Climatic Change (2023) 176:129
https://doi.org/10.1007/s10584-023-03592-3

What is a heat(wave)? An interdisciplinary perspective

Zofia Boni[1] · Zofia Bieńkowska[1,2] · Franciszek Chwałczyk[1] · Barbara Jancewicz[3] · Iulia Marginean[4] · Paloma Yáñez Serrano[1]

Received: 30 December 2022 / Accepted: 22 July 2023 / Published online: 11 September 2023

Abstract
Excessive summer heat is becoming people's daily reality creating an urgency to understand heatwaves and their consequences better. This article suggests an interdisciplinary analytical framework of heat(waves) as multiple objects. It brings together data and perspectives from social anthropology, sociology, climate science, epidemiology, and meteorology to map the gaps in knowledge about heat(waves) and their impacts on one of the most vulnerable groups: older adults. Based on research in Poland and Spain, we look at heat(waves) as simultaneously individual experiences, biophysical changes, and socio-political phenomena. Climatologists and meteorologists define heat(waves) as prolonged episodes of abnormally high temperatures. Epidemiologists perceive heat(waves) through raising morbidity and mortality rates. For policymakers, they are an emergency defined by duration and temperature thresholds. Older adults living in Warsaw and Madrid recognize a heat(wave) when they feel it in their bodies, when they cannot sleep, or when they need to change their daily routines. Such differently situated scientific definitions and embodied knowledge stem not only from varied epistemological perspectives but demonstrate that heat(waves) are ontologically different. By looking at convergences and divergences between these perspectives, we see that the length of heat(waves) varies and that older adults often experience longer periods of excessive heat than climate measurements or policy alerts indicate; that the impact of nighttime temperatures is more important than daily temperatures; and that there is a discrepancy between heat(waves) as anomalies and as increasingly common events. The article addresses an important gap between biophysical definitions of heatwaves and the experiences of the most vulnerable groups.

Keywords Climate change · Heatwaves · Definitions · Knowledge · Ontology · Vulnerability · Health

✉ Zofia Boni
zofia.boni@amu.edu.pl

1 Institute of Anthropology and Ethnology, Adam Mickiewicz University, Poznań, Poland

2 Institute of Sociology, University of Warsaw, Warsaw, Poland

3 Centre of Migration Research, University of Warsaw, Warsaw, Poland

4 Center for International Climate Research, Oslo, Norway

1 Introduction

Increasing summer heat harms people's health and well-being across the world (Seneviratne et al. 2021). Already, over one-third of warm-season, heat-related deaths can be attributed to anthropogenic climate change (Vicedo-Cabrera et al. 2021, 37% in 43 countries). Such heat-related deaths and hospitalizations are projected to increase (Gasparrini et al. 2017), with some groups, such as infants, women, people in difficult socio-economic situations, and adults above the age of 65, being particularly at risk and vulnerable (Conlon et al. 2020).

Despite the increasing urgency to address the impact of and adapt to more intense and frequent heatwaves, research on this topic remains dominated by biophysical sciences. People's experiences of heat are often reduced to mortality and morbidity rates of entire populations, while the individual lived reality of heatwaves is understudied (e.g., Klinenberg 2015). A biophysical perspective is useful for generalization and transferability of findings but falls short in accounting for the perspectives of the most vulnerable groups, and consequently hinders preparing adequate and effective adaptation measures. This paper aims to address this gap by asking what a heatwave is according to different disciplinary perspectives. Building on climate science, epidemiology, sociology, and social anthropology, we bring to the foreground the biophysical definitions, policy perspectives, and the experiences of older adults living in two European cities.

Climate scientists define heatwaves as prolonged episodes of abnormally high temperatures. They developed multiple heatwave indicators which, apart from temperature, consider meteorological variables such as humidity, wind speed, and solar radiation (Schwingshackl et al. 2021). Such indicators, however, confine our knowledge to the disciplines of meteorology and climatology, because they focus on external factors, the "environmental stressors." Epidemiology focuses on the relationship between temperature and health outcomes. While studies show that hot weather has more severe consequences for some population groups, including adults over the age of 65 (Conlon et al. 2020), research on the impacts of heat on human health focuses mostly on total population mortality and morbidity outcomes, without differentiating between vulnerable groups. Policymakers use meteorological and epidemiological measurements to develop mitigation and adaptation plans, which, however, often omit the social context. For older adults, excessive heat often means body pain and mental tiredness, sleepless nights, and increased isolation from friends and family for extended periods of time—perspectives that are not easily quantifiable and cannot be reduced to one definition. The impact of heat depends both on biophysical and socio-economic contexts and people's vulnerability and degree of exposure as well as their physiological and social capacity to adapt (Singer et al. 2016; Simpson et al. 2021). As Klinenberg (2015) pointed out, in order to better understand the impact of excessive heat on people's lives and prepare better adaptation measures, it is not only important to know how hot it gets—which we assess through biophysical measurements—but also to recognize the lived reality of a heatwave and its varied consequences—which we can understand best through qualitative research with vulnerable groups.

To address this diversity, we propose an interdisciplinary conceptualization of heat(waves) as multiple objects, which recognizes the epistemological and ontological differences of varied perspectives and definitions. Excessive heat or a heat(wave) is not only based on different kinds of knowledge (epistemology), but it *is* a different *thing* to climate scientists and older adults (ontology). We use the neologism "heat(wave)" to account for the multiplicity of definitions and recognize that excessive heat periods are not necessarily defined through the concept of a wave by older adults. We argue that heat(waves) are simultaneously biophysical and socio-cultural events. As Schnegg (2021) noticed, natural scientists often claim “objectivity,” while in fact disconnecting climate from culture and its subjective experiences (see also Knox 2015). At its origin, a heatwave is a physical phenomenon, but how it is understood and represented by natural scientists or media outlets[1], how it is managed by policymakers, and how it is experienced by groups of vulnerable people are inherently social processes. Recognizing this epistemological and ontological multiplicity of heat(waves) is central to advancing the research on this phenomenon.

Following this Introduction, we describe our methodology to then discuss heat(waves) as multiple objects based on four perspectives. We show what a heat(wave) is for (1) climate science, (2) epidemiology, (3) policy in Poland and Spain, and (4) older adults living in Warsaw and Madrid. Then, we discuss convergences and divergences (Nightingale 2016) between them, by focusing on multiple heat(waves) in the summer of 2022. We show why it is important to treat heat(waves) as simultaneously biophysical and social events and recognize the multiple ways of understanding and experiencing them, especially by the most vulnerable groups.

2 Methods

This article stems from the interdisciplinary research project on older adults and urban heat conducted in two European cities, Warsaw (Poland) and Madrid (Spain). We chose those two cities for their distinctive climate and weather conditions and cultural histories of heat (see Appendix 1). This article builds on different datasets and methods:

- (1) Analysis of climate data for the two case study cities; (2) review of climate change literature (presented in section 3.1);
- (3) Review of epidemiology literature (presented in section 3.2);
- (4) Discourse analysis of Polish and Spanish national and local policy (presented in section 3.3);
- (5) Ethnographic research conducted in Warsaw and Madrid with 10 participants in each city in 2021 and 2022; (6) group interviews with 81 participants above the age of 65 years old conducted in Warsaw in 2021 (presented in section 3.4).

The last two methods gather qualitative data, which is deeply localized, individualized, and not easily scalable or replicable. Such data provides an in-depth and detailed understanding of the social and cultural aspects of heat(waves) by investigating the perspectives and experiences of people within a particular community. All the group interviews followed the same set of open questions for discussion. However, each group interview was slightly different, reflecting the dynamics and the interests of a particular group of participants. Ethnographic research was based on building a prolonged relationship with participants that enabled the researchers not only to study participants’ narratives but also to observe their daily practices. Besides interviews and participant observation, ethnographic

[1] Analyzing media’s influence is beyond this article’s scope; however, media play an important role in how people interpret and respond to weather events, such as heatwaves (e.g., Strauss et al. 2022).

research also included thermo-diaries which the participants filled out on a daily basis. The names of all the participants were pseudonymized. For more details, see Appendix 1.

For Fig. 1 below, we used percentile computations of the 90p and 99p (relative) thresholds from HadISD.3.3.0 sub-daily, in situ observation dataset (Dunn et al. 2016), for maximum, minimum, and average temperatures as well as the heat stress indices that were readily available in HadISD (for more details see Appendix 3).

3 Conceptualizing heat(waves)

Hulme (2012) showed how a particular heatwave, which occurred in July 1900 in Norfolk County in England, was differently perceived in LP Hartley's novel *The Go Between*, the historical accounts of local newspapers, and the "digital" world of climate sciences. He contrasted literary description, journalists' accounts, and scientific analysis to showcase different epistemologies and demonstrate that a heatwave is a multifaceted phenomenon.

We develop this line of inquiry by suggesting a new interdisciplinary conceptualization of heatwaves that considers not only different epistemologies but also ontologies of heat. Anthropologists often demonstrate how environmental events might have multiple ontologies, meaning that they are considered different kinds of *things* by local people and scientists (Holbraad and Pedersen 2017). Schnegg (2021) for instance showcased how less frequent rain in Namibia was understood by local people as a force shaped by socio-political changes and simultaneously explained through increasing concentrations of "carbon dioxide molecules" by natural scientists. Similarly, a heat(wave) is a biophysical object for natural scientists and an entirely different, embodied socio-cultural object for older adults. This means that heat(waves) are not only epistemologically different (we understand them with different kinds of knowledge), but that they are also ontologically multiple (they are different things to different people). We use the neologism "heat(wave)," to account for the multiplicity of disciplinary, linguistic, and semantic perspectives, and to open the understanding of what this phenomenon is to different people, without confining it only to climate science.

We treat heat(waves) as complex and messy thermal objects (Law and Singleton 2005; Begerow 2018) that are measured, understood, and experienced in varied ways. They are mediated via numbers by scientists (Hastrup and Skrydstrup 2014; Knox 2015), via governing systems by policymakers (Starosielski 2021; Roesler et al. 2022), and via their bodies by older adults (Singer et al. 2016; Allen-Collinson 2018). These multiple heat(waves) while different are also connected and overlapping. For many older adults, heat(waves) are scientific facts presented on tv, and, simultaneously, they are sleepless nights, physical and mental pain, isolation, and apathy. Recognizing this multiplicity enables a holistic understanding of heat(waves), with the aim to bridge the gap between various scientific disciplines and people's local knowledge.

In studying heat(wave) knowledge gaps, we treat the viewpoints of scientists, policymakers, and older adults as equally valid. We assume knowledge is situated in a particular positionality and context, and that each knowledge is equally important to recognize (Haraway 1988). As Nightingale (2016) argues, recognizing different kinds of knowledge through interdisciplinary research enables revealing new insights, as well as silences and gaps between perspectives, which remain hidden in single disciplinary approaches.

3.1 Heat(waves) as extreme climatic events

Climate research perceives heat(waves) as natural phenomena and commonly defines them as periods of excessively hot weather through temperature measurements, which can coincide with high humidity (Marx et al. 2021). However, definitions of heatwaves vary in their degree of detail, meteorological variables, and computation methods (e.g., Robinson 2001). These definitions can be categorized into two broad types: (1) based on physical attributes (e.g., temperature) with their absolute or relative thresholds and (2) based on exceedance of sector-relevant thresholds (e.g., health sector). While the climate research community acknowledges that there is no universal definition of heatwaves, as with other types of extremes, some characteristics are very common, such as intensity, frequency, duration, timing, and spatial extent (Perkins-Kirkpatrick and Lewis 2020).

The World Meteorological Organization (WMO) set a milestone by introducing indices to describe extreme events, which was agreed upon by a wider scientific community in the 3rd IPCC report (IPCC 2001). In conjunction, Frich et al. (2002) proposed 10 such indices, of which 5 are temperature-related. They were chosen based on their robustness, applicability in multiple sectors, and the possibility of their calculation from the available data. Building on Frich et al. (2002), the Joint WMO Commission for Climatology and the World Climate Research Programme project on Climate Variability and Predictability, Expert Team on Climate Change Detection, Monitoring and Indices (ETCCDI) developed a set of 27 indices, 17 of which measure extreme temperatures. The ETCCDI list includes a variety of relative and absolute thresholds as well as duration and range-based indicators (Alexander et al. 2006). Even though widely used today, the individual ETCCDI indices limit their measurement to one of the extreme events' aspects. To address this issue, scientists developed several indices to incorporate other characteristics. For example, Meehl and Tebaldi (2004) examine projected changes in intensity, frequency, and duration of heatwaves based on the minimum and maximum temperatures. Other studies use relative threshold exceedance (e.g., 95p) for a predefined number of days (e.g., Fischer and Schär 2010). The climate research community developed this further and created a wide variety of impact-specific indices for different sectors, such as health, agriculture, and infrastructure.

Spatial and temporal variability are important characteristics of heat(waves). For example, climate change impacts daily temperatures unevenly, with nighttime (minimum) temperatures increasing faster than daytime maximums (Cox et al. 2020). Also, the history of local climatic conditions influences what is considered a heat(wave) since its definitions are relative to the "usual" weather in an area and the "usual" temperatures for the season. The climatic conditions in Warsaw and Madrid differ due to their geographic location. Madrid is significantly hotter than Warsaw, with more frequent and intense heatwaves (see statistics in Appendix 1). Conditions perceived as a heat(wave) in Warsaw could be just another warm summer day in Madrid. To include geographical and temporal variability in heatwave definitions, climate researchers compute location and calendar-specific thresholds, against which they evaluate different meteorological variables. Some of the most common variables employed are maximum (Tmax), minimum (Tmin), and average (Tmean) temperatures. Thresholds are typically computed relative to a "baseline period" or "reference period" for the studied area. The WMO recommends baseline periods of the most recent 30-year timeframe, ending in a year with a zero, e.g., 1991–2020 (WMO 2017). Put simply, if we want to determine the temperature anomalies for the summer of 2022, we compare the temperatures of each day in the summer of 2022 with the temperature distribution for that day and location in summers between 1991 and 2020.

The analysis of climatic conditions from the baseline period (e.g., 1991–2020) enables scientists to create a precise heatwave definition for a specific time and place. Such definitions often employ thresholds, which can be absolute (e.g., above 35°C) or relative (e.g., above 95p). Absolute thresholds are simpler, and thus more often they permeate into policy than relative thresholds, as is the case of Warsaw and Madrid (see section 3.3). However, if the research covers a larger area or is interested in comparability between locations, relative thresholds are more useful as they better reflect the local climatic conditions. Therefore, climate research often uses relative thresholds, i.e., percentiles (p) (Alexander et al. 2006). Percentile-based ETCCDI indices are calculated by counting the days in a season for which daily values exceed a time-of-year-dependent threshold. The threshold is defined as a percentile of Tmax, Tmin of Tmean in a baseline period (e.g., 1991–2020). Percentiles for determining temperature extremes range from 90 to 99p, depending on the scope of the study. Changes in heatwaves over time are commonly assessed using the 90p as it ensures a selection of a large enough sample for analysis, although some not-so-extreme cases get included in the data. A rigorous criterion, 99p, is more appropriate for identifying events with severe consequences. However, there is a high degree of uncertainty in the analysis of heatwave changes defined above 99p, because even though with the warming climate recently such events occurred more often, they remain statistically rare (Sulikowska and Wypych 2020).

For the climate definitions of heat(waves) in Fig. 1 (see the Discussion section below), we identified heatwave days by comparing daily 2022 data against 90p and 99p thresholds for seven heat stress indices readily available in the HadISD dataset, namely Tmax, Tmin, Tmean, THI, WBGT, Humidex, and Apparent Temperature for the 1991–2020 baseline. The 90p and 99p values are listed in Appendix 3. Furthermore, we evaluated the temperature trends in both cities by computing the difference between 1991–2020 and 1981–2010 in the 90p and 99p thresholds for Tmin, Tmean, and Tmax. We found consistent increasing trends in all values except for 99p in Tmax for Warsaw. These trends show an increase in heat(wave) intensity in both cities. To account for frequency, we evaluated the trends of Tmax > 30 °C between 1974 and 2022. In Madrid, 2016 registered the highest number of heat(wave) days, 87, and in Warsaw, 2015 registered a maximum of 20 heat(wave) days. The full climate trends analysis is described in Appendix 1.

Heat's influence on human health is a growing research area, and excess mortality is one of the most frequently discussed heatwaves' impacts in the scientific literature. Overall, between 2000 and 2020, the number of articles on heatwaves increased by a factor of 33.6, whereas articles on mortality related to heatwaves increased by a factor of 51.5 (Marx et al. 2021). The impact of heat(waves) on human health is often captured by the term "heat stress" (Schwingshackl et al. 2021) and an extensive number of climate indicators aim to describe it. De Freitas and Grigorieva (2015) found over 160 human thermal climate indicators showing that potentially a heatwave could be defined in 160 ways.

3.2 Heat(waves) as the cause of raising morbidity and mortality rates

Epidemiologists focus on the relationship between temperatures and health outcomes, so they perceive heat(waves) through their impact on human health. These impacts are visible not only during extreme events but also at lower temperatures. Physiologically, heat stress occurs when a human body cannot thermoregulate due to excess heat in the surrounding environment. Prolonged exposure to heat can exacerbate a range of illnesses (morbidity) including organ failure and cardiovascular and pulmonary diseases and, in extreme situations, leading to premature death (mortality) (Meade et al. 2020; Broczek 2021). The latest Lancet Countdown report finds that, globally, in the period 2017–2021, heat-related deaths increased by 68%, compared to 2000–2004 (Romanello et al. 2022).

Epidemiological studies show a direct and robust association of death and disease rates with ambient temperature (Gasparrini et al. 2017; Luo et al. 2017). Heat is rarely listed as a cause of death or hospitalization. Thus, to show the heat's contribution, epidemiology uses an excess mortality and morbidity approach, which assumes that the number of deaths or hospitalizations which exceed a certain reference and cannot be attributed to other causes is related to temperatures. Exposure-response functions (ERFs) are perhaps the most common tool epidemiologists use to determine the relationship between temperature and health outcomes. ERFs, also known as dose-response associations, are developed based on different types of regression models that describe a U-, J-, or V-shaped curve, representing the non-linear relationship between temperature and relevant health outcomes (Aunan 1996). Cold and hot conditions are associated with increased health impacts. Gasparrini et al. (2015) derive the minimum mortality temperature, corresponding to the minimum mortality percentile between 1p and 99p, from the best linear unbiassed prediction of the overall cumulative exposure-response association. In Madrid, they find the optimal temperature threshold—when the least amount of people might die due to heat stress—at approximately 22°C (Tmean-daily). Daily mean temperatures above and below this optimal threshold represent non-optimal temperatures (Gasparrini et al. 2017). Such epidemiological thresholds are usually determined based on mortality data, which is more easily acquired than morbidity data. Input data for epidemiological models often represent the entire population. Therefore, the ERFs and respective thresholds are not specific to vulnerable population groups. The thresholds vary greatly from one location to another and are often close to the average temperatures in any one place (Gasparrini et al. 2015).

While the most common methods to determine epidemiological thresholds rely on daily mean temperatures (Tmean) and daily mortality, some approaches evaluate optimal temperature thresholds for minimum (Tmin) and maximum (Tmax) temperatures and replace daily mortality with residual series resulting from Autoregressive Integrated Moving Average (ARIMA) models (Montero et al. 2010). By defining thresholds with minimum and maximum temperatures (instead of the means), mortality data can be integrated easier into the existing warning systems, which typically use Tmin, Tmax, and duration of heat events (in days). In the aftermath of the 2003 heatwave, Spain and a few other European countries (e.g., Portugal, France), introduced heat-related excess mortality into their heat(wave) definitions. In Madrid, days when Tmax ≥ 34°C (82p) and Tmin ≥ 22°C (92p) are considered heat(wave) days, causing warnings to be issued (see 3.3.2). These thresholds were identified based on mortality residual exceedance of the 95% confidence interval (Díaz Jiménez et al. 2015). This example shows that as in climate research, epidemiology also has multiple definitions of heat(waves). While Gasparrini et al. (2015) find Tmean threshold at 22°C, Díaz Jiménez et al. (2015) identify Tmin at 22°C and Tmax at 34°C. In section 3.1, we showed that scientists developed complex climate indicators that include temperature and sometimes humidity to better describe the climate-health relationship (de Freitas and Grigorieva 2015). To this date, there is still no consensus on the most representative climate indicators for heat stress.

Even though experimental evidence shows increased physiological heat stress with higher humidity (Bröde et al. 2012), and some studies find apparent temperature (a metric that combines temperature and humidity) was the most important predictor of heat-related mortality (Zhang et al. 2014), epidemiological models consider average daily temperatures to be the best predictor of heat-related mortality. While humidity plays an important role in heat stress in some locations, isolating the effect of humidity, before deciding whether to include it in the analysis, can become a cumbersome task. Therefore, it is more convenient to proceed with the analysis of Tmean if one could expect adequate results. Furthermore, Tmean includes variations of both Tmax and Tmin. As we point out throughout this paper, Tmin impacts people's health and in many cases increases faster with climate change than Tmax (Cox et al. 2020). As with humidity, it might be difficult to assess the individual effects of both Tmin and Tmax. While epidemiologists usually conduct their analysis for total populations in a particular location (e.g., a city), research has shown that vulnerable groups, such as older adults, are most affected by heat stress. Therefore, it is likely that even the small increases in mortality and morbidity rates above an epidemiological threshold are driven by cases from vulnerable groups. This can perhaps explain why the epidemiological threshold is significantly lower than most meteorological thresholds.

3.3 Heat(waves) as an undetermined emergency

Similarly to the biophysical perspectives described above, the policy uses multiple definitions and understandings of heat(waves). The state's attempts to define and govern heat(waves) can be called thermopolitics (Starosielski 2021) or thermal governance (Roesler et al. 2022). As in biopolitics (e.g., Lemke 2011), it is about the power to delimit normal from abnormal or from an emergency. For example, the fallout of the European 2003 heatwave, which shaped the policies in Spain, is a form of thermopolitics. In this section, we study heat(waves) on two levels: national (Poland, Spain) and municipal (Warsaw, Madrid). For each level, there are two points of focus: (1) understanding of heat(waves) and thresholds distinguishing norm from emergency, and (2) warning/alert systems.

3.3.1 Heat(waves) in the Polish national policy

Many European countries have a Heat-Health Action Plan (HHAP, plus Warning System – HHWS). Poland does not and it regulates heat(waves) through the national emergency management plan prepared every 2 years by the Governmental Centre for Security (RCB 2022, from here on the Polish Plan). The Polish Plan is organized around a list of threats. Excessive heat is recognized as a threat but categorized together with drought ("drought/heat"). The Polish Plan contains multiple definitions of heat-related phenomena (see Appendix 2). It is mostly devoid of references, presenting itself as autonomous and sovereign except for one reference to an annual publication by the Institute of Meteorology and Water Management, which contains "warm waves" (IMGW-PIB 2021). But there is no such entity as a "warm wave" in the Polish Plan. This lack of references taken together with some differences in definitions and thresholds (see Table 1) suggests a disconnection between policymakers and scientists when defining heat(waves) in Poland.

Out of the four stages of emergency management in the Polish Plan (mitigation, preparedness, response, recovery), there are no mitigation measures specifically targeting heat and only one preparedness measure: monitoring the weather conditions and issuing warnings to public institutions (RCB 2022, 101). The response and recovery stages are agriculture-oriented, with no measures concerning urban planning, housing, or development which are important in heat(wave) mitigation and adaptation (Torrego Gómez 2021; Zielonko-Jung 2021).

Monitoring and warning are assigned to the Institute of Meteorology and Water Management (IMGW-PIB), which issues warnings based on their forecast and thresholds defined in the Polish Plan (see Table 1). To inform the public, IMGW-PIB sends its warnings to state agencies and the media and publishes them on its website and in a downloadable app. However, the most direct communication channel in Poland, sending alerts directly to people's phones via text messages, is used for storms (based on IMGW-PIB warnings), pandemic regulations, and even elections, but not for heat(waves). The RCB officials who run the service informed us that the alerts focus on "dynamic atmospheric phenomena." [2]

Overall, Polish national policy approaches heat(waves) narrowly and in conjunction with droughts not recognizing them as eligible for direct warnings. It mostly focuses on the effects of heat(waves) on the agricultural sector, while impacts in urban areas are neglected.

3.3.2 Heat(waves) in the Spanish national policy

Spain also has an emergency management strategy, which focuses on heat(waves) less than other events, such as fires. Although the document states that weather events are responsible for 83% of fatalities from natural phenomena over the last 100 years, and heatwaves are one of the three with the greatest impact (Ministerio de la Presidencia, Relaciones con las Cortes e Igualdad 2019, 45), heatwaves are framed as "adverse weather phenomena" and as elements accentuating risk.

Unlike in Poland, in Spain, heat(waves)—or "excessive temperatures"—have their own policy in the form of the Heat-Health Action Plan and warning system (HHWS) (Ministerio de Sanidad 2022, from here on the Spanish Plan). The Spanish Plan is renewed annually and active throughout the summer suggesting that heat(waves) are an annual constant in Spanish policy.

The Spanish Plan approaches heat(waves) as a health hazard, relying on the scientific literature. One of the institutions involved in the creation and overview of the Plan is the State Meteorological Agency (AEMET). According to the AEMET's annual report on heatwaves, they "are considered episodes of at least three consecutive days, in which at least 10% of the stations register maximums above the 95p of their series of maximum daily temperatures for the months of July and August of the period 1971–2000" (AEMET 2022). While AEMET perceives heat(waves) through time (in a wide range of scales: days-months-decades) and temperature thresholds, the Spanish Plan focuses more on biopolitics and health impacts.

The Spanish Plan coordinates and establishes heat prevention and control. It emphasizes the vulnerability of older adults, the need for societal cooperation (e.g., with Social Services), and advice on actions for other public institutions. The heat protocol advises drinking water, eating fresh and healthy, going to the health center if worried about a symptom, protecting the house, your baby, and yourself from the heat, refreshing yourself, and helping older adults. The Spanish Plan also recognizes the role of social and architectural aspects of heat(waves) in the city and its impact on vulnerable groups (see Torrego Gómez

[2] In 2023, the RCB sent their first alerts about heatwaves across different regions in Poland.

Table 1 Thresholds for heat warning systems in Poland and Spain. Levels 0/green/normal were not included. *In Poland, thresholds are determined by RCB, but institution issuing warnings, IMGW-PIB, adds another condition for level 1: "or Tmax ≥ 35°C, duration ≥ 1 day regardless of the Tmin"

Country	**POLAND**		**SPAIN**						
Source	"Polish Plan" (RCB 2022)		Casanueva et al. 2019			"Spanish Plan" (Ministerio de Sanidad 2022)		"Madrid Plan" (Comunidad de Madrid 2022)	
Name of alert and/or institution issuing them	IMGW-PIB		Meteoalerta/AEMET			HHWS based on HHAP		Comunidad de Madrid, Direccion General de Salud Publica	
Types of thresholds	Tmax, Tmin, duration		Tmax on a given area			Tmax, Tmin, duration		Tmax, duration	
Area / *Alert levels*	The same conditions for all of Poland		North	Center and Med.	South	Madrid		Madrid	
1/ Yellow	30°C ≤ Tmax ≤ 34°C, Tmin <18°C*	≥ 2 days	34°C	36°C	38°C	Tmin≥22°C, Tmax≥34°C	1-2 days	36.5°C < Tmax ≤ 38°C	current or one of the next 4 days; ≤ for next 3 days
2/ Orange	30°C ≤ Tmax ≤ 34°C, Tmin ≥ 18°C,		37°C	39°C	40°C		3-4 days	Tmax > 36.5°C	≥ next 4 days
								Tmax > 38°C	current or one of the next 4 days
3/ Red	Tmax> 34°C		40°C	42°C	44°C		≥ 5 days	(there are only 2 levels for this alert)	
*In Poland thresholds are determined by RCB, but institution issuing warnings, IMGW-PIB, adds another condition for Level 1: "or Tmax ≥ 35°C, duration ≥1 day regardless of the Tmin".									

2021). But the policy approach is mainly reactive—the eight core elements of HHAP focus on cooperation, alert systems, information acquisition, and dissemination, while neglecting—similarly to the Polish Plan—the long-term urban planning (see Martínez-Solanas and Basagaña 2019).

There are two national heat(wave) warning systems in Spain (Casanueva et al. 2019). The first one is meteorologically determined. It uses AEMET's definition of a heat(wave) based on temperature thresholds and three geographical zones. The second one (HHWS) is epidemiologically determined. It considers Tmin along with Tmax and the warning threshold is the temperature triggering "significant" excess mortality for a given city or area (see section 3.2). While the first perceives heat(waves) as localized weather phenomena, the second one defines them more as biopolitical events, as it considers the human dimension through measuring mortality.

Both in Poland and Spain, policies perceive and govern heat(waves) mainly through the prism of their effects. Spanish definitions prove more diverse and more health focused. This focus probably stems from the 2003 heatwave which severely affected Spain, and which both the municipal and national policy mention as a reference point. Although policies in both countries recognize heat(waves) as an abnormal condition and an important issue, they approach and respond to it reactively—retreating from governance, pursuing what can be described as thermopolitics of minimal effort (monitoring, warning, and coordinating). The lack of proactive adaptation to extreme heat is common not only in Spain or Poland, but also in many other countries (Romanello et al. 2022).

3.3.3 Heat(waves) on municipal level: Warsaw and Madrid

The municipal policies in Warsaw and Madrid focus more on heat(waves) than the national ones. In Poland, the local emergency policy is secondary to the national one, and climate change policy is quite a recent endeavor. Warsaw's climate change adaptation strategy

(Rada Miasta Stołecznego Warszawy 2019, from here on the Warsaw Strategy) defines heat(waves) in the same way as the "heat period" in the Polish Plan: "sequence of at least 3 days in which the average Tmax reaches at least 30°C" (see Appendix 2—definitions differ from warning thresholds). But more generally, the Warsaw Strategy considers heat(waves) an effect of both local (Urban Heat Island) and global (climate change) conditions. The strategy assesses each neighborhood according to its hydrological and thermal risks; it also highlights the planning and development of green and blue spaces as one of the main local adaptation tools (see Zielonko-Jung 2021). Thus, Warsaw Strategy sees heat(waves) not only through temperature and duration but more as spatial, material, and localized objects. The Warsaw Strategy considers heat(waves) one of the most important and increasingly frequent threats.

The Warsaw Strategy not only prioritizes heat(waves) more than the Polish Plan, but also takes a more personalized approach, focusing not on agriculture or forestry, but rather on people's health and well-being. Older adults, children, and people with illnesses are indicated as vulnerable and at risk because of heat(waves). The policy suggests that their well-being is considered when making adaptation plans, but it is unclear what that means in practice. As for the alerts, in the event of dangerous weather—including heat(waves)—the Capital City of Warsaw publishes relevant messages based on IMGW-PIB warnings on city websites and social media and provides information via the Warsaw Notification System.

Madrid has a risk response plan strictly devoted to heat(waves) (Dirección General de Salud Pública, Consejería de Sanidad, Comunidad de Madrid 2022, from here on Madrid Plan) Similarly to Warsaw, Urban Heat Island effect is highlighted as an important factor. The Madrid Plan considers the morphology and intensity of the Urban Heat Island and the geographical distribution of vulnerable groups. The Madrid Plan, like the Spanish Plan, is issued annually. It contextualizes heat(waves) by providing summary information from the previous summer in Madrid and by considering the future, giving a detailed and wide temporal frame. It expands on the Spanish Plan regarding vulnerable groups, local context, and health impacts.

The city of Madrid has introduced its own local alert system (see Table 1 and Fig. 1) based on a 5-day forecast (starting with the forecast for the current day, see Appendix 3 for details). It is like the Spanish Plan, except that on level 2 it includes a direct intervention within the vulnerable population. Although, as we learned from ethnographic research, it is not well implemented (see 3.4.1), which seems to be a wider tendency (Vanderplanken et al. 2021).

3.4 Heat(waves) as embodied and relational experiences

From an anthropological perspective, the ontology of heat(waves) is represented not by definitions, but by what heat(waves) mean to people and how they impact everyday lives. Experiencing heat(waves) is relational, dependent not only on individual bodily physiology but also on the social context, and it changes with time. In this section, building on in-depth, localized qualitative research with one of the most vulnerable to heat stress groups, adults above 65 years old, we show how they experienced heat(waves) in Warsaw and Madrid during the summers of 2021 and 2022.

Heat(waves) are very different in Madrid and Warsaw. In Spain, excessive heat has been a long-term problem, prompting people to develop adaptation strategies and weave them into their daily routines. Whereas in Poland, excessive heat is only now becoming an issue.

Thus, Warsaw and Madrid have very different adaptation mechanisms, both at the urban and individual scales For instance, unlike in Madrid, in Warsaw, there are no passive cooling methods available (such as shutters/blinders), and air-conditioning units are relatively uncommon.

Even within a city, individual experiences and perceptions of excessive heat vary (Singer et al. 2016). Each person's body senses heat differently, some feel the heat on their heads or in their chests, others only on their fingertips. Our research participants not only have different thermoceptions, i.e., lived experience of a temperature (Allen-Collinson 2018), but also different—sometimes conflicting—ideas about what heat(waves) are. These distinct ways of being with heat are mediated through people's mental and physical health (Broczek 2021); their socio-economic situation (can they afford to use air-conditioning or leave the city in the summer?); location, structure, and building materials of their homes (e.g., Zielonko-Jung 2021; Torrego Gómez 2021); and their social capital and support from others (Klinenberg 2015). Therefore, ethnographic research shows that there are different ontologies or ways of being in the world with excessive heat.

3.4.1 *Mucho Calor* in Madrid

Heat is a distinct feature of Spanish summers; however, due to their increased occurrence over the last decade, heat(waves) have gained attention in Spanish media and society. In the summer of 2022, there were 60 days of heat(wave) alerts in Madrid (according to the Madrid Plan, see 3.3.3). While most ethnography participants claimed to endure the heat well, our study showed their different relationships with heat(waves) and that these relationships change as the summer evolves. Heat is an awaited phenomenon at the beginning of the summer, but it becomes dreadful at the end of it. Participants ascribed different characteristics to heat(waves), some considered them normal annual weather events; others saw heat(waves) as unnatural, ensuing from anthropogenic climate change; and some understood them as warnings from authorities that foresee a period of heat, but not necessarily entail what they considered to be unbearable heat. They were not aware that three different warning models exist or that they use different thresholds to measure heat(waves). For the information about heat(waves), they relied mainly on the State Meteorological Agency (AEMET), which stemmed from the long-term institutional trust built through weather reports. Participants acknowledged heat(wave) alerts and were familiar with the related health and safety recommendations. Some of them treated it very seriously, while others were critical and defended the use of traditional adaptation strategies that are not in the official heat(wave) protocol. However, what mattered to all of them most was their comfort and well-being, which were affected by the weather conditions and the alerts, but most importantly, by their bodily and mental perception of the heat(wave). In that sense, they often distinguished a scientific or a policy-defined heat(wave) from the moments when they experienced excessive heat in their bodies.

After experiencing an extreme heat period on the 11–17th of July 2021 (Tmax 41°C), which set off the national and city heat alarms, Teri (73 years old) argued that this was not *mucho calor* (too hot). Similarly, Joaquín (85) said, "this is not summer-summer yet". However, after many hot summer days, the heat(wave) from August 12th to 16th 2021 (Tmax 42.7°C), was recognized and acknowledged by most of the ethnographic study participants as an extremely, physically, and mentally impairing event. Joaquín described it this way:

> With the heatwave, I have noticed that I get more tired, usually, I walk around the park and [this time] I had to sit down because I was tired. It was simply too hot, and the biggest problem was that it did not cool down at night.

Joaquín explained that as the heat increased, his throat became more sore than usual, making him cough all the time. For him, the dryness of the air and the dust of the park became part of the heat(wave), aggravating existing health problems. The cough made him tired, and so did the heat, but also, the prolonged sleep deprivation due to persisting torrid nights.

A year later, after 60 days of heatwave alerts during the summer of 2022, the situation was different. Joaquín concluded, “this summer it’s a different story, I have only stayed at home, and I do not even have the will to open the door of the flat.” Joaquín’s example shows how a person might experience three official heat(wave) periods, with similarly high temperatures, completely differently. While our bodies might have a certain predisposition to withstand short periods of extreme heat, they become unbearable as they increase in an atypical way.

Juan Carlos (67) explained that during some heat(waves), especially early in the summer, you can still carry out your normal activities. You need to close the blinds and windows, but it becomes part of your routine. He defined a bodily felt heat(wave) as “a period of long-term heat during which at some point after a few days of heat, you look ahead, and you understand there is not going to be an escape from the heat.” Many participants described heat(waves) in terms of feeling trapped and unable to sleep for several consecutive nights. Some associated heat with a precise number, like Sara (70) who claimed 30°C inside the home and 34–37°C in the street was unbearable, making her “go mental”. Yet, beyond direct numerical connotations, based on thermometers or the weather news, most participants associated heat with direct body observations—a “sensitive state” as Eduardo (91) described it—which they assess every morning.

Through participant observations, we witnessed how participants’ emotional and physical states gradually changed over the summer. Sixty-nine-year-old Elisa told one of us during the August 2021 heatwave: “I’m waiting until I can no longer breathe at night, then I’ll bring the fan up to the flat, until then I have to accept that I need to keep the house closed, the windows closed, the shades down.” Elisa accepts suffering until the point when she “can no longer breathe,” not only because of a cultural tradition of austerity related to her upbringing, but also due to rising electricity bills in Spain, which she can barely pay. As the heat crept in, participants would shift from morning energy to a state of tiredness, slowing their movement, and limiting their physical strength and motivation to conduct daily activities, such as shopping or cooking. We observed how in their slowness they searched for their couches, unable to move around the house as usual, annoyed by the sweat and muscle swelling as these spread through their bodies, and overtaken by a need to sleep that put them in a state of daydreaming and confusion. Through this process, many participants developed apathy, telling us to leave them to rest on their own, out of the need to maintain their privacy while they attempted to deal with these bodily and sensorial changes. For many research participants, heat(waves) were a known risk they had historically coped with, so they did not follow the recommendations to stay indoors or to hydrate more, they just continued with normal life until their bodies pushed them back to their beds, sometimes through dizziness, stomach pain, inability to breath, or general tiredness.

3.4.2 *Upał* in Warsaw

Research participants in Warsaw rarely used the term "heatwave," describing the high summer temperatures as "heat" (*gorąco, upał*), which is the most common way of referring to it in Polish.[3] Heat(waves) are perceived as a weather phenomenon that people happen to live through and reflecting on it feels unusual. Participants often asked: "Heat is heat. It is hot. What else do you want to know?" They sometimes mentioned that summer heat brought pleasant memories, even though they currently suffered from excessive heat. Such comments, associating heat with holidays and pleasure, appeared both in the group interviews and in the ethnographic study. For example, Ela (84) kept repeating how she used to sunbathe during the summer and how healthy and pretty she felt with skin "dark as chocolate." She could not recall the sun or heat as difficult to bear in the past, in contrast to the present when it became intolerable.

Contrary to Madrid, our ethnographic research demonstrates that in Warsaw heat(waves) are still perceived as rare, even though statistically their frequency is increasing with the warming climate (Appendix 1). The historical lack of heat means that many Warsaw participants did not realize heat's negative consequences and initially underestimated them. When it became hot, at first, they looked forward to it, because it meant summer. Missing sunshine during long winter months in Poland means that once people can spend time outdoors, it is considered a relief and a positive experience. But after a few days of excessive heat, participants got tired and started complaining.

Such an ambiguous relationship with heat partially stems from Warsaw's geographic location. Warsaw is much better adapted to cold temperatures; this is inherent in urban planning and architecture (Zielonko-Jung 2021). For instance, apartments are hard to ventilate, since the aim was to keep warmth inside rather than to let the breeze through. Some participants understood and experienced heat(waves) in contrast to cold. They often referred to their memories of winters from their childhood—it was the cold that threatened people's lives, not the heat. But now, as some participants noticed, it is the heat, that becomes the problem. They worried about the future of their children and grandchildren, and less about themselves.

Participants often talked about hot weather using temperature thresholds. Ela (84) said "heat is a temperature above 24–25°C. 23°C to 25°C is still fine, but higher is already unbearable." Similarly, at least twenty participants from group interviews said that for them heat(waves) start at around 25–26°C. Though one participant, Janusz (83), observed that only a few years earlier people complained that it is too hot at 25°C, whereas in 2021 he noticed that higher temperatures, around 32°C, were more accepted. For him, heat(wave) starts above 30°C.

What is considered "too hot" changes not only over time but also with context. Maria (77) noted in her diary that one day when she went for a trip it was "hot, 30 °C." But when she recalled that day, she admitted she did not feel hot, she just knew this temperature should mean it is hot. The same temperature could mean a different thing depending on where a person is. Thirty-five degree Celsius might be pleasurable on holidays by the sea or in the forest but horrifying when one needs to stay at home in the city. It changes within the city as well, as some neighborhoods or buildings are better adapted to summer heat than others.

[3] Data for Warsaw consists of two separate qualitative sets: (1) longitudinal ethnography with 10 participants in 2021–2022 and (2) group interviews with overall 81 participants conducted in 2021. We present them together, since obtained results often overlapped and converged; however, if the data obtained is specific just to one of the methods used, we make a clear distinction.

Although it was unintuitive and hard for research participants to talk about bodily experience of heat, after time spent together, we could learn how the heat manifested in their bodies. Anna (73) is an active person who works out and engages in many activities, but when we met on a hot day in 2021, she could barely move. She spent all day on the sofa watching TV, her cheeks pink, and her forehead flecked with sweat. Her sofa stood near the window, exposed to the sun. The curtains were closed, but they were white and semi-transparent providing little shade. There was no fan nor other cooling devices like air-conditioning. The lack of movement frustrated Anna and she felt bad both in her body and her mind. The less she moved, the worse her body felt. She started feeling pain in different parts of her body and became even more frustrated. Many other research participants recognized that it is too hot (even if they did not use the word "heatwave"), based on their bodily reactions. Even though they might have lacked words to describe it, they *felt* the heat. For them, a heat(wave) was an embodied phenomenon—they were sleepy, tired, or irritated. Bożena (91) said: "sometimes [when it's hot] during the day, I must lie down, because when it's still so hot, I just must sleep a lot, somehow my body needs to sleep a lot. I say I'll sleep until I die."

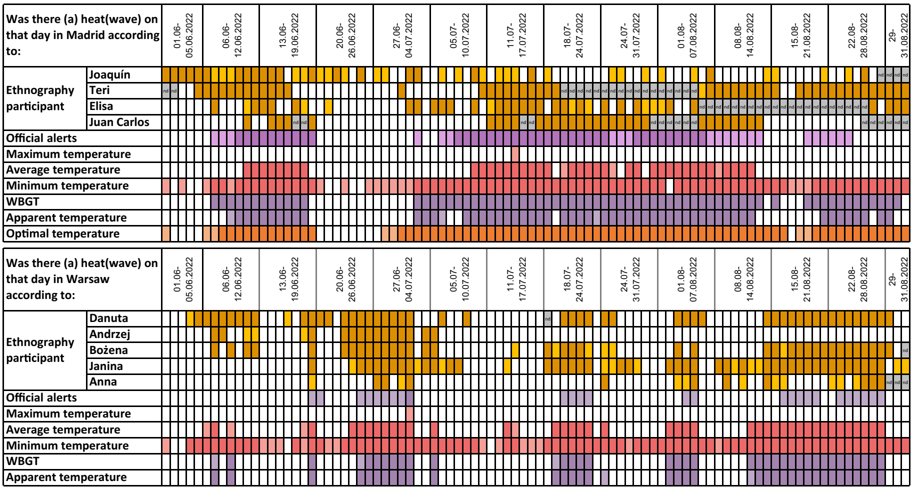
During group interviews in Warsaw, older adults talked a lot about how excessive heat increased their isolation. Some of them followed the policy advice and stayed at home, going out only in the early morning for groceries, or in the late evening to "catch a breath of fresh air." The participants rarely used the term "loneliness," but our results are similar to Klinenberg's findings about how the 1995 Chicago heatwave affected both people's health problems and increased their isolation. Our research participants often cancelled doctors' appointments and meetings with family and friends and stayed at home alone waiting for the heat(wave) to pass. Aldona (71), with great sadness, recounted: "My neighbour has a little garden, and we often used to meet there for coffee. But now when it's coffee time, it is too hot, we cannot meet, so sadly there is no more coffee and companionship in that little garden." Heat(waves) change older adults' routines and affect their social relationships, increasing their loneliness and impacting their physical and mental health.

Our qualitative research demonstrates that older adults, both in Warsaw and Madrid, recognize heat(waves) based on a mix of their life experiences, memories, formal knowledge and information from the media, transgenerational knowledge, emotions (both sadness and happiness), mental states such as loneliness, and embodied experiences including pain, sweating, loss of energy, or burning skin. The perceptions of heat(waves) differed among our research participants, but they were always socially situated, relational, and embodied objects. Participants often mentioned that they must survive it and live through it (*przetrwać)* as that is the only thing they can do.

4 Discussion: multiple heat(waves) over one summer

We used mixed methods to conceptualize heat(waves) from distinct disciplinary perspectives simultaneously as biophysical, embodied, and socio-cultural phenomena. The interdisciplinary conceptualization of heat(waves) as ontologically multiple objects allows us to integrate different perspectives and knowledge about heat(waves), accounting for perceptions and needs of those most vulnerable. In this section, we combine these different approaches and examine points of convergence and divergence between them (Nightingale 2016).

Figure 1 illustrates when variously defined heat(waves) occurred during the summer of 2022 according to climate science and meteorology, epidemiology, and policy, and based



Name	Definition	No	No colour	Colouring, intensity 1	Colouring, intensity 2
Ethnography participants	**How many hours was it too hot that day according to the participant?** The graph includes ethnography participants who filled at least 75% of the days in their time-diaries for the 2022 summer.	nd	no hours marked as 'too hot'	at least one hour marked as 'too hot'	at least four hours marked as 'too hot'
Officla alerts	**Were there heatwave alerts issued for that day?** (for Madrid these are local alerts in line with the Madrid Plan)	nd	no	yes, first level	yes, second or (in Warsaw only) third level
Maximum temperature	**Tmax equal or above the 90p or 99p threshold?**	nd	below 90p	equal or above 90p	equal or above 99p
Average temperature	**Tmean equal or above the 90p or 99p threshold?**	nd			
Minimum temperature	**Tmin equal or above the 90p or 99p threshold?**	nd			
WBGT	**Is WBGT equal or above the 90p or 99p threshold?**	nd	no	equal or above 90p	equal or above 99p
Apparent temperature (AT)	**Is apparent temperature (AT) equal or above the 90p or 99p threshold?**	nd			
Optimal temperature	**Was the average temperature that day equal or above the optimal temperature of 22 degrees Celsius?** (Only for Madrid for where Gasparrini et al. (2015) calculated it)	nd	no	yes, for one or two days	yes, for three days or longer

Fig. 1 Heat(wave) days during the summer of 2022 in Madrid and Warsaw according to different perspectives. Sources: own ethnography research; own calculation based on Warsaw's and Madrid's meteorological office's data; Warsaw's and Madrid's alerts. Note: detailed description of the data sources and how the graph was created can be found in Appendix 3

on thermo-diaries filled out by ethnographic research participants (for more details, see Appendix 3). The different perspectives often overlap, but interesting discrepancies arise. This data demonstrate why we need to include the perspectives of vulnerable groups to get a more holistic understanding of what heat(waves) are and how best to adapt to them. First, we show that according to different perspectives, heat(waves) have different lengths. Many older adults experience longer periods of excessive heat, or heat(waves), than biophysical measurements or policy alerts would indicate. Second, we demonstrate that nighttime temperatures are the closest measurement to account for people's experiences. Third, we argue that there is a discrepancy between heat(waves) perceived as scientific anomalies and as increasingly common daily experiences, which means that there is an important gap between biophysical data and the experiences of vulnerable groups.

First, recognizing the multiplicity of perspectives and their equal relevance means that the length of heat(waves) varies, and they often start and end on different days. Depending on whether we use maximum, average, or minimum temperature in both cities, we identify between 1 and 88 heat(wave) days in Warsaw and between 1 and 84 in Madrid in the summer of 2022 (out of 92 days of summer). Figure 1 also presents two heat stress indices with their 90p and 99p thresholds, namely the Wet Bulb Globe Temperature (WBGT) (37 days for Warsaw and 68 for Madrid) and the Apparent Temperature (38 days for Warsaw and 57 for Madrid), each corresponding to a slightly different heat(wave) definition. We compare these with the official alerts (for Madrid based on the Madrid Plan) and in Madrid, with optimal temperatures. Optimal temperature registers more heat(wave) days (79) than the official alerts in Madrid (60). These measurements use data from meteorological stations. Meteorological stations are almost never placed close to the city centers which are usually the hottest and most densely populated urban areas. Furthermore, meteorological data represents outdoor temperatures, while people, including our research participants, spend most of their time indoors. Therefore, in many cases, the measured values such as Tmean or Tmax are far from the heat people actually experience. This might, in part, explain the discrepancy between biophysical measurements of heat(waves) and people's individual experiences.

Indeed, each ethnography participant experienced and defined heat(waves) differently, each had their own individual embodied threshold which stemmed from their physiological and social capacity to adapt, their living arrangements, or how they might feel during a particular week. These individual thresholds were relational and their quantification is very problematic (see Appendix 3). In Warsaw, ethnography participants individually tended to report more heat(wave) days (between 17 and 54 with almost no missing data) than the official alerts indicated (26 days). Furthermore, taken together, there were 72 days during which at least one participant indicated that they felt "too hot," and 20 during which no excessive heat was indicated. While in Madrid, ethnography participants tended to report fewer heat(wave) days (between 31 and 47) in comparison to the official alerts (60), but data for many more days is missing. This, in fact, was due to heat, as we know from ethnography that all participants left Madrid to avoid hot weather for at least 4 days to different destinations, including the beach or the mountains, which corresponds with no data, colored in grey in Fig. 1. In Warsaw, only two participants travelled during the time of the study, which was not related to heat, they went for the summer holidays. Overall, there were 83 days during which at least one participant in Madrid indicated experiencing excessive heat, so during the summer there were only 9 non-heat(wave) days in Madrid. This shows that older adults, a group especially vulnerable to heat stress, often experienced longer periods of heat(waves) than climate or meteorological indices or policy warnings indicated.

Second, Tmin thresholds, referring to nighttime temperatures, converge particularly well with older adults' experiences. Without the opportunity to cool down during the night, the human body keeps storing heat until severe health effects may occur. One epidemiological study finds that the relative risk for mortality related to hot nights could be 50% higher than on hot days with non-hot nights (He et al. 2022; see also Murage et al. 2017). Many (15 out of 20) ethnographic research participants from Madrid and Warsaw mentioned nighttime temperatures as one of the worst experiences for them and an important way of recognizing heat(waves), though not all of them referred to the summer of 2022. They talked about their difficulties with sleeping, the inability to rest, and problems with breathing. Some of them mentioned remembering hot nights from the past. And only some of them indicated this in their thermo-diaries, so it is not fully represented in Fig. 1.[4] Still, our analysis of thermo-diaries in both cities shows that Tmin is the closest measurable value of temperature to the perceptions of vulnerable individuals. And our ethnographic research demonstrates that most participants recognized hot nights as especially problematic. However, the number of participants in our study is very limited and by no means representative of

[4] Interestingly, the Tmin-based definition closely correlates with optimal temperature measurements in Madrid. However, epidemiological data required to compute optimal temperature thresholds is less accessible than meteorological values such as Tmin. In Warsaw, optimal temperature is missing due to lack of data.

vulnerable groups in a city; and most participants did not fill out the thermo-diaries during sleepless nights so we cannot infer that the Tmin threshold coincides with sleepless nights. Further interdisciplinary research is required to study the role of nighttime temperatures in developing effective adaptation measures.

Third, our research shows a discrepancy between heat(wave) definitions in climate science, which view them as anomalies, and how heat(waves) are experienced and narrated by older adults or Spanish policy as increasingly common events. Climate science understands heat(waves) as rare events. Therefore, the temperature thresholds defining them will be moving up with the increasing frequency and intensity of heat(waves). What is currently defined as a heatwave may not be considered one in a few decades (see section 3.1). Similarly, if we consider an older baseline, e.g., 1961–1990, we will find a lower relative threshold for the 90p and 99p, compared to the 1991–2020 baseline, used in this article. As the climate warms, relative thresholds increase. However, for many older adults, heat(waves) start at lower thresholds. They already experience heat(waves) as common phenomena during summers, and not as an anomaly. This means thresholds that only consider meteorological variables, like Tmax, may become irrelevant for understanding heat(wave) impacts in the future, as they will be increasingly disconnected from people's experiences. For instance, for Warsaw, Tmax was calculated at 35°C for the 90p—and there was only one such day in the summer of 2022—while many research participants experienced excessive heat already at 25°C. Furthermore, many people who do not present acute symptoms of overheating, but whose mental and physical health and well-being deteriorate during summer months, may not need immediate help but still get worse in the long term and at lower temperatures. This has important consequences for people's lives, health, and well-being, as well as for public health systems.

Above, we showed how heat(waves) can be conceptualized by distinct disciplinary perspectives and demonstrated some convergences and divergences between the resulting outcomes. Recognizing these differences is important, not for bringing forth a universal, one-size-fits-all definition of a heat(wave), which would be unfeasible and futile, but to acknowledge and incorporate into research practice that we might need these various perspectives for different purposes. Different disciplines have different research goals and agendas, but one discipline's viewpoint should not be used to understand all the perspectives. As we showed, biophysical or epidemiological data does not allow us to fully understand the experiences of heat(waves) of the most vulnerable groups; therefore, we should not rely only on climate or meteorological thresholds for understanding what heat(waves) are when designing policy and adaptation. No temperature, humidity, or other meteorological variables' measurement can account for the socio-cultural and relational aspects of a heat(wave) in people's experiences. Thus, when choosing a definition, one should be explicit about the goals of their study and how they align their heat(wave) definition to that aim. Acknowledging other heat(wave) ontologies might help in noticing situations where the goals and definitions misalign, and where we need input from other disciplines or perspectives.

Recognizing the ontological multiplicity of heat(waves) affects adaptation. When adapting to heat(waves), we need more localized, usage-dependent, and bottom-up approaches. While meteorologists need universal comparability, local governments need definitions and alert systems that represent local conditions and include the most vulnerable groups. While heat(waves) remain "messy thermal objects," more interdisciplinary research is required to identify which perspectives and thresholds are most useful or how to address the differences between them in case-specific local decision-making: (1) does the existing policy correspond to people's experiences? What input do vulnerable groups have for local adaptation policy? (2) Should we develop multiple definitions of heat(waves) based on different levels of vulnerability? (3) Should vulnerable groups be alerted differently than the general population and how should they be prioritized and targeted? (4) How to address in research and policy the disconnection between heat(waves) defined as rare events of abnormally high temperatures and heat(waves) as a common summer experience, and assess the scale of the hidden impacts of heat(waves) on health and well-being? Addressing those questions requires further interdisciplinary research, using both qualitative and quantitative methods to study the impacts of heat(waves) on vulnerable groups and assessments of their adaptive capacity.

5 Conclusion

To answer the question asked in the title of this article: there is no one definition of or ontological perspective on heat(waves). Heat(waves) are multiple. This article shows why it is important to recognize the multiplicity of heat(waves) by demonstrating that (1) the length of heat(waves) varies between the different perspectives, which means that many older adults experience longer periods of excessive heat than biophysical measurements or policy alerts indicate; (2) the role of nighttime temperatures is more important than daily temperatures for understanding the impact of heat(waves); (3) and there is a discrepancy between heat(waves) as scientific anomalies and as increasingly common daily experiences. Through that, we demonstrate that people's embodied knowledge, the perspectives of vulnerable groups, should be treated as equally important to biophysical knowledge, if we want to get a more holistic understanding of what heat(waves) are and inform effective and localized bottom-up adaptation measures.

As IPCC reports demonstrate, heat(waves) will become an even more common phenomenon, and we urgently need to look for ways to expand our knowledge about them and increase our resilience and adaptive capacity. Since heat(waves) are multiple objects, simultaneously individual experiences, biophysical changes, and sociopolitical phenomena, we need interdisciplinary research to understand this multiplicity and prepare better adaptation measures. An interdisciplinary analytical framework of heat(waves) as multiple objects is an important step in that direction. It allows us to highlight some gaps in knowledge about excessive summer heat and its impact on those who are most vulnerable.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10584-023-03592-3.

Acknowledgements We would like to thank all research participants for their time and involvement in the project. We would also like to thank the three anonymous reviewers for their valuable comments which helped improve the quality of this manuscript, and to Clemens Schwingshackl for his constructive feedback on the manuscript during revision.

Author contribution All authors had substantial contributions to the article. The co-authors are listed in alphabetical order. Research design and funding acquisition were performed by Zofia Boni, Barbara Jancewicz, and Iulia Marginean. Conceptualization of the paper and writing of the first draft were performed by Zofia Boni. Data curation and analysis as well as writing of parts 3.1 and 3.2 (climate science and climate epidemiology) was performed by Iulia Marginean. Data curation and analysis as well as writing of part 3.3 (policy analysis) was performed by Franciszek Chwałczyk (with consultations from Paloma Yáñez Serrano). Research, analysis, and writing of part 3.4.1 (ethnography in Madrid) was performed by Paloma Yáñez Serrano. Research, analysis, and writing of part 3.4.2 (ethnography in Warsaw) was performed by

Zofia Bieńkowska, with input from Zofia Boni. Research in Warsaw (focus groups) was performed by Zofia Boni and Franciszek Chwałczyk. Data curation for Fig. 1 was done by Barbara Jancewicz with input from Iulia Marginean, Franciszek Chwałczyk, Paloma Yáñez Serrano, and Zofia Bieńkowska. All the authors contributed to the Discussion. The editing and reviewing of the article were done by Zofia Boni, Iulia Marginean, and Barbara Jancewicz. All authors worked on revisions, and read and approved the final version of the manuscript.

Funding The article stems from the research project "Embodying Climate Change. Transdisciplinary Research on Urban Overheating" (EmCliC) funded from the EEA grants 2014–2021 under the Basic Research Programme operated by the Polish National Science Centre in cooperation with the Research Council of Norway (grant no 2019/35/J/HS6/03992).

Data availability The ethnographic data and data from group interviews that support the findings of this study are available on reasonable request from the corresponding author. The data are not publicly available because they contain information that could compromise the privacy of research participants.

Meteorological data from HadISD is openly available and can be downloaded at https://www.metoffice.gov.uk/hadobs/hadisd/index.html.

Declarations

Ethics approval and consent to participate The research which is the basis of this article received approval from the Ethics Committee for Research Involving Human Participants at Adam Mickiewicz University in Poznań (decision no 6/2020/2021). All the participants, who are pseudonymized in the article, provided written consent and were informed about the possibility to withdraw their consent and participation from the research at any time.

Consent for publication All authors read and approved the manuscript and give their consent for submission and publication (under a CC-BY 4.0 license).

Competing interests The authors declare no competing interests.

References

AEMET (2022) *Olas de calor en España desde 1975*. [Heatwaves in Spain since 1975]. Agencia Estatal de Meteorologia https://www.aemet.es/es/conocermas/recursos_en_linea/publicaciones_y_estudios/estudios/detalles/olascalor. Accessed 13 March 2023

Alexander LV, Zhang X, Peterson TC et al (2006) Global observed changes in daily climate extremes of temperature and precipitation. J Geophys Res 111:D05109. https://doi.org/10.1029/2005JD006290

Allen-Collinson J (2018) 'Weather work': embodiment and weather learning in a national outdoor exercise programme. Qual Res Sport Exerc Health 10:63–74. https://doi.org/10.1080/2159676X.2017.1360382

Aunan K (1996) Exposure-response functions for health effects of air pollutants based on epidemiological findings. Risk Analysis 16:693–702. https://doi.org/10.1111/j.1539-6924.1996.tb00818.x

Begerow E (2018) Thermal objects: theorizing temperatures and the social. Culture Machine 17: 1-18. https://culturemachine.net/vol-17-thermal-objects/thermal-objects-theorizing/. Accessed 16.03.2023

Broczek K (2021) Health-related effects of heat exposure. Zenodo https://zenodo.org/record/5798640

Bröde P, Fiala D, Błażejczyk K et al (2012) Deriving the operational procedure for the Universal Thermal Climate Index (UTCI). Int J Biometeorol 56:481–494

Casanueva A, Burgstall A, Kotlarski S et al (2019) Overview of existing heat-health warning systems in Europe. IJERPH 16:2657. https://doi.org/10.3390/ijerph16152657
Conlon KC, Mallen E, Gronlund CJ et al (2020) Mapping human vulnerability to extreme heat: a critical assessment of heat vulnerability indices created using principal components analysis. Environ Health Perspect 128:097001. https://doi.org/10.1289/EHP4030
Cox DTC, Maclean IMD, Gardner AS, Gaston KJ (2020) Global variation in diurnal asymmetry in temperature, cloud cover, specific humidity and precipitation and its association with leaf area index. Glob Change Biol 26:7099–7111. https://doi.org/10.1111/gcb.15336
De Freitas CR, Grigorieva EA (2015) A comprehensive catalogue and classification of human thermal climate indices. Int J Biometeorol 59:109–120. https://doi.org/10.1007/s00484-014-0819-3
Díaz Jiménez J, Carmona Alférez R, Linares Gil C (2015) Temperaturas umbrales de disparo de la mortalidad atribuible al calor en España en el periodo 2000-2009. In: [Mortality Trigger Threshold Temperatures attributable to heat in Spain in the period 2000-2009]. Instituto de Salud Carlos III, Escuela Nacional de Sanidad, Madrid. http://gesdoc.isciii.es/gesdoccontroller?action=download&id=24/07/2015-fe69310aba. Accessed 16 March 2023
Dirección General de Salud Pública, Consejería de Sanidad, Comunidad de Madrid (2022) Vigilancia y Control de los Efectos de las Olas de Calor 2022 Plan de Respuesta ante los riesgos. [Surveillance and Control of Heatwaves' Effects. 2022 Risk Response Plan]. Madrid. https://www.comunidad.madrid/sites/default/files/doc/sanidad/calo/20220614_plan_vigilancia_olas_de_calor_2022.pdf. Accessed 13 March 2023
Dunn RJH, Willett KM, Parker DE, Mitchell L (2016) Expanding HadISD: quality-controlled, sub-daily station data from1931. Data base. . https://gi.copernicus.org/preprints/gi-2016-9/gi-2016-9.pdf. Accessed 12 March 2023
Fischer EM, Schär C (2010) Consistent geographical patterns of changes in high-impact European heatwaves. Nat Geosci 3:398–403. https://doi.org/10.1038/ngeo866
Frich P, Alexander LV, Della-Marta P et al (2002) Observed coherent changes in climatic extremes during the second half of the twentieth century. Climate Res 19:193–212. http://www.jstor.org/stable/24866781. Accessed 12 March 2023
Gasparrini A, Guo Y, Hashizume M et al (2015) Mortality risk attributable to high and low ambient temperature: a multicountry observational study. The Lancet 386:369–375. https://doi.org/10.1016/S0140-6736(14)62114-0
Gasparrini A, Guo Y, Sera F et al (2017) Projections of temperature-related excess mortality under climate change scenarios. The Lancet Planetary Health 1:e360–e367. https://doi.org/10.1016/S2542-5196(17)30156-0
Haraway D (1988) Situated knowledges: the science question in feminism and the privilege of partial perspective. Feminist Studies 14:575. https://doi.org/10.2307/3178066
Hastrup K, Skrydstrup M (eds) (2014) The social life of climate change models: anticipating nature, 1. issued in paperback. Routledge, New York, NY
He C, Kim H, Hashizume M et al (2022) The effects of night-time warming on mortality burden under future climate change scenarios: a modelling study. Lancet Planet Health 6:e648–e657. https://doi.org/10.1016/S2542-5196(22)00139-5
Holbraad M, Pedersen MA (2017) The ontological turn: an anthropological exposition. Cambridge University Press, Cambridge
Hulme M (2012) 'Telling a different tale': literary, historical and meteorological readings of a Norfolk heatwave. Climatic Change 113:5–21. https://doi.org/10.1007/s10584-012-0400-1
IMGW-PIB (2021) Klimat Polski 2020. [Climate in Poland 2020]. Institute of Meteorology and Water Management—National Research Institute, Warsaw. https://www.imgw.pl/sites/default/files/inline-files/imgw-pib-report_climate-od-poland-2021.pdf. Accessed 13 March 2023
IPCC (2001) In: Houghton JTY, Ding DJG, Noguer M, van der Linden PJ, Dai X, Maskell K, Johnson CA (eds) Climate Change 2001: the scientific basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA
Klinenberg E (2015) Heat wave: a social autopsy of disaster in Chicago, 2nd edn. University of Chicago Press, Chicago, London
Knox H (2015) Thinking like a climate. Distinktion. J Soc Theory 16:91–109. https://doi.org/10.1080/1600910X.2015.1022565
Law J, Singleton V (2005) Object lessons. Organization 12:331–355
Lemke T (2011) Biopolitics: an advanced introduction. New York University Press, New York

Luo K, Li R, Wang Z et al (2017) Effect modification of the association between temperature variability and daily cardiovascular mortality by air pollutants in three Chinese cities. Environ Poll 230:989–999. https://doi.org/10.1016/j.envpol.2017.07.045

Martínez-Solanas È, Basagaña X (2019) Temporal changes in temperature-related mortality in Spain and effect of the implementation of a Heat Health Prevention Plan. Environ Res 169:102–113. https://doi.org/10.1016/j.envres.2018.11.006

Marx W, Haunschild R, Bornmann L (2021) Heat waves: a hot topic in climate change research. Theor Appl Climatol 146:781–800. https://doi.org/10.1007/s00704-021-03758-y

Meade RD, Akerman AP, Notley SR et al (2020) Physiological factors characterizing heat-vulnerable older adults: a narrative review. Environ Int 144:105909. https://doi.org/10.1016/j.envint.2020.105909

Meehl GA, Tebaldi C (2004) More intense, more frequent, and longer lasting heat waves in the 21st century. Science 305:994–997. https://doi.org/10.1126/science.1098704

Ministerio de la Presidencia, Relaciones con las Cortes e Igualdad (2019) *Estrategia Nacional de Protección Civil*. National Civil Protection Strategy, Madrid. https://www.boe.es/eli/es/o/2019/04/26/pci488. Accessed 13 March 2023

Ministerio de Sanidad (2022) Plan Nacional de actuaciones preventivas de los efectos del exceso de temperaturas sobre la salud. [National Plan of preventive actions of the effects of excess temperatures on health], Madrid. https://www.sanidad.gob.es/ciudadanos/saludAmbLaboral/planAltasTemp/2022/docs/Plan_Calor_2022.pdf. Accessed 13 March 2023

Montero JC, Mirón IJ, Criado JJ et al (2010) Comparison between two methods of defining heat waves: a retrospective study in Castile-La Mancha (Spain). Sci Total Environ 408:1544–1550. https://doi.org/10.1016/j.scitotenv.2010.01.013

Murage P, Hajat S, Kovats RS (2017) Effect of night-time temperatures on cause and age-specific mortality in London. Environ Epidemiol 1(2):e005. https://doi.org/10.1097/EE9.0000000000000005

Nightingale AJ (2016) Adaptive scholarship and situated knowledges? Hybrid methodologies and plural epistemologies in climate change adaptation research. Area 48:41–47. https://doi.org/10.1111/area.12195

Perkins-Kirkpatrick SE, Lewis SC (2020) Increasing trends in regional heatwaves. Nat Commun 11:3357. https://doi.org/10.1038/s41467-020-16970-7

Rada Miasta Stołecznego Warszawy (2019) Strategia adaptacji do zmian klimatu dla m.st. Warszawy do roku 2030 z perspektywą do roku 2050. Miejski Plan Adaptacji. [Adaptation strategy to climate change for the Capital City of Warsaw until 2030, with a perspective until 2050. Urban Adaptation Plan], Warsaw. https://eko.um.warszawa.pl/documents/63448/23542443/strategia_2030.pdf. Accessed 13 March 2023

RCB (2022) Krajowy Plan Zarządzania Kryzysowego Aktualizacja 2021/2022. In: National Crisis Management Plan Update 2021/2022. Rządowe Centrum Bezpieczeństwa, Warsaw. https://www.gov.pl/web/rcb/krajowy-plan-zarzadzania-kryzysowego. Accessed 13 March 2023

Robinson PJ (2001) On the definition of a heat wave. J Appl Meteor 40:762–775. https://doi.org/10.1175/1520-0450(2001)040<0762:OTDOAH>2.0.CO;2

Roesler S, Kobi M, Stieger L (2022) Coping with urban climates: comparative perspectives on architecture and thermal governance. De Gruyter

Romanello M, Di Napoli C, Drummond P et al (2022) The 2022 report of the Lancet Countdown on health and climate change: health at the mercy of fossil fuels. The Lancet 400:1619–1654. https://doi.org/10.1016/S0140-6736(22)01540-9

Schnegg M (2021) Ontologies of climate change: reconciling indigenous and scientific explanations for the lack of rain in Namibia. Am Ethnol 48:260–273. https://doi.org/10.1111/amet.13028

Schwingshackl C, Sillmann J, Vicedo-Cabrera AM et al (2021) Heat stress indicators in CMIP6: estimating future trends and exceedances of impact-relevant thresholds. Earth's Future 9. https://doi.org/10.1029/2020EF001885

Seneviratne SI, Zhang X, Adnan M et al (2021) Weather and climate extreme events in a changing climate. In: Masson-Delmotte V, Zhai P, Pirani A et al (eds) Climate Change 2021: the physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, pp 1513–1766

Simpson NP, Mach KJ, Constable A et al (2021) A framework for complex climate change risk assessment. One Earth 4:489–501. https://doi.org/10.1016/j.oneear.2021.03.005

Singer M, Hasemann J, Raynor A (2016) "I feel suffocated:" understandings of climate change in an inner city heat island. Med Anthropol 35:453–463. https://doi.org/10.1080/01459740.2016.1204543

Starosielski N (2021) Media hot & cold. Duke University Press, Durham

Strauss N, Painter J, Ettinger J et al (2022) Reporting on the 2019 European heatwaves and climate change: journalists' attitudes, motivations and role perceptions. J Pract 16:462–485. https://doi.org/10.1080/17512786.2021.1969988

Sulikowska A, Wypych A (2020) Summer temperature extremes in Europe: how does the definition affect the results? Theor Appl Climatol 141:19–30. https://doi.org/10.1007/s00704-020-03166-8

Torrego Gómez D (2021) Urban planning – architectural report on thermal stress in the city of Madrid. Zenodo. https://zenodo.org/record/5771522

Vanderplanken K, van den Hazel P, Marx M et al (2021) Governing heatwaves in Europe: comparing health policy and practices to better understand roles, responsibilities and collaboration. Health Res Policy Sys 19:20. https://doi.org/10.1186/s12961-020-00645-2

Vicedo-Cabrera AM, Scovronick N, Sera F et al (2021) The burden of heat-related mortality attributable to recent human-induced climate change. Nat Clim Chang 11:492–500. https://doi.org/10.1038/s41558-021-01058-x

WMO (2017) WMO Guidelines on the Calculation of Climate Normals. World Meteorological Organization, Geneva. https://library.wmo.int/index.php?lvl=notice_display&id=20130#.ZBOA1HbMJaQ. Accessed 13 March 2023

Zhang K, Li Y, Schwartz JD, O'Neill MS (2014) What weather variables are important in predicting heat-related mortality? A new application of statistical learning methods. Environ Res 132:350–359. https://doi.org/10.1016/j.envres.2014.04.004

Zielonko-Jung K (2021) Urban planning – architectural report on thermal stress in the city of Warsaw. Zenodo. https://zenodo.org/record/5767264