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Urban heat stress and health: A systematic literature review of dimensions and indicators for planning and design

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ABSTRACT

In recent years, extreme temperatures have gained significant attention in urban studies, leading to the search for various adaptation and mitigation measures. While many studies employ heat-related indicators to assess climate-related health impacts, a better understanding of the multi-dimensional nature of these indicators can enhance their integration into urban policies, planning and design. This research aims to examine various dimensions of urban heat stress in built environments, using a systematic review of scientific articles ($n = 146$) and consequently, establishing a framework for effectively stratifying examples of related indicators across different dimensions. The results showcase dimensions including demographic, economic, health, urban climate, social, urban morphology, and institutional. However, literature disproportionately emphasizes demographic, health and climate dimensions, while social, urban morphology and institutional ones receive comparatively less attention. On the other hand, the co-occurrence analysis reveals connections among these dimensions and their related indicators, underlining the need for a holistic understanding of heat stress impacts. Additionally, the spatial distribution of the selected papers brings attention to the lack of studies in the regions identified as most exposed according to the Koppen Climate Classification. Accordingly, we advocate for more multidimensional and context-specific studies that bridge existing gaps. This research provides valuable insights for policymakers, planners, urban designers and researchers on advancing the understanding of urban heat stress in built environments and its impact on urban health.

1. Introduction

The study of urban heat is expanding annually, driven by escalating global temperatures and the growing prominence of heatwaves in urban areas (Domeisen et al., 2022; Luber and McGeehin, 2008). The scientific community has widely recognized the intensification of heatwaves, which have become more frequent, longer-lasting and severe, especially in urban environments (Ballester et al., 2023; Mazdiyasnani et al., 2019; Perkins et al., 2012; Perkins-Kirkpatrick and Lewis, 2020). This concern is not confined solely to the study of the city's built environment; heatwaves can also directly impact people's health and well-being. As noted by WHO (World Health Organisation), excessive urban temperatures pose a notable threat to the health of inhabitants, giving rise to various heat-related health issues. Moreover, the increasing urbanization of the world's population has heightened the importance of

addressing heat-related urban health concerns (World Health Organisation, 2021).

As a discipline, urban health emerged in the mid-1980s, and it remains rooted in a long-standing recognition of the intricate interplay between urban living and public health (Sclar and Volavka-Close, 2011). This field addresses the health, well-being, and overall quality of life in urban settings (Galea and Vlahov, 2005; Wuerzer, 2014), examining an array of factors that include the physical environment and social aspects, all of which collectively shape the health of urban populations (Galea and Vlahov, 2005; Sclar and Volavka-Close, 2011; Wuerzer, 2014).

Exposure to a hot environment, particularly during vigorous work, can cause perceived discomfort and physiological strain, which is also defined as heat stress (Bouchama and Knochel, 2002). Urban heat stress refers to the amplification of this physiological strain due to the compounded effects of anthropogenic heat, urban form, and microclimatic

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conditions. Heat stress can manifest in any environment where the body cannot effectively cool itself due to prolonged exposure to severe heat, resulting in severe health consequences. Nevertheless, heat stress in countries with extreme climate can emerge regardless of heatwaves due to hot weather conditions and their long duration.

Indeed, the ramifications of heat stress extend beyond mere thermal discomfort; they involve elevated heat-related fatalities and hospitalizations, encompassing respiratory diseases, hyperthermia, heat strokes, and cardiovascular events, thereby endangering vulnerable groups (Bouchama and Knochel, 2002; Hatvani-Kovacs et al., 2016; Kovats and Hajat, 2008; Luber and McGeehin, 2008). In urban areas, multiple factors influence the severity and impact of heat stress. During the day, exposure to direct solar radiation significantly affects outdoor heat stress (Aleksandrowicz and Pearlmutter, 2023; Middel et al., 2021). At night, the urban heat island (UHI) effect, where urban areas experience higher temperatures than the surrounding areas (Mills, 2008; Oke et al., 2017) can intensify heat stress leading to heat-health-related problems.

Heatwaves can exacerbate pre-existing health conditions, leading to untimely fatalities (Wilhelmi and Hayden, 2010). For instance, studies predict that the regional increase in heat-related premature mortality rates in the United States may surge by 47% to 95% (Knowlton et al., 2007) by 2050, statistics that have raised significant concern among governments, planners and designers, compelling them to focus on heat stress mitigation and climate adaptation strategies.

In addition to the direct effect on people's health, the indirect consequences of heatwaves present significant challenges in urban studies. The surge in energy consumption, driven by the extensive use of air conditioning and fans during periods of heatwaves, can result in adverse effects. These include the exhaustion of resources and an escalation in greenhouse gas emissions, heightened strain on power grids (e.g., leading to potential blackouts, disrupting essential services, and further jeopardizing public health) and economic burden. The latter is due to higher energy bills that can lead to financial stress, particularly for low-income populations, exacerbating social inequalities.

Furthermore, these increased emissions intensify the greenhouse effect, thereby exacerbating the impacts of global warming. This issue is studied in various scales and contexts (Akbari et al., 1997; Dorer et al., 2013; Ihara et al., 2008; Magli et al., 2015; Quah and Roth, 2012; Santamouris et al., 2001). For instance, the UHI effect leads to a substantial increase in both the peak demand for electricity and the overall energy needed to cool buildings in urban areas (Salvati et al., 2017; Santamouris et al., 2001), contributing to higher emissions and exacerbating the greenhouse effect. Another study reveals that buildings, due to air conditioning, contribute significantly to anthropogenic heat, with notable diurnal and weekly variations, highlighting the potential impact on the urban climate (Quah and Roth, 2012).

Thus, the quest for heat-resilient cities to prevent, or at least reduce, urban heat stress has gained paramount importance in political agendas worldwide. In general, heat-resilient cities are urban areas designed to withstand higher temperatures, associated with climate change and UHIs. The strategies they employ reduce heat absorption, increase shading, and enhance livability during heatwaves. Key characteristics of heat-resilient cities encompass UHI mitigation, climate-adaptive infrastructure (notably blue and green infrastructures) and considerations related to health and economics. Also, they actively engage communities to create tailored solutions and address the needs of the most affected populations (Albert et al., 2021; Patel and Nosal, 2016).

In this manuscript, we focus primarily on understanding the complexity of urban heat stress and its effects on urban health, through multiple dimensions encountered in the selected literature, while this approach may also inform planning and design strategies to enhance urban heat resilience to heatwaves in the future. Within the scope of this study, the term *dimensions* refer to distinct domains that focus on different aspects of investigation. Therefore, in our discussion on integrating a multi-domain perspective, we use the term *multidimensional* to capture this approach. The choice and prioritization of these dimensions

could be due to disciplinary perspective, data availability and applications context. Recent work has emphasized the need for place-specific approaches, cautioning against generalized frameworks that obscure contextual drivers of vulnerability (Karanja et al., 2025). This review synthesizes peer-reviewed English-language studies linking urban heat stress and urban health, with a specific focus on planning and design relevance. The proposed dimension, aspect and indicator stratification was derived from the reviewed literature, rather than from an a priori or exhaustive taxonomy. Accordingly, the framework does not aim to capture all possible physiological or spatial processes related to heat exposure. Instead, it aims to provide a transparent organizing framework within a broader multidimensional approach.

Aspects denote specific characteristics inherent to each examined dimension, while *indicators* are mostly measurable metrics employed to quantify or explain specific issues within their respective dimensions. While many indicators are directly measurable, others represent proxy or composite measures that capture institutional, morphological, or social processes. As noted in recent research (Fotheringham and Li, 2023), such unmeasurable contextual effects can influence how exposure translates into health outcomes without being explicitly quantified. Accordingly, the proposed framework should be understood as a structured synthesis of observable or proxied dimensions rather than a complete representation of all underlying social processes. Although the review does not encompass all heat-related research approaches, the proposed stratification remains applicable as an interpretative framework. For instance, spatial analyses of heat hazard primarily align with the urban climate dimension and may link to exposure or sensitivity when population context is incorporated. Physiological modelling and causal or experimental studies can use the framework to situate hazard-health relationships and identify relevant vulnerability dimensions, while acknowledging that detailed thermoregulatory mechanisms lie beyond its scope.

This research tries to address the critical questions: "Which domains study the health impacts of urban heat stress that can be related to urban planning and design, and what heat-stress related indicators or concepts were referred to address the problem?" It aims to fill a knowledge gap concerning the comprehensive understanding of the urban heat stress dimensions through a systematic literature review, developing a framework for a multidimensional approach.

Through this research, we seek to complement previous studies addressing urban heat stress issues. While it is widely recognized that urban heat stress is a multifaceted problem spanning various scientific disciplines (Browning et al., 2006; He et al., 2023; O'Neill and Ebi, 2009), scholars and practitioners have traditionally worked in isolation, focusing on some specific aspects. For instance, some studies analyze various heat mitigation strategies (Aleksandrowicz et al., 2017; Aleksandrowicz and Pearlmutter, 2023), heat-vulnerability (Cheng et al., 2021; Gonzalez-Trevizo et al., 2021) or heat stress indices (Beshir and Ramsey, 1988; Feng et al., 2022), to address various aspects of urban heat stress. While several frameworks for heat risk and vulnerability have been proposed (e.g., Cutter et al., 2008; Luo et al., 2024; Macharia and Kiage, 2024; Turner et al., 2003), there remains limited synthesis of how these conceptual approaches are translated into empirical dimensions and indicators in urban heat-health studies relevant to planning and design.

Although there have been attempts in the literature to incorporate multiple heat-related indicators divided across aspects (e.g. gender, ethnicity, income, urban temperatures), these aspects represent only a limited set of dimensions, namely demographic, social, climate, and health, with occasional references to urban morphology, whether explicitly or implicitly mentioned or used (Cutter et al., 2003; Guo et al., 2022; Harlan et al., 2013; He et al., 2022; Knowlton et al., 2009; Naughton et al., 2002; Samuelson et al., 2020; Semenza et al., 1996; Vandentorren et al., 2006; Xiang et al., 2022; Yardley et al., 2011). To our knowledge, only a few studies have sought to categorize indicators across different dimensions yet considering only a few of them (Mazzone

et al., 2023; Seebaß, 2017). However, these studies often concentrate on aspects, overlooking wider urban planning and design perspectives, and thus lacking an integrative taxonomy of different dimensions that can be useful for future research. To this end, several dimensions were identified within this systematic literature review, each contributing significantly to our understanding of these complex interactions with built environment.

Several studies have developed and applied heat vulnerability indices (HVIs) to spatially assess population-level susceptibility to extreme heat (e.g., (Bao et al., 2015a; Johnson et al., 2012; Nayak et al., 2018; Reid et al., 2009)). While these approaches provide important insights, they primarily focus on composite index construction and vulnerability mapping. The present review complements this literature by examining how various dimensions and indicators are used explicitly or implicitly address urban heat and health problems.

The main contribution of the paper is to provide a taxonomy that integrates various dimensions related to urban heat stress and its impact on health, offering a more holistic approach to understanding how current literature reflects on urban heat stress in several fields. This taxonomy can be elaborated to become a comprehensive and detailed framework outlining various dimensions that would be of great help for urban planning and design considerations, where examples of indicators can be classified depending on the nature of the dimension.

This approach will allow future research to look at the problem from a multidimensional perspective, providing them with examples of indicators *per* dimension as a starting point. The main outcome is a classification of dimensions into a taxonomy that highlights the multidimensional nature of heat stress issues within the context of the urban environment.

The flow of this paper is structured as follows. Section 2 introduces the reader to a step-by-step explanation of how the review was conducted, ensuring transparency and reproducibility. Then, the findings from the research are analyzed in detail in Section 3, with a summary of prior studies on urban heat stress and heat-resilient cities presented, highlighting the need for greater intersectionality. Sections 4 and 5 conclude with a discussion, limitations, future research directions, and a concise summary of the systematic review's insights.

2. Methods

2.1. Search strategy

To identify the most pertinent publications within the study's scope and objectives, we utilized Scopus and Web of Science (WoS) bibliographic databases. Both Scopus and WoS offer valuable tools for accessing articles and covering research areas relevant to our chosen keywords, ensuring multidimensional coverage across various research fields from numerous international publishers. In response to our study's requirement, we selected a set of keywords, as detailed in Table 1. Prior to finalizing the keywords used (see Table 1), an exploratory scoping exercise was conducted to test alternative keyword combinations related to urban heat and health. The finalized search string was then applied consistently across all databases to ensure methodological transparency and reproducibility. Following multiple rounds of testing, targeted searches were conducted focusing on (i) heat-related events, (ii) their

associated impacts and (iii) the respective areas of focus. This search process continued until December 15, 2025.

2.2. Review process

The review process, which follows the PRISMA flow, has three key stages. It starts with systematic paper identification and screening, followed by an eligibility phase that refines focus by excluding articles lacking case studies or highly specific to non-relevant issues.

The criterion of including (a) case study(s) was deemed essential, as they investigate a phenomenon within real-life contexts pertinent to urban studies. The ultimate selection paves the way for full-text analysis, delving into key dimensions and analytical approaches to comprehensively understand heat stress resilience indicators. The workflow structure is outlined in Fig. 1 (The flowchart design was inspired by Kim (Kim and Brown, 2021)), and each step is explained in detail in the following sections.

2.2.1. Identification and screening

This review included peer-reviewed English-language journal articles on urban heat stress and human health relevant to planning and design; non-peer-reviewed and non-urban heat-health studies were excluded at the initial phase of the review process. The initial phase of the review involved identifying and screening papers by their titles, abstracts, and keywords using a systematic search based on the keywords outlined in Table 1. Accordingly, 3014 articles from Scopus and 2143 from WoS resulted in a dataset of 3304 articles after 1853 articles with inaccessible abstracts, duplicates or publications in languages other than English were excluded. During the initial screening phase, we focused on titles, keywords, and abstracts to identify potentially relevant studies. Of the initially identified articles, 2796 were excluded because they addressed broader climate-related topics not aligned with the aim of this study. Excluded studies primarily focused on environmental or climate issues (e.g., air pollution, agriculture, water or soil processes, wildfires, marine or rural systems), non-urban contexts, ecological or animal studies, cold exposure, or health outcomes not directly related to urban heat stress. Studies addressing compound or concurrent hazards were retained only when urban heat stress was the primary exposure of interest and health impacts were directly attributed to heat in an urban context; studies in which heat played a secondary or contextual role within broader multi-hazard analyses were at first excluded.

2.2.2. Eligibility and full text analysis of the selected papers

A systematic process was undertaken to refine the focus of each article and determine its eligibility for inclusion in the analysis. In this phase, a full-text assessment was conducted to scrutinize articles that meet the review criteria. Initially, 184 articles lacking case study were excluded. Additionally, as the review prioritizes urban heat challenges with a close focus to human health, 195 papers were excluded with reasons due to their focus on issues that fall outside the scope of this research, for instance, papers exclusively focused on indoor thermal perception, or combining with specific medical aspects related to heat and pregnancy, animal and plant studies during heat, or dysfunctions of specific body parts.

Following these exclusions, the total number of papers included in

Table 1
Databases consulted and keywords employed by event, impact, and focus areas.

DATABASE	EVENTS		AREAS OF FOCUS		IMPACT	RESULTS
Scopus	'Extreme heat' or	OR	'Urban climate planning' or	AND	'Heat stress*' or	3014
Web of Science	'Heatwave*' or		'Climate-proof design' or		'Heat stroke' or	2143
	'Heat events'		'Climate-proof planning'		'Health risk' or	
					'Human health'	

Notes: (*) captures keyword variations.

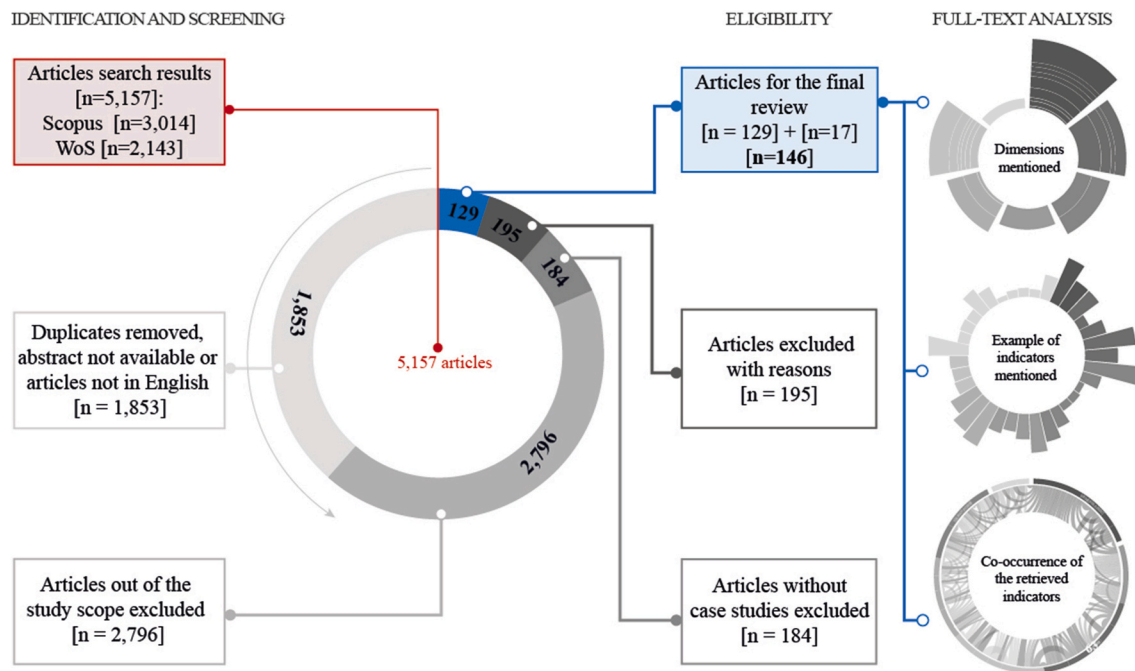


Fig. 1. Flowchart of the review process.

the study was narrowed down to 129. To strengthen coverage of the multidimensional nature of urban heat stress, a targeted snowballing approach was applied during full-text assessment. Reference lists of included studies were screened, and 17 additional articles were retained to provide conceptual or theoretical insights into urban heat stress.

These articles primarily consisted of theoretical approaches, which provided perspectives for a multidimensional understanding of the topic of urban heat stress or resilience in general. Consequently, the final selection of reviewed research comprised 146 articles.

To ensure a detailed and systematic analysis of the publications, leading to a broader understanding of the dimensions related to urban heat risks, this study has specifically addressed the following review questions during the full-text article assessment phase:

- **Review Q1:** What dimensions were explored?
- **Review Q2:** What heat-related indicators or concepts were referred to, either explicitly or implicitly?
- **Review Q3:** Which major aspects explored in the literature can help address urban heat stress resilience in planning and urban design?

By systematically addressing these questions, the study aims to identify key heat-stress dimensions and associated indicators that can inform climate-resilient planning and design. The proposed stratification was developed through an iterative, inductive process during full-text review, guided by the review questions and operationalized through the concurrent construction of Table 2, which documents the extracted dimensions and indicators.

Table 2
Framework for the in-depth analysis: dimensions, aspects, and examples of indicators.

DIMENSIONS	ASPECTS	EXAMPLES OF INDICATORS
Demographic	Age	% of elderly or children
	Gender	% of men or women
	Ethnicity	% of African-Americans % of Asian or Latino
Economic	Education	% of low education
	Poverty	Low income No air conditioner
Health	Heat-related illness	CVD (cardiovascular diseases), respiratory Number of emergency calls or department visits
Urban Climate	Environmental	Air temperature (TA)/UHI Land surface temperature (LST)/UHI
	Biometeorology	Universal thermal climate index (UTCI) Physiological equivalent temperature (PET) Mean radiant temperature (MRT)
Social	Social isolation and safety	Living alone Lack of social ties and safety
Urban Morphology	Urban form and materials/LULC	Housing characteristics (e.g., building heights, materials, apartment floor, and size) Built-up density % of green spaces per capita
Institutional	Public support	Absence of caretakers Lack of resources or awareness

3. Results

3.1. The dimensions and major aspects appearing in literature

In response to the review questions and to facilitate a structured overview of the outcomes, we have organized the review results to avoid overlap and repetition by articulating the found dimensions into aspects (see [supplementary material 2](#)) and corresponding examples of indicators, as will be shown in [Table 2](#) and explained in more detail in Section 3.3.

The demographic dimension stands out as one of the most extensively explored domain within the literature review, after urban climate and urban health. Within this dimension, researchers delve into crucial indicators such as age, gender, ethnicity, and education ([Aboubakri et al., 2020](#); [Argaud et al., 2007](#); [Bai et al., 2014](#); [Bao et al., 2015b](#); [Guolo et al., 2022](#); [Mushore et al., 2018](#); [Naughton et al., 2002](#)). Many investigations generalize the demographic dimension, often referring to it as either socio-demographic or socio-economic ([Guo et al., 2022](#); [Heaton et al., 2014](#); [Johnson et al., 2009](#); [Liu et al., 2013](#); [Mushore et al., 2018](#)). The economic dimension mainly refers to poverty-related issues such as low-income communities or urban problems that include population density, a lower percentage of green spaces, poor building insulation and materials, and no access to air conditioning, which are often associated with poverty, health, or social aspects ([Browning et al., 2006](#); [Cutter et al., 2003](#); [McGeehin and Mirabelli, 2001](#); [Semenza et al., 1996](#)).

Some studies investigate the role of social network dimensions in communities' responses to extreme weather events such as heatwaves ([Heaton et al., 2014](#); [Klinenberg, 2001b](#); [Laaidi et al., 2012](#); [Naughton et al., 2002](#); [Samuelson et al., 2020](#); [Seebaß, 2017](#); [Wolf and McGregor, 2013](#)). For instance, studies examine the role of community networks in mitigating heat-related health impacts and find that neighborhoods with stronger social ties experienced lower mortality rates during heatwaves ([Browning et al., 2006](#)). Another study provides evidence that social vulnerability, including social isolation and lack of community resources, significantly increases the risk of heat-related health issues in urban populations ([Harlan et al., 2013](#)). Notable emphasis has been placed on explicitly linking neighborhood social contexts to variations in death rates during heatwaves, particularly among older individuals from different racial backgrounds. Of relevance is Eric Klinenberg's investigation of the 1995 Chicago heatwave, characterized as a 'social autopsy' ([Klinenberg, 2002](#)). The author underscores that fatalities during such events cannot be solely attributed to climate conditions and individual health. Instead, they must be examined within the context of socially constructed vulnerability, which increases the risk for certain individuals over others ([Klinenberg, 2001a, 2002](#); [Klinenberg et al., 2020](#)).

Especially in crises like heatwaves, the significance of social infrastructure (e.g. schools, libraries) plays a pivotal role in enhancing heat stress resilience ([Klinenberg, 2016](#)). In the case of the 1995 Chicago heatwave, a significant proportion of victims were older, impoverished, and socially isolated people ([Klinenberg, 2002](#); [Semenza et al., 1996](#)).

The climate dimension significantly informs our understanding of heat stress. This dimension encompasses the examination of UHIs and heatwaves, with a particular focus on indicators such as air temperature (T_a), land surface temperature (LST), humidity, mean radiant temperature (T_{mrt}), and other derived variables ([Bartolini et al., 2008](#); [Conti et al., 2005](#); [Fallah Ghalhari and Mayvaneh, 2016](#); [Kysely, 2004](#); [Matzarakis and Mayer, 1991](#); [Michelozzi et al., 2010a](#); [Arellano & Roca, 2022](#)). The climate dimension provides insights into the environmental factors contributing to heat stress and its impact on health. Heat-related health problems, including cardiovascular diseases (CVD), respiratory issues, mortality rates, and emergency calls or hospital admissions, have predominantly featured within the health dimension of heat stress research ([Argaud et al., 2007](#); [Bouchama and Knochel, 2002](#); [Giang et al., 2014](#); [Hoffmann et al., 2008](#); [Hu et al., 2017](#); [Matzarakis et al.,](#)

[2011](#); [Poumadère et al., 2005](#); [Sharafkhani et al., 2018](#)). This perspective delves into the critical health implications of heat stress, emphasizing the urgency of mitigating its adverse effects.

The combination of urban morphology and social aspects emerges from the literature as relevant in addressing urban heat stress. As these dimensions often intersect, distinguishing them can be complex. While some studies attempt to address both urban form and social aspects simultaneously to explore heat vulnerability ([Mushore et al., 2018](#)), others argue they should be considered separately, as they serve distinct objectives ([Xiang et al., 2022](#)). Urban form indicators primarily relate to mitigating the direct impacts of environmental stressors, while social factors predominantly inform indirect adaptation strategies ([Wolf and McGregor, 2013](#)). Some studies explicitly investigate urban form indicators that directly impact heat stress-related challenges, encompassing factors like population density, proximity to retail centers, and specific building attributes such as orientation, ventilation, and insulation materials ([Hatvani-Kovacs et al., 2016](#); [Heaton et al., 2014](#); [Samuelson et al., 2020](#); [Seebaß, 2017](#); [Stewart and Oke, 2012](#); [Wilhelmi et al., 2004](#)). Conversely, other scholars emphasize the broader influence of urban form on social interactions, extending to aspects like mental well-being, underscoring the intricate relationship between urban structure and social dynamics ([Krause, 1993](#); [Mouratidis, 2018](#); [Mushore et al., 2018](#); [Rinner et al., 2013](#); [Sharifi, 2019](#)). The interplay of these dimensions can profoundly impact urban heat stress resilience during heatwaves, and urban form's influence on daily social life can fundamentally shape social cohesion ([Naughton et al., 2002](#); [Seebaß, 2017](#); [Sharifi, 2019](#)).

While the institutional dimension is less frequently explored, it remains essential, and the relevant studies reference governance and institutional services as effective means to cope with extreme heat. These may include alert systems, caretaker support, awareness programs, knowledge dissemination on heat-related issues, warning systems, and the significance of transportation and resource access during heatwaves ([Hayhoe et al., 2010](#); [Klinenberg et al., 2020](#); [Nitschke et al., 2011](#); [Tomlinson et al., 2011](#); [Vandentorren et al., 2006](#)). This perspective emphasizes the role of governance and support structures in strengthening a community's resilience to heat stress.

Overall, the literature analysis highlights the intricate interplay among various dimensions of urban heat stress and its impact on urban communities, emphasizing the need for a broader understanding of this complex issue.

3.2. Distribution of works by dimension and co-occurrence of the indicators

While we acknowledge the fundamental significance of each considered dimension for comprehending the impacts of heat stress in the built environment, the examined body of work reveals variable distribution across dimensions, underscoring the diversity of research interests. This variance is crucial for pinpointing existing gaps. This section delves into the distribution of analyzed studies across dimensions, spotlighting the prevalence of specific dimensions and their associated indicators. As depicted in [Fig. 2](#), certain dimensions, notably urban climate, health and demographic dimension recur in numerous studies, followed by economic, social and urban morphology dimensions. In contrast, institutional dimension receive comparatively less attention.

[Fig. 3](#) illustrates the global spatial distribution of the 146 selected publications addressing heat-health-related issues alongside the Koppen climate classification map ([Beck et al., 2023](#)). The intensity of the shading represents the number of publications from each country, with darker shades indicating a higher number of relevant studies. The map highlights that a significant portion of the research originates in the United States, Australia, and Europe, followed by other countries, and most importantly, that research remains limited in the regions identified as most exposed according to the Koppen Climate Classification (KCC).

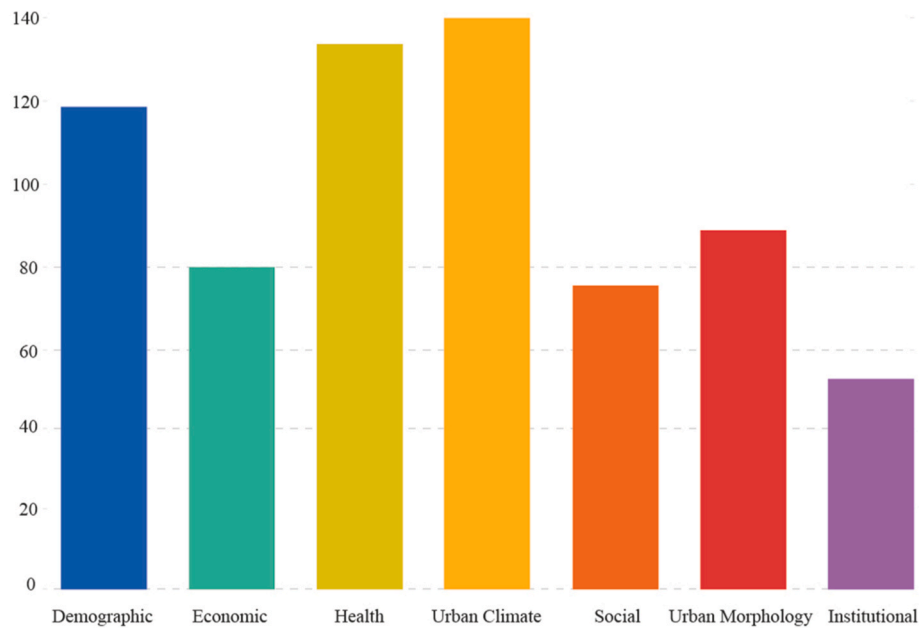


Fig. 2. Frequency of each dimension in the 146 studies.

According to the KCC system, the colors from red to yellow indicate high temperatures. Whereas the UTCI global map shows the physiological heat stress highlight regional exposure patterns.

In addition, Fig. 4 provides an overview of the most frequently mentioned urban heat stress indicators in the examined literature, detailing the frequency of each indicator relative to the total number of studies (146). Notably, categorizing urban morphology indicators posed challenges, sometimes requiring a derivation process. For articles implicitly referring to urban morphology, we identified relevant elements emerging from the review, mainly associated with the built environment, such as building characteristics (building heights, materials, apartment floor and size, ventilation, building orientation, etc) and the vegetation fraction or percentage of green spaces per capita. Despite the apparent absence of direct attention to urban morphology in many studies, it is evident from the figures that this dimension holds significance, as numerous studies indirectly refer to the relevant characteristics. However, as this dimension is not explicitly explored in most of the papers that surfaced through our selection process, it is important for future studies to delve deeper into this dimension. While our taxonomy includes only a few examples of these indicators, we recognize the need to explore a broader range of relevant factors that reflect the diverse contexts in which urban morphology plays a critical role.

The distribution in Fig. 4 highlights the indicators that are found to be highly explored in the reviewed literature regarding urban heat stress; especially the percentage of older people, low-income people, heat-related mortality rates, air temperature, percentage of people living alone, housing characteristics (building heights, materials, apartment floor and size, ventilation, building orientation, etc.), and built-up density. Moreover, at the local or micro-climate level, the review suggests that indicators such as MRT, PET, or UTCI prove more effective than air temperature in providing an accurate representation of heat impacts, as they are more sensitive to shadow variations and consider physiological parameters (Chen et al., 2016; Di Napoli et al., 2018; Fallah Ghalhari and Mayvaneh, 2016; Kim et al., 2014).

Also, recognizing susceptibility variations, it is crucial to acknowledge that not only older people but also children (sometimes mentioned as very young or under five years old) (Bouchama and Knochel, 2002; Cutter et al., 2003; Fouillet et al., 2006; Nakai et al., 1999) and middle-aged adults (Bai et al., 2014; Fouillet et al., 2006; Ghada et al., 2021; Kilbourne, 2002) seem to be particularly vulnerable to heat.

Similarly, it is well documented that men and women have different physiological responses to heat (Folkerts et al., 2022; Ishigami et al., 2008). Likewise, ethnicity becomes a pertinent indicator in certain geographic contexts, emphasizing the importance of considering equity, as seen in the fundamental need to understand, for instance, the impact of heat stress on African-American communities in the United States (Browning et al., 2006; Cutter et al., 2003; Semenza et al., 1996; Yardley et al., 2011).

To enhance our understanding of the relative importance of heat stress dimensions and their interrelationships, this study includes a co-occurrence analysis of the most occurrent identified indicators that were mentioned or used in the considered articles, as depicted in Fig. 5. To investigate their frequency, we have used total counts of each time a dimension and its related indicators were mentioned in relation to the other indicators for every paper (e.g. how many times elderly and poverty were mentioned out of 146 papers, or elderly and living alone). Counts between two indicators that were below ten or insignificant relation (those that had lower co-occurrence, or those with insignificant co-occurrence, i.e., male and female) were not considered in the final analysis. The outer circle of the chord graph represents the indicator mentioned with the corresponding dimension color, i.e., most mentioned indicators visually are wider, the arches' width represents how many times an indicator was mentioned together with another indicator, i.e., elderly and mortality or living alone and so on.

Utilizing a chord diagram, we visually represent the complexity of the interplay and prevalence of these dimensions and the related indicators, providing insights into their co-occurrence and interconnections. Fig. 5 captures the multidimensionality inherent in studies examining the impacts of urban heat stress all combined. Some studies explore the synergies among a few dimensions, such as the intersection of older people and those who live alone, low-income and African-Americans or Latinos, urban density and a lack of social ties, and UTCI and a lack of green spaces, to name but a few. Gaining insights into the interconnectedness of dimensions and their indicators enhances our understanding of the principal ones at play during extreme heat events and illuminates areas that necessitate further exploration.

Nevertheless, the chord graph emphasizes that certain dimensions and their connections remain little explored. This is particularly relevant if we consider such dimensions as institutional, social, and urban morphology. Expanding the knowledge about the interplay throughout

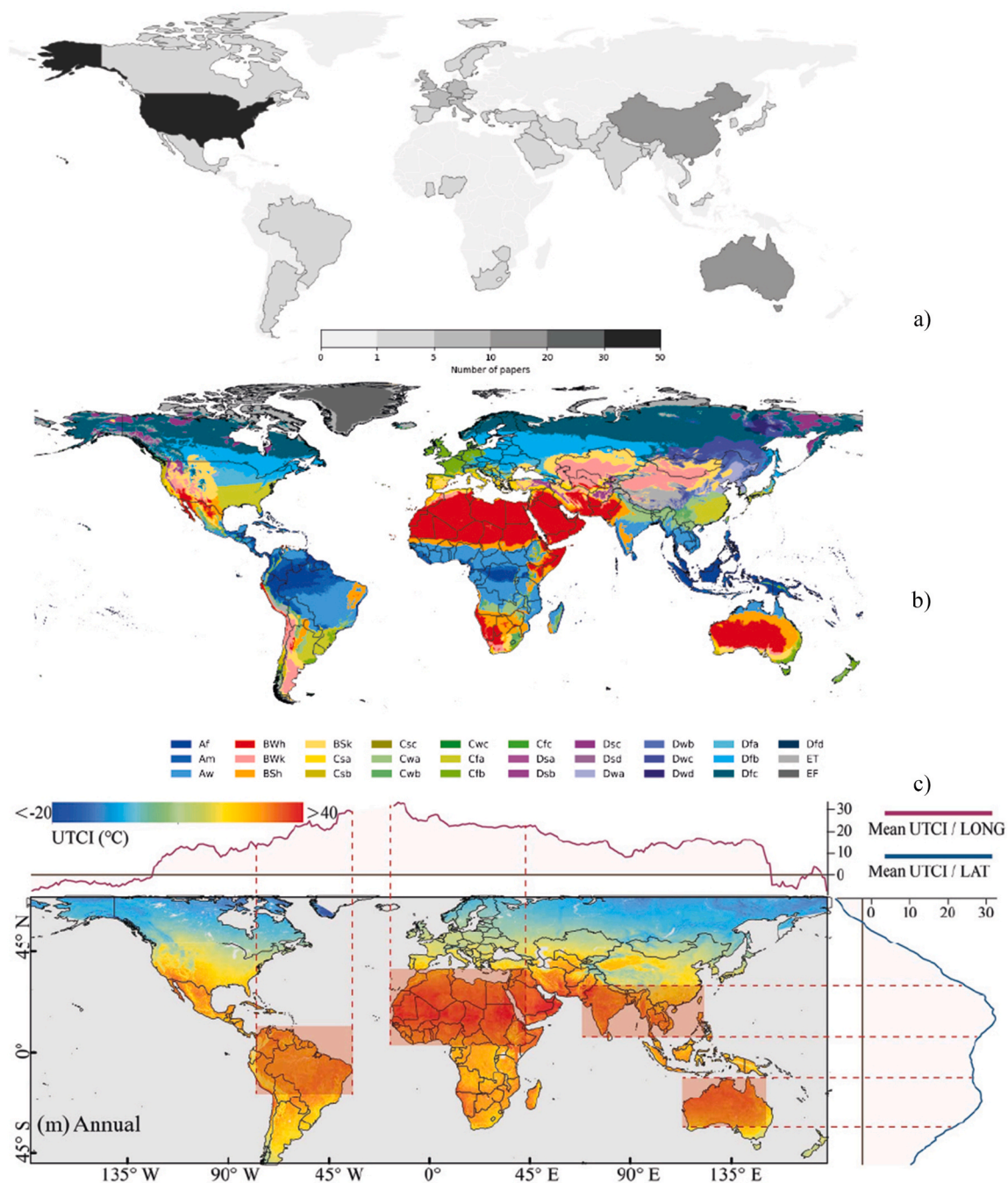


Fig. 3. a) Spatial distribution of the selected publications (146); b) Koppen climate classification (Beck et al., 2023); c) The UTCI's global distribution in 2021 (source: Earth System Science Data (Yang et al., 2024)).

all dimensions can guide the development of much more effective and targeted strategies to mitigate the impacts of urban heat stress.

Moreover, Fig. 6 illustrates the multi-dimensional structure of indicators contributing to urban heat vulnerability and risks, organized in alignment with the IPCC conceptual framework. On the left, seven key dimensions serve as the foundational categories from which specific indicators are drawn. These indicators are systematically grouped into three components: Exposure, Sensitivity and Adaptive Capacity, which collectively inform the broader understanding of heat vulnerability to better inform urban planning and design. In parallel, indicators from the Urban Climate dimension are assigned to a separate Hazard category, representing direct environmental conditions contributing to thermal stress. The flow-based structure of the Sankey diagram enables a

transparent visualization of how each dimension feeds into the conceptual components of vulnerability or hazard, supporting integrative assessments and policy targeting.

3.3. Taxonomy of the examined studies

Utilizing the framework delineated in Table 2 and drawing from the pool of 146 selected studies, we have crafted an integrative taxonomy of important dimensions and examples of related indicators presented in Table 3 (a version with an explanation of the acronyms and references is available in the supplementary material 1). The taxonomy is designed to ensure that each dimension and its corresponding indicators are clearly delineated, avoiding any overlap, and is organized based on dimension

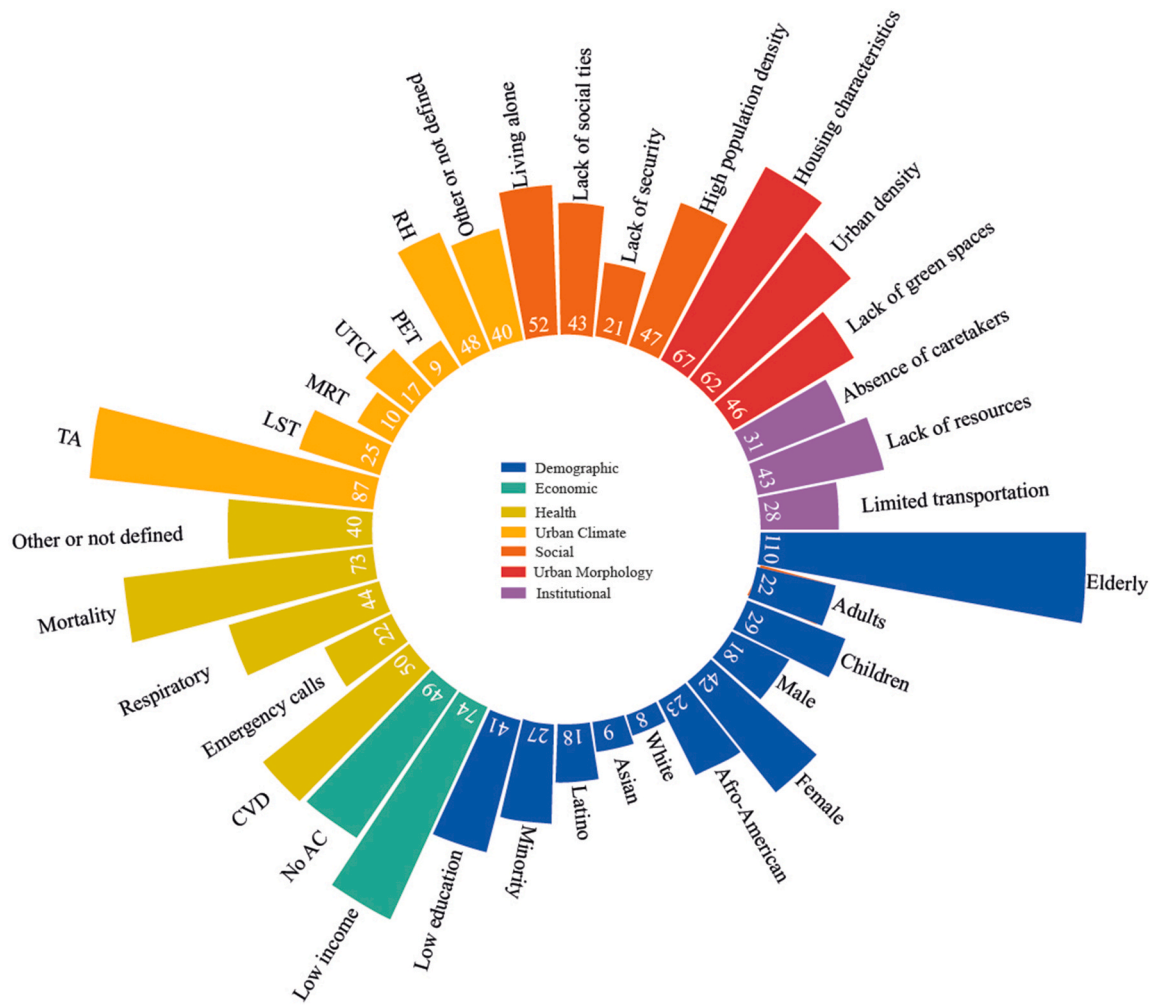


Fig. 4. The most commonly recurring indicators from the related dimensions in the selected articles.

(D), aspect, and indicator. Additionally, pertinent details, such as examples of data sources and geographical context, are listed. In fact, besides the variety of data sources, spanning national statistics, census data, health departments, emergency agencies, remote sensing imagery, meteorological stations, and surveys, among others, studies span world regions, encompassing America, Asia, Australia, Europe, and Africa. Insights and indicator thresholds vary according to geographical context, underscoring the need for more localized approaches. For instance, a temperature of 35 °C may be perceived as thermally pleasant in Houston, Texas, while constituting thermal stress in New York City (Wilhelmi et al., 2004).

The taxonomy presented in Table 3 includes the various dimensions and the related aspects and indicators, which can serve as a valuable reference for understanding the multidimensional nature of urban heat stress studies. It may aid scholars and practitioners in identifying key aspects for effectively addressing extreme heat. By providing a structured overview of the existing research facilitates the development of effective strategies, ultimately contributing to societal heat resilience against heatwaves.

4. Discussion

4.1. On the societal impact of urban heat stress

This research highlights urban heat-related dimensions, and their intricate relations as identified in existing literature, emphasizing the complexity of urban heat stress. The study draws attention to the

multidimensional nature of the health impacts during heatwaves, which arise from the interaction of multiple dimensions rather than from a single factor. For instance, individuals living in densely populated urban areas with limited green spaces are more susceptible to heat stress, particularly if they belong to lower socio-economic groups with restricted access to cooling systems. Demographic indicators spanning age, gender, or poverty underscore the diverse susceptibility within different population segments (Aboubakri et al., 2020; Argaud et al., 2007; Guolo et al., 2022; Mushore et al., 2018; Naughton et al., 2002). The climate dimension provides valuable insights into the intensity of heatwaves and UHI, with indicators such as air temperature, land surface temperature, and humidity offering a comprehensive view of the environmental factors contributing to urban heat stress (Bartolini et al., 2008; Fallah Ghalhari and Mayvaneh, 2016; Michelozzi et al., 2010a; O'Neill et al., 2005). The urban morphology dimension further contributes to this understanding by highlighting how the configuration and characteristics of the built environment can contribute to shaping heat-related challenges, including the influence of the intensity of UHI and heatwaves and associated health impacts (Hatvani-Kovacs et al., 2016; Samuelson et al., 2020; Seebaß, 2017). The related indicators such as built-up density, the orientation of buildings, width-to-height ratio, urban canyon, percentage of green spaces, or the materials used can significantly influence these problems.

The health dimension focuses on the consequences of heat stress on human health, bringing attention to issues such as cardiovascular diseases, respiratory problems, mortality rates, and emergency calls, providing critical information on the heat-health impact (Argaud et al.,

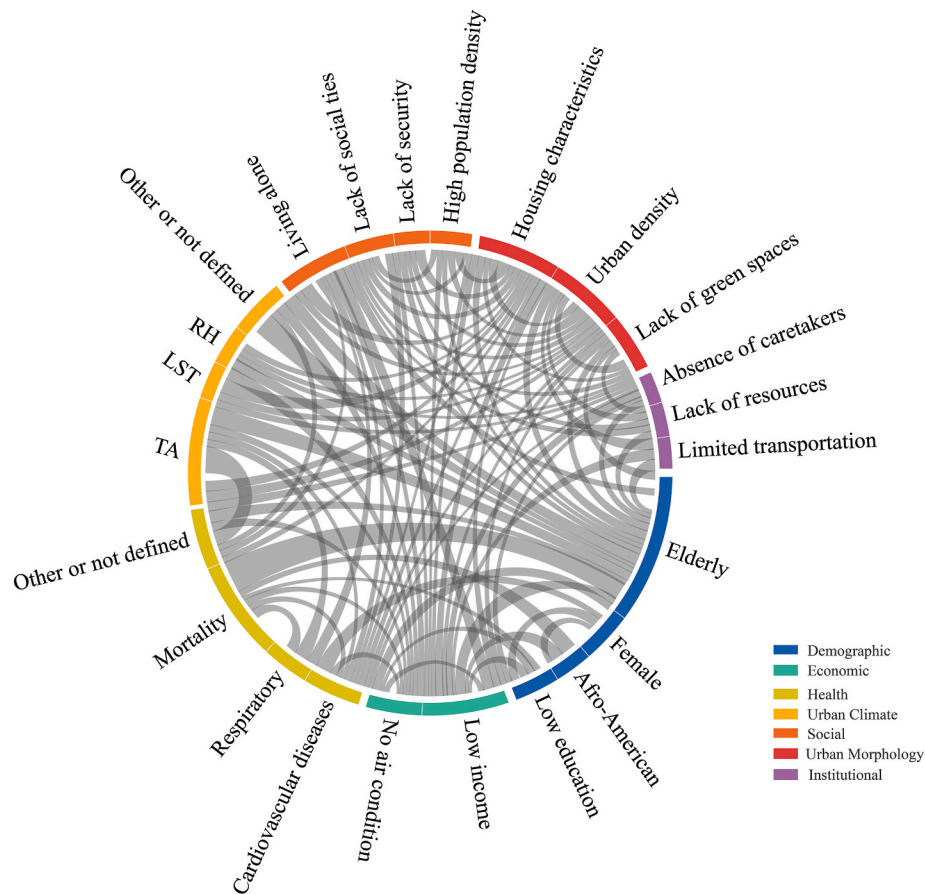


Fig. 5. Co-occurrence of the most recurring indicators from the different dimensions and their connections.

2007; Luber and McGeekin, 2008; Matzarakis et al., 2011; Nitschke et al., 2011; Poumadère et al., 2005; Sharafkhani et al., 2018). Additionally, the social dimension explores the impact of living arrangements, social bonds, and community connections, demonstrating their significance in enhancing or compromising resilience during challenging times such as heatwaves (Browning et al., 2006; Klinenberg, 2001b; Williams et al., 2022). The institutional dimension, encompassing aspects like heat warning systems and healthcare services, further contributes to the societal response to extreme heat events (Browning et al., 2006; Klinenberg, 2002; Rinner et al., 2013; Semenza et al., 1996).

Overall, this study underscores the importance of considering various dimensions to grasp the impact of heat stress on health and inform future research for the development of effective and targeted responses for building heat-resilient communities. This interconnection was highlighted in Fig. 5. The co-occurrence analysis of dimensions and related indicators show a complex connection that collectively influences heat stress resilience. Policymakers, urban planners, and public health officials can leverage this understanding to develop effective interventions addressing the multifaceted challenges of heatwaves. Table 3 presents the taxonomy of studies as a practical resource for practitioners and researchers, offering a structured overview of the main dimensions and examples of indicators needed to inform heat stress resilient actions. Beyond supporting future research, this taxonomy provides a structured framework for organizing applied case-study evidence and fostering dialogue between academic analyses and municipal heat-adaptation practice. It may also serve as a foundational reference for international policy-oriented networks such as C40, the Resilient Cities network, or United Nations initiatives in the development of heat-adaptation strategies and planning instruments. A limited subset of the reviewed studies already engages with operational systems, including heat-health warning systems developed in collaboration with public

health authorities (e.g., Kapwata et al., 2022; Michelozzi et al., 2010b). While such applied evidence remains fragmented, strengthening translational pathways, including engagement with municipal reports and practitioner-oriented city networks represents an important direction for future research beyond the scope of this review.

4.2. Advocating more comprehensive and multidimensional studies

The pursuit of heat stress resilient cities necessitates a multidimensional study approach that assesses various aspects influencing both mitigation and adaptation to heatwaves.

Fig. 2, depicting the frequency of each dimension across the selected studies, highlights discrepancies. While demographic, health, and climate considerations have received significant attention in previous studies, social and institutional dimensions crucial in shaping vulnerability and coping capacity remain relatively understudied. To achieve a holistic understanding of the complex interplay of urban heat stress, it is imperative to bridge this gap by giving due consideration to less used dimensions.

The frequency analysis of the examples of heat-related indicators, as illustrated in Fig. 4, further accentuates the need to delve deeper into additional indicators. For instance, understanding certain dimensions and their related indicators, such as MRT, PET, or UTCI, and connecting them to other dimensions, will offer a more nuanced representation of heat stress impact, beyond air temperature or land surface temperature only. Additionally, several spectra of analyses and methods used in the literature (see supplementary material 3) point out relevant approaches that should be considered towards the direction for advancing multidisciplinary study on heat stress issues which is among the main reasons motivating this research.

In advocating for more comprehensive studies, it becomes evident

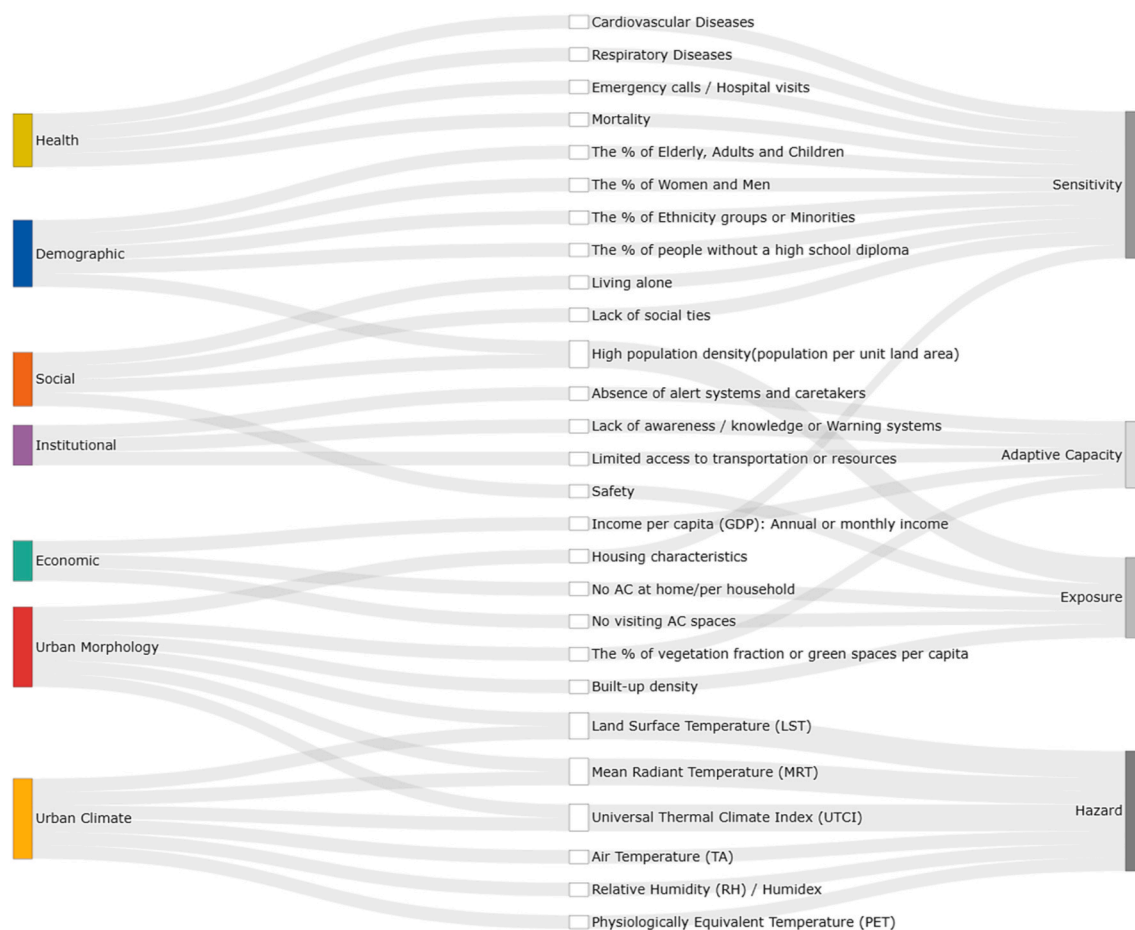


Fig. 6. The connection of the dimensions and heat-stress indicators contributing to heat vulnerability and hazard.

that while demographic, health and climate factors are extensively explored, the complexity of urban heat extends beyond their assessment alone. Tailoring strategies and interventions to diverse communities is crucial, as the impact of extreme heat is influenced by local conditions, whether environmental, social, health, economic, or political. A narrow focus considering on a single or two dimensions may overlook critical interactions and synergies between various factors, leading to suboptimal solutions. This may not comprehensively account for the complex interplay of factors in urban environments during extreme heat events. To gain nuanced insights into heat-prone areas within urban settings, it is crucial to integrate a broader spectrum of heat stress indicators into research frameworks. This call for a more integrated and multidimensional approach is essential to capture the intricacies of the multidimensional challenge posed by urban excessive heat, such as heatwaves, recognizing the interplay of various dimensions in shaping heat stress resilience.

Given the complexity of urban heat–health interactions and the lack of a single unifying framework, multidimensional integration should be approached pragmatically. Studies can adopt phased strategies, analyzing hazard, vulnerability and urban form separately before integrating them using different methods depending on the context, data availability, scale and objectives.

4.3. Limitations and pathways toward actionable knowledge

A few limitations regarding the review need to be pointed out. First, only peer-reviewed publications in English were included, cutting out numerous world regions, even those highly affected by heatwaves. Further, studies on tangential aspects (e.g., only air quality, indoor climate and comfort) or highly specific topics (e.g. studies on pregnant

women, workers, plants, or agriculture in relation to heat stress) were not included to avoid overextending the selection of studies. Even though the review acknowledges the importance of the urban morphology dimension, the need for context-specific studies should be addressed in future studies.

While our review reflects how urban heat-health related issues are addressed in scientific literature, we recognize that this is only one genre of writing on the matter. Our review did not include official publications of planning bodies or other non-academic sources, providing significant insights into how heat stress is managed in practice (e.g., see the work Ulpjani, 2024; Ulpiani et al., 2024). Future research could benefit from more comprehensive reviews that systematically incorporate grey literature, including municipal reports and applied case studies, to better support operational planning, implementation, and evaluation of heat adaptation and mitigation actions.

Also, studies that focused only on the environmental causes of urban heat stress (i.e. modelling and sensing studies) were mainly excluded, leaving a few studies that explicitly or implicitly addressed heat-health related research.

This study does not include heat stress caused by endogenous factors such as physical exertion or metabolic activity (e.g., occupational heat stress among outdoor workers). This exclusion was intentional to maintain focus on urban environmental stressors that affect the general urban population in outdoor settings. Future work could build on this taxonomy by integrating occupational and labor-related vulnerabilities into the multidimensional framework.

Our review does not provide an application study. This aspect falls outside the scope of our research and should be explored in future case-study applications. Furthermore, there is a notable lack of studies on arid regions (Fig. 3), and Northern Europe also features rarely due to more

Table 3
Established taxonomy of dimensions and indicators of urban heat stress.^a

<i>D</i>	Aspects	Indicators	Data sources	Context
DEMOGRAPHIC	AGE	<i>The % of Elderly, Adults and Children</i>	Census tract, Dept. of Health, NCS	US, China, Australia, Asia, EU ^b , Africa
	GENDER	<i>The % of Women and Men</i>	Census Tact, Dept. of Health, NCS	US, Asia, Australia, EU
	ETHNICITY	<i>The % of Ethnicity groups or Minorities</i>	Census tract, Dept. of Health, NCS	US, Asia, Australia
	EDUCATION	<i>The % of people without a high school diploma</i>	National Institute of Statistics/Census tract, NCS, surveys	US, Asia, Australia, EU
ECONOMIC	POVERTY	<i>Income per capita (GDP): Annual or monthly income</i>	National Institute of Statistics/ Census tract, surveys	US, Asia, Australia, EU, Africa
		<i>No AC at home/per household No visiting AC spaces</i>	National Institute of Statistics/Census tract, Structured interviews	US, Asia, Australia
HEALTH	HEAT-HEALTH ILLNESS	<i>Cardiovascular Diseases</i>	Dept. of Health, Agency of Emergency, Hospital admission	US, Asia, EU, Australia
		<i>Respiratory Diseases</i>	Dept. of Health, Agency of Emergency, Hospital admission	US, Asia, EU, Australia
		<i>Emergency calls/Hospital visits</i>	Dept. of Health, Agency of Emergency, Hospital admission, City Public Health, Research Data Centre/Statistics Office	US, EU, Australia
		<i>Mortality</i>	Dept. of Health, Research Data Centre/Statistical Office INSSE	US, Asia, EU, Australia, Africa
		<i>O(Other)/ND (Not defined)^c</i>	/	Australia, EU, Asia, Africa, US
URBAN CLIMATE	ENVIRONMENTAL	<i>Air Temperature (TA)</i>	Meteorological services, National Climate Centre, <i>Weather stations</i>	US, Asia, EU, Australia, Africa
		<i>Land Surface Temperature (LST)</i>	<i>Remote sensing</i> <i>Landsat TM MODIS, NOAA, USGS</i>	US, EU, Asia, Africa
		<i>Relative Humidity (RH)/Humidex</i>	Meteorological services, National Climate Centre	US, Asia, EU
	BIOMETEOROLOGICAL	<i>Mean Radiant Temperature (MRT)</i>	<i>Remote sensing</i> Copernicus SOLWEIG	Asia, EU
		<i>Universal Thermal Climate Index (UTCI)</i> <i>Physiologically Equivalent Temperature (PET)</i>	Meteorological Services, ERA-Interim, <i>Weather stations</i> World Weather Online, ERA-Interim	EU, Asia EU, Asia
		<i>O(Other)/ND (Not defined)</i>	/	Australia, EU, US
SOCIAL	SOCIAL ISOLATION AND SAFETY	<i>Living alone</i>	Questionnaires, Interviews, NCS, NSSO	US, Asia, Australia, EU
		<i>Lack of social ties</i>	Questionnaires, NCS, NSSO	US, Asia, Australia, EU
		<i>Safety</i>	Census of retail trade Questionnaires, NCS, NCS Interviews	US, Asia, Australia, EU
		<i>High population density (population per unit land area)</i>	Census tract, NCS,	US, Asia, EU, Australia, Africa
URBAN MORPHOLOGY	URBAN FORM AND MATERIALS/LULC	<i>Housing characteristics (e.g., building heights, materials, apartment floor and size, ventilation, building orientation)</i> <i>Built-up density</i>	Remote Sensing, Census (build. heights materials). USR, BY Census, Remote Sensing, LULC, GSI FSI or FAR, DEM	US, Asia, Australia, EU Asia, Australia, US, Africa
		<i>The % of vegetation fraction or green spaces per capita</i>	Remote Sensing, NASA, Planet Scope Pleiades-1A satellite-Derived - NDVI/Vegetation fraction, Tree Canopy	Australia, EU, Asia, US, Africa
INSTITUTIONAL	LACK OF PUBLIC SUPPORT	<i>Absence of alert systems and caretakers</i> <i>Lack of awareness/knowledge or Warning systems</i> <i>Limited access to transportation or resources</i>	NCS, NCSO NCS, NCSO NCS, NCSO, POI	Australia, US, Asia US, Australia, Asia Australia, US, Asia

^a For acronyms see [supplementary material 1](#).

^b Refers to Europe as a continent (both EU and non-Eu members).

^c Studies focused on heat-related mortality without explicitly utilizing climate indicators, and/or climate studies addressing heat-health problems without specifically employing health indicators.

favorable climate conditions during summer. Addressing these gaps, particularly in regions with extreme climates, is crucial for a comprehensive understanding of heat-health issues. Beyond identifying research gaps, this review highlights the need for more impact-oriented and translational research that supports the evaluation and deployment of applied heat related solutions, including building technologies, passive cooling strategies and space-conditioning systems. The proposed taxonomy can help align academic research with the practical information needs of municipalities and industry actors involved in urban heat adaptation and mitigation.

Although the dimensions addressed are extensive, the indicators included are not exhaustive, and others may address these dimensions, which can be explored further. The imbalances observed across dimensions in the reviewed literature depend on how studies prioritize specific dimensions due to disciplinary focus, data availability or methodological feasibility, rather than an oversight of other relevant aspects.

Lastly, the literature review was conducted until December 15, 2025 and other relevant studies may have been published after that date.

5. Conclusions

This paper contributes to a more holistic understanding of the complexity of urban heat-health issues from a multidimensional approach, which can help policymakers, practitioners, and researchers in these interconnected fields better understand and address such problems in the urban context. The results provide significant insight into the complexity of urban heat stress studies, which require a multidimensional approach. While the multidimensional nature of urban heat stress is well established in the literature, our study aims to further this understanding by developing a taxonomy of dimensions and examples of indicators that can help future research addressing such problems more effectively. By highlighting these patterns, our research provides a taxonomy of various dimensions, offering valuable insights for scholars, policymakers, planners, and designers in developing heat-stress-resilient urban strategies.

We point out that, based on our review, we found that many research efforts focus on few aspects, but there is a critical need to integrate multiple dimensions to comprehensively grasp the consequences of heatwaves and health impact fully. Also, we emphasize that some key dimensions, as the institutional one, are less explored.

Ultimately, the key innovation of our study lies in the taxonomy we developed through our careful literature analysis. This taxonomy reflects how science measures and evaluates the phenomenon of urban heat stress across different disciplines, providing valuable insights for both academia and practice.

CRedit authorship contribution statement

Doruntina Zendeli: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Nicola Colaninno:** Conceptualization, Supervision, Writing – original draft, Writing – review & editing. **Marjolein van Esch:** Supervision, Writing – review & editing. **Ahmed Hazem Eldesoky:** Writing – review & editing. **Eugenio Morello:** Conceptualization, Supervision, Writing – review & editing. **Arjan van Timmeren:** Supervision, Writing – review & editing.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.healthplace.2026.103643>.

Data availability

Data will be made available on request.

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