition of different measures with a cumulative effect (optimal scenario design).

These studies are focused on direct correlations between the design and layout of buildings, green areas, water amenities, surface materialization, and bioclimatic performance. These studies explain the causes and effects of the cool island concept in cities. The quasi-experimental research design approach is mainly used, while user groups in different time series (weather and urban design conditions) are observed or interviewed and compared. Different comparison aspects make for the subcategorization of this cluster into subclusters: IIIa green–blue–grey infrastructure, IIIb urban square morphology and geometry (H/W, SVF), IIIc surface materialization, IIId small urban elements, and IIIe wind and design scenario evaluation.

This group of studies is focused on quantifying different strategies and design factors for reducing UHI, with quantitative referring to the results obtained and most often using a simulation analysis. Research in these studies paid a lot of attention to assessing the overall spatial structure of the urban heat island mitigation techniques, including those utilizing green roofs, cool materials, vegetation, and water supplies.

IIIa Cluster: Green—blue—grey infrastructure

Research on green–blue–grey infrastructure factors in urban squares is the most frequent subtype of OTC-related urban square design research. Several studies empirically advocate the potential of trees, grass, and water amenities (fountains, water spray mist, and other water elements) for improving thermal conditions and reducing heat stress. In these studies, the research aims to find the correlation between air temperature increasing/lowering and engineered greenspace variables, such as the amount of vegetation (grass and shrubs cover percentage, number of trees, etc.) and vegetation type (species, foliage density LAD, LAI, vegetation canopy shape, vegetation arrangement design, tree canopy shade). The methods used for data collection combined the collection of objective data—microclimatic monitoring—and subjective data—observation and questionaries. The main objective of these studies is to determine the impact of the vegetation mentioned above and water entities on the urban microclimate and the overall OTC.

Studies with alternative vegetation and water redesign scenarios on urban squares with mitigation measure solutions were assessed through different scenario simulations using specific software tools (ENVI-met, SOLWEIG) for squares in Thessaloniki, Greece [78]; in Padua, Italy [79,80]; in Sétif, Algeria [81]; in Porto, Portugal [82]; in Achen, Germany [83]; in Cesena, Italy [84]; in Munich, Germany [85]; in Pécs, Hungary [86]; in Athens, Greece [87]; in Zurich, Switzerland [88]; in Guelma, Algeria [89]; in Mendoza, Argentina [90]; in Rome, Italy [91]; in Milan, Italy [92]; in Ishikawa, Japan [18]; and in Dalian, China [93].

The evaluation of the influence of vegetative and water factors through comparative POS case studies was performed in different urban squares [94–99], urban squares and parks [100–102], urban squares and streets [103], and sun or tree shade [104,105].

A study for Niš, Serbia, considered a comparative thermal evaluation of different measuring points considering applied materials: greenery (grass lawns and trees) and standard pavement material (asphalt and concrete) [106]. For comparison, field measurements in Belgrade were conducted at the following locations: Obilićev venac, Đure Jakšić Street, Studentski park, Košutnjak, and the Institute for Biological Research "Siniša Stanković" [107].

The findings indicate that the temperature contrast between green spaces and densely populated areas on hot summer days in Belgrade can average up to 7 degrees Celsius. Field measurements in Novi Sad were conducted at the Liberty Square-main square in the city, a small urban street canyon in the pedestrian zone of the city center, and a small urban park near the city center [108]. The most significant differences in the average air temperature were noticed between the city square on one side and the street and park on the other.

A similar study was conducted at Xi'an Eurasia University, China, where several squares with different landscape designs were compared to air and surface temperatures [109]. Some studies focused on the vegetation growth stage and the impact of tree shade on OTC [110,111] and a comparison of the energy budget influenced by tree shading in different growth stages using the COMFA model [112].

In the study for Strasbourg [113], the main aim of the research was to evaluate green areas with thermal cold stress and thermal heat stress in city squares compared to rural areas using the method of UHI studies. A similar study in Shanghai, China [114], investigated the effect of landscape microclimates on human thermal comfort and health using questionnaires and physiological measurements to compare landscape sites with greenery and open spaces without greenery. Interesting OTC studies about different mitigation scenarios with varying species of trees, different planting distances, leaf area density, leaf area index, crown width, and tree planting layout designs were undertaken for squares in Guangzhou, China [115], and Munich, Germany [116], using ENVI-met simulation tool.

IIIb Cluster: Urban square morphology and geometry

In this cluster, the impacts of urban geometry on OTC urban square design are usually assessed through the ratio between the height of buildings (H) and the distance between buildings (W) and the sky view factor (SVF) that represents the percentage of free sky at specific locations. These parameters directly influence the amount of incoming and outgoing radiation and air temperature. This kind of study is usually used for street design research because of street canyon effects, but several studies have compared the impact of urban squares and streets. The methodology usually included software modeling and simulation tools: ENVI-met, RayMan, SkyHelios, DUTE, and Ecotect for calculating SVF and OTC indices. Studies of OTC urban square design that have focused on urban square morphology and geometry were performed in Gothenburg, Sweden [117], using Solweig; in Curitiba, Brazil [118], using ENVI-met; in Esfahan, Iran [119,120], using ENVI-met; in Lisbon, Portugal [121], using RayMan and SkyHelios; Chillán, Chile [122]; and Szeged, Hungary [123]. Several research studies were conducted at different university campus squares considering different geometry [124,125], using the RayMan model and DUTE 1.0 simulation tools.

Assessing the impact of façade orientation, shading from buildings, and woody vegetation on radiation heat load (mean radiant temperature) is the main research aim for studying medium-sized rectangular squares in Szeged, Hungary [126]. The applied methodology uses field measurements and numerical models using different modeling software programs (ENVI-met, SOLWEIG, and RayMan Pro). A comparison between modern and traditional (historical) urban block layouts and OTC in urban squares was analyzed in Harbin, China [127]. Before this study, a similar study was conducted in Fez, Morocco [128]. The "Thermal walks" study was a longitudinal study approach with randomly selected participants in order to evaluate pedestrian OTC perception in urban squares and streets [129].

IIIc Cluster: Surface materialization

The studies of this subcluster showed how pavement materialization using cool materials with low albedo could significantly impact the heat island effect on urban squares. Important factors for OTC urban square design are the size of the surface exposed to solar radiation and the characteristics of materials for the pavement—albedo, emissivity, and thermal inertia. Comparison studies in the cluster used monitored microclimate data and albedo measurements to compare surface materials and perceived OTC for different places observed on the square. Numerous comparison studies examined the relations between different surfaces on urban square materialization [88,106,109,125,130–134]. Simulation studies for checking cool materialization mitigation measures for OTC in different design scenarios, albedo or pavement scenario redesign, and urban squares usually used software models ENVI-met, RadTherm, Fluent, PHOENICS, and SOLENE, [79,80,82,91,95,135–137].

New methods and solutions are used for building redesigns of the façade to achieve better OTC. Their influence was compared through CFD (ENVI-met) software in the past few years [138,139]. Some studies first measure and compare characteristics of ground surface materials in urban design and then use monitored data for calibration and further examination through simulation tools [140].

IIId Cluster: Small urban elements and wind

Research on biometeorological measurements in different outdoor environments—under "piloti" (space with colonnade attached to square) compared with a location in an open square was conducted in Wuhan [141]. Subjective data were collected using a questionnaire, and objective environmental physical measurements were carried out simultaneously. Specific research with an integrative approach on acoustic, visual, and thermal comfort mitigation measures for POS during summer night activities has been undertaken for Matteotti Square in Citta di Castello, Italy [142]. The evaluation of different scenarios of heat exhaust impact on pedestrian thermal comfort in urban squares is the main objective of the study for El Hussein Square in Cairo, Egypt [143]. The research was conducted using field measurements, data collection using an infrared camera, data from referent microclimate stations, and simulations and modeling using ENVI-met. Possibilities for wind environment improvement for better OTC were researched in the study for Grand Canal Square in Dublin, Ireland [144]. Field measurements and the computational model ENVI-met are used as the main research method.

IIIe Cluster Design Scenario evaluation

Several research studies in these subclusters use an exploratory approach with simple weather measurement and diagnostic and analytic tools to propose new mitigation strategies for better OTC urban squares [145–152]. These studies lack any CFD model assessment for scenario comparison or subjective thermal perception evaluation. Most studies are with microclimate data monitoring, CFD model scenario simulation with thermal comfort assessment for different mitigation strategies, and an evaluation of microclimatic improvements [15,18,81,82,84,88–91,94,95,137,153–166]. Developing and testing alternatives, such as the process "research by design", this research paper describes design outcome, evaluation, and design process—mitigation model or strategy. Some of these comparative case studies analyze two or more urban squares or compare urban squares to other POS (urban parks, streets, community open areas). A study of the worst-case scenario of temperature climate change effect on OTC within the urban square was undertaken for square Rossio, Lisbon [167]. Some studies have complex methodologies with microclimate data monitoring and data gathering, CFD model simulation with OTC assessment and qualitative part, and the pedestrian-based response interview for scenario design evaluation [168–170]. Specific research on a microclimate analysis in urban design competitions was followed by testing and evaluating competition-rewarded design proposals for the urban redesign of the main square in Leskovac, Serbia [16]. The research evaluates the influences of urban morphology and urban design parameters on pedestrian thermal comfort in a generic universal square design [171]. Every parameter, such as street and building geometry, landscape elements, vegetation types, water surfaces, and materials, is ranked according to the influence on pedestrian thermal comfort.

A case study of urban square redesign with a long-distance period comparison was conducted for Antofagasta, Chile, where data ex ante measurements from 1990 and ex post data results from 2014 were compared [172]. The variables compared were land surface temperature, humidity, wind speed, amount of light, and square use frequency.

IV Cluster—Outdoor thermal comfort perception comparison

IVa Cluster: Measured vs calculated and subjective vs objective estimation of thermal comfort in urban squares

Numerous OTC perceptional-based studies were undertaken during this cluster's review period (2001–2023). These studies, which are used as an important input factors for the urban design of POS, usually have mixed qualitative and quantitative approaches, with two parts: (a) on-field objective weather parameters measurements with subjective questionary survey and (b) a comparison-calculated rational thermal comfort index (PMV, PET, SET*, UTCI) with measured subjective estimation. This research section focuses on the relationship between biophysical environments and subjective thermal comfort, thermal index comparisons, different neutral temperature perception ranges, acceptable thermal perception ranges, thermal perception thresholds, and various groups' perception comparations (old, young, tourists, domestic). Several studies were undertaken to assess the correlation between the subjective comfort level (perceptions and preferences) and weather parameters through a questionnaire survey [69,173–176]. Some studies have compared cross-sectional measurements for summer and winter [75,177–181]. One study compared the measured actual wind speed with the wind sensation vote (WSV), wind preference vote (WPV), and wind comfort vote (WCV) [182]. A lot of studies evaluated the OTC by comparing the Fanger model [183], PMV (predicted mean vote), and PPD (predicted percentage of dissatisfied) indices and actual thermal sensation votes (ASVs) in urban squares and other urban spaces. [9,68,178,184]. Some studies compare PET [185,186] (physiologically equivalent temperature) vs ASV (actual thermal sensation vote) in urban squares and other urban spaces [76,77,174,175,179,187–192]. Likewise, several studies compare calculated SET* [193,194] vs ASV in these spaces [141]. Other studies compare calculated UTCI [195,196] vs ASVs in urban squares and other urban spaces [176,197].

IVb Cluster: Neutral temperature perception thresholds in urban squares

The studies in this subcluster conduct research about the different meanings and semantics of "thermal neutrality", first conducted by Humphreys [198,199], and primarily for indoor environments. The acceptable air temperature range is a concept similar to an acceptable thermal climate, as defined by ASHRAE Standard 55 [200]. According to this, it is the environment that most users (more than 80%) find thermally acceptable. In studies of neutral temperature perception in urban squares, used methods for research data gathering are qualitative and quantitative approaches, which include (a) on-field objective weather parameter measurements with a subjective questionary survey and (b) a comparison-measured objective and subjective parameters, usually using statistical tools (correlation regression analysis, linear regression analysis, frequency distribution, and others). In research about neutral temperature perception thresholds in urban squares, the main focus is on the validation of local–regional thresholds of neutral comfort and the acceptable thermal range during the night and day, summer, winter, and transitional seasons [9,56,69,177,190,201–206].

IVc Cluster: Special group analysis on thermal perception comparison in urban squares

This subcluster considers studies on particular groups of people for OTC assessments in urban squares. Some researchers have focused on specific weather and microclimate conditions ideal for city tourism, recreation, and leisure activities [168,191,207–209]. In these studies, different thermal indices were compared for the activity and behavior of tourists and recreationists. In some OTC studies in urban squares, only marginal groups of users participated in the questionnaire, such as students [125,141,210], or older people [211].

V Cluster: Development of new methodology and instrument techniques applied for OTC assessment in urban squares

Studies were conducted to develop a methodological framework for OTC assessments with a case study in an urban square [150,212–216]. The innovation data collection method was explored for the passive activity observation method to estimate outdoor thermal adaptation [217] and for mobile field microclimate measurements [152]. New approaches for OTC assessments by combining terrestrial laser scanners (TLS) and areal ortho-photography with computational fluid dynamics (CFD) are developed [135]. Several studies compared different methods for obtaining and calculating Tmrt—mean radiant temperatures in squares [123,218,219]—from simple ones that use simple calculation formulas and simple instruments to address complicated calculations with computer software. OTC assessment case studies for computer CFD calculation model development were tested and assessed in urban squares [133,134,220,221]. The adaptive neuro-fuzzy inference system, ANFIS, for the investigation of the thermal comfort of visitors in a public square [222,223] is one of the more developed models with an advanced algorithm for OTC assessment. Other computational model development studies [224] were conducted within urban square verification.

3.3. Statistical Comparison of Clusters Main Research Characteristics

3.3.1. Primary Geometric Characteristics of Selected and Analyzed Urban Squares

In most selected papers for this review, the primary geometry of the urban square is often not presented explicitly. Therefore, for the analysis in this review, every square is marked and measured, and its geometry is defined using the Google Earth platform (Tables S2 and S4. Google shape data, kmz file, in Supplementary Materials). The total number of studied urban squares is 316. Studies of the same square are counted because of the applied different methodologies and the scope of the research approach. The analysis of geometric characteristics does not apply to the three studies because the study is unavailable or the square is of a generic type. A tabular overview of the studied geometric/physical characteristics of squares is presented in Table 2. The typology of small, medium, large, and extra-large squares, based on Wolfurm's study [225], was used to differentiate square sizes. Most studied squares (47.28%) have an area between 5000 m^2 and 15,000 m^2. Many polygonal squares (36.10%) do not fit into the traditional orthogonal concept of urban square shape. The dominant orientation of squares and the facades of buildings is an important parameter that determines solar access, and in combination with wind speed and building volume, it influences OTC [126,139].

Dominant axel orientation is south–north (21.08%) and west–east (15.01%), and the least number of squares is with ESE-WNW and WSW-ENE orientations. This is probably because half of the studied squares are in the traditional urban fabric; by function, they are usually the main city squares with religious buildings. Most of the SSW-NNE orientation is in the Cfb climate classification region. The distribution of studied square orientations via Köppen–Geiger classification is given in Figure 7.

Table 2. Overview of studied geometric/physical characteristics of squares (Authors data).

Studied Built Environment	Parameter	Number of Urban Squares Studied	Percent of the Total Number of Urban Squares Studied (%)
Size of squares	Small < 5000 m^2	114	36.42
	5000 m^2 $\leq$ Medium < 15,000 m^2	148	47.28
	15,000 m^2 $\leq$ Large < 25,000 m^2	25	7.99
	Extra Large $\geq$ 25,000 m^2	26	8.31
Square shape	Square	48	15.33
	Rectangular	112	35.78
	Trapezoidal	22	7.02
	Polygonal	113	36.10
	Triangular	15	4.79
	Rounded	2	0.63

Table 2. *Cont.*

Studied Built Environment	Parameter	Number of Urban Squares Studied	Percent of the Total Number of Urban Squares Studied (%)
Dominant axel orientation	W-E	47	15.01
	WSW-ENE	28	8.94
	SW-NE	38	12.14
	SSW-NNE	42	13.41
	S-N	66	21.08
	SSE-NNW	41	13.09
	SE-NW	38	12.14
	ESE-WNW	15	4.79
Square genesis	N (new—modern)	144	46.01
	T (traditional)	169	53.99

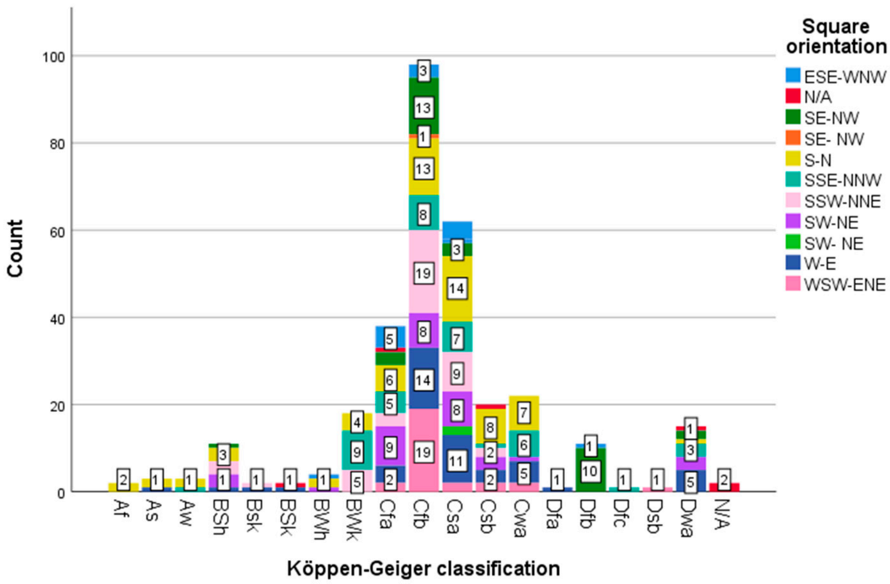

Figure 7. Distribution of studied different square orientations via Köppen–Geiger classification.

Several studies regarding squares in new and traditional urban fabric are almost the same (46.01% in new urban fabric and 53.99% in old urban fabric). Possibilities for the urban redesign of urban squares in the old traditional and modern urban fabric provide various and different opportunities for mitigation strategies [15,79,80,158,160,166].

3.3.2. Analyzed Characteristics of the Built Environment in Urban Squares

Sky view factor and height/width aspect ratios are the primary and standard physical parameters in understanding built morphology and their impact on OTC in urban squares [121,226]. There is no specific geometric typology of urban squares' geometric configuration developed for OTC studies, while there are several for urban streets: "street canyons" with descriptions "deep" if the H/W is more than 2, uniform if the aspect ratio is 1,0, and "shallow" if the aspect ratio is below 0.5; "short" (L/H = 3), "medium" (L/H = 5), and "long" (L/H = 7); "symmetric" and "asymmetric"; and so on [227,228]. The terms "open square" and "enclosed square" for the geometry of urban squares are more appropriate for the description of urban squares [229,230], but that is a problem for another research paper. This systematic overview has classified OTC urban square studies focused on different built environment parameters: SVF—sky view factor, H/W—height/width aspect ratio, Alb—Albedo, VT—Vegetation type, VAD—Vegetation arrangement design, AV—Amount of vegetation, LAD—Leaf area density, GSM—ground surface materials, Col—Color, VOA—Volume and object arrangement design, and FM—Façade materials.

Most papers focus on the amount of vegetation (31.79%) and ground surface materials (22.54%). Also, it is interesting that only six papers (3.47%) evaluated different vegetation arrangements with the same amount of vegetation. A smaller number of research papers is noticeable for assessing the influence of colors and used façade materials on OTC in urban squares (Table 3).

Table 3. Overview of studied urban morphology, greenery, and configuration parameters.

Studied Built Environment	Number of Studies	Percent of the Total Number of Studies (%)
SVF—Sky view factor	30	17.34
H/W—Height/width aspect ratio	28	16.18
Alb—Albedo	22	12.72
VT—Vegetation type	35	20.23
VC—Vegetation canopy	15	8.67
VAD—Vegetation arrangement design	6	3.47
AV—Amount of vegetation	55	31.79
LAD—Leaf area density	16	9.25
GSM—ground surface materials	39	22.54
Col—Color	11	6.36
VOA—Volume and object arrangement design	24	13.87
FM—Façade materials	9	5.20

3.3.3. Data Collection Methods Used in Selected Studies

The data collection method defines the primary research approach (see Section 2), and this aspect of the research has changed in the last twenty years. However, it still lacks standardization [27]. Digitalization, new and cheaper microclimate instruments, online data for referent micrometeorological stations, and new computer software and techniques allow for a much more detailed simulation and visualization assessment than ever before. However, the data collection from people relies merely on on-site data collection. For this review, 13 data collection methods were defined, and an overview of the data collection method is given in Table 4.

Table 4. Overview of the data collection method.

Data Collection Method	Number of Studies	Percent of the Total Number of Studies (%)
NP—On-site counting of the number of people	18	10.40
AK—Manual Recording activity of people	30	17.34
F—On-site taking photos for people activity measures	18	10.40
FED—Fish Eye diagram	7	4.05
Sen—On-site sensors micrometeorological measurement	16	9.25
DM—on-site measurements with a portable meteorological station	120	69.36
IRC—On-site Infra-red camera recording	7	4.05
PMS—using data from the referent meteorological station	74	42.77
INT—On-site filled out Structured interview—questionary	55	31.79
VR—on-site video recording	2	1.16
AlbM—on-site albedo measurement	3	1.73
Sim—using computer simulation	78	45.09
PS—using data from previous studies	12	6.94

Most studies (69.36%) use data from on-site measurements with the portable meteorological station. Using data from a computer simulation is the primary data collection method for 45.09% of all studies, and referent meteorological stations is the primary method for data collection (42.77%). On-site structured interviews and questionnaires are the data collection methods for 55 studies (31.79%). Some relatively demanding methods, such as on-site infra-red camera recording (4.05%) and on-site albedo measurements (1.73%), are less common.

3.3.4. Used Thermal Indices in Studies

Thermal indices are very useful for describing heat exchange between a human body and the surrounding environment, and various comfort indices were developed for thermal comfort evaluation [25,231,232]. Different thermal indices used in studies about OTC urban squares (Table 5), PET [185], PMV and PPD [183], Tmrt [116,123,225–227,233–235], UTCI [195,196], OUT-Set [236], and MOCI [237], are based on different theoretical models and different purposes (outdoor and indoor measurement), and every model has different basic parameter valuation (Table 6).

Table 5. Overview of used thermal indices in studies.

Studied Built Environment	Number of Studies	Percent of the Total Number of Studies (%)
Tmrt—Mean radiant temperature	50	28.90
PMV—Predicted mean vote	36	20.81
PPD—Predicted Percentage of dissatisfied	3	1.73
PET—Physiological equivalent temperature	76	43.93
UTCI—Universal Thermal Climate Index	22	12.72
OUT-Set—Outdoor Standard Effective Temperature	3	1.73
MOCI—Mediterranean Outdoor Comfort Index	1	0.58

An examination of the indices used in outdoor studies for urban square assessment shows that the PET index was the most used in 43.93% of the studies. Tmrt is an environmental parameter calculated from the environment model of the studied area. It has an important effect on OTC during clear-sky days with extreme radiation, and it was used in 28.90% of papers. PMV index was used for reporting in 20.81% of studies and UTCI in 12.72%. Some studies used two or more thermal indices to describe it better and understand thermal influences. Studies for thermal neutrality compared indices in different geographical areas (see Section 3—Outdoor Thermal Comfort Perception Comparison).

3.3.5. Collected Micrometeorological Measurements in Studies

Collected micrometeorological measurements (Table 6) were used for climate comfort assessments or as input data for index calculations, computational model input, or validation. The standard parameters in studies were Ta—air temperature (dry bulb temperature) (°C), RH—relative humidity (%), AP—atmospheric pressure (hPa), Tg—globe thermometer temperature (°C), Tw—wet bulb temperature (°C), Tsurf—ground surface temperature, Tfac—façade surface temperature, SW—short wave irradiance (W/m^2), LW—long wave irradiance (W/m^2), Gr—global solar radiation, Ws—wind speed, Wd—wind direction, CC—cloud cover, PM particles, and SH—soil relative humidity (Table 6).

Microclimate data about air temperature and relative humidity are the most used parameters in almost every study (94.22%). Wind speed is another very used parameter (84.39%). Long wave and short wave radiation is collected in 17.92% and 14.45% of studies. The problem of estimating the effects of every single parameter in the studies is evident, and some of the studies tried to isolate these effects by exploring parameters one by one. Interestingly, the façade surface temperature was considered in only 3.47% of all studies (Table 6).

Table 6. Overview of studied micrometeorological parameters.

Studied Built Environment	Number of Studies	Percent of the Total Number of Studies (%)
Ta—air temperature (dry bulb temperature) (°C)	163	94.22
RH—Relative humidity (%)	163	94.22
AP—Atmospheric pressure (hPa)	5	2.89
Tg—globe thermometer temp—(°C)	59	34.10
Tw—wet bulb temperature (°C)	3	1.73
Tsurf—ground surface temperature	32	18.50
Tfac—Façade surface temperature	6	3.47
SW—Short wave irradiance (W/m^2)	31	17.92
LW—Long wave irradiance (W/m^2)	25	14.45
Slux—solar illumination (cd/m^2, lum)	3	1.73
Gr—global solar radiation	39	22.54
Ws—wind speed	146	84.39
Wd -wind direction	65	37.57
CC—cloud cover	12	6.94
PM particles	3	1.73
SH—Soil relative humidity	2	1.16

3.3.6. Human-Based Parameters and the Subjective Perception of the Environment in Studies

For calculating indices or evaluation and comparison elements in studies, 12 different human-based parameters and subjective perceptions of the environment were recognized. The measurement scales are used to determine personal thermal states in comfort studies, described as follows: actual sensational vote (thermal, wind, sun, or humidity)—(TSV, WSV, SSV, and HSV), affective vote—comfort satisfaction (OCV, WPT, WPV), and preferential vote [238] (Table 7).

Table 7. Human-based parameters and subjective perception of the environment.

Questionary Survey	Number of Studies	Percent of the Total Number of Studies (%)
Clo—Clothing level	40	23.12
Ma—metabolism	34	19.65
TSV Thermal sensation vote	37	21.39
ACV—Actual comfort vote	9	5.20
ATCV—Actual thermal comfort vote	6	3.47
ASV Actual sensational vote	14	8.09
EAS—Emotion about space	5	2.89
WPT—Weather perception today	3	1.73
WPV—weather preference vote	4	2.31
APM—actual personal mood	5	2.89
OCV—Overall comfort vote	3	1.73
Tperc—Subjectively estimated temperature	1	0.58

Clothing level and metabolism are important input data for calculating bioclimatic indices used in 23.12% and 19.65%. The most used descriptive thermal scale parameter is the TSV—thermal sensation vote, used in 37 studies (Table 7).

4. Discussion and Conclusions

This study presented a systematic review of OTC-related studies for the urban design of city squares published in the last two decades in academic peer-reviewed journals in English. The typology of five different research designs and methodological approaches is developed. The research is described by different research clusters and statistically presented by the main characteristics. This study represents a comprehensive systematization of the extensive literature regarding OTC-related studies. It deepens the knowledge of the diversity of possible methodological approaches in preselected OTC studies, which mainly focus on the urban design of open public spaces and, more precisely, the urban design of city squares.

The majority of the OTC-related studies on the urban redesign of city squares were conducted in three countries: China, Italy, and Greece. There is apparent unevenness in studied climatic areas about OTC for the urban design of city squares. Most of the research is based in cities with Cfa, Cfb, and Csa climate types, even though climate change and extreme weather events affect urban squares in other climate areas.

Based on four criteria, the research method, research approach, time duration, and measured outcome, five different types of research designs in OTC for the urban redesign of city squares were defined:

(I) Human behavior–user activity studies are based on the environmental–behavioral non-obstructive observation methodological approach. All of the studies use methods for studying people's behavior in their natural settings, such as field studies or non-obstructive observations in natural settings. These studies usually do not have scenario redesign comparisons; they are typically carried out through time series: different weather seasons, different daytime, or before and after the square reconstruction.

(II) Psychological and cultural factor. Adaptive behavior studies have for research data gathering methods: questionary–pedestrian based interview and parallel collection of microclimate data in the field (environmental monitoring). Essential for these urban studies is that a thermal comfort assessment relies not only on microclimate weather parameters but also primarily on assessing user-specific social and cultural factors. Different subjective thermal sensations are interpreted concerning users' social, cultural, and economic conditions.

(III) Thermal comfort and heat mitigation measures. Comparison studies focus on a user OTC comparison and mitigation measure comparison, with the most attention paid to the physical factors of the urban environment. The study design approach is mixed with the use of (a) qualitative (questionary survey, analytical time series observation) and (b) quantitative data collection methods (in situ weather measurements, computer spatial analysis, modeling, and simulation scenario data output). A different comparison aspect makes subcategorization of this research: green–blue–grey infrastructure, urban square morphology and geometry (H/W, SVF), surface materialization, small urban elements, and wind and design scenario evaluation.

(IV) Outdoor thermal comfort perception comparison studies. These studies are used as an important input factor for the urban design of open public spaces and usually have mixed qualitative and quantitative approach, with two parts: (a) an on-field objective weather parameter measurement with subjective questionary survey and (b) comparison-calculated rational thermal comfort index (PMV, PET, SET*, UTCI) with measured subjective estimation. This part of the research focuses on the relationship between biophysical environments, subjective states of thermal comfort, thermal index comparisons, different neutral temperature perception ranges, acceptable thermal perception ranges, thermal perception thresholds, and various groups' perception comparations (old, young, tourists, domestic).

(V) Development of new methodology and instrument techniques for OTC assessment in urban squares. These studies are quantitative, cross-sectional, and have a quasi-experimental research design; their primary objective is to explore the development of a methodological framework of an outdoor comfort assessment with a case study in the urban square.

Considerable diversity in the methods, variables, and subject focus was found. Because of diversity, direct comparisons between studies using meta-analysis or border generalizations about the topic are limited. The developed research design typology of five different study types for OTC for the urban redesign of city squares are as follows: (1) human behavior—user activity, (2) psychological and cultural factors, (3) thermal comfort and heat mitigation measures—comparison, (4) outdoor thermal comfort perception comparison, five measurement methods and techniques development. This typology can be used for the subsequent narrower meta-analysis, improving teaching and studying urban design.

The majority (54.3%) of OTC-related studies for urban square design are those which study thermal comfort and heat mitigation measures on (1) green-blue infrastructure, (2) urban square morphology and geometry, (3) surface materialization, (4) small urban elements and wind, and (5) design scenario evaluation.

The most common geometry of the studied urban square is medium sized and rectangular with dominant axel orientation south–north and in the traditional urban tissue. More than half of the papers focused on the amount of vegetation and used surface materials on urban squares. Most studies for data collection use portable meteorological stations, computer simulations, referent meteorological stations, and structured interviews.

Psychological and cultural-based OTC for the urban redesign of the city square uses main methods for research data gathering, such as questionary pedestrian interviews and collecting microclimate data in the field.

Most studies are based on a quantitative research approach and environmental data collection (data about urban geometry and urban microclimate). The qualitative-based research approach, with a collection of human-based parameters, is still partially used.

No specific geometric typology of urban squares' geometric configuration was developed for OTC studies, as it exists for urban streets. More attention is needed to describe and explain urban fabric genesis because the possibility of urban redesign of urban squares in traditional and contemporary urban tissue demands different mitigation strategies. SVF and H/W parameters remain the most important for comparisons in different spatial and cultural contexts. The various arrangements of water and trees (with the same amount in squares) also deserve attention for subsequent research. Another research gap is using façade colors and green wall technology to mitigate thermal effects in urban squares. Studies about outdoor thermal comfort in urban squares do not cover underground objects and underground passages.

Every country needs to develop an optimum local methodological approach—a design model for assessing and improving the thermal comfort of city squares' urban design. The primary constraints are optimum data collection methods, standards for instruments and techniques, thermal indices, necessary and mandatory morphology analysis effects, and people's participation in local sensational, affective, and preferential votes about local outdoor thermal comfort in urban squares. The continued evaluation, management, and modification of mitigation measures are also important aspects of the urban design model for the following research period.

A mixed quantitative and quantitative approach applied for data collection, the combination of rational environment data, and subjective local human-based assessment is necessary for successful climate-sensitive urban design. The future development and evaluation of different combinations of mitigation measures and evaluating the effects via a one-by-one factor are also required.

Still, there are a small number of studies about psychological and cultural factors for OTC for the urban redesign of city squares. The psychological- and cultural-based research is represented only by 10%. Psychological–cultural approaches, different social and cultural groups of people in urban squares, have not been sufficiently studied. Also, this paper identified a research gap regarding the psychological aspects of thermal evaluation in squares.

Thermal comfort in urban squares can improve the quality of open spaces in cities, human health, and the city economy, so it is vital to consider the future development of research design approaches for urban city squares redesign. The increased number of reviewed papers from 2001 proves a strong interest in research in outdoor microclimates for urban square redesign.

Current research in OTC for the urban redesign of city squares is focused on areas with temperate climates. Main research gaps remain on the geographical scope of the study outside of traditionally considered climate areas for OTC studies (Cfa, Cfb, Csa, Csb, and Cwa), the development of a typology of urban square geometry configuration based on thermal comfort assessment, and the development of a local design model for assessing and improving the thermal comfort of city squares' urban design based on a mixed qualitative and qualitative approach.

Urban square geometry, greenery, and human-based parameters remain the main characteristics of OTC for the urban design of city squares studies. Still, there is a need for a deeper psychological–cultural approach. The green and blue infrastructure of attached buildings around city squares and their effects in cooling and mitigating urban heat islands to improve human thermal comfort [162,239–241] needs to be systematized in the following period. Furthermore, OTC studies for the urban design of inland or coastal city squares should also be differentiated in the future.

This review concluded that there is a great variety of geometric characteristics of studied urban squares, data collection methods, used thermal indices, collected micrometeorological measurements, and human-based parameters, as was reported before for general outdoor thermal comfort studies [27]. Diversity in the methods, variables, and subject focus found in this review is a limitation and an opportunity for future research.

The database of peer-reviewed papers about OTC urban design of urban squares in this review is incomplete and can be supplemented, as the scope was limited to the period 2001–2023 and in academic peer-reviewed journals in English. The results of this research can contribute to a better understanding and greater clarity of the research study design of OTC of urban squares as well as a better methodological approach and assessment in urban design projects.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/su16124920/s1, Table S1. Data for study classification, Table S2. Geometry of squares data, Table S3. Studied parameters, S4. Google shape data, kmz file.

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Appendix A

Table A1. Details of the 173 studies that examined assessing and improving urban (re)design of city squares.

Author	Year of Res. Study Publication	Study Type (1–5)	Country of Study	Name of the City	Name of the Square	Köppen Geiger Classification Rubel 2017
Yannas [145]	2001	3.5	United Kingdom, Greece	1. London 2. Athens	1. Russel square 2. Victoria square	1. Cfb 2. Csa
Nikolopoulou, Baker, Steemers [9]	2001	2,4.1, 4.2	United Kingdom	Cambridge	Market Square	Cfb
Zacharias, Stathopoulos, Wu [53]	2001	1	Canada	Montreal	1. Place de la Cathédrale 2. Phillips Square 3. Square Frère André 4. Place Ville-Marie 5. Royal Trust	Dfb
Picot [110]	2004	3.1	Italy	Milan	Piazza dell Scienza	Cfa
Stathopoulos, Wu, Zacharias [173]	2004	4.1	Canada	Montreal	1. Place de la Cathédrale 2. Phillips Square 3. Square Frère André 4. Place Ville-Marie 5. Royal Trust	Dfb
Zacharias, Stathopoulos, Wu [7]	2004	1	USA	San Francisco	1. Monument 2. 101 California 3. Bank of America 4. McKesson 5. Trinity 6. Fermont 7. 1 Bush	Csb
Scudo and Dessì [146]	2006	3.5	Italy	Milan (Cinisello Balsamo)	1. Piazza Costa 2. Piazza Gramsci	Cfa
Robitu, Musy, Inard, Groleau [220]	2006	3.1	France	Nant	Fleuriot Square	Cfb
Knez and Thorsson [242]	2006	2	Sweden	Göteborg	Gustav Adolfs torg	Cfb
Chatzidimitriou, Yannas [140]	2006	3.3	Greece	Thessaloniki,	1. Archaias Agoras Square 2. Platia Megalou Alexandrou 3. The square at the corner of the streets Leof. Stratou and Aggelaki	Csa

Table A1. *Cont.*

Author	Year of Res. Study Publication	Study Type (1–5)	Country of Study	Name of the City	Name of the Square	Köppen Geiger Classification Rubel 2017
Nikolopoulou, Lykoudis [201]	2006	4.1, 4.2	Greece Italy United Kingdom Germany	1. Athens—Alimos 2. Athens—Alimos 3. Thessaloniki 4. Milan 5. Milan 6. Sheffield 7. Sheffield 8. Kassel 9. Kassel	1. Karaiskaki square 2. Septembriou square 3. Makedonomahon square 4. Piazza Petazzi 5. Piazza IV Novembre 6. Peace Garden 7. Barker's Pool 8. Florentiner Platz 9. Bahnhofsplatz	Csa
Zambrano, Malafaia, Bastos [184]	2006	4.1	Brazil	Rio de Janeiro	Concordia Plaza	
Johansson [128]	2006	3.2	Morocco	Fez	Place Seffarine	Bsh
Eliasson, Knez, Westerberg, Thorsson, Lindberg [65]	2007	2	Sweden	Göteborg	Gustav Adolfs torg	Cfb
Thorsson, Lindberg, Eliasson, Holmer [219]	2007	5	Sweden	Göteborg	Gustav Adolfs torg	Cfb
Nikolopoulou, Lykoudis [54]	2007	1	Greece	Athens (Alimos)	Karaiskaki Square, Athens, Greece	Csa
Thorsson, Honjo, Lindberg, Eliasson, Lim [66]	2007	2	Japan	Matsudo	Matsudo Station Square	Cfa
Lindberg, Holmer, Thorsson [218]	2008	5	Sweden	Göteborg	Gustav Adolfs torg	Cfb
De Castro Fontes, Aljawabra, Nikolopoulou [55]	2008	1	United Kingdom	Bath	Queen Square	Cfb
Georgi and Tzesouri [100]	2008	3.1	Greece	Drama	Dikastirion Square	Csk
Matzarakis, De Rocco, Najjar [113]	2009	3.1	France	Strasbourg	Market square—Place Kléber	Cfb
Lin [177]	2009	2, 4.1, 4.2	Taiwan	Taichung City	NTMOFA	Cwa
Georgi and Dimitriou [101]	2010	3.1	Greece	Chania	square of Courts, Platia Eleftherias	Csa
Lenzholzer and van der Wulp [243]	2010	2	Netherlands	1. Den Haag 2. Eindhoven 3. Groningen	1. Spuiplein 2. Neckerspoel 3. Grote Markt	1. Cfb 2. Cfb 3. Cfb
Lenzholzer and Koh [10]	2010	2	Netherlands	1. Den Haag 2. Eindhoven 3. Groningen	1. Spuiplein 2. Neckerspoel 3. Grote Markt	1. Cfb 2. Cfb 3. Cfb
Lenzholzer [67]	2010	2	Netherlands	1. Den Haag 2. Eindhoven 3. Groningen	1. Spuiplein 2. Neckerspoel 3. Grote Markt	1. Cfb 2. Cfb 3. Cfb

Table A1. *Cont.*

Author	Year of Res. Study Publication	Study Type (1–5)	Country of Study	Name of the City	Name of the Square	Köppen Geiger Classification Rubel 2017
Kariminia, Sh Ahmad, Ibrahim, Omar [244]	2010	2	Iran	Isfahan	1 Emam Square (Naqsh-e Jahan Square) 2. Jolfa Square	BWk
Lin, Matzarakis, Hwang [124]	2010	3.2	Taiwan	Huwei	1. Student union square 2. Center square	Cwa
Tseliou, Tsiros, Lykoudis, Nikolopoulou [187]	2010	4.1	Greece Italy United Kingdom Germany	1. Athens—Alimos 2. Athens—Alimos 3. Thessaloniki 4. Milan 5. Milan 6. Sheffield 7. Sheffield 8. Kassel 9. Kassel	1. Karaiskaki square 2. Septembriou square 3. Makedonomahon square 4. Piazza Petazzi 5. Piazza IV Novembre 6. Peace Garden 7. Barker's Pool 8. Florentiner Platz 9. Bahnhofsplatz	Csa
Aljawabra, Nikolopoulou [68]	2010	2, 4.1	Morocco	Marrakech	Al Koutoubia Plaza	Bsh
Lindberg, Grimmond [245]	2011	5	Sweden	Göteborg	Guldhedstorget	Cfb
Thorsson, Lindberg, Björklund, Holmer, Rayner [117]	2011	3.2	Sweden	Göteborg	Gustav Adolfs torg	Cfb
Gaitani, Spanou, Saliari, Synnefa, Vassilakopoulou, Papadopoulou, Pavlou, Santamouris, Papaioannou, Lagoudaki [154]	2011	3.5	Greece	Athens	Messolongiou Square	Csa
Lenzholzer [155]	2011	3.5	Netherlands	1. Den Haag 2. Groningen	1. Spuiplein 2. Grote Markt	1. Cfb 2. Cfb
Krüger, Minella, Rasia [118]	2011	3.2	Brazil	Curitiba	1. Santos Andrade Square 2. General Osório Square	Cfb
Kariminia. Ahmad, Omar, Ibrahim [202]	2011	4.2	Iran	Esfahan	Emam Square (Naqsh-e Jahan Square)	BWk
Fintikakis, Gaitani, Santamouris [153]	2011	3.5	Albania	Tirana	Sheshi Fan S. Noli (Square Fan S. Noli)	Csa
Stavrakakis, Tzanaki, Genetzaki, Anagnostakis, Galetakis, Grigorakis [221]	2012	5	Greece	Heraklion, Gazi	1. Michael Katsamani Square 2. Square on the corner of Kondailaki and Nikos Kazantzakis street	Csa
Axarli and Chatzidimitriou [78]	2012	3.1	Greece	Thessaloniki	1. Chemistry square 2. Administration square	Csa

Table A1. *Cont.*

Author	Year of Res. Study Publication	Study Type (1–5)	Country of Study	Name of the City	Name of the Square	Köppen Geiger Classification Rubel 2017
Lenzholzer [74]	2012	2	Netherlands	1. Den Haag 2. Eindhoven 3. Groningen	1. Spuiplein 2. Neckerspoel 3. Grote Markt	1. Cfb 2. Cfb 3. Cfb
Kantor, Égerházi, Unger [175]	2012	4.1	Hungary	Szeged	1. Ady Square 2. Honvéd Square	Cfa
Kantor, Unger, Gulyas [174]	2012	4.1	Hungary	Szeged, Montreal, Taichung City and RUROS	1. Ady Square 2. Honvéd Square	Cfa
Xi, Li, Mochida, Meng [125]	2012	3.2, 3.3	China	Guangzhou	Distributor Square	Cwa
Cohen, Potchter, Matzarakis [102]	2012	3.1	Israel	Tel Aviv,	1 Rabin Square 2. Kupa Square	Csa
Makaremi, Salleh, Jaafar, GhaffarianHoseini [76]	2012	2, 4.1	Malesia	University Putra Malaysia	Square 1 Square 2	Af
Pantavou, Theoharatos, Santamouris, Asimakopoulos [176]	2013	4.1	Greece	Athens	Syntagma Square	Csa
Fröhlich, Matzarakis [156]	2013	3.5	Germany	Freiburg	Place of the Old Synagogue	Cfb
Maras, Buttstädt, Hahmann, Hofmeister, Schneider [83]	2013	3.1	Germany	Aachen	Bahnhofsplatz	Cfb
Szucs [144]	2013	3.4	Ireland	Dublin	Grand Canal Square	Cfb
Gómez, Cueva, Valcuende, Matzarakis [103]	2013	3.1	Spain	Valencia	1 Plaza de la Virgen, 2 Plaza del Ayuntamiento	Bsh
Lindner-Cendrowska [207]	2013	4.3	Poland	Warsaw	Old Town Marketplace	Cfb
Zhou, Chen, Deng, Mochida [141]	2013	4.1	China	Wuhan	N/A	Cfa
Kariminia, Ahmad [75]	2013	4.1	Iran	Esfahan	Emam Square (Naqsh-e Jahan Square)	BWk
Kariminia, Ahmad, Ibrahim [56]	2013	4.2	Iran	Esfahan	Emam Square (Naqsh-e Jahan Square)	BWk
Cohen, Potchter, Matzarakis [188]	2013	4.1	Israel	Tel Aviv	Rabin Square	Csa
Tsitoura, Tsoutsos, Daras [178]	2014	4.1	Greece	Chania, Rethymnon	1. Talo Square—Chania 2. Square of Liberty—Heraklion 3. Square of Archanes, 4. Square Agnostos Stratiotis, Rethymno, Greece	Csa
Maragkogiannis, Kolokotsa, Maravelakis, Konstantaras [135]	2014	5	Greece	Crete, Chania	Square 1866	Csb

Table A1. *Cont.*

Author	Year of Res. Study Publication	Study Type (1–5)	Country of Study	Name of the City	Name of the Square	Köppen Geiger Classification Rubel 2017
Rossi, Anderini, Castellani, Nicolini, Morini [142]	2015	3.4	Italy	Citta di Castello	Matteotti Square	Cfb
Ballout, Lacheheb, Bouchahm [81]	2015	3.1, 3.5	Algeria	Sétif	The Square of Independence	Csa
Mazzotta, Mutani [130]	2015	3.3	Italy	Turin	Bottesini square	Cfa
Battistella & Noro [79]	2015	3.1	Italy	Padua	Prato della Valle	Cfa
Martinelli, Lin, Matzarakis [57]	2015	1	Italy	Rome	Piazza di San Silvestro	Csa
Noro & Lazzarin [80]	2015	3.1, 3.3	Italy	Padua	Prato della Valle	Cfa
Chatzidimitriou and Yannas [131]	2015	3.3	Greece	Thessaloniki	1. Archaias Agoras Square 2. Platia Megalou Alexandrou 3. the square at the corner of the streets Leof. Stratou and Aggelaki	Csa
Acero, Herranz-Pascual [189]	2015	4.1	Spain	Bilbao	1. Unamuno Miguel Plaza 2. Indautxu Plaza	Cfb
Stocco, Cantón, Correa [94]	2015	3.1, 3.5	Argentina	Mendoza	1. San Martín square 2. Chile square 3. Manuel Belgrano square	BWk
Kariminia, Ahmad, Saberi [120]	2015	3.2	Iran	Esfahan	Emam Square (Naqsh-e Jahan Square)	BWk
Tseliou, Tsiros, Nikolopoulou, Papadopoulos [203]	2016	4.2	Greece	Athens	Fighting workers square Square IRO,	Csa
Chatzidimitriou and Yannas [171]	2016	3.5	generic square	-	Generic square	-
Salata, Golasi, Vollaro R, Vollaro A. [190]	2016	4.1, 4.2	Italy	Rome	Piazzale Della Minerva	Csa
Tseliou and Tsiros [157]	2016	3.5	Greece	Athens	Fighting workers square Square IRO,	Csa
Kantor, Kovacs, Takacs [104]	2016	3.1	Hungary	Szeged	Dugonics Square	Cfa
Djukic, Vukmirovic, Stankovic [16]	2016	3.5	Serbia	Leskovac	Main city square	Cfa
Cortesão, Alves, Corvacho, Rocha [82]	2016	3.1, 3.3, 3.5	Portugal	Porto	Poveiros Square	Csb
Hirashima, Assis, Nikolopoulou [204]	2016	4.2	Brazil	Belo Horizonte	1. Liberdade square 2. Sete de Setembro square	Cwa
Piaskowy, Krüger [58]	2016	1	Brazil	Curitiba	Praça do Japão	Cfb
Girgis, Elariane, Elrazik [143]	2016	3.4	Egypt	Cairo	El Hussein Square	BWh

Table A1. *Cont.*

Author	Year of Res. Study Publication	Study Type (1–5)	Country of Study	Name of the City	Name of the Square	Köppen Geiger Classification Rubel 2017
Kariminia, Motamedi, Shamshirband, Petković, Roy, Hashim [222]	2016	5	Iran	Esfahan	Emam Square (Naqsh-e Jahan Square)	BWk
Kariminia, Shamshirband, Hashim, Saberi, Petković, Roy, Motamedi [224]	2016	5	Iran	Esfahan	1 Emam Square (Naqsh-e Jahan Square) 2. Jolfa Square	BWk
Kariminia [119]	2016	3.2	Iran	Esfahan	1 Emam Square (Naqsh-e Jahan Square) 2. Jolfa Square	BWk
Sharifi, Sivam, Boland [61]	2016	1	Australia	Adelaide	1 Hayek Plaza (Festival Center) 2 Hindmarsh Square	Csb
Morille and Musy [95]	2017	3.1, 3.3, 3.5	France	Lyon	1. Francfort square 2. Square between the two Moncey building blocks	Cfb
Tseliou, Tsiros, Nikolopoulou [179]	2017	4.1	Greece	Athens	Square IRO Fighting workers square	Csa
Nouri and Costa [169]	2017	3.5	Portugal	Lisbon	Rossio	Csa
Nouri, Costa, Matzarakis [121]	2017	3.2	Portugal	Lisbon	Rossio	Csa
Piaskowy, Krüger [59]	2017	1	Brazil	Curitiba	Praça do Japão	Cfb
Lancellotti, Ziede Bize [172]	2017	3.5	Chile	Antofagasta	Plaza de Armas	Csk
Nasrollahi, Hatami, Taleghani [168]	2017	3.5, 4.3	Iran	Esfahan	1. Emam Square (Naqsh-e Jahan Square) 2. Jame mosque	BWk
Sharifi, Boland [217]	2017	1	Australia	1. Sidney 2. Melbourne 3. Adelaide	1. Friendship Plaza 2. Federation Square 3. Hayek Plaza (Festival Center)	1. Cfa 2. Cfb 3. Csb
Laureti, Martinelli, Battisti [158]	2018	3.5	Italy	Rome	Piazza di San Silvestro	Csa
Gaspari, Fabbri, Lucchi [84]	2018	3.1, 3.5	Italy	Cesena	Piazza Bufalini	Cfa
Piselli, Castaldo, Pigliautile, Pisello, Cotana [170]	2018	3.5	Italy	Perugia	Piazza Vittorio Veneto	Csa
Ebrahimabadi, Johansson, Rizzo, Nilsson [158]	2018	3.5	Sweden	Kiruna	New square	Dfc
Kantor, Chen, Gal [105]	2018	3.1	Hungary	Pécs	1. Széchenyi Square 2. Sétatér Square	Cfb
Kantor, Gal, Gulyas, Unger [126]	2018	3.2	Hungary	Szeged	Bartok Square	Cfa

Table A1. *Cont.*

Author	Year of Res. Study Publication	Study Type (1–5)	Country of Study	Name of the City	Name of the Square	Köppen Geiger Classification Rubel 2017
Hirashima, Katzschner, Ferreira, Assis, Katzschner [205]	2018	4.2	Germany, Brazil	1. Kassel 2. Belo Horizonte 3. Belo Horizonte	1. Opernplatz 2. Sete de Setembro Square 3. Liberdade Square	Cfb
Đekić, Mitković, Dinić-Branković, Igić, Đekić, Mitković [106]	2018	3.1, 3.3	Serbia	Niš	Liberation square (King Milan Square)	Cfa
Djekic J, Djukic, Vukmirovic, Djekic P, Dinic Brankovic [132]	2018	3.3	Serbia	Niš	Liberation square (King Milan Square)	Cfa
Nouri, Lopes, Pedro Costa, Matzarakis [167]	2018	3.5	Portugal	Lisbon	Rossio	Csa
Lindner-Cendrowska, Blazejczyk [191]	2018	4.1, 4.3	Poland	Warsaw	Old Town Marketplace	Cfb
Jin, Zhao, Liu, Kang [127]	2018	3.2	China	Harbin	1. Chinese–Baroque square 1 2. Chinese–Baroque square 2 3. Floods square 4. Beer Culture square 5. Sophia Church square	Dwa
Smith, Henríquez [122]	2018	3.2	Chile	Chillan	Plaza de Armas	Csb
Sharifi, Boland [61]	2018	1	Australia	Adelaide	1 Hayek Plaza (Festival Center) 2 Hindmarsh Square	Csb
Taleghani, Berardi [136]	2018	3.3	Canada	Toronto	Yonge-Dundas square	Dfa
Aljawabra, Nikolopoulou [69]	2018	2, 4.1	Morocco	Marrakech	Al Koutoubia Plaza	Bsh
Battista, de Lieto Vollaro, Zinzi [160]	2019	3.5	Italy	Rome, Centocelle district	Piazza dei Mirti	Csa
Peng, Wang, Li [62]	2019	1	United Kingdom	Cambridge	Market Square	Cfb
Klok, Rood, Kluck, Kleerekoper [71]	2019	2	Netherlands	Amsterdam	1. Dam Square, 2. Frederiksplein 3. Statonsplein square, 4. Leidseplein square, 5. Mahlerplein square, 6. Rembrandtplein, 7. Thorbeckeplein,	

Table A1. *Cont.*

Author	Year of Res. Study Publication	Study Type (1–5)	Country of Study	Name of the City	Name of the Square	Köppen Geiger Classification Rubel 2017
Peng, Feng, Timmermans [212]	2019	5	Netherlands	Eindhoven	1. Central plaza in city center 2. Paved square of Steven Simonplein 3. A small paved square in Kennedyplein 4. Neckerspoel, the northern square of the central railway station 5. Small square between Verigo and Matrix	Cfb
Albdour and Baranyai [148]	2019	4.1	Hungary	Pécs	Széchenyi square	Cfb
Albdour and Baranyai [86]	2019	3.1	Hungary	Pécs	Széchenyi square	Cfb
Zölch, Rahman, Pfleiderer, Wagner, Pauleit [85]	2019	3.1	Germany	Munich	Bordeauxplatz	Cfb
Jin, Wang, Qiao [211]	2019	4.3	China	Changchun	N/A	Dwa
Kicovic, Vuckovic, Markovic, Jovic [223]	2019	5	Serbia	N/A	N/A	N/A
Kubilay, Derome, Carmeliet [133]	2019	3.3, 5	Switzerland	Zurich	Münsterhof	Cfb
Xi, Wang, Wang, Lv [210]	2019	4.3	China	Harbin	Square of the school library	Dwa
Liu, Lian, Brown [114]	2019	3.1	China	Shanghai	Century Square	Cfa
Dafri, Alkama [147]	2019	3.5	Algeria	Annaba	Square el Houria	Csa
Krüger, Piaskowy, Moro, Minella	2019	1	Brazil	Curitiba	Praça do Japão	Cfb
Marçal, da Silva, Santos, Santos [180]	2019	4.1	Brazil	1. Teixeira 2. Patos	1. Cassiano Rodrigues 2. Getúlio Vargas	Aw
Zabetian, Kheyroddin [70]	2019	2, 5	India	Tehran	1. Imam Hussain Square 2. Imam Khomeini Square	CSk
Kubilay, Derome, Carmeliet [134]	2020	3.3, 5	Switzerland	Zurich	Münsterhof	Cfb
Vasilikou and Nikolopoulou [129]	2020	3.2	Italy	1. Rome 2. Rome 3. London	1. Piazza Benedetto Cairoli 2. Campo dei Fiori 3. Covent Garden square (part)	1. Csa 2. Csa 3. Cfb
Battisti [137]	2020	3.3, 3.5	Italy	Rome	Piazza Bainsizza	Csa
Del Campo, Aseguinolaza, Aja, Lopes [150]	2020	3.5, 5	Spain	Madrid	1. de Mayo square 2. Pedro Zerolo square	Csa
Gatto, Buccolieri, Aarrevaara, Ippolito, Emmanuel, Perronace, Santiago [96]	2020	3.1	Finland	Lahti	Market Square	Dfb
Huang, Peng [192]	2020	4.1	China	Chongqing	Three Gorges Square	Cfa

Table A1. *Cont.*

Author	Year of Res. Study Publication	Study Type (1–5)	Country of Study	Name of the City	Name of the Square	Köppen Geiger Classification Rubel 2017
Jin, Jin, Kang [197]	2020	4.1	China	Harbin	1. Gexin Cathedral Square 2. Sports Square 3. Century Square	Dwa
Li, Wang, Ni, Chen, Xia [162]	2020	3.5	China	Guangzhou	Haixinsha Square	Cwa
Boumaraf, Amireche [63]	2020	1	Algeria	Biskra	Liberty square	BWh
Manavvi, Rajasekar [77]	2020	2, 4.1	India	New Delhi	1. Hanuman Mandir Square 2. Gurudwara Bangla Sahib Square	BSh
Gal, Kantor [123]	2020	3.2, 5	Hungary	Szeged	Bartók Square	Cfa
Ibraheem, Hassan [149]	2020	4.1	Iraq	Baghdad	Al-Ghurery Square	BWh
Dursun, Yavas, Yilmaz [161]	2020	3.5	Turkey	Erzurum	Yakutiye Square	Dsb
Sharifi, Boland [217]	2020	5	Australia	1. Sidney 2. Melbourne 3. Adelaide	1. Friendship Plaza 2. Federation Square 3. Hayek Plaza (Festival Center)	1. Cfa 2. Cfb 3. Csb
Apostolopoulou and Tsoka [87]	2021	3.1	Greece	Athens, Ilioupoli,	War Heroes Square	Csa
Peng, Feng, Timmermans [213]	2021	5	Netherlands	Eindhoven	1. Central plaza in the city center 2. Paved square of Steven Simonplein 3. A small paved square in Kennedyplein 4. Neckerspoel, the northern square of the central railway station 5. Small square between Verigo and Matrix	Cfb
Urrutia del Campo, Grijalba Aseguinolaza, Hernandez Minguillon [151]	2021	3.5	Spain	Madrid	de Mayo square	Csa
Silva Lopes, Remoaldo, Ribeiro [208]	2021	4.3	Portugal	Porto	Liberdade Square	Csb
Kubilay, Strebel, Derome, Carmeliet [88]	2021	3.3	Switzerland	Zurich	Münsterhof	Cfb
Lehnert, Brabec, Jurek, Tokar, Geletič [97]	2021	3.1	Czech Republic	1. Brno 2. Brno 3. Olomouc 4. Ostrava 5. Plzen	1. Moravske Namesti (Moravian Square) 2. Náměstí Svobody, 3. Horni namesti, Olomouc 4. Masarykovo namesti, Ostrava 5. Namesti Republiky, Plzen	1. Cfb 2. Cfb 3. Cfb 4. Cfb

Table A1. *Cont.*

Author	Year of Res. Study Publication	Study Type (1–5)	Country of Study	Name of the City	Name of the Square	Köppen Geiger Classification Rubel 2017
Lehnert, Brabec, Jurek, Tokar, Geletic [98]	2021	3.1	Czech Republic	1. Brno 2. Brno 3. Olomouc 4. Ostrava 5. Plzen	1. Moravske Namesti (Moravian Square) 2. Náměstí Svobody (Librety Square) 3. Horni namesti (Upper Square) 4. Masarykovo Square 5. Square of Republic	1. Cfb 2. Cfb 3. Cfb 4. Cfb 5. Cfb
Rudisser, Weiss, Unger [215]	2021	5	Austria	Graz	1 Freiheitsplatz 2 Karmeliterplatz	Cfb
Liu, Zhao, Xu, Ahmadian [246]	2021	3.1	China	Zhanjiang, Lingnan Normal University	1. Square A 2. Square B 3. Square C 4. Square D	Cwa
Luo, Hao, Wang, Xu [109]	2021	3.1, 3.3	China	Xi'an	East Gate Square, Eurasia University	Cwa
Peng, Peng, Feng, Zhong, Wang [214]	2021	5	China	Changsha	Wuyi square	Cfa
Fang, Zheng, Feng, Shi, Lin, Gao [181]	2021	4.1	China	Guangzhou	University square—North	Cwa
Fan, Du, Li, Zhang [163]	2021	3.5	China	Maling Village	1. Basketball square 2. Pavilion square 3. Triangle square 4. Fitness square	Cwa
Sayad, Alkama, Rebhi [89]	2021	3.1, 3.5	Algeria	Guelma	Martyrs square	Csa
Stocco, Canton, Correa [90]	2021	3.1, 3.5	Argentina	Mendoza	Plaza Chile	BWk
Teixeira [99]	2021	3.1, 3.3	Brazil	Aracaju	1. Gal. Valadao 2. Bandeira 3. Camerino	As
Kenawy, Elkadi [72]	2021	2	Australia	Melbourne	1. Federation Square 2. Burwood campus Square	Cfb
Battista, Vollaro, Evangelisti [165]	2022	3.5	Italy	Rome	1. Mancini square 2. Carracci square	Csa
Del Serrone, Peluso, Moretti [91]	2022	3.1, 3.3, 3.5	Italy	Rome	St. Peter in Chains' square	Csa
Pereira Guimarães and Dessì [92]	2022	3.1	Italy	Milan	Angilberto II Square	Cfa
Tseliou, Koletsis, Pantavou, Thoma, Lykoudis, Tsiros [15]	2022	3.5	Greece	Athens	Syntagma square	Csa

Table A1. *Cont.*

Author	Year of Res. Study Publication	Study Type (1–5)	Country of Study	Name of the City	Name of the Square	Köppen Geiger Classification Rubel 2017
Karimi, Mohammad [209]	2022	4.3	Spain	1. Sevilla 2. Sevilla 3. Sevilla 4. Madrid 5. Madrid 6. Madrid	1. Plaza de España 2. Alameda de Hercules 3. Plaza Nueva 4. Plaza de Colón 5. Plaza Mayor 6. Plaza de Santa Ana	Csa
Zhang, Hu, Cao, Liu [164]	2022	3.5	China	Qingdao	May Fourth Square	
Yang, Zhao, Zou, Xia, Lou, Liu, Ji [115]	2022	3.1	China	Guangzhou	University square—Center	Cwa
Zhen, Chen, Zheng [182]	2022	4.1	China	Xi'an	Scientific and Technological Innovation Harbor Square	Cwa
Yu, Fukuda, Zhou, Ma [19]	2022	3.5	China	Xi'an	Big Wild Goose Pagoda Square	Cwa
Xiao, Yuizono [18]	2022	3.1, 3.5	Japan	Ishikawa	Komatsu Station square	Cfa
Eltanboly, Afify [138]	2022	3.3	Egypt	Cairo	Opera square	BWh
Wei, Lian, Liu [206]	2022	4.2	China	Shanghai	1. Knowledge and Innovation square 2. NAM square	Cfa
Kim, Kim, Jo, Kim [152]	2022	3.5, 5	Korea	Seoul	Gwanghwamun Square	Cwa
Boeri, Longo, Fabbri, Roversi, Coulanger [64]	2023	1	Italy	Bologna	1 Piazza Verdi 2 Piazza Scaravilli	Cfa
Battista, de Lieto Vollaro E., Ocłoń, de Lieto Vollaro R. [166]	2023	3.5	Italy	Rome	1. Mancini square 2. Carracci square	Csa
Stark da Silva, Duarte, Pauleit [116]	2023	3.5	Germany	Munich	1. Alpenplatz 2. Alter Hof 3. Bordeauxplatz 4. Hohenzollernplatz 5. Marstallplatz	Cfb
Palomo Amores [111]	2023	3.1	Spain	Seville	Los Naranjos de Arias Montano Square	Csa
Huang, Yao, Xu, Zhang [73]	2023	2	China	Chongqing China	1. Guanyinqiao Square, Chongqing China 2. Sanxia Square, Chongqing China	Cfa

Table A1. *Cont*.

Author	Year of Res. Study Publication	Study Type (1–5)	Country of Study	Name of the City	Name of the Square	Köppen Geiger Classification Rubel 2017
Manavvi, Rajasekar [216]	2023	4.2, 5	India	Chandigarh, New Delhi Gurugram	1. Plaza, Chandigarh, 2. Dilli Haat, INA, New Delhi 3. Dilli Haat, Pitampura, New Delhi 4. Cyber hub, Gurugram	Bsh
Gholami, Jalilisadrabad, Amrollahi [139]	2023	3.3	Iran	Isfahan	Jolfa square	BWk
Guo, Guo, Zhang, Dong, Zhao [93]	2023	3.1	China	Dalian	1. Square A-1, 2. Square A-2, 3. Square B, 4. Square C, 5. Square D	Dwa

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