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Relationship between Vegetation, Sky View Factor and Thermal Comfort: A Systematic Literature Review

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ABSTRACT

The relationship between urban morphology and thermal conditions has been subject of several scientific studies and, recently, the role of vegetation in this context has been investigated, aiming to understand its contributions to the improvement of thermal comfort in outdoor environments. This study aimed to understand the relationship between urban vegetation present in the sky view factor (FVC) and thermal comfort. A systematic literature review on the subject was carried out by applying an adaptation of the Preferred Reporting Items methodological approach for Systematic Reviews and Meta-Analyses (PRISMA), seeking to guarantee a transparent and replicable work. The evaluated materials were obtained through database searches using the terms vegetation AND “thermal comfort” AND “sky view factor” and selected by criteria defined by the “PICOS” strategy. parameters referring to the main characteristics of the researches and results achieved, through the reading and tabulation of data with the help of electronic spreadsheets. The results obtained highlight the growing interest in the subject in scientific research, but demonstrate a lack of studies in Latin American countries. It is also observed that most studies indicate a positive relationship between vegetation in the FVC and thermal comfort, with the incidence of negative results at night, winter or interference with wind speed. Such scenarios indicate the need for more studies that seek better understand the particularities of the behavior of urban vegetation in different ways. between climatic and morphological contexts.

KEY WORDS: Vegetation. Sky view factor. Thermal comfort.

1 INTRODUCTION

Comprehending the effects of the different aspects that make up the microclimatic conditions of urban space on thermal comfort plays a fundamental role in the development of cities, because in this way spaces can be designed for encouraging public use. (NIKOLOPOULOU; BAKER; STEEMERS, 2001).

Fundamental parameters such as air temperature, vapor pressure, wind speed and mean radiant temperature are known to affect the human energy balance characterized as thermal comfort. (MATZARAKIS; MAYER; IZIOMON, 1999). In this context, vegetation, through processes such as evapotranspiration, can cool the temperature around it, in addition to providing impacts on humidity and airflow different from urban waterproof materials. (BOWLER et al., 2010).

The shading provided by vegetation structures such as trees is capable of lowering the air temperature by simply intercepting solar radiation and preventing surface heating. (BOWLER et al., 2010). An existing way to calculate this shading is the sky view factor (SVF), a parameter that allows you to quantify the portion of sky visible in a given area, ranging from 1 to zero, with 1 being fully open sky spaces and zero indoor environments. (OKE, 1988). This index is commonly used as a way of understanding the relationship between urban morphology and thermal comfort, initially related to the heat island effect. (CHAPMAN; THORNES; BRADLEY, 2002).

However, Bowler et al. (2010) point out that, despite evidence of cooling generated by green areas, the broader impacts of adding vegetation in urban areas and the best way to carry out this incorporation have not yet been demonstrated, requiring further studies on this subject. In this way, the present work proposes a systematic literature review to verify the scientific advances made about the understanding of the impact generated by the shading of urban vegetation, characterized through SVF, on the thermal comfort of users of urban environments.

2 OBJECTIVE

To present scientific evidence of the relationship between the vegetation present in the SVF and the thermal comfort of users of urban spaces.

3 METHODOLY

The method used was the systematic review of the bibliography. At first, the questions that were intended to be answered with the research were formulated, guiding the literature review: 1. which researches studied urban vegetation using SVF?; 2. what is the influence of vegetation on the thermal comfort of users in urban areas? Thus, the review was limited to articles that address the two issues concomitantly.

The review process was based on an adaptation of the methodology Preferred Reporting Items for Systematic Reviews and Meta Analyses (PRISMA) (MOHER et al., 2015) for the topic studied, since this method was developed for research in the area of health. The checklist proposed by PRISMA, with 27 items to be fulfilled by a review study, was reformulated for this study, excluding aspects referring to the analysis of clinical studies and the review record, resulting in a total of 14 items.

3.1 Material Selection

The terms *vegetation* **AND** *"thermal comfort"* **AND** *"sky view factor"* were extracted from the research questions through the "PICOS" strategy (*population, intervention, context, outcomes and study type*), in which: P: vegetation; I: SVF; C: urban environments; O: the influence on the thermal comfort of users; e S: case studies. The search was carried out in title, abstract and keywords in the Scopus databases (Elsevier) and Web of Science (Clarivate) on September 10th, 2021, without applying any other filters or limits during this process. After collecting materials and excluding duplicate works, the first step of selecting the articles was carried out, through the analysis of the abstracts of the works, being kept only the studies that fit all the criteria defined by "PICOS". Then, the same criteria were sought in the full content of the studies, and those that were included passed to the content analysis process.

3.2 Bibliographic analysis

Electronic spreadsheets with the bibliographic information of all the studies obtained through the search in the databases were generated using the data export tools from Scopus (Elsevier) and from the Web of Science (Clarivate). The parameters analyzed were: year of publication, country of origin of the study, journal of origin and its impact factor and number of citations.

3.3 Content Analysis

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The content analysis was performed through the integral and individual reading of the included works, with the help of electronic spreadsheets for the tabulation and statistical analysis of the extracted information. Initially, information regarding the characteristics of the studies was extracted, as follows: main objective of the research; research particularities; country, climate and type of study site. Finally, the results achieved by the works related to: positive and negative aspects of the relationship between vegetation, SVF and thermal comfort were raised; relationship with vegetation characteristics; and other factors that affect the relationship between vegetation. It was intended, with the analysis of such information about the evidence found, to avoid the bias of this study regarding the research object.

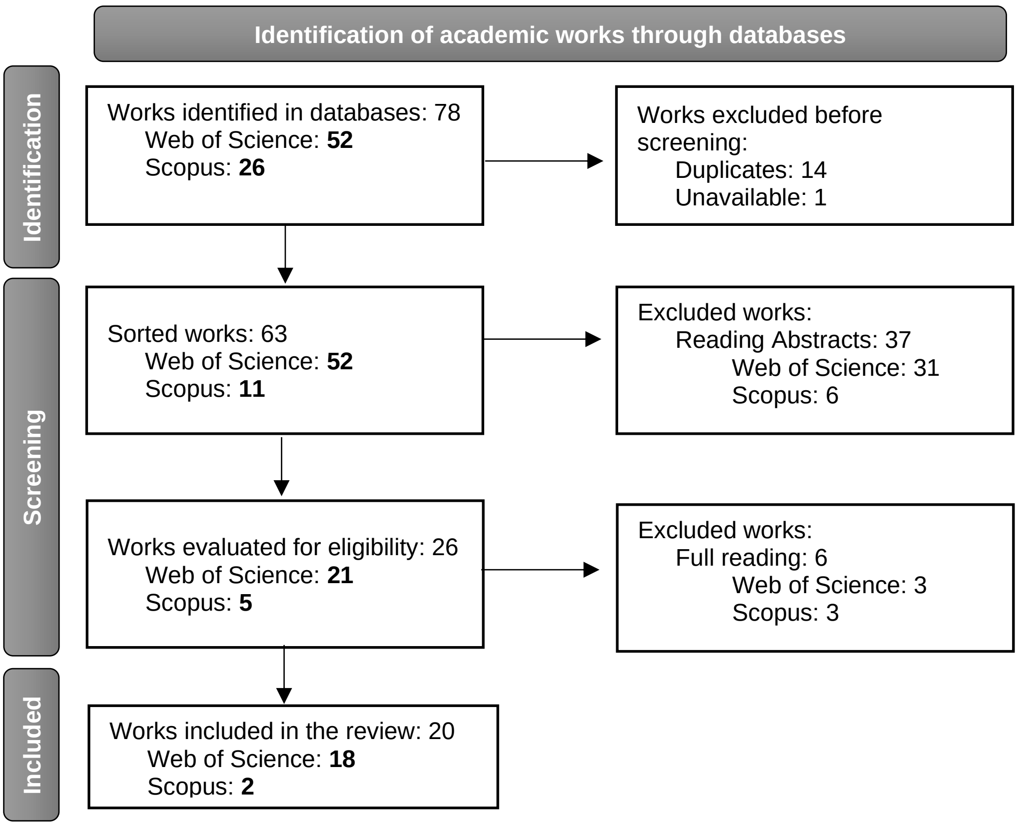
4 RESULTS

For better understanding, the results were analyzed individually for each of the investigation stages of the study.

4.1 Seleção de material

Following the process mentioned above, 78 works were identified in the consulted databases, of which 20 were selected for the content analysis stage after screening by the criteria defined by the "PICOS" strategy.

Figure 1 - Flowchart of results according to PRISMA.



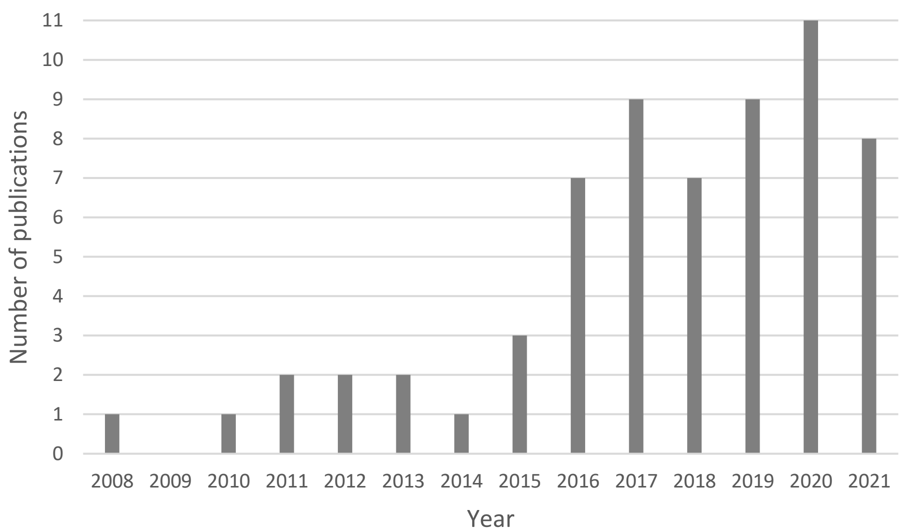
Source: Prepared by the authors, 2021.

4.2 Bibliographic analysis

The analyzes of bibliographic information were carried out in all studies obtained through the databases, after the exclusion of duplicate works, with the intention of verifying possible trends in the research scenario that relate vegetation, thermal comfort and SVF. What can be observed is that, although the research does not establish any time limit for the search for materials, the identified works are concentrated between the years 2010 and 2021 (Graph 1), with only one article published before this period, with significant increase from the year 2016, demonstrating a growing interest in the subject in the academic environment. Among these studies, most were carried out with the participation of institutions from the United States (14) and China (14), but the diversity of countries involved in this type of research is visible (Graph 2).

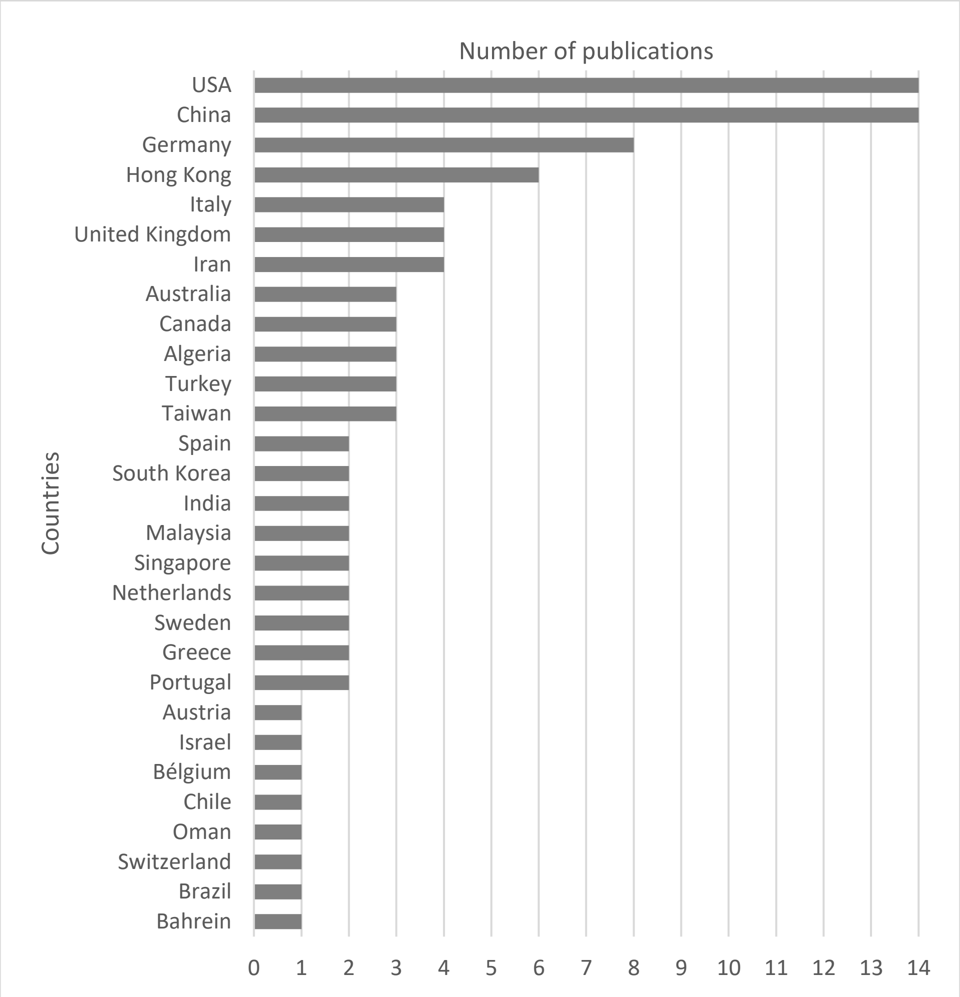
The journal Build and Environment (impact factor FI = 5,032) stands out as a vehicle for disseminating research on the topic, with 11 publications (Graph 3), while 25 have only 1 publication each (absent in the graph), including among these the journals with the highest and lowest impact factor among those surveyed, respectively, Renewable and Sustainable Energy Reviews (FI = 14.280) and Environmental and Ecological Statistics (FI = 0.952). Among the three most cited articles, Lin, Matzarakis and Hwang (2010), Wang, Berardi and Akbari (2016) and Tan, Lau e NG (2016), respectively with 379, 205 and 181 citations, the first belongs to the journal with the most publications, Building and Environment and the other two to Energy and Buildings. Journal impact factors were obtained from the Journal Citation Reports (Clarivate) on October 4th, 2021.

Graph 1 – Annual evolution of selected publications on the topic.



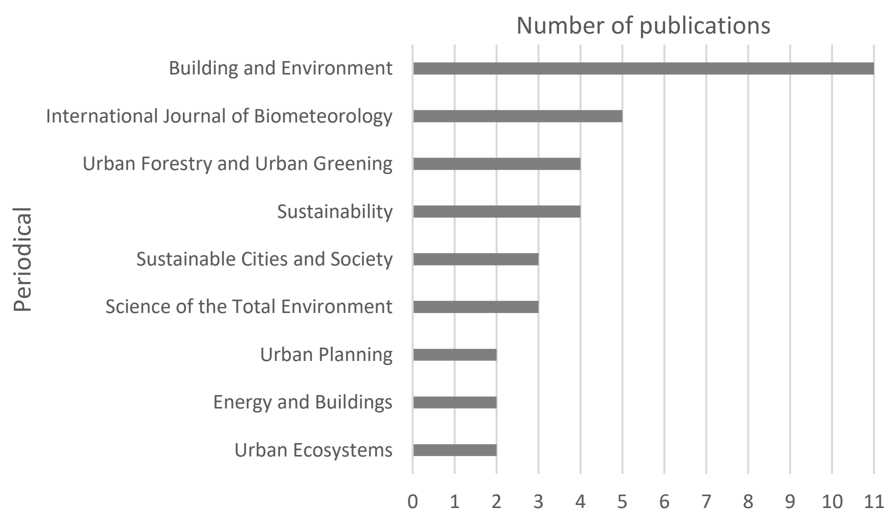
Source: Prepared by the authors, 2021.

Graph 2 – Geographical distribution of selected publications.



Source: Prepared by the authors, 2021.

Graph 3 – Distribution of selected publications by journal.



Source: Prepared by the authors, 2021.

4.3 Content Analysis

As mentioned before, in the content analysis phase, aspects were raised about the main characteristics of the works and their results; thus, the information presented in Tables 1 and 2 are presented separately.

4.3.1 General characteristics of the studies

The studies selected for content analysis essentially aim to understand the influence of aspects of urban morphology on its thermal environment, with variations only on which characteristics and circumstances are evaluated. Among the 20 studies, 10 carried out tests of different scenarios of urban configuration to better understand the factors investigated and 5 compared the performance of urban vegetation in winter and summer conditions, with 4 combining the two strategies. Also as a way of evaluating the behavior of vegetation, 4 studies used separate SVF for buildings and trees, while another 4 used leaf area density. Only Song and Jeong (2016) used questionnaires to estimate the thermal comfort of users in this context.

As well as the places of origin of the institutions responsible for the research, the countries where they were applied are also very diverse, especially Iran, with 3 studies. However, the Subtropical, Semi-arid and Desert climates, classified according to Köppen-Geiger, stand out at this moment, denoting the concern for the urban thermal environment in such conditions. More specifically, the places evaluated by the surveys were streets (5), university campuses (4), urban districts (5), parks (4) and cities as a whole (2).

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Table 1- Main results of the selected works (2011 to 2018).

Year	Authors	Country	Weather	Local	Results			
					Positive aspects	Negative aspects	Vegetation factors	Other factors
2011	LINDBERG; GRIMMOND	England	Temperate oceanic climate	City	MRT reduction	Decreased air speed	-	-
2013	CHARALAMPOPOULOS et al.	Greece	Semi-arid climate	Campus	Low SVF and vegetation reduce PET	Negative relationship between SVF and PET at night	-	-
2015	WANG; BERARDI; AKBARI	Canada	Temperate climate	Districts	Low SVF and vegetation reduce PET and MRT	Negative effect in winter	-	-
2016	SONG; JEONG	Korea	Humid subtropical climate	Streets	Greater comfort on tree-lined streets	-	-	-
2017	SUN et al.	China	Continental climate	Parks	PET reduction	Decreased air speed	Height of trees increases thermal comfort	-
	LIN; TSAI	Taiwan	Subtropical úmido	Parks	Low SVF and vegetation reduce PET	-	Larger cups reduce the temperature	-
	CHARALAMPOPOULOS et al.	Greece	Semi-arid climate	Campus	Low SVF and vegetation reduce PET	Negative relationship between vegetation and PET at night	Vegetation must be planned	-
2018	YAHIA et al.	Tanzania	Tropical climate	Districts	Vegetation contributes to thermal comfort	Decreased air speed	Cup density reduces PET	-
	SANTOS NOURI et al.	Portugal	Mediterranean climate	Districts	PET reduction	Negative effect in winter	*Tipuana tipu* had low performance in winter	-

Subtitle: MRT: Mean radiant temperature; PET: physiological equivalent temperature.

Source: Prepared by the authors, 2021.

Table 2- Main results of the selected works (2019 to 2021).

Year	Authors	Country	Weather	Local	Results			
					Positive aspects	Negative aspects	Vegetation factors	Other factors
2019	AHMADI VENHARI; TENPIERIK; TALEGHANI	Iran	Arid climate	Streets	Low SVF and vegetation reduce PET	-	Cup size reduces PET	Planting orientation affects thermal comfort
	FARHADI; FAIZI; SANAIEIAN	Iran	Semi-arid climate	Districts	Tree shadows enhance comfort	Decreased air speed	-	-
	ZHANG et al.	Australia	Humid subtropical climate	Parks	Low PSVF reduces MRT	Decreased air speed	-	-
	MIDDEL; KRAYENHOFF	USA	Desert climate	Campus	MRT reduction	Negative relationship between vegetation and MRT at night	-	Improved thermal comfort in lawns and trees
	VANOS et al.	Japan	Humid subtropical	Streets	Low SVF and greenery reduce radiant heat	Decreased air speed	-	Shade and cool surfaces reduce the temperature
2020	KARIMI et al.	Iran	Semiarid climate	Parks	Trees improve daytime thermal comfort	Negative relationship between SVF and PET at night	Height of trees reduces PET	Low albedo and trees improve comfort
	WAI et al.	Hong Kong	Humid subtropical climate	Districts	PET reduction	-	Relationship between leaf area index and PET	-
	DU et al.	China	Desert climate	Campus	MRT reduction	Negative relationship between vegetation and MRT at night	-	-
2021	SABRIN et al.	USA	Humid subtropical climate	Streets	Vegetation contributes to thermal comfort	Indifferent presence in places with already low SVF	-	-
	YILMAZ; SEZEN; SARI	Turkey	Humid Continental climate	Streets	Vegetation contributes to thermal comfort	-	The species Betula spp. performed well	Planting orientation affects thermal comfort
	BACK et al.	Austria	Hemiboreal climate	City	-	-	-	The temperature depends on the SVF and the surface

Subtitle: MRT: Mean radiant temperature; PET: physiological equivalent temperature.
Source: Prepared by the authors, 2021.

4.3.2 Results

Most of the studies analyzed do not only investigate the role of urban vegetation present in the SVF index in thermal comfort, but the results raised by the present research are limited to those referring to this relationship.

4.3.2.1 Positive aspects influence of vegetation on thermal comfort

In their review of urban vegetation, Bowler et al. (2010) pointed to the ability of tree shadows to reduce local temperature, with positive results on the impact of shading by vegetation on thermal comfort. Only Back et al. (2021) do not point to clear results on this issue.

Exemplifying the studies that corroborate the positive aspects of the presence of vegetation in the SVF, Karimi et al. (2020) and Farhadi, Faizi and Sanaieian (2019), with studies in semi-arid climate, point to a significant decrease in PET in scenarios where SVF was reduced with the addition of trees. In the humid continental climate, benefits are also seen, not only in hot periods, but also in winter, according to Yilmaz et al. (2021), who report the increase in maximum temperature in this season in spaces with the presence of vegetation. Zhang et al. (2019) show that MRT is reduced when the park sky view factor (PSVF), composed of treetops, decreases.

In addition to shading, the property that vegetation has of providing a more pleasant thermal environment may be linked to its processes of evaporation and absorption of radiation for photosynthesis. (BOWLER et al., 2010; ZHANG et al., 2019).

4.3.2.2 Negative aspects influence of vegetation on thermal comfort

Although most of the results observed during the review demonstrate positive questions about urban vegetation, some events with a negative influence on thermal comfort were raised. The main one is related to wind speed, an important variable that influences thermal comfort, according to Hsieh, Jan and Zhang, (2016). The authors expose the fact that densely wooded areas without planning, can reduce the speed of the air and, consequently, increase its temperature at the height of pedestrians. (HSIEH; JAN; ZHANG, 2016). Yahia et al (2018), Zhang et al. (2019) and Lindgerg and Grimmond (2011), in studies carried out in tropical, humid subtropical and oceanic temperate climates, respectively, showed the importance of this variable in their climatic conditions.

Densely vegetated areas can also make it difficult to dissipate heat accumulated throughout the day during the night, generating an increase in temperature in these places, (GILLNET et al., 2015). The studies of Charalampopoulos et al. (2013) and Charalampopoulos et al. (2017), both in semi-arid location, of Middel and Krayenhoff (2019), in a desert climate, and Karimi et al. (2020), in semiarid region, found a reduction in the frequency of nocturnal thermal comfort in areas with low FVC due to vegetation.

Among the works that sought to understand the differences in vegetation behavior in winter and summer, Santos Nouri et al. (2018) and Wang, Berardi e Akbari (2015), carried out in Mediterranean and temperate climates, respectively, found that it maintains low levels of comfort during both seasons, which is not a favorable scenario in winter periods. However, Yilmaz et al. (2021), as previously mentioned, it obtained positive results for the relationship between vegetation and thermal comfort in winter in a humid continental climate. This information demonstrates the need to better understand the performance of vegetation in times of low temperature.

4.3.2.3 Relationship of vegetation characteristics in the influence on thermal comfort

Plant characteristics related to their species, such as height, leaf size and canopy density, as well as their arrangement, can affect their ability to influence the local temperature. (BOWLER et al., 2010). Nine of the 20 articles evaluated presented clear data and specifically related to the variation of the effects of vegetation on thermal comfort depending on its characteristics or the species to which it belongs. (AHMADI VENHARI, TENPIERIK e TALEGHANI, 2019; KARIMI et al., 2020; LIN e TSAI, 2017; YILMAZ et al., 2021; YAHIA et al., 2018; WAI et al., 2020; SUN et al., 2017; CHARALAMPOPOULOS et al., 2017; SANTOS NOURI et al., 2018). Among the results achieved by these studies, Lin and Tsai (2017), with experiments carried out in humid subtropical climate, report that the larger the canopy of a tree and, consequently, the lower the sky view factor index, the lower the values from PET are. Karimi et al. (2020) and Sun et al. (2017) present results indicating the influence of tree canopy height on air flow, therefore, on thermal comfort in semi-arid and continental climate conditions, respectively. Another characteristic capable of affecting the thermal environment in spaces with vegetation is the density of leaves, according to surveys by Wai et. al (2020), in a humid subtropical location, and Yahia et al. (2018), in a tropical climate.

4.3.2.4 Other factors that influence the relationship between vegetation and the sky factor index in thermal comfort

Through the evidence raised by the articles in this review, it is clear that the amount of vegetation present in the FVC is not the only factor that interferes with thermal comfort, but also depends on the morphological context in which it is inserted. An example of this statement is the different effect observed in the PET depending on the albedo of the floors below the vegetation, present in the work of Karimi et al. (2020), Middel and Krayenhoff (2019), Vanos et al. (2019) and Back et al. (2021), and according to the knowledge we have of the ability of the albedo of surfaces to influence the local temperature, as pointed out by Erell et al. (2014).

As seen earlier, wind speed is another aspect capable of interfering with thermal comfort (HSIEH; JAN; ZHANG, 2016); In this way, studies of Ahmadi Venhari, Tenpierik and Taleghani (2019) and of Yilmaz et al. (2021) report the importance of taking into account the orientation in which a vegetation mass will be located, to ensure that this variable is not harmed. Another aspect, despite not being pointed out individually by any of the studies, but possible to observe when comparing them, is that the ability of the amount of vegetation present in the FVC to contribute to urban thermal comfort also depends on the climatic context in which it is inserted.

5 CONCLUSION

The present research evaluated, through a systematic literature review, works that related urban vegetation, SVF and thermal comfort, seeking to understand the scientific advances on this topic. The bibliographic results indicate that from 2015 onwards there was an intensification of studies in this area, with the main participation of institutions in the United States and China and in various publication sources. The research experiments were carried out in different countries and climates, however, no studies were identified in Latin American countries, indicating a possible field for academic research.

Evaluating the results of the experiments carried out by the works that composed this review, in general the impact observed by the presence of vegetation in the SVF was positive in all the comfort indexes used, as they contributed to the decrease in temperature, corroborating other studies on the subject. However, conditions were reported in which the presence of trees caused an increase in the level of discomfort, either by decreasing the wind speed or by preventing the dispersion at night of the radiation absorbed throughout the day.

The observed scenario points to the fact that there are still aspects about the behavior of urban vegetation that need to be better understood, such as which species and arrangement are most suitable for specific climatic and morphological contexts, given that to avoid negative effects on thermal comfort, there must be planning in the planting of green areas. The existence of simulation software can contribute to this process, helping to test different possibilities and diversifying knowledge about this topic.

This review contains limitations regarding the number of studies present in the databases, but the results obtained were satisfactory to better understand the way in which the academic environment has dealt with the issue of urban vegetation.

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