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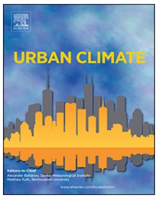

The heat-health nexus in the urban context: A systematic literature review exploring the socio-economic vulnerabilities and built environment characteristics

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ABSTRACT

Of all-natural disasters, extreme high temperatures events are the main cause of weather-related mortality. The compact urban settings of cities, the dependency on infrastructural systems as well as the larger concentration of people and economic activities make urban areas particularly vulnerable to health risks due to heat. To investigate vulnerabilities to heat, the study illustrates how vulnerability factors together with the hazard and the urban parameters determine the nexus between the heat and the health outcome, here called *heat-health nexus*. Peer-reviewed articles with no language limitations were searched from the first available record subjected to the imposed selection criteria. First, the information related to the study area were analysed, taking into consideration the level of resolution to investigate the scale of analysis. Then, the specific hazard parameters, divided in simple or combined weather indices, were evaluated. For sensitivity and adaptive capacity aspects, the study considered four distinct categories of determinants: mental and physical health, demographics, social and economic status. Finally, when looking at enhanced exposure, groups of determinants of vulnerability, divided between those describing indoor and outdoor environment conditions were analysed. Results demonstrated a heterogeneous spatial distribution of the identified case studies about heat and health in the urban context and highlighted different characteristics related to climate hazard, exposure, vulnerability and enhanced exposure factors in relation to the health of the population. This literature review demonstrate that a detailed identification of sensitivity, adaptive capacity and enhanced exposure elements is crucial in the implementation of effective adaptation measures in the health context.

1. Introduction

As is widely acknowledged, due to the large concentration of population, economic activity, transport and energy infrastructures, cities and metropolitan areas play an important role in contributing to climate change (Orimoloye et al., 2019; Khavarian-garmsir et al., 2019; Ropo et al., 2017). At the same time, they are the sites where the most pressing current challenges brought about by climate change are visible (Barber, 2017). Moreover, cities and metropolitan areas are the heart of today's world economy,

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increasingly concentrating political, economic, financial, cultural, technological and innovation capabilities. For this reason, climate change and the different local, regional and national capacity to address its effects, might also have important consequence on urban competitiveness and competition, at a variety of spatial scales (Kamal-Chaoui, 2008; Sharma, 2019). However, cities are not only part of the problem; yet they can also be regarded as a vital part of the global response to climate change and its impacts. As a point of fact, there is today growing evidence showing that many cities are becoming key players in shaping and implementing new initiatives aimed at dealing with the challenges brought about climate change, both at urban scale, through mitigation and adaptation measures (Carter, 2011; Carter et al., 2015; Leichenko, 2011) and at inter-urban scale, through the shaping and designing of new cooperation networks and efforts (Kern and Bulkeley, 2009; Gordon, 2013; Castán Broto and Bulkeley, 2013).

Against this background one of the more challenging issue cities and metropolitan areas need to address is the increasing magnitude and frequency of heatwaves. In fact, over the last half-century, the probability of heat extreme events has already changed by orders of magnitude in almost every region of the world, with occurrences that are now up to a hundred times more in respect to a century ago (Eckstein et al., 2019; WMO, 2019). As a result, the frequency and severity of extreme heat spells have become more visible for high- and low-income countries (Hintz et al., 2018). Because of these phenomena, heatwaves are one of the major cause of damages in the last years, especially in the Northern Hemisphere (Eckstein et al., 2019). Recent research has found that of all natural disasters, extreme high temperature events are the main cause of weather-related mortality (de' Donato et al., 2015; Petkova et al., 2014; Gabriel and Endlicher, 2011), and they are also expected to be the main factor responsible for additional deaths due to climate change in the coming years (WHO, 2018). In this context, to understand how cities and urban authorities plan to anticipate and cope with extreme high temperature events, in terms of monitoring and data organization, identification of main stressors and relationships between diverse and relevant factors and providing input for sound political responses is of paramount importance. As a point of fact, cities are hotspot locations, because they are characterized by an addition of several degrees warmer than their surroundings due to specific urban features and their albedo as well as urban waste heat and GHG emissions from infrastructure (Oppenheimer et al., n.d.; Rosenzweig et al., 2011). Therefore, the compact urban settings of cities - through the reduced evaporative cooling caused by lack of vegetation and the production of waste heat - bring to elevated surface and air temperature, generating the condition for the urban heat island (UHI) phenomenon (Rosenzweig et al., 2011; Oke, 1982; Breil et al., 2018). At a closer look it becomes evident that conditions within cities are not equal in all their parts, and identifying those areas which are particularly vulnerable to heat, either to their physical form or particular characteristics of their inhabitants, is particularly important. To date, more than 54% of the world's population live in urban areas and by 2050 this portion is projected to include two-thirds of the people around the globe (United Nations D of E and SA, 2014). Moreover, as mentioned above, cities are the heart of the contemporary economy, which means that heatwaves can hamper the economic structures of many regions and can promote budgetary problems and loss of competitiveness (Kamal-Chaoui, 2008). Climate projections (Representative Concentration Pathways, RCPs) as well as socio-economic scenarios (Shared Socio-Economic Pathways, SSPs), which describe respectively alternative climate pathways associated to emission levels (van Vuuren et al., 2011) and societal development trends (Jiang and O'Neill, 2017), estimate an increase of UHI effects due to changes related among others to urban density and urban land cover (Oke, 1982; Chapman et al., 2017).

The heat-related epidemiology literature emphasizes that population expansion under an increasing frequency, intensity, and duration of heatwaves is increasing the social vulnerability, exacerbating the temperature-mortality relationships (de' Donato et al., 2015; Petkova et al., 2014; Martinez et al., 2018; Michelozzi et al., 2008; McMichael et al., 2008). In order to investigate urban vulnerabilities to heat stress, many researchers assess the risks evaluating the mortality rates in relation to temperature trends. While this nexus provides insightful results, it fails to take into consideration specific heat stress conditions as well as specific characteristics of the local population and the physical environment (Lindley et al., 2018; Klein Rosenthal et al., 2014). In fact, the temperature-mortality relationship does not occur in a territorial vacuum. Rather, it is 'embedded' within the urban fabric, according to the context-specific way natural and socio-economic processes interact. Population health risk due to heat in cities is driven by a still undefined combination of sub-systems such as the spatial distribution of the UHI, the built environment characteristics, the land use, the infrastructures, the social, natural and productive systems, the bio-geophysical factors as well as the socio-economic aspects (Breil et al., 2018; Tapia et al., 2017; Kaźmierczak and Cavan, 2011; Georgi et al., 2016). A good understanding of the complexity of interactions between exposure, sensitivity and adaptive capacity and of relevant determinants of vulnerability is crucial for the informing interventions at local level and can contribute to developing instruments for diagnosis, as heat vulnerability indices (HVI). Such assessment studies translate the knowledge about determinants of heat vulnerability in composite indicators, while should be able to support local policy making in detecting potentially vulnerable areas and communities within their territory (Bao et al., 2015; Wolf et al., 2015).

For this reason, in this review, the authors explore - together with the urban climate parameters – which vulnerability factors jointly with the exposure have been found to determine the nexus between the heat and the health outcome, here called *heat-health nexus*. Managing urban climate hazards and understanding the causes of intra-urban spatial heterogeneity is complex, as it requires a deep knowledge of how the hazard unfolds within urban areas and how it interacts with environmental circumstances and the spatial distribution of the most vulnerable population (Rosenzweig et al., 2011; Breil et al., 2018; Klein Rosenthal et al., 2014; Georgi et al., 2016; Araya-Muñoz et al., 2016; Urban et al., 2016).

Several studies have been conducted in order to assess the current and future hazard-exposure, but less effort has been spent in research to analyse environmental and social factors related to health issues (Lindley et al., 2018). In order to highlight the fundamental social and environmental characteristics, which have the potential to influence the heat-health outcomes within urban areas, this research focused on the three main pillars defining risk: *hazard* that here is defined as the potential occurrence of summer extreme temperatures amplified by urban conditions that can bring to heat stress status in the short and long term; *exposure* that reflects the urban population which could be adversely affected by extreme temperature conditions in urban areas, and *vulnerability* that describes the propensity or predisposition to be affected to extreme temperatures (Oppenheimer et al., n.d.). Among these factors the present review focusses on the concept of vulnerability. To facilitate the comprehension of the analysed material, vulnerability factors have been disaggregated into three main components that constitute the socio-spatial vulnerability index (Lindley et al., 2018): (i) *sensitivity*, that here represents the personal biophysical and social characteristics driving vulnerability, and (ii) *enhanced exposure*, which reflects aspects of the physical environment that can exacerbate (or mitigate) climate impacts within different places across cities. The aggregation of these indicators helps to explain which factors drive vulnerability at the intra-urban scale and which factors related to the characteristics of the built environment further enhance the exposure, taking into account the insights linked to each study location (Breil et al., 2018). In addition, all these dimensions are associated with (iii) *adaptive capacity* indices which reflects the ability of citizens, policy makers, local businesses and institutions within cities to respond to heat-stress conditions (Breil et al., 2018; Lindley et al., 2018). Understanding of these aspects - together with the level and distribution of health outcomes – and eventually their aggregation into heat vulnerability indices – could indeed be crucial to identify and implement efficient social and physical infrastructure measures through the use of ad hoc spatial planning considerations and urban governance decisions (Hintz et al., 2018; Wolf et al., 2015). In this context, higher-resolution data in relation to both heat hazard and health impacts and to determinants of vulnerability can facilitate the urban climate and the health governance in understanding the pattern of current and future human health risk in the next future in order to better shape adaptation measures at the local scale. Therefore, assessing the health risk due to heat in diversified intra-urban context is necessary to improve our understanding of the *heat-health nexus* and to evaluate the innovative progresses of urban adaptation strategies. In fact, while it is widely acknowledged that cities and metropolitan areas play a basic role in tackling climate change, both in terms of mitigation and adaptation policies, more research effort is needed to understand how management measures have to be differentiated at intra-urban scale, according to the specific local parameters and socio-economic vulnerabilities.

To this perspective, based on the available literature, 40 articles on health issues due to heat within urban contexts have been analysed to support the identification of enhanced exposure factors, sensitivity, adaptive capacity characteristics and health outcomes, highlighting common features and differences with emphasis on the urban parameters and the socio-economic vulnerabilities. This paper is organized as follows: *section 2* focusses on the methodology. It first refers to the systematic literature review approach; then it turns to the specific content of the 40 final articles. *Section 3* offers an insight into the achieved results of the analyses. In *section 3.1,* a discussion on the exposed sample to health impacts of heat stress in urban areas is proposed with the aim to analyse the urban geographical provenance of the case studies as well as the major causes of mortality due to heat. *Section 3.2* focussed on the parameters that the authors of the papers are using in order to evaluate the climate hazard. In *sections 3.3* and *3.4* the social dimensions of vulnerability (sensitivity and adaptive capacity) as well as the urban environment characteristics, which constitute the enhanced exposure, have been investigated in detail. Finally, some conclusive remarks are provided in *section 4* and *5.* In particular, the need for further investigation on the importance of social and economic parameters in affecting the evolution of the *heat-health nexus* is pointed out in *section 4*. A sound knowledge on the role played by these factors can support cities and urban authorities to tackle climate change impacts with more effective adaptation policies.

2. Methods

2.1. Literature review process

This paper is based on a systematic literature review approach to investigate the state-of-the-art literature on factors that link characteristics of the urban environment to vulnerability to heat during extreme temperature events. The review as well as the qualitative content analysis process was based on several known guidelines (Pullin and Stewart, 2006; Luederitz et al., 2016). The *PubMed* and *Scopus* database were used to identify and provide relevant literature through the developed research algorithm. The used search terms were selected through an initial screening process highlighting the most frequent keywords in almost 700 articles selected from the simple initial algorithm (see *Appendix A*). Peer-reviewed articles with no language limitations were searched from the first available record subjected to the imposed selection criteria until March 2019. The first step of the review returned in 1445 results for the selected time-period. For each record, title and abstract were filtered twice by the authors for inclusion in the list of potentially relevant papers (476). The remaining articles were then reviewed based on the set of criteria that have been imposed within the systemic review approach (see Fig. 1). First, the papers had to include at least one empirical case study together with the nexus between the heat and the health outcome, here defined *heat-health-nexus* (1st Set of Criteria). In fact, articles that focused solely on health sector were judged being beyond the scope of this study. Second, the papers had to describe connections with the built environment characteristics, which include the indoor conditions as well as the urban outdoor environment (2nd Set of Criteria). From the above sets of criteria, 31 papers were considered. Finally, a “snowballing method” was used to include in the list also those articles identified from the bibliographies of the previous selected papers (Pullin and Stewart, 2006). Although, at present, health impacts from extremely low temperatures are potentially more important in terms of morbidity and mortality (Hajat and Gasparrini, 2016), this study focuses on heat related impacts. In fact, only few studies inquire on factors related to enhanced exposure for the analysis of cold related health impacts, and including factors related to indoor conditions, generally related to energy poverty and poor building insulation. The selection process led to 40 papers and it is described in the following flowchart.

2.2. Content analysis

The analysis was performed following the most recent Intergovernmental Panel on Climate Change (IPCC) conceptual framework for risk that explicitly considers the presence of the elements exposed as an additional component (Oppenheimer et al., n.d.). As mentioned

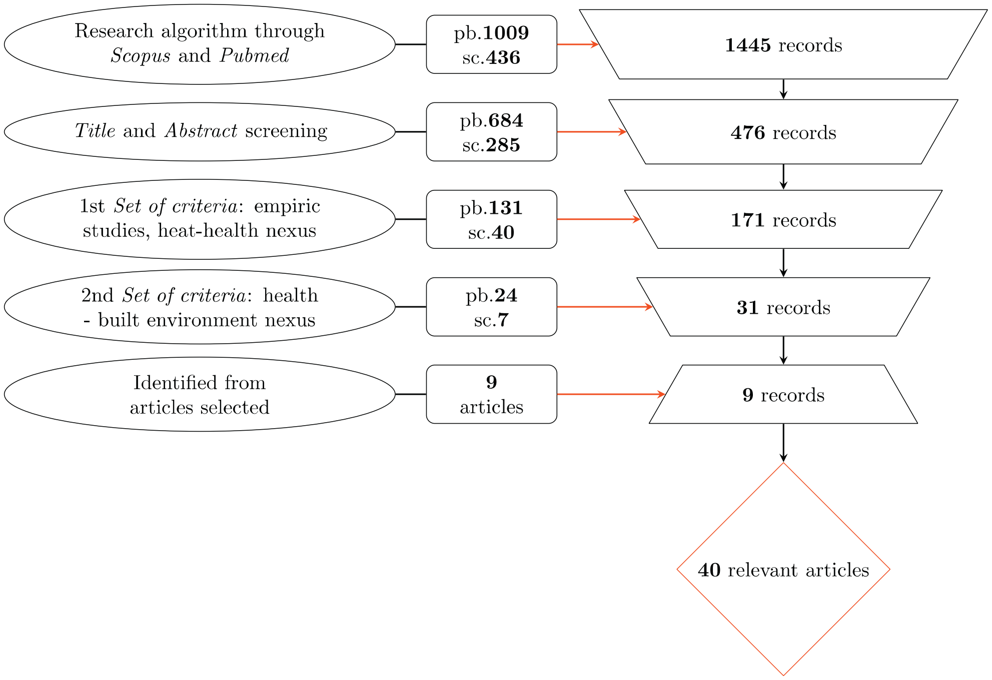

Fig. 1. Steps of the selection process.

in the previous chapter, in order to highlight the main variables related to the *heat-health nexus*, this study focused on the hazard-exposure relations (hazard and exposure), but also on the main components that constitute the socio-spatial vulnerability: sensitivity, adaptive capacity and enhances exposure. The content of the 40 final articles assessing variability in the impacts of heat through the analyses of health outcomes (when accessible) was investigated with the aim to identify relevant issues and common features. On this basis, the information was organized in this paper through the following classification method. Starting with the geographical dimension, information related to the area of study was collected, taking into consideration the level of resolution to investigate the scale of analysis. Then, the first step was to define the hazard parameters as well as the applied methodologies to collect and analyse the climatic data. Concerning enhanced exposure, the information was divided between *Indoor Environment* and *Outdoor Environment*. Under indoor environment, elements that influence the indoor heat stress were inserted, while under outdoor environment were included those variables that influence the outdoor urban heat stress. In order to investigate whether there were geographic differences in how single parameters are understood, due to different socio-economical contexts, the geographic environment in which the single studies are located have been considered. To differentiate all the information related to sensitivity and adaptive capacity, variables are here categorized into five different classes: physical and mental health, demographics, social and economic status. Finally, to investigate the main component of the research, the paper analysed if data related to the health sector (studies on heat morbidity or heat mortality) were available and, if any, which methodology each article decided to apply in the reference study.

3. Results

3.1. The health impacts of heat stress: the urban population (exposure)

Taking into account all variables that seem to influence the heat-exposure of urban population, the 40 papers was investigated looking at the geographical and spatial scale, focusing on the most prevalent health factors. A strong geographic bias within the analysed articles shows how most of the studies were conducted in USA, followed by Australia, UK and China. Diverse articles focused on single case studies within one European country, but only one refers to South America (Inostroza et al., 2016). In addition, it must be highlighted how, despite the heat stress risks faced by African cities, no comparable study dedicated to African urban areas was found, highlighting how the African continent is still underrepresented due to the lack of proper data (Eckstein et al., 2019).

Results show that the scale of application changes in respect to the analysed case: 27 articles reflect a city-scale analysis, 8 papers consist of a multi-cities analysis, 5 include entire metropolitan areas (all in USA), and one is considering a wider territorial area, consisting of urban and rural areas in the Yangtze River Delta (China). In a second moment, the paper focussed on the geographical resolution of urban exposure data to identify which units of analysis significantly elucidate intra-urban variations of risk. Yet, understanding differences at this scale is key for the definition of the spatial health risk distribution with respect to existing urban areas (see Table B.1 in *Appendix B* for further details). Of the 40 articles, just the half mentioned the analyses carried out to quantitatively determine how heat affects population health in a specific urban area. Research based on mortality generally contains georeference information and socio-demographic and -economic data for each death. On the other hand, morbidity case studies mostly refer to the investigation of the admissions to hospitals in the warmest periods of the year. At this stage, we found three cases based on survey data. Of those, one is focusing on self-reported perceived health effect (Bélanger et al., 2015), a second one on self-reported household thermal comfort (Loughnan et al., 2015) and the last one on self-reported perceived heat stress (see Table B.2 in *Appendix B*) (Henseke and Jürgen, 2014). Despite the qualitative approach, these perceived reported health effects contribute to identify a reliable and valid subjective measurement that reflect certain health aspects difficult to identify clinically (Bélanger et al., 2015). In addition, they also support policymakers in the identification of population groups most likely at-risk, promoting ad hoc services and preventive measures to mitigate the health consequences during very hot and humid conditions (Bélanger et al., 2015).

The majority of the case based on mortality indicate more clearly which diseases they took into consideration based on the International Classification of Diseases (specifically ICD-9 and ICD-10). In this context, if the ICD code was not explicit, it was derived from the classification provided by the World Health Organization (WHO) (WHO, 2016). By majority, *all-causes of death* (ICD 10: A00-Y89) together with *natural causes of death* (ICD 10: A00-R99) are the most common used classification methods. However, if a greater specification was available and the models allow to disrupt subdivide the population under analysis, a greater detail on causes of mortality contributes to enhance the quality of the analyses. For example, several case studies refer to ICD10 T67 and ICD10 X30 (Johnson and Wilson, 2009; Smoyer et al., 2000; Uejio et al., 2011; Gronlund et al., 2015; Nayak et al., 2018), which reflect specific diagnosis due to the effect of heat (e.g. heatstroke, heat syncope, heat cramp, etc.) as well as the exposure to natural heat as cause of sunstroke (e.g. ictus).

3.2. Climate parameters for heat (hazard)

Extreme temperatures significantly increase the risk of mortality and morbidity around the world. In order to evaluate the perceived thermal comfort of the population within a specific environment, several studies used simple temperature anomalies or combined weather indices (Barnett et al., 2010; Kim et al., 2014; Blazejczyk et al., 2012). In fact, some authors consider these measures to be efficient predictors for the heat-related health impacts assessment and were able to express an equivalent perceived temperature of the referent environment providing information on the physiological response of a reference population (Kim et al., 2014). In this context, the work of Barnett et al. is important (Barnett et al., 2010): they analysed the relationship between temperature related parameters and daily counts of deaths to identify the best predictor in the association between temperature and mortality. The results of the study proved how there is not a best climate parameter of mortality, but the choices must depend on practical concerns (e.g. data availability, missing data, etc.). However, due to its simplicity and efficacy to illustrate health impacts of heat, to date ambient temperature is still the most used variable in the heat risk assessment analyses (Barnett et al., 2010; Aubrecht and Özceylan, 2013). In addition to the climate parameters investigation, separate analyses by location (e.g. specific cities) or within the same location (e.g. districts) can increase the power of the study and can provide information on heterogeneity of environmental exposures (Bhaskaran et al., 2013).

In this chapter, the focus is on climate parameters used in the 40 papers to connect heat stress perceived in a specific location with the health effects. In fact, different climate factors contribute to heat stress, among these temperature variations, humidity and wind. Epidemiological studies frequently use observations from weather stations within the analysed city, emphasizing the relation between ambient heat and excess mortality (and morbidity) under extreme climate condition (Hu et al., 2019). Due to the limited number of parameters available from the stations, most of the research in the field used univariate heat measure and temperature-based heat-wave definitions (Aubrecht and Özceylan, 2013). The articles have been screened looking at the climate parameters (see Table B.3 in *Appendix* for climate indices description). From the analyses, it emerged that indicators were all based on daily parameters, and there was no difference in the use of specific patterns of climate indicators between countries under study. The identification of specific hot days within the hot season was based either on mean daily temperature (means of daily maximum temperatures or apparent temperature) or in some cases, specific definitions of heat wave duration were used for the selection of the period of investigation. With this term the state-of-the-art literature refers to a period of hot weather with a duration of at least two or three days in which days and nights reach high values of temperatures and humidity (Wolf and McGregor, 2013). Table 1 shows the studies that considered simple indicators related to temperature - such as ambient temperature, indoor temperature, maximum, mean and minimum daily temperature - as well as those who adopted more complex indices, such as maximum apparent temperature, relative humidity, heat stress and heat wave. Among these, land surface temperature represented the most frequently used parameter (almost 30% of the papers) since it is indeed particularly interesting for the analysis of urban heat distributions. In fact, the latter allow to overcome the limitations of single-station data provided by most of the meteorological stations and are able to represent intra-urban temperature differences at relatively small scales, which correspond to the spatial detail of information needed for the design of interventions in the urban space (Hu et al., 2019). Thermal data from remote sensing measurements provide a natural extension of the non-direct measurement of earth-based systems to investigate more in detail how environmental features can affect health for the study of UHI (Johnson et al., 2011). In addition, satellite images classification of surface temperature is being used for gaining insights into surface heat island morphology (e.g. MODIS image of land use cover) (Wolf and McGregor, 2013). However, remote sensing alone is considered insufficient to significantly elucidate intra-urban variations of health risk within an urban area and as results include higher level of uncertainty, due to the generally rare number of measurements. On the other hand side, remote sensing measurements represent an attractive source of information, due to their coverage and as short-term thermal imaginary is very often the only sensor available (Johnson and Wilson, 2009). In more data-rich situations, it is becoming increasingly common to use land surface as an integration to ambient air temperature as significant variables in modelling vulnerability from extreme temperature events in the urban environment (Johnson and Wilson, 2009; Hu et al., 2019; Wolf and McGregor, 2013).

Finally, this section focussed on studies related to indoor temperatures since people spend a lot of time indoors during extreme events. Therefore, it is essential to understand how they use the building to protect themselves (Loughnan et al., 2015). Some of the studies

Table 1
Climate indicators, case study location and temperature thresholds.

Climate Indicator	Respective thresholds	Case study	Time	Reference
Ambient temperature	30.0 °C	Australia	1999–2004	(Loughnan et al., 2010)
	27.0 °C, 3 days			
Ambient temperature	–	USA	2013	(Sharma et al., 2018)
Ground surface temperature				
Ambient temperature	26.6 °C	USA	1997–2006	(Klein Rosenthal et al., 2014)
Relative humidity (RH)	40%			
Apparent temperature	–	UK	2003, 2006	(Macintyre et al., 2018)
Heat index (HI)				
Daily excess heat factor (EHF)	–	Australia	1980–2010	(Hatvani-Kovacs et al., 2016a)
Heat index (HI)	40.0 °C	USA	2003	(Harlan et al., 2006)
Human thermal comfort index (HTCI)	200			
Heatwave	Tmax: 32.0 °C, 2 days	USA	2000–2011	(Madrigano et al., 2015)
Heat index	95 °F, 2 days			
Heatwave	Tmax: 30.0 °C, 3 days	USA	2010	(Aubrecht and Özceylan, 2013)
	–	Serbia	2015	(Savić et al., 2018)
	Tmax: 32.0 °C	USA	2003–2013	(Hu et al., 2019)
Heatwave	LST: 51 °C	USA	2006	(Jiang et al., 2015)
Heatwave	Tmax: 27.0 °C, 2 days	Estonia	2014	(Sagris and Sepp, 2017)
Land surface temperature (LST)				
Indoor temperature under extreme heat	Tmax: 37.0 °C, RH: 9%	USA	Not specified	(Nahlik et al., 2017)
	Tmax: 44.0 °C, RH: 2%			
Indoor temperature	–	Australia	2012	(Loughnan et al., 2015)
Outdoor temperature	24.8 °C	UK	2006	(Taylor et al., 2015)
Land surface temperature (LST)	–	USA	1993	(Johnson and Wilson, 2009)
	55 °C	USA	1970–2000	(Jenerette et al., 2018)
	–	UK	1976	(Tomlinson et al., 2011)
	–	USA	1999, 2005	(Uejio et al., 2011)
	–	USA	2000	(Harlan et al., 2013)
	–	Netherlands	2006	(Van Der Hoeven and Wandl, 2015)
	–	Chile	2002–2010	(Inostroza et al., 2016)
	–	USA	2013–2014	(Méndez-Lázaro et al., 2018)
Maximum apparent temperature	32.0 °C	Canada	1980–1996	(Smoyer et al., 2000)
	–	USA	2008	(Hondula et al., 2012)
Maximum, mean and minimum temperature	95th percentiles for Tmax, Tmean, Tmin	UK	1990–2006	(Wolf and McGregor, 2013)
Maximum temperature	–	Australia	2007–2011	(Hondula and Barnett, 2014)
	40.0 °C	China	2013	(Chen et al., 2018)
Mean temperature	–	Australia	2004	(Yu et al., 2010)
Mean relative humidity (RH)				
Minimum temperature	97th and 99th percentiles	USA	1990–2007	(Gronlund et al., 2015)
Maximum temperature				
Mean apparent temperature				
N° of heat-wave days in a year (DH)	Tmax: 32.0 °C, 3 days	China	2008–2011	(Dong et al., 2014)
N° of extremely high temperatures in a year (DE)	Tmax: 35.0 °C, 3 days			
Summer days	30.0 °C	Germany	Not specified	(Blättner et al., 2010)
Tropical nights	20.0 °C			

referred to indoor monitored data (e.g. portable data loggers) while some others reflected the personal evaluation by household members (e.g. householders' thermal comfort) (Loughnan et al., 2015; Van Der Hoeven and Wandl, 2015; Taylor et al., 2018; Nahlik et al., 2017). Studies based on indoor temperatures in dwellings is vitally important since several analyses proved how dwelling characteristics and occupant behaviour play a key role in the risk of mortality (Taylor et al., 2015). In addition, the duration of the exposure is also a crucial aspect that authors considered in order to explore the delayed ('lagged') associations between an outcome today (mortality) and an exposure (extreme heat) in previous days (Bhaskaran et al., 2013). This dimension represents a space over which the association within the *heat-health nexus* is defined, adding a backward (Gronlund et al., 2015; Hondula et al., 2012) or forward (Madrigano et al., 2015) lag-response relationship in addition to the usual exposure-response function (Hajat and Gasparrini, 2016). Between the peer-reviewed articles, just 3 considered the lag-delayed effect (Gronlund et al., 2015; Hondula et al., 2012; Madrigano et al., 2015), and all of them reported a short period lasting some days before/after the heat occurrences. As a matter of fact, this is in line with the state of art literature, which express how in case of investigation of health effects under heat, the relative risk of the outcome is often distributed over the nearest lags (from 0 to 7), depending on the population under analysis (Braga et al., 2020; Armstrong et al., 2018; Gasparrini, 2011).

3.3. The biophysical and social dimensions of vulnerability (sensitivity and adaptive capacity)

In this section, the paper focused on the biophysical and social dimensions of vulnerability to climate change that have been recognized within the 40 identified peer-reviewed articles. In fact, climate change impacts, as explained before, do not happen in isolation, but they are, inter alia, determined by the characteristics of the urban environment and socio-economic system often associated with a general concept of *vulnerability (*Lindley et al., *2018)*. Here, *vulnerability* is intended as the propensity or predisposition at which individuals (or communities) are affected by heat stress events driven by climate change (Oppenheimer et al., n.d.; Leal Filho et al., 2018). Since this concept is dynamic and context specific, it encompasses a variety of components such as sensitivity aspects of people that are determined by human behaviour and societal organization (Field et al., 2012; European Environment Agency, 2018). While most of the studies focussed on the analysis between current and future heat-mortality, less attention is paid to address personal factors that influence the social vulnerability of citizens (Klein Rosenthal et al., 2014); that is why this dimension of vulnerability is not sufficiently recognized in urban adaptation measures and policies (Lindley et al., 2018). For this reason, in this section the analyses focused on the social and biophysical personal characteristics that emerged from the 40 articles, which are expected to influence the likelihood that a heat stress event can have on the health outcomes in a specific urban context. To produce a representative overview from the studies analysed, Table 2 shows the subdivision that have been here applied to highlight the main social vulnerability components. Based on the WHO subdivision (WHO, 2019), four distinct categories of determinants have been chosen: (i) *mental and physical health*, that refers to the individual health status as well as access of services that prevent and treat disease influences health; (ii) *demographics*, which includes basic person's individual characteristics, such as age and gender; (iii) *social status*, that refers to the conditions in which people are born, grow up, live, and work, such as social support networks and education. And, finally, (iv) *economic status*, which includes information on the economic status, such as occupation and income.

3.3.1. Mental and physical health

Since “people in poor health are more prone to heat-related mortality and health impacts” (WHO, 2019), the first analysis focusses on the mental and physical health category that directly or indirectly refer to the pre-existing health factors. In this context, the first section of Table 2 highlights the main elements to understand the most common predisposing factors for heat-related illnesses in the analysed state-of-the-art-literature. To facilitate reading comprehension, three main groups have been developed to which the different variables belong to: health status, mobility-health status and mobility-health services. Factors related to previous medical status and to the use of substances that influence the temperature regulation – such as drugs or alcohol - were included in the first class. Physical disadvantages (e.g. handicap) as well as the degree of reliant on social services for home care were included in the second one, and finally, in the last class was included the elements relating to the accessibility of health services and their degree of efficiency.

3.3.2. Demographics

With regard to the demographic category, about the majority of the analysed paper (90%) introduced the concept of age differentiation and gender differences. By looking at gender, most of the case studies highlighted how females were found at higher risk in respect to males during heatwaves (Bélanger et al., 2015; Hatvani-Kovacs et al., 2016a; Yu et al., 2010). When dealing with the age groups, different approaches have been found. In fact, since age is one of the main personal factors that determine heat vulnerability (Yu et al., 2010; Seebaß, 2017), different age-thresholds for the increase of heat related mortality and morbidity have been considered. About 67% of the studies investigated the relation between elderly and health outcomes considering in general citizens over 65 years old as well as 75 years old (see Table 2 for detailed information). In addition, since there is some evidence of an increase of health issues among very young individuals (Leone et al., 2013), the analyses also took into account this variable (“People under 5 years old”). And, almost a quarter of the total of the studies considered individuals with less than 5 years old, without a common geographical pattern.

3.3.3. Social status

Among the social drivers relevant for increased heat vulnerability, all the relevant variables related to this category can be subdivided into five groups: education, social status, household structures, social interaction and service dependency. Starting from education, several studies highlighted how an individual's educational background may also influence the respective health outcomes (Urban et al., 2016; Török, 2017), because it is assumed that higher degree of education can bring to more appropriate reactions during experience of subjective heat stress (Aubrecht and Özceylan, 2013; Loughnan et al., 2010; Seebaß, 2017). Differentiation between the degree of education as well as the geographical area of the case studies have been investigated. Of the 16 case studies that include the variable education, more than a half refer to the threshold corresponding to high school diploma for people with more than 25 years old, and all took place in American urban areas. Finally, the remaining variables refer to a more general categorization of the urban population, such as the number of enrolled population in public school (Méndez-Lázaro et al., 2018), the total years of study from zero to elementary school (Inostroza et al., 2016), the illiteracy or the semi-illiteracy rates of population (Chen et al., 2018), respectively related to USA, Chile and Yangtze River Delta urban areas.

When dealing with *social status* variables, the focus of the studies is on ethnic minorities. In fact, while there is no evidence on racial differences to heat-stress mortality (Harlan et al., 2006), some studies found a positive association between ethnicity and intra-urban variability of temperatures due to social, cultural and economic inequalities (Klein Rosenthal et al., 2014; Johnson and Wilson, 2009; Hondula et al., 2012), while some others found no significant mortality difference using races as an indicator (Kalkstein and Davis, 2010; Green et al., 2010). That is why ethnic minority was considered in the research, which – in the sampled studies – is often differentiated in African-, Hispanic-, Asian-, and Native-American communities and individuals (Uejio et al., 2011; Sharma et al., 2018; Harlan et al., 2006). Less frequent but still important under this category was the association between mortality and social indicators like female-headed household (Harlan et al., 2013) (as a *proxy* for household income) and rate of property tax delinquencies (Klein Rosenthal et al., 2014). In fact, while female-headed households imply low access to resources, education and income (VMK, 2011) as well as a limited access to protective social network (Flatø et al., 2017), the rate of property tax delinquencies corresponds to housing violations, and deteriorating and dilapidated buildings, suggesting that the quality of seniors' housing is a

Table 2
Sensitivity and adaptive capacity determinants by categories, groups and referent variables.

Categories	Groups	Variables	Reference
Mental and Physical Heath	Health status	Asthma (> 18 years old)	(Oppenheimer et al., n.d.; Hondula et al., 2012)
		Cardiovascular disease:	(Hondula et al., 2012; Gasparrini, 2011; Loughnan et al., 2010)
		- Chronic obstructive disease (> 18 years old)	
		- Coronary heart disease (> 18 years old)	
		- High blood pressure (> 18 years old)	
		- High cholesterol (> 18 years old)	
		Diabetes (> 65 years old)	(Oppenheimer et al., n.d.; Chen et al., 2018; Field et al., 2012)
		Pre-existing illness	(Blazejczyk et al., 2012; Loughnan et al., 2010; Tomlinson et al., 2011)
		Hypertension diagnosis (> 65 years old)	(Klein Rosenthal et al., 2014)
		Kidney disease (> 18 years old)	(Sharma et al., 2018)
		Long absence from work (*proxy* for health status)	(Bélanger et al., 2015)
		Mental health and illness (> 18 years old):	(Oppenheimer et al., n.d.; Blazejczyk et al., 2012; Hondula et al., 2012; Gasparrini, 2011)
		- Psychiatric conditions	
		Obesity (> 18 years old)	(Oppenheimer et al., n.d.; Hondula et al., 2012)
		Physical health status (and self-reported)	(Oppenheimer et al., n.d.; Méndez-Lázaro et al., 2018)
		Renal disease	(Jiang et al., 2015)
		Respiratory disease:	(Hondula et al., 2012; Gasparrini, 2011)
		- Pulmonary disease (> 18 years old)	
		Use of drugs (e.g. diuretic)	(Luederitz et al., 2016; Madrigano et al., 2015)
	Mobility and health status	Disability/ies (handicap, blindness, deafness, muteness, paralysis, mental illness and multiple physical disabilities)	(Jiang et al., 2015)
		Requirement of public assistance	(Hondula and Barnett, 2014)
	Mobility and health services	Accessibility to emergency services	(Loughnan et al., 2015)
		Bed confinement	(Jiang et al., 2015)
Demographic	Age	Age thresholds	(Madrigano et al., 2015; Sagris and Sepp, 2017; Méndez-Lázaro et al., 2018)
		Elderly	(Loughnan et al., 2010; Hatvani-Kovacs et al., 2016a)
		People under 5 years old	(Hajat and Gasparrini, 2016; Inostroza et al., 2016; Loughnan et al., 2015; Bhaskaran et al., 2013; Hondula et al., 2012; Armstrong et al., 2018; Gasparrini, 2011; Sharma et al., 2018)
		People over 60 years old	(Pullin and Stewart, 2006; Inostroza et al., 2016)
		People over 65 years old	(Araya-Muñoz et al., 2016; Urban et al., 2016; Armstrong et al., 2018; Gasparrini, 2011; Sharma et al., 2018) (Harlan et al., 2006; Savić et al., 2018; Jiang et al., 2015) (Hajat and Gasparrini, 2016; Jenerette et al., 2018; Chen et al., 2018; Field et al., 2012) (Loughnan et al., 2015; Henseke and Jürgen, 2014; WHO, 2016; Johnson and Wilson, 2009) (Blazejczyk et al., 2012; Bhaskaran et al., 2013; Van Der Hoeven and Wandl, 2015)
		People over 75 years old	(Johnson and Wilson, 2009; Tomlinson et al., 2011)
	Gender	Male and female	(Luederitz et al., 2016; Hajat and Gasparrini, 2016; Johnson and Wilson, 2009; Johnson et al., 2011; Braga et al., 2020; Sagris and Sepp, 2017; Méndez-Lázaro et al., 2018; Chen et al., 2018)

(*continued on next page*)

Table 2 (*continued*)

Categories	Groups	Variables	Reference
Social	Education	Education, in general	(Nayak et al., 2018; Hondula et al., 2012; Madrigano et al., 2015; Gasparrini, 2011; Savić et al., 2018; Méndez-Lázaro et al., 2018)
		Without education	(Chen et al., 2018)
		Primary education	(Inostroza et al., 2016)
		High school education	(Oppenheimer et al., n.d.; Urban et al., 2016; Hajat and Gasparrini, 2016; Loughnan et al., 2015; Johnson and Wilson, 2009; Van Der Hoeven and Wandl, 2015; Armstrong et al., 2018; Harlan et al., 2006; Chen et al., 2018)
	Social status	Ethnic minorities	(Oppenheimer et al., n.d.; Loughnan et al., 2015; WHO, 2016; Johnson and Wilson, 2009; Blazejczyk et al., 2012; Van Der Hoeven and Wandl, 2015; Hondula et al., 2012; Armstrong et al., 2018; Harlan et al., 2006; Chen et al., 2018)
		Female-headed household	(Harlan et al., 2013)
		Overcrowding renters (*proxy* for social isolation)	(Jiang et al., 2015)
		Rate of property tax delinquencies	(Klein Rosenthal et al., 2014)
	Household structures	Household size	(WHO, 2016; Méndez-Lázaro et al., 2018)
		Marital status (e.g. married, widower, etc.) (*proxy* for family structure)	(Pullin and Stewart, 2006; Hajat and Gasparrini, 2016; Johnson and Wilson, 2009)
		Single pensioner households	(Wolf and McGregor, 2013)
	Social interaction	Linguistic isolation	(Araya-Muñoz et al., 2016; WHO, 2016; Taylor et al., 2018; Hondula et al., 2012)
		Marital status: living alone (*proxy* for social isolation)	(Pullin and Stewart, 2006; WHO, 2016; Johnson and Wilson, 2009; Van Der Hoeven and Wandl, 2015; Loughnan et al., 2010; Harlan et al., 2006; Savić et al., 2018; Chen et al., 2018; Field et al., 2012)
		Living alone + older ages	(Oppenheimer et al., n.d.; Araya-Muñoz et al., 2016; Hajat and Gasparrini, 2016; Loughnan et al., 2015; Johnson and Wilson, 2009; Nayak et al., 2018; Van Der Hoeven and Wandl, 2015; Chen et al., 2018; Field et al., 2012) (Hondula et al., 2012; Harlan et al., 2006; Jiang et al., 2015)
		Occupation (*proxy* per social isolation)	(Jiang et al., 2015)
	Service dependency	Accessibility to health services	(Loughnan et al., 2015)
Economic	Access to communication	Household with mobile phone, internet connection, vehicle availability	(Pullin and Stewart, 2006; Gasparrini, 2011)
	Income	“Gold” retirement	(Tomlinson et al., 2011)
		Families receiving public assistance	(Urban et al., 2016; Taylor et al., 2018)
		Health insurance (y/n)	(Gasparrini, 2011; Savić et al., 2018)
		Home ownership	(Oppenheimer et al., n.d.; WHO, 2016; Hondula et al., 2012; Hatvani-Kovacs et al., 2016a)
		Income	(Oppenheimer et al., n.d.; Araya-Muñoz et al., 2016; Van Der Hoeven and Wandl, 2015) (Hondula et al., 2012; Madrigano et al., 2015; Braga et al., 2020; Armstrong et al., 2018) (Macintyre et al., 2018; Harlan et al., 2006; Jenerette et al., 2018) (Tomlinson et al., 2011; Méndez-Lázaro et al., 2018) (Urban et al., 2016; Luederitz et al., 2016; Hajat and Gasparrini, 2016; Loughnan et al., 2015; WHO, 2016; Johnson and Wilson, 2009; Nayak et al., 2018; Blazejczyk et al., 2012; Chen et al., 2018; Field et al., 2012)
		Pro-capite GDP	(Chen et al., 2018)
	Professional condition	Employment (y/n)	(Araya-Muñoz et al., 2016; Pullin and Stewart, 2006; Hajat and Gasparrini, 2016; Van Der Hoeven and Wandl, 2015; Madrigano et al., 2015; Braga et al., 2020; Savić et al., 2018; Méndez-Lázaro et al., 2018)
		Occupation qualification	(Wolf et al., 2015; Braga et al., 2020)

population-level risk factor for heat-associated mortality (Klein Rosenthal et al., 2014).

Subsequently, all the socio economic household variables (Inostroza et al., 2016; Loughnan et al., 2015; Hu et al., 2019) have been categorized as *household structure*. Often, this factor corresponded to a census variable called marital status, that is sub-divided in single, married, unmarried, divorced, separated or widower (Inostroza et al., 2016). And, while some studies used the marital status as a proxy for the family structure (Inostroza et al., 2016; Gronlund et al., 2015) or to evaluate the number of people living in the same dwelling (Loughnan et al., 2015), some others used this variable as a proxy for social isolation (e.g. single-person households) (Inostroza et al., 2016). The latter is also one of the principal variables classified in the following category: the *social interaction*. In fact, among the socio-economic drivers relevant for increased heat vulnerability, most case studies took into account the degree at which an individual is integrated into networks and social relationships (Breil et al., 2018; Harlan et al., 2006; Blättner et al., 2010), because "the more social interactions a person has, the lower their perception of heat stress is" (Seebaß, 2017). Since the access to this type of information is very limited, the analyses rely frequently on proxies such as household structure data, as mentioned before. In particular, "living alone" is often used as a proxy for social isolation (Uejio et al., 2011; Gronlund et al., 2015; Wolf and McGregor, 2013; Savić et al., 2018; Tomlinson et al., 2011; Harlan et al., 2013; Méndez-Lázaro et al., 2018; Reid et al., 2009; Bradford et al., 2015), and – when available - it usually associated with the age of the individual (see Table 2 for referent studies). Then, the remaining studies included information targeting citizens in regard to the linguistic isolation of the households where they live (Loughnan et al., 2015; Uejio et al., 2011; Nayak et al., 2018; Madrigano et al., 2015; Sharma et al., 2018; Bradford et al., 2015), their availability of phone services (Klein Rosenthal et al., 2014; Inostroza et al., 2016) as well as their availability of vehicles (Jiang and O'Neill, 2017) as further proxies for social isolation and for access to services that can strengthen social interactions. Neighbourhood stability have been also included in the *social interaction* group (e.g. vacant households, quality of life of the neighbourhood, etc.), because there were evidence that social interaction with neighbours can strengthen the ability to master periods of high temperatures (Jiang and O'Neill, 2017; Uejio et al., 2011; Van Der Hoeven and Wandl, 2015).

The last group of the social determinants is here defined as *service dependency*. Under this category, included studies that use the indicators for the existence and accessibility of health services have been included, given the importance of these services for supporting vulnerable populations during the occurrence of extreme heat events (Garbutt et al., 2015). Therefore, studies using variables such as services on wheels (Tomlinson et al., 2011) and number of aged care facilities (Loughnan et al., 2015) have been inserted within this class.

3.3.4. Economic status

In conclusion, economic drivers of sensitivity considered in heat-health related studies are usually built on indicators that refer to economic status and disadvantages (Breil et al., 2018; Smoyer et al., 2000; Sagris and Sepp, 2017; Seebaß, 2017). At first, the majority of the studies were found to agree on relates to the professional condition, in particular related to the position on the labour market, so being employed or not and the type of qualification (Wolf et al., 2015; Pullin and Stewart, 2006; Barnett et al., 2010), followed by home ownership (Klein Rosenthal et al., 2014; Uejio et al., 2011; Sharma et al., 2018; Tomlinson et al., 2011), all proxies to represent the income. On the other hand, some more studies considered isolated factors, such as the percent of families receiving public assistance (Madrigano et al., 2015), the availability of health insurance coverage (Jiang et al., 2015) or the access to a "golden" retirement (Tomlinson et al., 2011). Finally, in cases in which limited high-resolution data has been used, e.g. some aggregated indices such as GDP per capita (Chen et al., 2018) and average income per district (Jenerette et al., 2018; Dong et al., 2014; Seebaß, 2017) have been found as further indicators.

3.4. The neighbourhood environmental contribution on heat stress (enhanced exposure)

Urban residents are particularly exposed to heat and heatwaves due to UHI effects, which is owed to the fact that built up areas have a higher capacity for storing energy from sunlight and release it in form of higher temperatures than vegetated areas. Intensity of the UHI and resulting air temperatures can vary not only between urban and rural areas, but also within urban areas, creating different heat conditions at relatively small scales (Grimmond et al., 2010). Such differences create further disadvantages for parts of the urban population, which are directly related to features of urban morphology, in terms of density of urban fabric and activity, quality and typologies of buildings and presence of intra-urban green areas. As the analysis by Klinenberg on the Chicago heatwave of 1995 shows, there are furthermore causal links between levels of mortality and socio economic conditions and quality of urban life in the neighbourhood leading to different mortality rates despite similar urban morphology features (Klinenberg, 1999). Such conditions include levels of crime, urban decay and concentration of socially disadvantaged groups, for instance ethnic minorities (e.g. African Americans in the case of Chicago, the city studied by Klinenberg, during the heatwave in 1995). According to this seminal analysis, socio-economic conditions within the neighbourhoods determined differences in rates of mortality between neighbourhoods with similar physical conditions (Klinenberg, 1999). Epidemiological studies following up on these findings, need to join data from different sources regarding the physical elements characterizing the urban environment as well as those regarding the elements "enhancing" exposure, consisting of precarious living conditions, decaying urban environments, poverty or low incomes. Such investigations encounter again some limits in the possibility of combining a sufficiently big amount of health data with the sufficient spatial detail of urban living conditions, aiming at identifying those urban areas with physical and socio-economic conditions, which favour high ambient and/or surface temperatures.

3.4.1. Outdoor environment

On the side of physical conditions, one of the most frequently used proxy that we found for urban environments favouring uncomfortable conditions during days with extreme high temperatures are high rates of impervious surfaces or, on the contrary, high rates of green or vegetated surfaces. These two proxies are used in most studies for describing neighbourhood environmental qualities (see Table 3 for further details) (Araya-Muñoz et al., 2016; Johnson and Wilson, 2009; European Environment Agency, 2018). In some of the case studies, also population densities are used as a proxy for urban density (Henseke and Jürgen, 2014; Smoyer et al., 2000; Hondula and Barnett, 2014), while only in few cases building densities have been used. For instance, Kim et al. (Kim et al., 2014) compare temperatures and mortality for historic and new settlement patterns for Seoul, finding that, compared to traditional forms of high-density inner-city morphologies, newly developed areas with high rise buildings demonstrated a reduction of heat-stress related mortality by about a half despite similar population density. Impacts of urban and building morphologies on urban outdoor temperatures and comfort is investigated by several studies, yet, without the possibility of direct comparison such an investigation requires more detailed observations for characterizing elements of urban morphology. For example, orientation and symmetry of buildings (Loughnan et al., 2015; Harlan et al., 2006), size and shading options of windows (Blättner et al., 2010) and building and roofing materials (Sharma et al., 2018; Hatvani-Kovacs et al., 2016a), which rarely are feasible for larger urban areas. Only few articles were found which go beyond these physical characteristics, attempting to capture also aspects of socio-economic disadvantages as determinants for negative health outcomes, like for instance Sharma et al. (Sharma et al., 2018). In fact, in their investigation, the authors combine the analysis of physical outdoor characteristics, as roof surface temperatures, with socio economic indicators, using intensity of the use of air conditioning as a proxy for economic status of residents and focus on building characteristics, quality of housing and indoor conditions as an indicator for exposure to heat. Despite focussing on outdoor conditions, most studies rely on statistics on mortality cases that are registered with the residential address, rather than with working places or other outdoor places where people eventually stayed before feeling bad. Referring to residential conditions might not have interfered with the heat stress if this was related to outdoor or working place conditions.

3.4.2. Indoor environment

On the other hand side, indoor qualities have been explored for their relevance for heat outcomes for a series of buildings characteristics focussing mainly on energy efficiency (Van Der Hoeven and Wandl, 2015), and using in many cases proxies such as building age for insulation efficiency (Hajat and Gasparrini, 2016; Hu et al., 2019; Tomlinson et al., 2011). Only rarely, indoor conditions are actually estimated or measured in order to obtain more precise information of exposure to heat (Taylor et al., 2015), while building characteristics are used more frequently as an indicator for the socio-economic status of residents and neighbourhoods such as building conservation or need for repair (Oppenheimer et al., n.d.; Luederitz et al., 2016; Braga et al., 2020; Armstrong et al., 2018; Gasparrini, 2011) or living in public or low-rent housing (Bélanger et al., 2015; Wolf and McGregor, 2013). Other indicators for

Table 3
Enhanced Exposure determinants by categories, groups and referent variables [(*) refers to variables used as a proxy].

Categories	Groups	Variables	Reference
Indoor Environment	Building standard	Aeration capacity in summer	(Bélanger et al., 2015)
		Air Conditioning	(Oppenheimer et al., n.d.; Luederitz et al., 2016; Hajat and Gasparrini, 2016; Smoyer et al., 2000; Kim et al., 2014; Aubrecht and Özceylan, 2013; Armstrong et al., 2018; Jiang et al., 2015; Yu et al., 2010)
		Blinds	(Loughnan et al., 2015)
		Cooling energy for workplaces	(Van Der Hoeven and Wandl, 2015)
		Double-glazed windows	(Hatvani-Kovacs et al., 2016a)
		Fans	(Loughnan et al., 2015)
		Lack central air conditioning	(Bradford et al., 2015)
		Lack of air conditioning of any kind	
		Not having working air conditioning	(Wolf and McGregor, 2013)
		Type of cooling system	(Harlan et al., 2006)
		Housing types	(Hatvani-Kovacs et al., 2016a)
		Indoor temperature (good/bad)	(Bélanger et al., 2015)
		Insulated roofs and walls	(Hajat and Gasparrini, 2016; Yu et al., 2010)
		Thermal insulation	(Luederitz et al., 2016; Hajat and Gasparrini, 2016)
		Need for maintenance/repairs on the dwelling*	(Bélanger et al., 2015)
		Solar panels on roof	(Loughnan et al., 2015)
	Building/Housing standard	Elevator in building*	(Bélanger et al., 2015)
		Thermo isolation of home	(Wolf and McGregor, 2013)
	Housing standard	Access to water supply	(Inostroza et al., 2016)
		Balcony Downsizers	(Tomlinson et al., 2011)
		Expansion of top floor flats	(Blättner et al., 2010)
		Housing materials (wall/floor types and material)	(Loughnan et al., 2015)
		Living on a high floor of multi storey buildings*	(Savić et al., 2018; McGeehin and Mirabelli, 2001)
		Living in communal establishment*	(Wolf and McGregor, 2013)
		Low-rent housing*	(Bélanger et al., 2015)
		Pergolas/outdoor living areas	(Loughnan et al., 2015)
		Presence or absence of swimming pool (private)	(Harlan et al., 2006)
		Roofing construction (e.g. form and material)	(Loughnan et al., 2015)
		Type of building (dwelling type,floor level)	(Savić et al., 2018)
		Walls and ceiling	(Loughnan et al., 2015)

(*continued on next page*)

Table 3 (*continued*)

Categories	Groups	Variables	Reference
Outdoor Environment	Building standard	Building status*	(Blättner et al., 2010)
		Direction of the window front	
		Need for maintenance/repairs*	
		Reflectivity of roofing material	(Harlan et al., 2006)
		Size and shading options for windows	(Blättner et al., 2010)
	Urban morphology & Building standard	Green Roofs	(Sharma et al., 2018)
		Material Index: n° of houses per hectare with light materials in external walls	(Inostroza et al., 2016)
	Residential standard	Building age*	(Hajat and Gasparrini, 2016) (Henseke and Jürgen, 2014; WHO, 2016; Johnson and Wilson, 2009) (Johnson et al., 2011; Nahlik et al., 2017; Taylor et al., 2015; Harlan et al., 2006; Yu et al., 2010)
		Built up surfaces and open spaces	(Inostroza et al., 2016)
		Dwelling age	(Hatvani-Kovacs et al., 2016a)
		Housing materials (wall/floor types and material)	(Klein Rosenthal et al., 2014)
		Neighbourhood rating (good or excellent)*	
		Roofing construction (tiles, colorbond, flat vs pitched)	(Loughnan et al., 2015)
		Structure n° of floors	(Hondula and Barnett, 2014)
	Residential standard & Urban morphology	Population and residential density*	(Oppenheimer et al., n.d.; Urban et al., 2016; Inostroza et al., 2016; Henseke and Jürgen, 2014; Smoyer et al., 2000; Madrigano et al., 2015; Hatvani-Kovacs et al., 2016a)
		Building density (building volume per unit area)*	(Kim et al., 2014)
	Urban morphology	Amount of open space (%)	(Harlan et al., 2006)
		Building types (geometries)	(Taylor et al., 2015)
		Distance from river area	(Hsu et al., 2017)
		Enhanced vegetation index (EVI)	(Chen et al., 2018)
		Environment index: land surface temperature from infrared remote sensing data	(Dong et al., 2014)
		Heat stress resistant features (e.g. insulation, garden vegetation)	(Hatvani-Kovacs et al., 2016a)
		Land cover (impervious surface: stone, asphalt, concrete or sand)	(Araya-Muñoz et al., 2016; Johnson and Wilson, 2009; Nayak et al., 2018; Kim et al., 2014; Bhaskaran et al., 2013; Gasparrini, 2011)
		Land Use	(Nayak et al., 2018; Aubrecht and Özceylan, 2013; Bhaskaran et al., 2013; Braga et al., 2020; Hatvani-Kovacs et al., 2016a; Harlan et al., 2006)
		Lack of (nearby) green spaces (NDVI)	(Pullin and Stewart, 2006; Smoyer et al., 2000; Uejio et al., 2011; Sharma et al., 2018)
		Roads: km/km2 of roads per census tract	(Inostroza et al., 2016)
	Outdoor & Environmental qualities	Shadows by trees	(Blättner et al., 2010)
		Shady plants	(Oppenheimer et al., n.d.; Nayak et al., 2018; Johnson et al., 2011; Braga et al., 2020)
		Stone mulch in garden	(Loughnan et al., 2015)
		Type of landscaping	(Harlan et al., 2006)
		Urban vegetation (%)	(WHO, 2016; Kim et al., 2014)
		Vegetation density (SAVI)	(Harlan et al., 2006)
	Environmental qualities	Access to indoor public swimming pools	(Bélanger et al., 2015)
		Access to outdoor public swimming pools	
		Lack of benches on the main streets	
		Need for maintenance/repairs	(Blättner et al., 2010)
		Traffic density	(Madrigano et al., 2015)
	Services	Access to medical services (distance of the centroid of the built-up area in the census block to the nearest health care centre)	(Inostroza et al., 2016)
		Cooling Centers (and public buildings)	(Bradford et al., 2015)
		Distance from the city center (km)	(Harlan et al., 2006)
		Total beds of health institutions	(Chen et al., 2018)
	Sensible population	Locations of sensible receptors (e.g. hospitals, care homes, schools, prisons, etc.)	(Macintyre et al., 2018)

the impact of housing conditions on heat mortality refer to technical installations. This group of indicators refers to measures which, while mitigating heat conditions inside buildings, might not be available in all cases in low cost housing or not accessible for low income groups or for renters with limited possibilities in changing installations, such as air conditioning (Wolf and McGregor, 2013; Van Der Hoeven and Wandl, 2015; Hatvani-Kovacs et al., 2016a; Bradford et al., 2015), fans (Loughnan et al., 2015), shading facilities for windows (Blättner et al., 2010) or elevators (Bélanger et al., 2015). The lack of elevators might limit the possibility of leaving overheated dwellings and search for cooling outside for elderly or physically impaired persons.

Further to the fact that high outdoor temperatures directly influence indoor temperatures, some qualities of the outdoor spaces influence furthermore the conditions of livelihoods in urban areas, as the presence of shady green areas where to cool down (Bélanger et al., 2015), or the availability of services in the neighbourhood where to find medical assistance or cooling spaces (Harlan et al., 2006; Chen et al., 2018; Bradford et al., 2015). Many authors find overlaps between qualities of the physical environment and socio-economic characteristics to favour higher rates of heat related mortalities. For instance, Dong et al. (Dong et al., 2014), who surveyed surface temperatures for particular land use types and imperviousness rates and associated average temperatures per type of land, found heat health risk more effectively described by these environmental factors than only by the hazard (surface temperatures) and vulnerability related indices (population densities, age and income) (Dong et al., 2014). Potentially, high levels of enhanced exposure to overheating exist also in other urban areas, such as for the State of New York (Nayak et al., 2018). In this case, Nayak et al. (Nayak et al., 2018) found not only indicators for heat related sensitivity (as age and social isolation), but also spatial characteristics (such as the low availability of green areas and shading to be concentrated in some parts of the state), especially in the metropolitan areas. Klein Rosenthal et al. (Klein Rosenthal et al., 2014) confirm that indicators characterizing the socio-economic position of citizens (e.g. poverty rates and income levels) together with those describing housing quality like rates of serious housing violations, property tax delinquencies, and deteriorating and dilapidated buildings were significantly correlated with the mortality rate ratios of elderly above 65 in New York (Klein Rosenthal et al., 2014). Relationships between income levels and sensitivity to heat were found also by Harlan et al. (Harlan et al., 2006), with the amount of un-vegetated (impervious) area as factor able to predict, alongside with indicators describing socio economic characteristics, heat related vulnerabilities in the Maricopa County (Arizona), for the period between 2000 and 2008 (Harlan et al., 2006). They found evidence for lower mortality rates in less dense, greener and wealthier areas. A direct relationship between low income and spatial disadvantages was found to increase mortality only in the very specific case of homeless people, who were more frequently found dead in central urban areas. This brings to the conclusion that the relationship between place based characteristics (which account for "exposure" and mortality) together with indicators for vulnerability, such as health, wealth and age, should be used as complements and not substitutes for person-level risk variables (Harlan et al., 2013). There is evidence from the analysed studies that some of the conclusions and indicators used for the description of enhanced exposure to heat are very much dictated by the situation of US metropolitan areas. In these cases, some cautious translations is needed before being applied to other contexts, as have been found for instance for London (Taylor et al., 2015) or for the small city of Kassel (Blättner et al., 2010). For instance, both studies found that elderly do not live predominantly in densely built city centres, but may suffer from overheating in poorly isolated houses in the peripheries, places where crime might not play the same dominant role for social isolation of elderlies, but lack of services and lack of awareness alongside with poor housing quality may nevertheless increase the impact from heat despite relatively high levels of vegetation..

4. Discussion

Climate scenarios reveal how over the next 30 years there will be a consistent global warming shifts in the climate of major cities around the world, with the most direct health risk due to heat (Oppenheimer et al., n.d.; Bastin et al., 2019). Therefore, urban administrations need a deep knowledge and awareness on the context specific aspects of socio-spatial vulnerability with respect to heat, so to be able to understand the structure and the distribution of the heat related vulnerability (Hintz et al., 2018; Breil et al., 2018; O'Neill et al., 2009; Lindley et al., 2018). Based on this international literature review, results confirm not only on the role of urban morphologies, green spaces and urban transformation processes (context specific physical characteristics), but also the relevance of interactions between socio-economic status and heat related impacts (context specific socio-economic characteristics) on the urban population have been recognized as essential drivers to understand the *heat-health nexus* at the intra-urban scale. While high outdoor temperatures in urban areas can be exacerbated by urban morphologies, with a predominance of sealed surfaces and some building characteristics all contributing to the so called UHI effect, socio-economic and health conditions can make it more difficult for vulnerable persons to seek for help and receiving appropriate assistance. Yet, both realities are represented by indicators characterizing the urban environment as well as by those synthesizing processes and social status. Such indicators can change in accordance to the geographic and socio-economic context in which they are used (Lindley et al., 2018) since they describe factors which in a certain places may have different meanings than in others. For example, in the Santiago de Chile case study proposed by Inostroza et al. (Inostroza et al., 2016), kilometers of roads per census tract was considered as a measure of adaptive capacity, because roads play a central role to determining social responses to heat hazards (e.g. providing access to the hospital), especially in a context with a low density of infrastructures. In contrast, Dong et al. (Dong et al., 2014) found, for Beijing, a positive correlation between the amount of road surfaces as part of the overall impervious surfaces and mean hazard, leading to a significant increase in the UHI effects (Dong et al., 2014).

Several studies in USA and Australia have identified drivers of vulnerability that have been translated into indicators that are hardly reflected in European urban policies. For instance, a study on the 1995 heatwave in Chicago, highlighted how the original provenance of ethnic minorities groups could be used as a proxy for low social status and qualities of social networks (Klinenberg, 1999). In fact, Klinenberg stresses differences between Hispanic and Afro-American communities in coping with heat impacts, underlining that the former have much stronger social networks in their neighbourhood which has a positive impact on the health outcomes during the heatwave, although the quality of the urban environment for both communities was comparable (Klinenberg, 1999). In the European context, some studies might attempt to transfer such indicators based on the findings made for Chicago in a period of urban decay, but this requires further to an accurate knowledge about socio-economic inequalities in urban cities and their consequences, the availability of data which would be able to describe such disadvantages. In some cases, ethnic minority was used as a proxy for linguistic isolation (Wolf and McGregor, 2013), while in some others a positive association between ethnicity and intra-urban variability of temperatures was related to economic inequalities (Klein Rosenthal et al., 2014; Johnson and Wilson, 2009; Hondula et al., 2012). Another example is the rate of property tax delinquencies (Harlan et al., 2013; Flatø et al., 2017), a statistical indicator for economic decline of households, again specific to the US (Török, 2017), and indicates the economic decline of the a neighborhood (Klein Rosenthal et al., 2014) rather than rising levels of delinquency tout court. In contrast, within the European context, there was no evidence of the use of this indicator.

When dealing with future scenarios, there are some important critical aspects to be highlighted. While the modelling of future scenarios for the heat risk at the national, regional or local scale has become a relatively common exercise which is based on physical drivers (Solomon et al., 2007), modelling future socio-economic developments in such a detail is far more difficult (Breil et al., 2018). Scenarios on future heat conditions are based on numerical models, while the socio-economic systems, such as cities, are more complex (O'Neill et al., 2014) and evolve following different political and social dynamics and trajectories of development. Therefore, discovering the interactions among variables within those systems is extremely difficult due to their complex nature, where the related elements and dynamics are characterized by non-physical returns and feedback mechanisms (Vasileiadou and Safarzyńska, 2010). While climate scenarios indicate that climate change will increase risks for the urban population (Leary et al., 2013) in the world, which are expected to increase the number of potentially vulnerable persons due to age related sensitivities. Nevertheless, social dynamics as climate induced increase of migration as well as the growing proportion of single households are trends which will contribute to further shaping vulnerabilities of urban population in addition to climate stressors (European Environment Agency, 2018).

The above arguments are crucial for a wider discussion on the changing systems of climate governance, and the role that cities and metropolitan areas play in this regard. In this perspective, in addressing the challenges brought about climate change, represented by the *heat-health nexus*, cities are today laboratories in which new systems of multi-level governance are being experimented, with the aim of exploring new ideas and initiatives in a context of increasing uncertainty. Greater coordination of policy responses, more efforts for integrating urban and regional plans, and new public-private cooperation efforts aimed at implementing ‘economic convergence’ scenarios are basic elements in this respect (Bulkeley and Betsill, 2004; Hughes and Chu, 2018; Giddens, 2015). However, it is clear that a deeper understanding of the role that social and economic characteristics plays in affecting the vulnerability of urban population is imperative for increasing the local awareness and preparedness to natural hazards as well as for designing and implementing effective adaptation policies. For defining the *heat-health nexus* at urban scale the availability of data representing factors which determine socio-economic disadvantages and physical exposure to heat are crucial, and needed not only for Europe and North America, where most of the studies included in this review are concentrated, but also for African and Asian cities.

5. Conclusion

Due to climate change, extreme temperature events in cities and urban centers are expected to become a global concern in the near future. This is a global concern with local implications and differences. The impacts of extreme heat events on cities differ very much according to geographical, institutional, social and economic features. The *heat-health nexus* is ‘embedded’ in the context-specific combination of physical and socio-economic characteristics. Vulnerability is not the simple outcome of temperature, but it is produced in and by society. This review study has demonstrated that despite several efforts have been done in order to understand the dynamics beyond the heat exposure and the health outcome relationship, more research is still required to connect these aspects together with the built environment characteristics. Such evidence could be used for informing the creation of “ready to use indicator sets” or tools which can support local adaptation policies with indication for risk analysis, design of strategies (Wolf et al., 2015) and monitoring of implementation in a meaningful way, if necessary local specificities are respected and suitable data for indicators is available. A detailed identification of elements influencing sensitivity as well as the consideration of conditions of enhanced exposure is indeed essential to facilitate the comprehension of the context-specific form of the *heat-health nexus*, which is crucial in the implementation of effective adaptation measures. The identification of these locally relevant variables within each specific urban system are the first step to determine drivers of inequalities with regards to exposure and sensitivity of urban populations both across and within urban areas. Such a diagnosis would represent a fundamental step towards the design of policies for adaptation which are best tailored for addressing effectively specific challenges presented of the *heat-health nexus* in the local context and can help identify the appropriate combination of forms of intervention and levels of governance which should compose such local adaptation policies regarding the challenge represented by rising temperatures and increasing frequencies of heatwaves. Adaptation policies aimed at copying with extreme high temperature events, particularly at urban level must therefore be grounded on a sound understanding of how the various elements of the socio-economic system interact with the physical environment in territorializing and socializing climate change.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Appendix

A.1. The research algorithm

The final search string that authors decide to apply on *Scopus* and *Pubmed* search platform to identify the desired articles was developed through a start screening process highlighting the most frequent keywords in almost 700 articles selected from the following initial algorithm on *Scopus:*

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TITLE-ABS-KEY ("extreme temperature*" AND "climate change" AND ( mortality OR morbidity ) AND ( urban OR city OR cities ) )
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(( "impact assessment" OR risk OR "risk assessment" OR "spatial risk assessment" OR gis OR "vulnerability index" ) AND ( city
OR cities OR "urban" OR "urban area*" ) AND ( "climate change" OR "climate impact*" OR "climate risk*" OR "climate hazard"
OR "extreme event*" OR "extreme weather" OR temperature* OR "ambient temperature*" OR heat OR "heat wave*" OR
heatwave* OR heat PRE/3 stress OR uhi OR urban PRE/5 heat AND island OR cold OR "cold wave*" ) AND ( "heat exposure"
OR "cold exposure" OR "temperature exposure" OR population* OR "population density" OR "building density" OR "urban
density" ) AND ( health OR "public health" OR "human health" OR "health effect*" OR "health risk*" OR "health impact*" OR
"thermal comfort" OR "child health" OR "hospital admission*" OR hospitalization OR morbidity OR "heat-related illness*" OR
"temperature-mortality relationship*" OR mortality OR "heat-related mortality" OR "human mortality" OR "excess mortality" OR
"excess death*" )  OR "cold wave*" ) AND ( "heat exposure" OR "cold exposure" OR "temperature exposure" OR population*
OR "population density" OR "building density" OR "urban density" ) AND ( health OR "public health" OR "human health" OR
"health effect*" OR "health risk*" OR "health impact*" OR "thermal comfort" OR "child health" OR "hospital
admission*" OR hospitalization OR morbidity OR "heat-related illness*" OR "temperature-mortality relationship*" OR mortality
OR "heat-related mortality" OR "human mortality" OR "excess mortality" OR "excess death*"))
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The pre-screening process was useful to identify the main keywords to include in the final research algorithm, related to the factor of interest: risk assessment terms, urban spatial scale, hazard parameters, exposure groups, enhanced exposure, sensitivity and adaptive capacity characteristics, and, finally, health impact terms.

The latter one, applied on *Scopus* and on *PubMed* platform, allowed the desired articles to be identified, as specified in the section *2.1 Literature review process*.

Appendix B. Appendix

B.1. In-depth descriptive tables

Table B.1
The geo-spatial details of the case studies by scale of resolution, country and urban areas.

Exposed sample	Resolution	Country	Urban area/s	Reference
Urban area	Census Block groups	United States of America	Philadelphia	(Johnson and Wilson, 2009)
	Census Block groups	United States of America	Phoenix	(Harlan et al., 2006)
	Census Block groups	United States of America	Pittsburgh	(Bradford et al., 2015)
	Census tracts	Chile	Santiago	(Inostroza et al., 2016)
	Census tracts	United States of America	Chicago	(Sharma et al., 2018)
	Census tracts	United States of America	New York	(Nayak et al., 2018)
	Census tracts	United States of America	New York City	(Madrigano et al., 2015)
	Census tracts	United States of America	San Juan	(Méndez-Lázaro et al., 2018)
	Census tracts	United States of America	(not specified)	(Reid et al., 2009)
	Community Districts (CDs) United Hospital Fund (UHF)	United States of America	New York City	(Klein Rosenthal et al., 2014)
	Household levels	Australia	(not specified)	(Loughnan et al., 2015)
	Household levels	Austria	Linz	(Henseke and Jürgen, 2014)
	Household level	Germany	Nuremberg	(Seebaß, 2017)
	Local Climate Zones	Serbia	Novi Sad	(Savić et al., 2018)
	Municipal personal records	Netherlands	Amsterdam	(Van Der Hoeven and Wandl, 2015)
	Statistical Local Areas	Australia	Brisbane	(Hondula and Barnett, 2014)
	Statistical Local Areas	Australia	Brisbane	(Yu et al., 2010)
	Statistical Local Areas	Australia	Melbourne	(Loughnan et al., 2010)
	Statistical Units	Estonia	Tallin	(Sagris and Sepp, 2017)
	Statistical Units	Germany	Kassel	(Blättner et al., 2010)
	Super Output Lower levels	United Kingdom	Birmingham	(Tomlinson et al., 2011)
	Super Output Lower levels	United Kingdom	London	(Wolf and McGregor, 2013)
	Ward units	United Kingdom	London	(Taylor et al., 2015)
	Zip Code Tabulation areas	United States of America	Los Angeles	(Jiang et al., 2015)
	–	Australia	Adelaide	(Hatvani-Kovacs et al., 2016b)
	–	China	Taipei	(Hsu et al., 2017)
	–	Korea	Seoul	(Kim et al., 2014)
Metropolitan area	Census Block groups	United States of America	Arizona	(Harlan et al., 2013)
	Census Block groups	United States of America	Washington	(Aubrecht and Özceylan, 2013)
	Census tracts	United States of America	Los Angeles & Phoenix	(Nahlik et al., 2017)
	Census tracts	United States of America	Phoenix	(Jenerette et al., 2018)
	Census Transportation Products	United States of America	Chicago	(Hu et al., 2019)
Multiple urban areas	Census Block groups	China	Beijing	(Dong et al., 2014)
	Census Block groups	United States of America	Philadelphia & Phoenix	(Uejio et al., 2011)
	Census subdivision	Canada	Toronto, Windsor, London, Kitchener, Waterloo, Cambridge, Hamilton	(Smoyer et al., 2000)
	Household level	Canada	Québec	(Bélanger et al., 2015)
	Zip Code Tabulation areas	United States of America	Michigan	(Gronlund et al., 2015)
	Zip Code Tabulation areas	United States of America	Philadelphia	(Hondula et al., 2012)
	–	United Kingdom	West Midlands	(Macintyre et al., 2018)
Sub-national area	–	China	Yangtze River Delta	(Chen et al., 2018)

Table B.2
Health data and methodologies to assess the health risk of population in urban areas.

Health Data	Causes of death: ICD (10)	Methodologies	Reference
Morbidity			
Heat stress emergency dataset by: - georeferenced data	Heat-related causes: T67, X30	Principal Component Analysis	(Nayak et al., 2018)
Hospital admissions dataset by: - georeferenced data	All-natural causes: A00-R99	Local regression smoother	(Hondula and Barnett, 2014)
Hospital admissions dataset by: - social-demographic data: age - georeferenced data	Myocardial infarction: I21	General linear model multiple analysis of Variance	(Loughnan et al., 2010)
Mortality dataset by:			
● causes of death	Heat-related causes: T67, X30	Spatial Generalized Linear and Mixed Models	(Uejio et al., 2011)
(heat related diseases)	Endocrine, nutritional and metabolic: E00-E99 Mental and behavioural: F00–99 Nervous system: G00–99 Circulatory system: I00–99 Respiratory system: J00–99 Not elsewhere classified: R00–99	Klima-Michel Model	(Kim et al., 2014)
● georeferenced data	Heat-related causes: T67, X30	Spatial analysis using the standard deviation ellipse	(Johnson and Wilson, 2009)
	All causes: A00-Y89	Excess mortality method	(Dong et al., 2014)
	All causes: A00-Y89	–	(Savić et al., 2018)
● georeferenced data ● socio-economic data: ● age, gender, race, place of death	Non-external mortality: A00-R99 (Cardiovascular disease: I00–I99) (Myocardial infarction: I21) (Congestive heart failure: I50) (Respiratory diseases: J40–J47)	Multinomial logistic regression	(Madrigano et al., 2015)
● georeferenced data ● social-demographic data: ● age, gender, education, ● marital status and race	All-natural causes: A00-R99, T67, X30 Heat-related causes: T67, X30 Cardiovascular causes: I0-I52 Respiratory causes: J9:J18, J40:J44, J47	Time-stratified case-crossover design	(Gronlund et al., 2015)
● georeferenced data	All causes: A00-Y89	Principal Component Analysis	(Hondula et al., 2012)
● socio-economic data: age	–	Binary logistic regression	(Harlan et al., 2013)
● georeferenced data ● social-economic data: ● income and race	These records included date of death, ZIP code of residence, marital status, race, age, sex and educational level.	Outdoor Human Thermal Comfort Index	(Harlan et al., 2006)
● social-economic data: age	Heat-related causes: T67, X30	Excess mortality method	(Smoyer et al., 2000)
	All-natural causes: A00-R99, T67, X30	Multivariate linear regression	(Klein Rosenthal et al., 2014)
● social-economic data: ● age, gender	All causes: A00-Y89	Time series regression with linear post-threshold	(Taylor et al., 2015)
● social-economic data: ● age, gender, socio-economic index for area (SES)	All-natural causes: A00-R99	Generalize Additive Model	(Yu et al., 2010)
Survey			
Self-reported perceived health effect			(Bélanger et al., 2015)
Self-reported household thermal comfort			(Loughnan et al., 2015)
Self-reported perceived heat stress			(Henseke and Jürgen, 2014)

Table B.3
Climate indicators description.

Type	Name	Description
Simple indicators	Indoor temperature	Temperature of the air in a given indoor place
	Maximum temperature	Highest temperature recorded in 24 h
	Mean temperature	Mean temperature recorded in 24 h
	Minimum temperature	Minimum temperature recorded during in 24 h
	Night air temperature	Minimal night temperature recorded during night-time
	Relative humidity	Amount of water vapour present in air expressed as a percentage of the amount needed for saturation at the same temperature
Complex indicators	Apparent maximum temperature	Measure that incorporate temperature and dew point temperature (humidity)
	Excess heat factor	Calculated from the deviation of the daily mean temperatures of the recent 3 days from the recent 30 days and the 95th percentile of the recent 30 days
	Heat stress index	Measure that incorporate ambient temperature and relative humidity
	Heatwave	Consecutive period of at least *x* days during which the daily maximum temperature is higher than or equal to a certain given threshold

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