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TOPICAL REVIEW

Social inequalities in exposure to heat stress and related adaptive capacity: a systematic review

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Abstract

Extreme heat is an important public health concern, and heat stress exposure and related adaptive capacity are not equally distributed across social groups. We conducted a systematic review to answer the question: What is the effect of social disadvantage on exposure to subjective and objective heat stress and related adaptive capacity to prevent or reduce exposure to heat stress in the general population? We systematically searched for peer-reviewed journal articles that assessed differences in heat stress exposure and related adaptive capacity by social factors that were published between 2005 and 2024. One author screened all records and extracted data; a second author screened and extracted 10% for validation. Synthesis included the identification and description of specific social groups unequally exposed to heat stress and with lower adaptive capacity. We assessed European studies for the potential risk of bias in their assessment. We identified 123 relevant publications. Subjective heat stress appeared in 18.7% of articles, objective heat stress in 54.5%, and adaptive capacity in 54.5%. Nearly half came from North America (47.2%), 22.8% from Asia, and 17.1% from Europe. Publishing increased from zero articles in 2005 to 21 in 2023. Most studies considered socioeconomic status (SES) (78.8%), and many considered age (50.4%), race/ethnicity (42.3%), and sex/gender (30.1%). The identified studies show that lower-SES populations, young people, immigrants, unemployed people, those working in outdoor and manual occupations, and racial/ethnic minorities are generally more exposed to heat stress and have lower adaptive capacity. Most studies of objective heat stress use inadequate measures which are not representative of experienced temperatures. European studies generally have a low or moderate risk of bias in their assessments. Social inequalities in heat stress exposure and related adaptive capacity have been documented globally. In general, socially disadvantaged populations are more exposed to heat stress and have lower adaptive capacity. These social inequalities are context-dependent, dynamic, multi-dimensional, and intersectional. It is essential to consider social inequalities during heat-health action planning and when developing and implementing climate change adaptation policies and interventions.

1. Background

Climate change is increasing the frequency, intensity, and duration of heatwaves and extreme heat events (IPCC 2023). The year 2024 was the warmest in recorded history, with global average temperatures reaching 1.55° Celsius above the pre-industrial baseline (World Meteorological Organization (WMO) 2025). Simultaneously, urbanization has shifted a large proportion of global populations into cities (United Nations 2019), where heatwaves and extreme heat events are more frequent and intense due to the 'urban heat island effect' (IPCC 2023). There is high confidence that the combination of rising temperatures and ongoing urbanization has led to a 200% increase in global exposure to extreme heat between 1983 and 2016 (Tuholske *et al* 2021), and that approximately nine percent of the global population (over 600 million people) are already exposed to historically unprecedented levels of extreme heat due to climate change (Lenton *et al* 2023).

Heat harms human health and wellbeing (Ebi *et al* 2021, Faurie *et al* 2022). Exposure to heat can lead to heat stress, which can subsequently cause heat stroke, heat exhaustion, heat cramps, and heat syncope (fainting) (Kovats and Hajat 2008). These conditions can lead to organ dysfunction, organ damage, and potentially death (Kovats and Hajat 2008). If individuals or populations are routinely exposed to extreme heat without adequate ability to avoid or adapt to heat stress, they may experience a heightened risk of cardiovascular disease, kidney disease, worsened mental health, and more (Oppermann *et al* 2021). Excess mortality due to heat has been documented globally (Vicedo-Cabrera *et al* 2021), in India (Azhar *et al* 2014), China (Pan *et al* 2023), Europe (Ballester *et al* 2023), Latin America (Kephart *et al* 2022), and North America (Weinberger *et al* 2020).

Existing research has shown that people in low- and middle-income countries, socioeconomically deprived people and communities, outdoor workers, and racial and ethnic minorities are more at risk of heat-related cardiovascular and other health outcomes, including mortality (Gronlund 2014, Benmarhnia *et al* 2015, Singh *et al* 2024, Son *et al* 2019). Social inequalities in heat-related mortality have been documented in France (Vanhems *et al* 2003, Poumadère *et al* 2005), the United States (O'Neill *et al* 2003, Medina *et al* 2006), and China (Huang *et al* 2015). These differences in heat-related health outcomes and mortality are likely exacerbated by existing social inequalities in chronic and non-communicable diseases that increase sensitivity to heat including type 2 diabetes, cardiovascular disease, cancers, chronic respiratory diseases, and obesity (Sommer *et al* 2015). While substantial evidence exists related to inequalities in heat-related health outcomes (Gronlund 2014, Benmarhnia *et al* 2015, Son *et al* 2019, Singh *et al* 2024), and social inequalities in current and future exposure to heat stress at regional and national levels have been documented (Alizadeh *et al* 2022), social inequalities in exposure to heat stress and related adaptive capacity at the sub-regional and sub-national levels are less well understood. There is evidence that exposure to extreme heat and the ability to avoid or reduce exposure to extreme heat are not equally distributed across countries and global populations (Alizadeh *et al* 2022, Birkmann *et al* 2022). This inequitable exposure to extreme heat and inequitable ability to cope with the effects of rising temperatures, a phenomenon that has recently been labeled 'thermal inequity', is considered a core issue within the realm of climate and environmental justice (Mitchell and Chakraborty 2018a).

The 2024 European Report of the Lancet Countdown on Health and Climate Change reports that EU policies include little engagement with aspects of equality, equity, and justice in climate research and policy, and that addressing inequalities in exposures and health risks is not explicitly included (Daalen *et al* 2024). In order to effectively prevent unequal harms related to heat exposure and unequal levels of adaptive capacity, governments, decision-makers, and actors on national, regional, and local levels require information on which groups are most vulnerable[5] (IPCC 2022). In other words, to prioritize and tailor heat health adaptation strategies and interventions, decision-makers need to know which groups are most exposed to heat stress and where these affected populations live and work. This knowledge can inform the development and implementation of heat adaptation measures across all sectors (including health, urban planning, and labor) that reduce thermal inequity, reduce heat-related health effects and health inequalities, and reduce heat-related productivity loss. This review attempts to guide and support such interventions by gathering and synthesizing the relevant evidence and by presenting policy recommendations emerging from the results.

To date, no known systematic review of social inequalities in exposure to heat stress or related adaptive capacity has been published. The objective of our review is therefore to identify and synthesize the results of studies of subjective[6] and objective[7] heat stress and related adaptive capacity[8] that examine social equality or inequality. Our research question uses the 'PECOS' format: Population, Exposure, Comparison, Outcome, and Study design (Morgan *et al* 2018): Among the (P) general population, what is the effect of (E) disadvantaged social status/factors as compared to (C) advantaged social status/factors on (O) (1) exposure to *subjective* heat stress, (2) exposure

[5] 'The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt' (IPCC 2022).

[6] Subjectively reported heat stress: Self-reported assessment of the extent to which participants experience heat as physically and/or mentally stressful.

[7] Objectively measured heat stress: Measurements of temperature (and often humidity) that document conditions that may lead to heat stress.

[8] Adaptive capacity: One's ability to reduce exposure to heat and reduce the negative impacts of heat exposure, such as heat stress.

to *objective* heat stress, and (3) adaptive capacity to prevent or reduce exposure to heat stress, as documented in (S) peer-reviewed original research publications pertaining to descriptive, observational, or ecological studies in which both the exposure and outcomes are measured through real-world and not simulated or synthetic data, and in which the research aims to measure differences in exposure to heat stress or adaptive capacity.

The results of this review are relevant for policy and can, for example, support the implementation of the updated German Strategy for Adaptation to Climate Change (Deutsche Anpassungsstrategie an Den Klimawandel 2008, Bundes-Klimaanpassungsgesetz (KAnG) 2023), and may be useful in updating guidance for heat health action plans and heat health prevention and protection globally.

2. Methods

We developed this protocol under the guidance of the Reporting Standards for Systematic Evidence Syntheses (ROSES) (Haddaway *et al* 2018). The completed ROSES checklist can be viewed in supplementary materials (supplementary file 1). Our protocol also follows the guidance of Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA-P) and is registered in PROSPERO under ID #CRD42023412520.

2.1. Eligibility criteria

The inclusion and exclusion criteria for this review are listed below in table 1 in the framework of our PECOS research question. Broadly, we considered original research studies published in English or German on or after 1 January 2005, for inclusion in the study. We chose 2005 as the starting point for our search because the first publications on the impacts of the 2003 European heatwave emerged during this year.

Our review is unique in that our exposure of interest is the broad category of social factors, and our outcome of interest is exposure to heat stress and related adaptive capacity (two factors that are normally included as exposures in health research). To capture all potentially relevant research, we did not limit our search to any specific set of social factors. We also took a broad approach to the definition of heat stress, including studies that measured personal feelings of discomfort due to heat, along with studies that used empirical measures such as land surface temperature, heat index, and air temperature. Our definition of adaptive capacity was also broad, including any factors allowing individuals or populations to avoid, reduce, or ameliorate the adverse effects of heat stress exposure.

2.2. Searches and screening

Four reviewers developed search strings using Boolean logic by referencing existing research, methods-focused publications, systematic reviews, and meta-analyses identified through non-systematic searches of the available literature. The reviewers then discussed and adjusted the search terms through an iterative process. Search strings were first developed for PubMed and included PubMed MeSH terms, then were adapted for Scopus and Web of Science. Search strings for all three databases can be found in supplementary materials (supplementary file 2). Because the review included three outcomes of interest, we developed three separate search strings: one for subjective heat stress, one for objective heat stress, and one for adaptive capacity. We took this approach to better adjust each search based on the particular outcome of interest, and to ensure the ability to adjust and re-do searches for a single outcome if needed.

Search strings were pilot-tested and refined to improve their performance and reduce irrelevant results. Refinement included adding and adjusting search terms and adding exclusion search terms to, for example, reduce many irrelevant search results that dealt with animal studies where animal temperatures were taken with results reported for male and female animals separately. Search terms were refined using a list of 'benchmark' articles, previously known to the authors or identified through informal database searches, that fulfilled our inclusion criteria (Harlan *et al* 2006, Seebass 2017, Chakraborty *et al* 2019, Dialesandro *et al* 2021, Kemen *et al* 2021).

We searched PubMed/Medline, Scopus, and Web of Science using the three pre-tested Boolean search strings for articles published between 1 January 2005, and 31 January 2024. Search results were downloaded as CSV files and imported into a reference management system (Zotero). The full list of records was then exported from Zotero into a spreadsheet for screening.

Screening took place in five stages. One author (SCS) removed records ineligible due to their type (e.g. conference abstract), publication date, or language. SCS then removed duplicates. SCS screened titles of all remaining records with another author (FMW) screening 10% of these to check for consistency. Decisions made on this 10% were compared and discussed to resolve disagreements, with a third author (AS) resolving conflicts. The screening process for titles was then replicated for the remaining abstracts (i.e. SCS screened all abstracts, FMW screened 10%, AS resolved conflicts). We obtained full texts for all articles remaining after abstract screening. At the full-text screening stage, SCS screened all English articles, while FMW screened all German articles plus 10% of the English articles. The decisions made on this 10% were compared and discussed. Initial agreement between the two screeners

Table 1. Inclusion and exclusion criteria for the systematic review protocol, organized according to the PECOS statement for the review.

PECOS	Inclusion	Exclusion
Population	General human population including all age groups	Non-human studies
Exposure	Disadvantaged social factors related to social status, socioeconomic status, cultural capital, or social position	Factors unrelated to social status, socioeconomic status, cultural capital, or social position
Comparison	Advantaged social factors related to social status, socioeconomic status, cultural capital, or social position	Factors unrelated to social status, socioeconomic status, cultural capital, or social position
Outcome	• Objective heat stress • Subjective heat stress • Adaptive capacity related to heat stress	• Body temperature • Health conditions • Mortality
Study design	1) Study aims to measure or observe differences in exposure to heat stress or adaptive capacity across social groups. 2) The following study types are considered: • Descriptive • Observational • Ecological • Cross-sectional • Cohort • Other human epidemiological studies	• Experimental studies • Simulations • Projected data/future scenarios • Studies using synthetic data • Development and application of social vulnerability indices • Qualitative • Animal studies • *In vitro* and *in vivo* studies • Reviews and studies not presenting original research

prior to discussion at all three stages ranged between 70% and 85%. Once the screening was completed, we retained a list of all articles excluded at the full-text screening stage with reasons for exclusion and we have retained PDF copies of all articles in case of future queries.

We then implemented a limited snowballing approach to identify any relevant and eligible articles that may have been missed by our searching and screening methodology. Using Google Scholar, SCS screened the lists of titles that have cited seminal articles identified through our systematic search and screening process: Harlan *et al* 2006 (cited by 1,220); Mitchell and Chakraborty (2015) (cited by 126); and Chakraborty *et al* 2019 (cited by 179). SCS screened abstracts and full texts of relevant articles identified from these lists of titles.

2.3. Data extraction

We extracted data from included studies using a structured process and a pre-designed extraction spreadsheet (Excel). Three reviewers developed the extraction sheet and an extraction guide through an iterative process, which included testing the spreadsheet and guide using five papers that metall inclusion criteria. SCS extracted data from all included studies published in English, and FMW extracted data from 10% of the included studies published in English, plus all studies published in German. The two authors compared and discussed extracted data from the 10% of studies to ensure the appropriateness and consistency of data extraction.

Authors extracted study characteristics including publication year, type of study (i.e. ecological, cross-sectional, or cohort), geographic location, and study timeframe. Authors also gathered characteristics of the study population, including the social factors of interest, along with the outcome of interest and details on how it was defined and gathered. If study authors noted any suspected root causes of inequalities in the outcome, policy recommendations, and research recommendations, they also captured those details. An overview of all extraction domains and characteristics is presented in table 2. The extraction guide is included in supplementary materials (supplementary file 3).

2.4. Analysis and synthesis

We summarized the characteristics of the included studies using descriptive statistics, including the proportion of studies by global region, study type, type of social factor exposure, type of outcome (subjective heat stress, objective heat stress, and adaptive capacity), and outcome measurement approach. We also developed a narrative synthesis of the aggregated data, including an assessment of which social factors may be most important in determining groups most at risk of heat stress exposure and least able to adapt to heat. Additionally, we described differences across studies in the definitions of study exposures (social factors), outcomes (subjective/objective heat stress exposure and adaptive capacity), and measurement approaches for outcomes. A synthesis of the main findings, root causes of inequalities, recommendations for policy,

Table 2. An overview of data extracted from included studies, organized by data domain.

Domain	Characteristics to be extracted
Reference and document characteristics	Authors Publication year DOI Research funder Any reported conflicts of interest
Study characteristics	Type of study (e.g. ecological, cross-sectional, or cohort) Timeframe (e.g. short-term or long-term) Continent, country, and state or city Study period
Study population characteristics	Level or unit of analysis (e.g. individuals, neighborhoods, cities, counties) Study population (e.g. children, people over age 65, pregnant women) Health condition, e.g. if the study only included people with diabetes or heart disease Sex, e.g. if the study only included males or females Other characteristics defining the population (e.g. recipients of social benefits, people living in rental units) Sample size Mean study population age Age range of population
Exposure: Social factors	Demographic (sex, gender, age group) Sociocultural (race, ethnicity, religious group, migration background) Health status (disability, in-need-of-care) Socioeconomic (level of education, occupation type, income level) Social and behavioral (social isolation, drug or substance use, housing factors or homelessness) Area characteristics (area-level socioeconomic characteristics, built environment disadvantages such as lack of greenness) Other social factor (to be identified during data extraction)
Outcome	Type of outcome (subjective heat stress, objective heat stress, adaptive capacity) Specific definition of the outcome within the paper Measurement methods and details
Statistical methods	Statistical methods and analytical approach Considered confounders
Findings and insights	Main results of analyses Root causes of inequities in experience of the outcome Policy recommendations Research recommendations Health outcomes reported, if any Social outcomes reported, if any

and gaps in the available research has informed discussion of the findings. The analysis and synthesis are international in scope.

2.5. Risk-of-bias rating

We used the Office of Health Assessment and Translation (OHAT) Risk of Bias Rating Tool for Human and Animal Studies (National Toxicology Program 2015, 2019). The OHAT Risk of Bias tool allows for the assessment of internal validity and risk of bias across a wide range of study types, including cohort and cross-sectional studies. As we anticipated that included studies would be heterogeneous in their design, this tool allowed us to assess the risk of bias across the spectrum of included research. Assessment questions cut across the following types of bias: selection, confounding, attrition/exclusion, detection, selective reporting, and other. Studies were rated in response to each question as having 'definitely low risk of bias', 'probably low risk of bias', 'probably high risk of bias', or 'definitely high risk of bias'. Studies were assigned to one of three 'tiers' based on our assessment of their risk of bias (National Toxicology Program 2019). We selected the following three criteria as 'key' for our assessment: (1) risk of bias in the selection of participants or observations ('Did the selection of study participants result in appropriate comparison groups?'), (2) risk of bias in the characterization of the exposure ('Can we be confident in the exposure characterization?' and (3) risk of bias in the assessment of the outcome ('Can we be confident in the outcome assessment?'). If a study was graded as having a 'definitely high' or 'probably high' risk of bias for all three key criteria, and a simple majority of other risk of bias criteria received a grade of 'definitely' or 'probably' high risk of bias, the study was assigned to Tier 3. Studies that received 'definitely low' or 'probably low' risk of bias grades across key criteria and a majority of other criteria were assigned to Tier 1. Studies that failed to meet the criteria of either Tier 1 or Tier 3 were assigned to Tier 2. For example, if a study was graded as having a high risk of bias across key criteria but a low risk of bias across all other criteria (or vice versa), it was assigned to Tier 2.

To ensure the appropriateness of this approach, we piloted the OHAT Risk of Bias tool and its related Tier system with three of the previously identified 'benchmark' papers: Chakraborty *et al* 2019, which focuses on objective heat stress; Harlan *et al* 2006, which focuses on objective heat stress and adaptive capacity; and Seebass 2017, which focuses on subjective heat stress and adaptive capacity. The tool was generally appropriate but required small modifications to meet the requirements of our unique set of studies. More details on these modifications and the rationale for these adaptations are described in supplementary materials (supplementary file 4).

Due to the large volume of included articles, we were unable to perform the risk-of-bias assessment of all studies. Because the review was originally motivated to inform the review and update of Germany's Strategy for Adaptation to Climate Change, and because of the authors' familiarity with the European context, the risk-of-bias assessment was limited to the included European studies. SCS rated all English-language studies, and FMW rated German-language studies plus 10% of the English-language studies. Decisions made for this 10% were compared and discussed to resolve any disagreements. Any conflicting decisions in the critical appraisal process that could not be resolved between the two reviewers were considered and decided by AS.

3. Results

3.1. Identification of relevant studies

The results of our systematic search and screening methodology are shown in figure 1. Our searches identified 32 018 potentially relevant records. The five stages of screening eliminated 2608 ineligible records, 16 410 duplicates, 9530 irrelevant titles, 3079 irrelevant abstracts, and 273 irrelevant full texts. This process resulted in the inclusion of 114 studies. We also identified nine additional studies through snowballing. A total of 123 studies were therefore included in our review.

3.2. Characteristics of included studies

Descriptive statistics from studies included in our review are displayed in table 3, and a table of all studies and their specific characteristics as well as a full bibliography of reviewed studies can be found in supplementary materials (Table S1, supplementary file 5).

More than half of studies included both objective heat stress ($N = 67$) and adaptive capacity ($N = 67$), but only 19% considered subjective heat stress ($N = 23$). There was substantial overlap in the inclusion of the three outcomes of interest, which is illustrated in a figure in Supplementary File 6. Adaptive capacity was considered alone in 28.5% of studies ($N = 35$), objective heat stress alone in 39.0% of studies ($N = 48$), and subjective heat stress alone in 6.5% of studies ($N = 8$). One study (0.8%) included all three outcomes. Thirteen studies (10.6%) included both adaptive capacity and subjective heat stress, one (0.8%) both subjective heat stress and objective heat stress, and 17 (13.8%) both adaptive capacity and objective heat stress. Nearly half of the studies described research conducted in North America, almost one quarter in Asia, and just over 17% in Europe. Few studies were identified from Africa, the Middle East, Latin America, and Oceania. Two studies included data from multiple regions. Nearly all studies were cross-sectional or concerning data from only one time-point, while only seven studies described changes over time. More than half of the studies used geographic areas as their units of analysis, while slightly fewer considered data collected from individuals, and a small group used data gathered from discrete locations such as residential parcels or transit stops. Sample sizes varied dramatically from two observations to more than 22 million. Almost all studies considered the general population, while a few studied specific occupational, age, or sociodemographic groups. For more details, see table 3.

Publication volume over time is displayed in figure 2. The volume of publications has grown dramatically over time, with more than half of the identified studies published in 2021–2023. While the publication of studies of objectively measured heat stress and adaptive capacity has steadily increased over time, studies of subjectively reported heat stress have not: we only identified one study published in 2023.

The included studies considered many social factors. Each category may include several definitions, as most social factor variables were

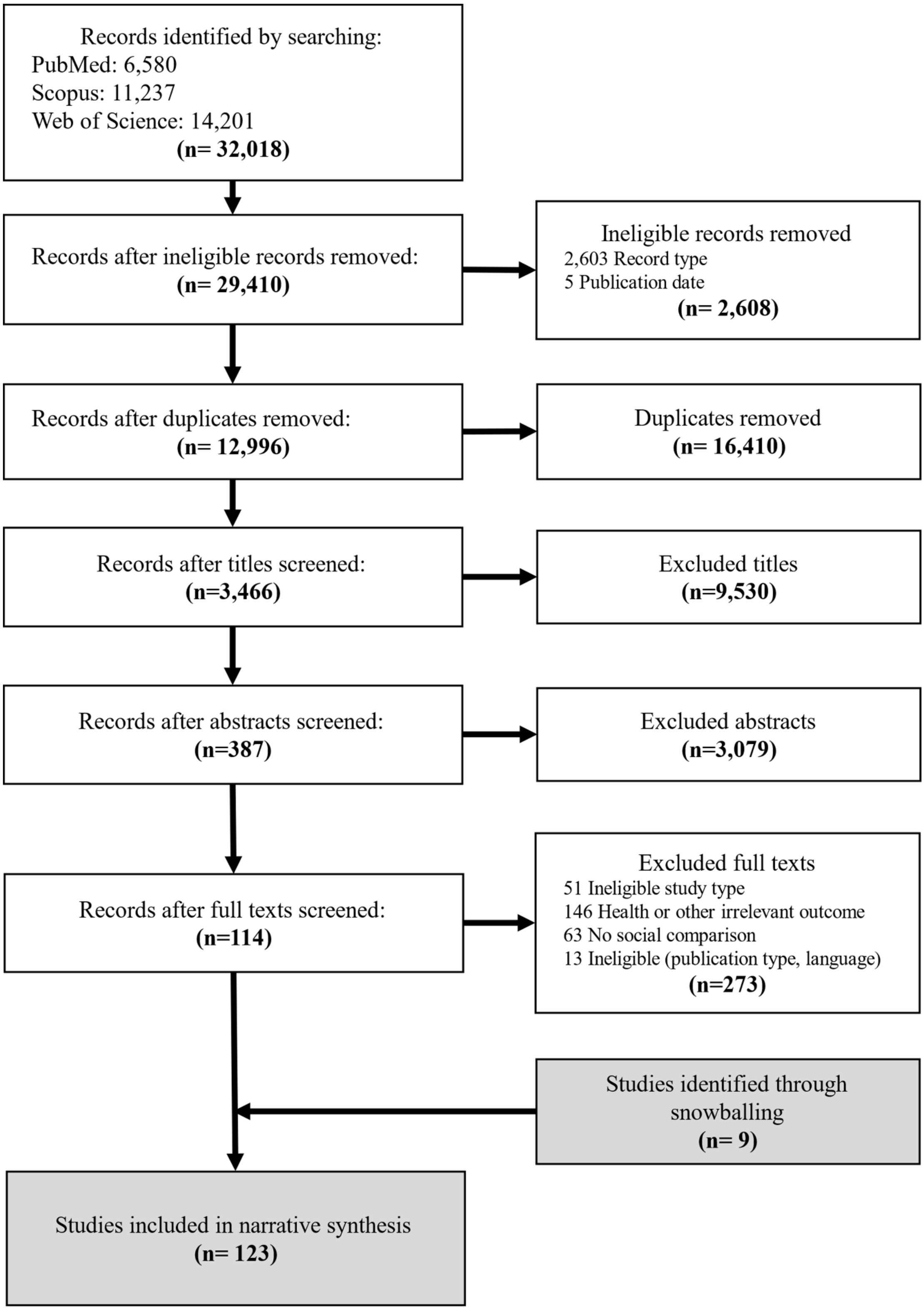

Figure 1. PRISMA flowchart describing the results of five stages of screening.

defined differently across studies. Examples of how each social factor was defined within the included studies, along with the number and proportion of studies that included each social factor, can be found in table 4.

Though the included articles considered many social characteristics, some stand out as being the most heavily studied. Age, sex/gender, social isolation, race/ethnicity, migration, socioeconomic status (SES), employment characteristics, housing characteristics, and neighborhood characteristics all appeared as social comparators in more than 10 studies. SES was the most studied characteristic, appearing in 97 articles.

Table 3. Characteristics of included studies.

Characteristic	All (*n*, %)	Subjective heat stress (*n*, %)	Objective heat stress (*n*, %)	Adaptive capacity (*n*, %)
Outcome	123 (100)	23 (18.7)	67 (54.5)	67 (54.5)
Region				
Africa	2 (1.6)	2 (8.7)	0 (0)	2 (3.0)
Asia	28 (22.8)	8 (34.8)	12 (17.9)	14 (20.9)
Europe	21 (17.1)	9 (39.1)	7 (10.5)	18 (26.9)
Latin America	6 (4.9)	0 (0)	6 (9.0)	1 (1.5)
Middle East	2 (1.6)	0 (0)	0 (0)	2 (3.0)
North America	58 (47.2)	4 (17.4)	40 (59.7)	26 (38.8)
Oceania	5 (4.1)	1 (4.4)	1 (1.5)	4 (6.0)
Global	2 (1.6)	0 (0)	2 (3.0)	0 (0)
Study design				
Single time point	116 (94.3)	23 (100)	62 (92.6)	64 (95.5)
Multiple time points	7 (5.7)	0 (0)	5 (7.5)	3 (4.5)
Unit of analysis				
Individuals	46 (37.4)	23 (100)	7 (10.5)	34 (50.8)
Specific locations	12 (9.8)	0 (0)	6 (9.0)	9 (13.4)
Geographic areas	65 (52.9)	0 (0)	54 (80.6)	24 (35.8)
Number of observations (range, median)	2–22 347 878 (688)	38–22 347 878 (688)	2–510 600 (923)	3–212 336 (624)
Number of observations				
Fewer than 100	13 (10.6)	1 (4.4)	10 (14.9)	6 (9.0)
100–999	42 (34.2)	10 (43.5)	15 (22.4)	28 (41.8)
1000–9,999	25 (20.3)	7 (30.4)	10 (14.9)	16 (23.9)
10 000–99 999	14 (11.4)	1 (4.4)	10 (14.9)	5 (7.5)
100 000 or more	5 (4.1)	2 (8.7)	3 (4.5)	2 (3.0)
Not reported	24 (19.5)	2 (8.7)	19 (28.4)	10 (14.9)
Study population				
General population	114 (92.7)	18 (78.3)	64 (95.5)	61 (91.0)
Specific age or demographic group	5 (4.1)	2 (8.7)	1 (1.5)	3 (4.5)
Workers	4 (3.2)	3 (13.0)	2 (3.0)	3 (4.5)

We found diversity in the way the three outcomes were defined and measured across included studies. Some examples of how these outcomes were defined are presented in table 5.

While all subjective heat stress measures were gathered using subjective responses to survey questions, objective heat stress measurement methods were more diverse. Four primary methods were used by study authors, namely: satellite imagery (47 studies), data from weather or meteorological stations (11 studies), data from fixed temperature and/or humidity sensors (12 studies), and data from thermocrons or hygrochrons worn by study participants (two studies). The most common approach was to use satellite data to estimate land surface temperature.

3.3. Summary of study findings for select social factors

Nearly all studies identified associations or relationships between social factors and the three outcomes of interest. A summary of findings by social factor and outcome can be found in table 6. Note that the summary in table 6 does not indicate the direction of association, only the presence of one. All identified papers found a relationship or association between the outcomes of interest and health status, single-parent households, religion, homelessness, HOLC security rating, and various social indices. Most studies related to age, sex/gender, marital status, household size, race/ethnicity, SES, employment, housing, and neighborhood characteristics found a relationship or association. Studies of disability and social isolation were less likely to find a relationship or characteristic.

In the following, we present narrative summaries of the results for select social factors identified in our review. Note that the cited articles are not exhaustive in all cases, especially in summaries for social factors with many citations, such as SES, race/ethnicity, and age.

3.3.1. Age

Several studies found that older people were *less* exposed to subjectively reported heat stress

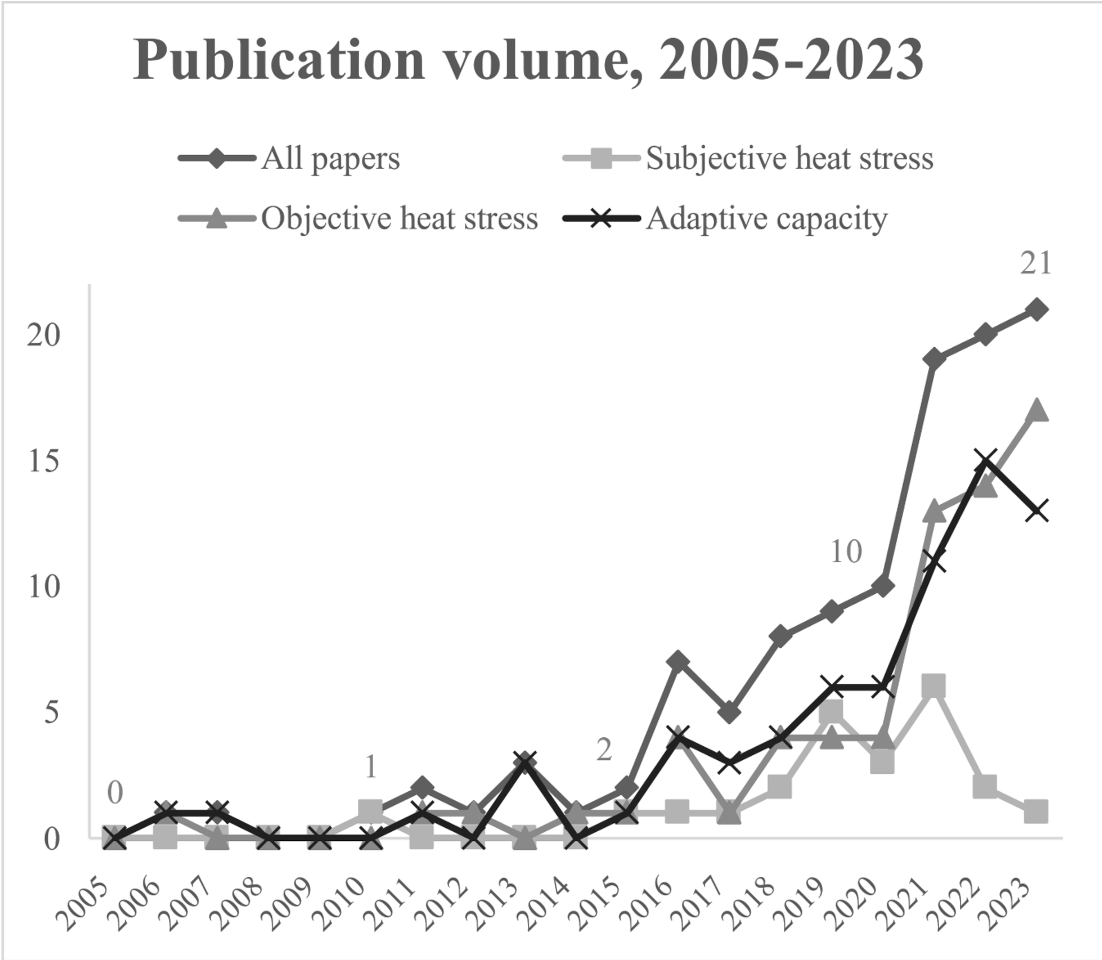

Figure 2. Publication volume over time, 2005–2023.

than younger people, while fewer studies found the opposite. For example, studies in Bonn and Nuremberg, Germany, found that those aged 75 years and over were the *least* exposed to subjective heat stress (Seebass 2017, Sandholz *et al* 2021) while another German study in Dresden found that those in that age group were the *most* exposed (Borchers *et al* 2020). Other studies in the United States (Wilhelmi *et al* 2021), Malaysia (Zander and Mathew 2019), Taiwan (Shih 2022), and the United Kingdom (Khare *et al* 2015) also found that older people were less likely to report subjective heat stress or heat stress symptoms than younger people.

Studies of objective heat stress echo these findings, with most showing that increasing age was associated with decreasing exposure to objectively measured heat. Three studies in the United States found that neighborhoods with higher proportions of children (with age cut-offs ranging from 5 years old to 18 years old) are more exposed to heat than older age groups (Mitchell and Chakraborty 2015, Li 2021, Renteria *et al* 2022). Moreover, increasing age and the proportion of people aged 65 and over were associated with lower temperatures in the United Kingdom (Zhou *et al* 2023) and the United States (Mitchell & Chakraborty 2018b, Voelkel *et al* 2018, Ilbeigi and Jagupilla 2020, Hsu *et al* 2021, Li 2021). In contrast, other studies in the United States (Hoehne *et al* 2018, Hass and Ellis 2019) and China (Zeng *et al* 2022) found that older people were more exposed to objectively measured heat.

In a few studies, older adults were found to have lower access to air conditioning at home and to cooling centers (Voelkel *et al* 2018, Kim *et al* 2021, Quick and Tjepkema 2023). In contrast, adaptive capacity related to greenspace, greenness, tree cover, and blue space seems to be stronger for older age groups across most but not all studies that considered these outcomes. For example, a study in the United Kingdom found that a higher average age was associated with higher tree canopy cover and higher area-level greenness but not with blue spaces (Zhou *et al* 2023). A study in Germany found that students, young professionals, and families with children had the lowest access to greenness (Sandholz *et al* 2021). In contrast, a study in Taiwan found that older populations had less access to greenness and greenspace, but had closer proximity to water (Shih 2022). Several studies also found that older people had more knowledge about the risks of heat and how to protect themselves from

Table 4. Number of studies that included each social factor and examples of how social factors identified within included studies were defined. Categories are ordered from highest to lowest by the proportion of the 123 included studies that considered each social factor.

Social factor	Number of studies (*n*, %)	Examples
Socioeconomic status	97 (78.9)	Income level, income category, poverty or at risk of poverty, level of education, proportion of population in poverty, median income, proportion without higher education, deprivation, education level of head of household, proportion literate, proportion with specific assets (e.g. television, car)
Age	62 (50.4)	Continuous age, age group, proportion of the population below 5 years or above 65 years
Race/ethnicity	52 (42.3)	Individual race or ethnicity, proportion of racial or ethnic minorities, proportion of indigenous or aboriginal people, proportion Caucasian or white, ratio of white to non-white population, proportion scheduled caste
Housing characteristics	42 (34.1)	Home ownership versus renting, housing materials, building type (e.g. single family detached, multi-unit, mobile home), subsidized housing, year of construction, number of rooms, presence of plumbing, floor of residence (e.g. ground floor, attic or top floor), housing size in square meters
Sex/gender	37 (30.1)	Male or female sex categorization, gender ratio of a population, female head of household
Neighborhood characteristics	32 (26.0)	Urban/suburban/rural, distance to nearest health facility, greenness, presence of parks, proportion vacant land, formal versus informal neighborhood, crime, neighborhood vulnerability
Employment characteristics	29 (23.6)	Unemployment, occupational category, work outdoors versus indoors, head of household employment status, proportion involved in agriculture, work hours, work time spent outside, workload (full, part, casual), employer (private, public, self)
Social isolation	11 (8.9)	Living alone, over 65 and living alone, elderly and living alone, social contacts per week or month, number and frequency of social contacts, social isolation index, proportion of people living alone
Migration	11 (8.9)	Migration background, language spoken at home, English or local language ability, monolingual English speakers, non-citizens, nationality, income level of country of origin, length of residence
Household size	10 (8.1)	Number of people living in a household, household composition and characteristics
Social index (various)	10 (8.1)	Social vulnerability index, composite social vulnerability score, hardship index, Territorial Welfare Index, Canada Index of Multiple Deprivation, New Zealand Deprivation Index, Gini coefficient
Marital status	8 (6.5)	Single, married, divorced, widowed
HOLC Security Rating	7 (5.7)	'During the late 1930s [in the United States of America], the Home Owners' Loan Corporation (HOLC) developed a series of area descriptions with color-coded maps of cities that summarized mortgage lending risk…black neighborhoods overwhelmingly received the lowest rating. To summarize neighborhood-level characteristics, the HOLC consulted with local real estate professionals and gave letter grades A, B, C, and D to neighborhoods with map colors of green, blue, yellow, and red, respectively.' (Fishback *et al* 2023)
Health status	7 (5.7)	Self-rated health, diagnosis with a chronic disease, general health status, health condition
Disability	3 (2.4)	Proportion of the population that is disabled, impairment or disability with restricted movement, problems climbing stairs
Religion	3 (2.4)	Religion (Christian, Catholic, Buddhist, other), participation in a religious fast
Single parents	2 (1.6)	Children with single parents, proportion of single parent households with children under 18
Homelessness	2 (1.6)	Proportion of population that is homeless, outdoor versus indoor sleeping space

Table 5. Examples of how outcomes were defined across different studies.

Subjective heat stress	Objective heat stress	Adaptive capacity
• Answer to, 'How strongly affected do you feel by persistent summer heat?' or 'On average, how affected are you by heat?'. • Experiencing symptoms during periods of heat such as lethargy, difficulty sleeping, trouble concentrating, or dizziness. • Answer to, 'During the last 12 months, how often have you experienced at work high temperatures that make you uncomfortable?' • Students reporting that classrooms get 'too hot' on hot days 'never,' 'some of the time,' 'most of the time,' or 'all of the time'.	• Land surface temperature • Surface urban heat island • Surface urban heat extremes • Urban heat island intensity • Urban heat island severity • Urban heat risk index • Area-level 'hot spot' (high temperature, surrounded by other high temperature areas) • Mean ambient or air temperature • Mean radiant temperature • Heatwave duration • Annual cooling degree days • Relative humidity • Individually experienced heat index • Human thermal comfort index • Wet bulb globe temperature • Temperature or heat index at a specific time of day, e.g. 7pm	• Ownership and use of air conditioners, fans, or evaporative coolers • Structural changes to home dwelling to adapt to heat such as insulation, window film • Area-level greenness or tree canopy • Proximity to blue space • Proximity and access to cooling centers or public parks • Knowledge of health risks of heat and protective behaviors

Table 6. Association between social factors and outcomes of interest. This table displays a summary of the results of analyses described within the identified studies. Within the table, each repetition of '✱' represents one study where the authors report an association or relationship between the social factor and outcome of interest. Each repetition of '×' represents one study where the association or relationship was not found.

Social factor	Subjective heat stress	Objective heat stress	Adaptive capacity
Age	✱✱✱✱✱✱✱✱✱✱✱ ✱✱✱✱×	✱✱✱✱✱✱✱✱✱✱✱✱ ✱✱✱✱✱✱✱✱✱✱××××	✱✱✱✱✱✱✱✱✱✱✱✱✱✱ ✱✱✱✱✱✱✱✱✱✱✱ ✱✱✱ ×××××××
Disability	✱	✱×	
Health status	✱✱✱✱		✱✱✱✱✱
Sex or gender	✱✱✱✱✱✱✱✱✱✱✱××	✱✱✱✱✱✱××	✱✱✱✱✱✱✱✱✱✱✱✱✱✱✱ ✱✱✱×××××××
Marital status	✱	✱	✱✱✱××
Household size or number of children	✱×	✱✱	✱✱✱✱✱✱✱×
Single parent household		✱	✱
Social isolation	✱××	✱✱×××	✱✱×××
Race or ethnicity	✱✱✱✱×	✱✱✱✱✱✱✱✱✱✱✱✱✱✱✱ ✱✱✱✱✱✱✱✱✱✱✱✱✱✱✱ ✱✱✱✱✱✱✱✱✱✱✱✱✱ ✱✱✱✱✱✱✱✱✱✱×××	✱✱✱✱✱✱✱✱✱✱✱ ✱✱✱✱✱✱✱✱×××××
Migration	✱✱	✱✱✱✱✱✱✱×	✱✱✱✱✱
Religion	✱		✱✱
Socioeconomic status	✱✱✱✱✱✱✱✱✱✱✱××	✱✱✱✱✱✱✱✱✱✱✱✱✱ ✱✱✱✱✱✱✱✱✱✱✱✱✱✱✱ ✱✱✱✱✱✱✱✱✱✱✱✱×××	✱✱✱✱✱✱✱✱✱✱✱✱✱✱✱ ✱✱✱✱✱✱✱✱✱✱✱✱✱ ✱✱✱✱✱✱✱✱✱✱✱✱✱✱✱ ✱✱✱✱✱✱✱✱✱✱✱✱ ✱✱✱✱✱✱✱✱✱✱✱✱✱ ×××××
Employment status or job characteristics	✱✱✱✱✱✱✱✱✱✱××	✱✱✱✱✱✱✱✱✱	✱✱✱✱✱✱✱✱✱✱✱✱×××
Housing characteristics	✱✱✱✱×	✱✱✱✱✱✱✱✱✱✱✱✱✱✱ ✱✱×××	✱✱✱✱✱✱✱✱✱✱✱✱ ✱✱✱✱✱✱✱✱✱×
Homelessness		✱✱	
Neighborhood characteristics	✱✱✱✱××	✱✱✱✱✱✱✱✱✱✱✱✱✱✱✱✱	✱✱✱✱✱✱✱✱✱✱✱✱✱××
HOLC security rating		✱✱✱✱✱✱	✱✱✱
Social index (various)		✱✱✱✱✱✱	✱✱✱✱✱✱

heat (Kalkstein and Sheridan 2007, He *et al* 2022, He 2023), while fewer found the opposite (Li *et al* 2016). Despite their higher knowledge, several studies found that elderly individuals were less likely to implement various personal adaptive behaviors to reduce their exposure to heat (Kalkstein and Sheridan 2007, Bai *et al* 2013, Khare *et al* 2015, Kussel 2018, Kemen *et al* 2021, Sandholz *et al* 2021).

3.3.2. Sex/gender

Several studies found that females were more likely to report subjective heat stress than males in China (He 2023), Taiwan (Shih 2022), Thailand (Arifwidodo and Chandrasiri 2020), Germany (McCall *et al* 2019, Borchers *et al* 2020, Kemen *et al* 2021), and the United States (Noelke *et al* 2016). Regarding objectively measured heat, two studies from Asia found that females were *more* exposed than males (Weitz *et al* 2022, Zeng *et al* 2022), while two studies from Europe and North America found that females were *less* exposed than males (Hoehne *et al* 2018, Zhou *et al* 2023).

Females were found to have higher knowledge related to heat adaptation than males in the country of Georgia (van Loenhout *et al* 2021), but lower knowledge than males in Saudi Arabia (El-Gamal *et al* 2021). Females were more likely during hot weather to implement behaviors such as increasing hydration (Zander *et al* 2018), wearing a hat or using an umbrella (Shih 2022), staying indoors during hot weather (Bai *et al* 2013), taking a cold shower or bath (McCall *et al* 2019), and other body-related and personal protective strategies (Khare *et al* 2015, Li *et al* 2016, Kemen *et al* 2021). Females were found to have higher access to greenness than males in the United Kingdom (Zhou *et al* 2023), but lower access in Taiwan (Shih 2022). Male-headed households were more likely to report housing interventions to improve their heat adaptive capacity in Germany (Kussel 2018, Osberghaus and Abeling 2022).

3.3.3. Social isolation

Higher social isolation was found to have a relationship with higher subjective heat stress in some studies (Seebass 2017, Wilhelmi *et al* 2021) but not in others (Kemen *et al* 2021). Several studies found no relationship between objectively measured heat and the proportion of people living alone or elders living alone (Huang *et al* 2011, Voelkel *et al* 2018, Renteria *et al* 2022). One study in the United States found that neighborhoods with a higher proportion of people living alone tended to have *lower* land surface temperature (Declet-Barreto *et al* 2016), while another found that stronger social ties between neighbors were correlated with lower neighborhood heat index (Harlan *et al* 2006). There is some evidence that people living alone are less likely to have air conditioning (Wilhelmi *et al* 2021, Quick and Tjepkema 2023).

3.3.4. Race/ethnicity and HOLC security rating

We identified only a few studies that examined inequalities in subjective heat stress by race or ethnicity. Studies in China showed mixed results, with one finding that ethnic minorities were *more* likely to perceive discomfort due to heat (Ye *et al* 2018), one finding that ethnic minorities were *less* likely to perceive discomfort due to heat (Li *et al* 2019), and one finding no significant difference between ethnic minorities and the Han majority (Shih *et al* 2022). One study from the US found no significant differences by race or ethnicity in self-reported heat symptoms during the first months of the COVID-19 pandemic (Wilhelmi *et al* 2021). No study examined differences in subjective heat stress exposure by HOLC security rating.

Of the 39 studies that included an analysis of objective heat stress exposure by race/ethnicity or HOLC security rating, only three reported no relationship or association. Most studies come from North America (32 from the US, one from Canada). In nearly all studies that found a relationship or association between race/ethnicity and objective heat stress exposure, the authors concluded that minority racial or ethnic groups were more exposed to heat than the majority group. One exemplary study in this category comes from Chakraborty *et al* (2023a), which assessed inequalities in exposure to average maximum summertime air temperature and moist heat stress across 481 urbanized areas in the US which are home to approximately 240 million people (Chakraborty *et al* 2023a). They found higher heat stress exposure in predominantly non-white census tracts, and that historically ‘redlined’ neighborhoods that received a ‘D’ HOLC security rating in the 1930s (a rating predominantly assigned to Black neighborhoods) experienced higher present-day heat stress (Chakraborty *et al* 2023a).

We found 27 studies that examined inequalities in adaptive capacity related to race/ethnicity and HOLC security rating. Of these, 22 found a relationship or association, while five did not. Most of these studies were also conducted in the US (22 of 27). Nearly all studies that found a relationship or association between race/ethnicity or HOLC security rating and adaptive capacity concluded that minority racial/ethnic groups had lower adaptive capacity than the majority group. Several studies found that ethnic and/or racial minorities were less likely to own or have access to air conditioning in Canada (Quick and Tjepkema 2023) and the US (Harlan *et al* 2006, Park 2020, Madrigano *et al* 2018, Voelkel *et al* 2018, Park *et al* 2020, Wilhelmi *et al* 2021, Romitti *et al* 2022, Ahn & Uejio 2023, Kim and Kim 2024). Racial/ethnic minorities were found to have less access to greenness, green space, and/or tree canopy in the US (Jesdale *et al* 2013, Huang and Cadenasso 2016, Benz and Burney 2021, Lanza and Durand 2021, Gabbe *et al* 2023b, Dong *et al* 2023, Rivera *et al* 2023). Three US studies found that neighborhoods with worse HOLC security ratings were characterized by more impervious surface coverage and fewer trees and/or lower levels of greenness (Hoffman *et al* 2020, Napieralski *et al* 2022, Schinasi *et al* 2022). The evidence for inequalities in access to cooling centers is sparse and mixed, showing that marginalized groups and Black populations had higher access to cooling centers in Montreal and Vancouver, Canada (Quick *et al* 2023) and Portland, Oregon (Voelkel *et al* 2018), respectively, while Black populations were found to have lower access in Boston (Sehgal and Sehgal 2023). A national study of racial/ethnic minority access to cooling centers in the US had mixed results dependent on geographic location (Kim *et al* 2021).

3.3.5. Migration

Evidence of inequalities related to migration is limited to 11 studies, most of them focused on objective heat stress. Research conducted in the US (Mitchell and Chakraborty 2015, Voelkel *et al* 2018, Benz and Burney 2021), the Netherlands (Mashhoodi 2021a), Germany (Klopfer and Pfeiffer 2023), and Norway (Venter *et al* 2023) found that areas with higher proportions of immigrants experienced higher temperatures or heat index levels than areas with lower proportions of immigrants. One study of objective heat stress among agricultural workers in Cyprus found that migrant workers from low- and middle-income countries and upper-middle income countries experienced greater heat strain than native workers from Cyprus (a high-income country) and that migrant workers spent more time in a state of heat strain on average compared to native workers (Ioannou *et al* 2023).

Evidence related to subjective heat stress and adaptive capacity is limited. In Southwest China, shorter residence time was associated with higher odds of perceiving warm temperatures (Li *et al* 2019), while in the Florence and Pistoia provinces of Italy, native workers had a stronger perception of heat during work than migrant workers (Messeri *et al* 2019). Studies of inequalities in adaptive capacity by migration background come exclusively from Europe. In Cyprus, in comparison to workers from upper middle- and high-income countries, migrant agricultural workers from low- and middle-income countries spent less time on unplanned breaks, performed their work at higher intensity, performed more physically demanding tasks, and were less able to cool their bodies during work (Ioannou *et al* 2023). In Italy, a study of workers found that industrial and agricultural migrant workers received inferior education on heat and health compared to native workers due to language barriers (Messeri *et al* 2019). A study in Spain and Portugal found that native residents were more knowledgeable about heat risk groups, heat-related symptoms, and other heat-related information than non-natives (Cuesta *et al* 2017). A German study found that areas with higher proportions of immigrants were less green (Klopfer and Pfeiffer 2023), and a Norwegian study found that areas with higher proportions of immigrants were located further from water bodies (Venter *et al* 2023).

3.3.6. SES

Inequalities by SES were the most studied among the identified social factors, appearing in 97 of the 123 studies (79%). Of these, 12.4% assessed differences in subjective heat stress, 51.5% objective heat stress, and 52.6% adaptive capacity.

More than 80% of the studies that looked for potential inequalities in subjective heat stress by SES found an association or relationship. One study in the US found that among more than 22 million students, those living in low-income zip codes were 6.2% more likely to report school classrooms being ‘too hot during hot days most or all the time’ than students living in high-income zip codes (Park *et al* 2020). Most of the other studies in this category came from Europe (specifically Germany) and Asia.

Nearly all (94%) of the 50 studies that considered inequalities in objective heat stress by SES found an association or relationship, with most concluding that low-SES individuals and populations experience higher exposure to objective heat stress than those with high SES. Two of these studies examined within-country or within-city inequalities across global regions. One study found that in 72% of 25 large and highly urbanized global cities, lower-income neighborhoods experienced higher exposure to heat (Chakraborty *et al* 2019). Another study used survey data from nearly 700 000 households across 52 low- and middle-income countries, and found a strong negative correlation between income and temperature in countries with higher average temperatures (‘hot countries’) and a strong positive correlation between income and temperature in countries with lower average temperatures (‘cold countries’) (Park *et al* 2018). Other studies that considered SES and objective heat stress predominantly came from North America (64%) and used satellite or weather station data to measure objective heat stress across geographic areas (70%) rather than individually experienced temperatures.

The relationship between SES and adaptive capacity was explored in 51 studies, with various definitions of adaptive capacity. One of the most predominant types of adaptive capacity, considered in 18 studies (35.3%), was neighborhood or area-level built environment, including coverage and access to greenness and green space. One example is a study of 133 344 residential units conducted in Belfast, Northern Ireland, that found that area-level education and income were positively correlated with greenness coverage, 'leaf area index,' and proximity to greenspace (Zhou *et al* 2023). Similar results were found in Taiwan (Shih 2022), the US (Jenerette *et al* 2011, Jesdale *et al* 2013, Huang and Cadenasso 2016, Benz and Burney 2021, Gabbe *et al* 2023b), Norway (Venter *et al* 2023), and India (Mitchell *et al* 2021). Access to and use of cooling interventions in the home were also highly studied (20 studies or 39.2%). Studies mostly focused on air conditioning, but some also considered fans, evaporative coolers, and passive cooling interventions such as reflective films on windows, anti-sun glass, shading devices or installations, and roof reflectivity. Several studies from the US found that lower-SES individuals, households, and neighborhoods were less likely to have access to or to use air conditioning than their high-SES counterparts (Madrigano *et al* 2018, Hass and Ellis 2019, Park *et al* 2020, Wilhelmi *et al* 2021, Kim and Kim 2024) including one study which found that among 45 995 US census tracts, those with the lowest median income and lowest educational attainment also had the lowest air conditioning coverage (Romitti *et al* 2022). Similar results were found by researchers in Canada (Quick and Tjepkema 2023), Germany (Kussel 2018, Osberghaus and Abeling 2022), China (Deng *et al* 2020, Gao *et al* 2020, Lo *et al* 2022), and Malaysia (Zander and Mathew 2019).

3.3.7. Employment characteristics

Subjectively reported heat stress was more common among outdoor workers than indoor workers in Taiwan (Shih *et al* 2022), India (Venugopal *et al* 2021), Malaysia (Zander and Mathew 2019), and Australia (Zander *et al* 2018). Studies also found that subjective heat stress was more common among workers with lower-earning and manual jobs in Taiwan (Shih *et al* 2022), Thailand (Tawatsupa *et al* 2010, Arifwidodo and Chandrasiri 2020), Germany (Kemen *et al* 2021), and Australia (Zander *et al* 2018). There is little research regarding whether unemployment is associated with subjective heat stress and results are mixed: one study in Germany found no relationship (Seebass, 2017), while a study in China found that employment was associated with lower odds of heat stress (Ye *et al* 2018).

One large global study of 52 low- and middle-income countries found that lower-income individuals were more likely to work in occupations with higher exposure to objectively measured heat, a pattern that emerged when comparing individuals across and within countries (Park *et al* 2018). Another study in China found that compared to managers and administrators, other occupational categories had higher odds of exposure to surface urban heat islands (Wong *et al* 2016). Outdoor and agricultural workers were more exposed to heat than indoor workers in India (Mitchell *et al* 2021, Venugopal *et al* 2021) and China (Zeng *et al* 2022). Studies in the UK (Zhou *et al* 2023) and the US (Ilbeigi and Jagupilla 2020) found that neighborhoods with higher levels of unemployment tended to experience higher temperatures.

Evidence related to the effect of employment characteristics on adaptive capacity is diverse and has mixed results. Two studies from the US examined the effects of hot weather on mobility by employment characteristics: one in car-dependent Houston, Texas, found that extreme heat inhibits the mobility of unemployed populations possibly due to low access to cars among this population (Gu *et al* 2024), while a study in New York City (which has a robust mass transit system) found low reductions in mobility in warm weather among unemployed people and people employed in heat-vulnerable industries such as agriculture and construction (Stechemesser and Wenz 2023). In the UK, one study found that areas with lower unemployment tended to have higher greenness (Zhou *et al* 2023). One study in the US found that employed people were more likely to employ personal heat-protective strategies during hot weather (Hass and Ellis 2019). A study in China found that employed people had higher knowledge of heat adaptation approaches (Li *et al* 2016), while another study in the country of Georgia found that those who were retired or who identified themselves as homemakers had higher knowledge than those who were employed (van Loenhout *et al* 2021). Studies of the implementation of active or passive cooling at home also had mixed results: while employed individuals in Italy and the US were more likely to implement passive or active cooling strategies at home (Pisello *et al* 2017, Wilhelmi *et al* 2021), individuals in Germany were less likely to install passive cooling devices at home if they were employed at least 20 hours per week (Kussel 2018). One German study that took a life stages approach found that students and young professionals were least able to cope with heat (Sandholz *et al* 2021).

3.4. Risk of bias rating

The risk-of-bias rating of European articles is summarized in supplementary file 7. Ten of the 21 studies were rated as 'tier 2', while a smaller number (8) were rated 'tier 1'; only three were rated as being 'tier 3'. Within the key criteria, exposure and outcome detection were generally found to have definitely or probably low risk of bias, except for a few studies. A higher risk of bias was found when assessing the possibility of selection bias. Within other criteria, little possibility of bias was identified within the domains of confounding, attrition/exclusion bias, and selective reporting, but statistical appropriateness had more mixed results.

4. Discussion

4.1. Summary of findings and implications

In this review, we systematically identified and synthesized the results of 123 peer-reviewed articles. We found that social inequalities in heat stress exposure and related adaptive capacity have been documented globally. In general, socially disadvantaged populations are more exposed to heat stress and have lower adaptive capacity. These results further confirm the urgent need to address climate injustice. The World Meteorological Organization has reported that 2024 was the warmest year in recorded history, with global average temperatures reaching 1.55° Celsius above pre-industrial temperatures (World Meteorological Organization (WMO) 2025). On a global scale, Central and South America, Southern Europe, Southern and Southeast Asia, and Africa will be most affected by increasing temperatures caused by climate change (United Nations 2024). However, we demonstrate that social inequalities in exposure to increasing temperatures occur within *all* global regions across cities, counties, neighborhoods, and households. Addressing these inequalities globally, but especially in regions most affected by increasing temperatures due to climate change, should be a top priority for policy- and decision-makers.

The findings of this review are generally in alignment with evidence of inequalities in heat-related health outcomes. We found that racial and ethnic minorities, people with low SES, and people engaged in outdoor and manual work were more exposed to heat stress and had lower adaptive capacity. These groups are also more likely to experience chronic and non-communicable diseases such as cancers, cardiovascular disease, type 2 diabetes, chronic respiratory disease, and obesity, which increase their susceptibility to heat (McNamara *et al* 2017, Sommer *et al* 2015). It is therefore not surprising that they are also among the groups most at risk of heat-related adverse health outcomes and mortality (Gronlund 2014, Benmarhnia *et al* 2015, Son *et al* 2019, Singh *et al* 2024). In contrast, we found that, in general, older people are less exposed to heat stress and have higher adaptive capacity than young adults and children, though it is well documented that older people have a higher risk of health impacts and mortality due to heat than younger people (Benmarhnia *et al* 2015, Son *et al* 2019, Singh *et al* 2024). We also identified a small number of studies that found social isolation, a known risk factor for heat-related health impacts and mortality (Bouchama *et al* 2007), to be related to lower heat exposure and higher adaptive capacity. This apparent contradiction is likely due to the multidimensionality of inequalities in heat stress exposure and adaptive capacity combined with higher sensitivity to heat among older individuals. While socially isolated older populations may experience lower temperatures and higher capacity on average, age is not the only factor contributing to exposure, capacity, or health outcomes. Because of older people's sensitivity to heat, it is essential that governments specifically design heat adaptation interventions for older people who *do* experience higher temperatures and have lower adaptive capacity due to their low level of income, poor housing quality and/or location, lack of access to green space and other cooling features in and around their home, social isolation, poor physical mobility, and/or reliance on public transportation. In fact, these older and socially deprived populations, especially those living in cities that experience an urban heat island effect, are likely the most in need of urgent support through social and medical services and structural interventions. In contrast, older populations who are relatively well-off and living in less urbanized areas may benefit from the promotion of adaptation behaviors but are less likely to benefit from structural interventions.

The identified studies suggest an understanding of heat stress exposure and adaptive capacity as being dependent on social and built environment contexts, influenced by multi-dimensional and dynamic social factors, and intersectional in nature. The majority of identified studies (62.7%) used geographic areas or specific locations as their units of analysis, underscoring the importance of context. Several studies considered commuting patterns, exposure when using public transportation, exposure and adaptive capacity at work and at school, and dynamic exposure during daily activities. Some studies also explored whether intersecting disadvantaged social identities may further exacerbate exposure or worsen adaptive capacity as compared to possessing only a single disadvantaged social identity. The common thread unifying these findings is the theme of economic and social power. Those with the highest economic and social power (men, those with high education and high income, non-migrants belonging to the dominant racial or ethnic group, those without a disability and in good health) are more able to avoid or protect themselves from heat because of their increased decision-making power and flexibility: they can choose to live in cooler and greener areas, purchase cooling appliances, travel in personal air-conditioned cars or stay home on hot days, work at indoor and non-manual jobs, and abstain from care work or home chores. The more advantaged social identities an individual has, the more they are likely to be able to protect themselves from heat, and vice versa. To address intersectional social inequalities in heat stress exposure and adaptive capacity, an intersectional climate justice framework, such as the one proposed by Amorim-Maia *et al* is therefore necessary when developing heat-health policies and interventions (Amorim-Maia *et al* 2022).

Recommendations for policy- and decision-makers in the field of climate change adaptation and resilience that can be drawn from the findings of this review are summarized in textbox 1.

4.2. Strengths and limitations

This review has several strengths. To our knowledge, this is the first systematic review of social inequalities in heat stress exposure and related adaptive capacity. We followed a rigorous and systematic protocol to identify many diverse studies. The global scope of the review allowed us to provide a comprehensive summary of the available evidence. The synthesis and summary of these studies allows for the identification of relevant policy recommendations and important research gaps. This review also has some limitations. Though the review was global in scope, we only included studies published in English or German, potentially excluding relevant articles published in other languages. We also limited our review to studies published on or after 1 January 2005, meaning that older relevant studies could have been missed. There is also a risk that our results and conclusions have been affected by publication bias because researchers do not tend to publish studies with null results, or in the case of our review, papers that find no evidence of inequalities. We were unable to conduct a meta-analysis or provide a quantitative summary of the direction of the associations or relationships between social factors and the three outcomes due for several reasons: first, the extreme heterogeneity in the statistical methods used; second, the extreme heterogeneity in the definitions for each exposure and outcome across the included studies; and third, our inability to perform a risk of bias or assessment of quality across all studies made it inadvisable to present a quantitative summary of findings in such a way. Finally, we were unable to perform a risk-of-bias assessment on all studies and could only present this assessment for European studies.

4.3. Evidence gaps and implications for future research

We identified several gaps within the available evidence. There is a substantial imbalance in the volume of research identified across global regions. Most studies come from North America (47.2%), Southeast Asia (17.1%), and Western and Northern Europe (13.8%). Very limited evidence is available from regions that are experiencing the worst impacts of increasing temperatures: Africa (1.6%), the Middle East (1.6%), Latin America (4.9%), Southern and Eastern Europe (5.7%), and South Asia (4.9%). Overall, research is dominated by high-income and upper middle-income countries, especially the United States (55 studies), China (15 studies), and Germany (10 studies), a pattern that is replicated in the literature related to both inequalities in heat-related mortality and heat-related health outcomes (Campbell *et al* 2018, Green *et al* 2019). Because of this imbalance, decision-makers at global, regional, and national levels may be creating policies using evidence that is only generalizable to one part of the population or even irrelevant to their context. More support is needed to fund and implement research on inequalities in heat stress exposure and related adaptive capacity in under-studied regions to support the development of appropriate policies.

Studies of unequal exposure to heat stress and related adaptive capacity are focused mainly on specific social factors, especially SES, age, and race/ethnicity. We identified very few or no studies comparing exposure and adaptive capacity by social factors related to the highest level of social vulnerability: lack of housing/ outdoor sleeping (two studies), physical or intellectual disabilities (three studies), severe mental illness (no studies), drug or alcohol use disorders (no studies), and incarceration (no studies). More research comparing the exposure and adaptive capacity of these groups with the general population will allow policymakers to better intervene and protect them during hot weather.

Most studies of objective heat stress exposure used satellite imagery to calculate land surface temperatures (LST) for geographic areas. LST can be similar to or greatly different from air temperature (the temperature people actually experience) depending on the season, built and natural environment characteristics, and building morphology (Li *et al* 2023, Naserikia *et al* 2023). LST also does not capture other exposures strongly related to whether or not someone may experience heat stress: solar radiation, wind speed, and humidity (Jendritzky *et al* 2012). Though LST is convenient for researchers due to the high accessibility of LST data, in the future, more studies should consider using indices such as the Universal Thermal Climate Index, which incorporate all climate factors relevant for heat stress exposure. Even when using measurements that include humidity and other climate factors, nearly all studies of objective heat stress exposure considered only outdoor environments for geographic areas, rather than individually experienced and/or indoor thermal environments. Only two of the identified studies included the use of worn thermocrons (temperature sensors) or hygrochrons (temperature and humidity sensors), allowing researchers to capture individually experienced thermal environments of participants. Given that most people spend most of their time indoors even during heatwaves, more research on social inequalities related to indoor thermal environments is urgently needed.

Few studies of objective heat stress exposure and adaptive capacity considered the dynamic and complex experience of daily life during hot weather. Nearly all studies only considered average temperatures or heat indices surrounding residential addresses, or for larger geographic areas such as counties. Given that most people do not spend all day at home, and are likely to commute or be transported to daycare, school, work, errands, or community spaces, more research is needed to understand how different social groups are differently exposed to heat stress and more or less able to protect themselves from heat while taking into account their level of decision-making power and flexibility, and their thermal environments at home, while traveling, at school or work, and during leisure time.

Textbox 1. Summary and recommendations for policy- and decision-makers

Social inequalities in exposure to extreme heat have been documented globally. Additionally, evidence from all global regions indicates that disadvantaged social groups have lower adaptive capacity, meaning that they are less able to avoid heat or protect themselves from it.

These social factors (socio-economic status, neighborhood environment, workplace and work characteristics, and race or ethnicity for example) are also likely to be connected with unequal exposures to other environmental risks such as air pollution, noise, and a lack of green space.

Social characteristics relate to higher exposure to heat stress and lower adaptive capacity in a context-dependent, dynamic, multi-dimensional, and intersectional way:

- Context-dependent: Social inequalities in exposure or capacity in one setting may be very different than in another, even within the same country.
- Dynamic: Inequalities may differ in specific settings (home versus workplace or school) or depending on the time of day (during a commute or at night while sleeping).
- Multi-dimensional: More than one social factor will influence whether someone is more or less exposed and has higher or lower adaptive capacity.
- Intersectional: Multiple social factors in combination affect someone's exposure or adaptive capacity. For example, a low-income woman responsible for childcare in an urban setting may have much higher exposure and lower capacity than a low-income woman with no children in a rural setting.

Policy recommendations

General recommendations

- It is essential to consider and incorporate social factors into heat-health action plans and climate change adaptation policies and interventions.
- It is important to use local data to develop local solutions that are relevant for local populations. Local data allows for spatial differences across neighborhoods and communities to be considered when developing and implementing policy. To make this possible, local and national governments can improve the availability of micro-spatial data.
- Heat-health action planning benefits greatly from the engagement of many sectors beyond healthcare and social services, including urban planning, housing, education, social protection, and more.
- Rural areas must also be considered in heat-health action planning.

Target groups

- Older people with one or more socially disadvantaged identities, especially those related to heat-relevant housing and neighborhood-built environment characteristics, must be specifically targeted for heat-health interventions.
- Young people, especially those with one or more socially disadvantaged identities, are also an important group to consider in heat health action planning, as they are among the most exposed populations. While they may not experience any immediate health effects from heat, over time, repeated exposures could cause chronic health issues later in life. Heat exposure can also reduce their school performance and overall productivity.
- It is important that heat-health action planning incorporates a sensitive and strategic consideration of cultural and language barriers so that immigrants and racial/ethnic minorities receive the support they need during hot weather.

Interventions

- Structural interventions in disadvantaged neighborhoods are likely to bring the most benefit in terms of reducing temperatures and protecting health. These interventions (which could include greening, green roofs and walls, white roofs, reducing impervious surfaces, etc.) are most effectively designed and implemented in collaboration with community members.
- Interventions to reduce exposure to heat and increase adaptive capacity among socially vulnerable groups can ideally aim to bring co-benefits related to reduced inequalities in air

pollution and noise exposure and increased access to green space.

- When implementing structural changes to reduce heat exposure, ensure that improved infrastructure in disadvantaged neighborhoods does not lead to gentrification of those neighborhoods, a phenomenon that has particularly been observed after greening initiatives ('green gentrification') (Anguelovski *et al* 2019, 2022). This can be prevented, for example, by distributing green space equally across cities to prevent certain neighborhoods from becoming more attractive than others.

5. Conclusion

Social inequalities in exposure to heat stress and related adaptive capacity have been documented globally. In general, socially disadvantaged groups (children, adolescents and young adults, those with lower income and less education, immigrants, racial and ethnic minorities, etc.) are more exposed to heat and have lower adaptive capacity than socially advantaged groups. These inequalities are context-dependent, dynamic, multi-dimensional, and intersectional.

More research is needed to document these inequalities. For example, research is especially needed within countries where evidence is scarce, along with studies related to workplace environments and occupations and different levels of engagement in household chores, childcare, and other care work.

It is highly important that policy- and decision-makers prioritize addressing social inequalities in heat health adaptation. This is in line with the need to strengthen equity assessment, monitoring, and evaluation in order to prioritize justice and equity in climate change adaptation and mitigation identified in the sixth assessment report of the IPCC (IPCC 2023). The 2024 Global Report of the Lancet Countdown on Health and Climate Change also underlines the importance of people-centered and inclusive actions across society to protect health and to tackle climate change (Romanello *et al* 2024) and using local data when planning and implementing climate change adaptation policies and interventions and during the development of heat-health action plans. Governments need to dedicate resources to monitoring and evaluating heat exposure, protection, and adaptation, including assessments of changes in inequalities over time. Heat-health interventions need to continue to promote behavioral adaptation while also focusing more on changing built environments to reduce temperatures through interventions such as greening and reducing impervious surfaces, while being careful to avoid the promotion of gentrification. In the big picture, policies that reduce broader social and income inequality will also greatly strengthen the resilience of communities and health services against climate change.

Data availability statement

No new data were created or analysed in this study.

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Conflict of interest

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

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Author contribution statement

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