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To cite this article: V Kelly Turner *et al* 2022 *Environ. Res. Lett.* **17** 064054

ENVIRONMENTAL RESEARCH
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OPEN ACCESS

RECEIVED
10 February 2022

REVISED
20 May 2022

ACCEPTED FOR PUBLICATION
26 May 2022

PUBLISHED
10 June 2022

LETTER

How are cities planning for heat? Analysis of United States municipal plans

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Keywords: urban climate, hazard mitigation, governance, systematic review, climate adaptation, extreme heat, urban heat island

Abstract

Heat has become a central concern for cities everywhere, but heat governance has historically lagged behind other climate change hazards. This study examines 175 municipal plans from the 50 most populous cities in the United States to understand which aspects of urban heat are included or not in city plans and what factors explain inclusion. We find that a majority of plans mention heat, but few include strategies to address it and even fewer cite sources of information. The term 'extreme heat event' (EHE) is significantly more likely to be paired with institutional actions as a part of hazard planning, while 'urban heat island' (UHI) is more likely to be paired with green and grey infrastructure interventions as a part of general planning. Disparity and thermal comfort framings are not significantly related to any solutions and are used least. Plan type, followed by environmental networks (e.g. C40, Urban Sustainability Directors Network, Rockefeller 100 Resilient Cities), explain variation in plan content; social and environmental context do not. Findings point to the emergence of two independent heat governance systems, EHE and UHI, and several gaps in heat planning: integration, specificity, solutions, disparity, economy, and thermal comfort.

1. Introduction

Heat is a central concern for cities everywhere. Fundamentally, the term 'heat'[7] describes a thermal state determined by multiple climate-related variables including air temperature, radiation, humidity, and air movement that have consequences for the human body and biophysical systems (Oke 1982, Parsons 2002, Kuras *et al* 2017). Those thermal states are consequential to cities as a set of impacts on people and places. For instance, extreme heat—a thermal state that has negative consequences for human bodies—is one of the deadliest climate change impacts globally and predicted to increase with future urban population growth and an extreme heat event (EHE) frequency and severity (WHO, C40, Madge 2011, Mora 2017, Buchanan 2021, Tuholske *et al* 2021). Impervious surfaces such as asphalt and other attributes of the built environment contribute to states such as local warming and the regional urban heat island (UHI) in most urbanized regions (Oke 1982, Grimm *et al* 2008, Imhoff *et al* 2010, Stewart and Oke 2012, Lazzarini *et al* 2013, Hardin *et al* 2018). The combined effects of global and urban-scale warming are disproportionately felt by marginalized groups due to higher heat exposure and lesser capacity to cope with hot conditions (Harlan *et al* 2006, Eisenman *et al* 2016, Hoffman *et al* 2020, Dialesandro *et al* 2021). Excess heat can amplify other environmental problems, worsening air and water quality, increasing wildfire

[7] From the AMS glossary: 'Heat, used as a noun, is confusing and controversial in its scientific meaning.'

risk, and greenhouse gas emissions through higher energy demand for cooling (Santamouris 2020). Heat has consequences for every aspect of urban life: it compromises critical urban infrastructure (Chapman *et al* 2013), lowers educational outcomes (Park *et al* 2020), increases pre-term births (Barrecca *et al* 2018, Barecca and Schaller 2020), and reduces labor productivity (Park 2021). Given that urban heat is a multi-faceted problem, cities will need to pursue a suite of different approaches to effectively govern a hotter future.

Few governing institutions at any jurisdictional scale have historically formally, directly, or comprehensively managed heat (Nordgren *et al* 2016, DeShazo *et al* 2021, Gabbe *et al* 2021, Keith *et al* 2021, Meerow and Keith 2021). Some of the first efforts to mainstream heat response and management by government and international non-government actors[8] laid the foundation for a current acceleration in action[9]. The distributed network of response to heat suggests that nascent urban heat governance systems are emerging. Environmental governance refers to the 'set of regulatory processes, mechanisms and organizations through which political actors influence environmental actions and outcomes' (Lemos and Agrawal 2006, p 298). Problem framing is a critical function in environmental governance, because it constrains what solution sets are deemed critical and which institutions take ownership of governance (Adger *et al* 2011, Whittemore and BenDor 2018), with downstream implications for what aspects of a problem are addressed or not. Heat governance framing directs attention to particular consequences of elevated temperature for people and places, with implications for what constitutes a desirable state and if and how to address it.

Municipal plans provide insight into prevailing problem framings through inclusion of particular policies, programs, and initiatives and alignment with a specific high-level 'vision' (e.g. sustainability, resilience) (Berke and Godschalk 2009). Those broad visions are an amalgamation of policy agendas set in consultation with environmental networks and local innovations (Broto and Bulkeley 2013, Nordgren *et al* 2016). Plans—or networks of plans—do not encompass the full variety of actors, tools, and narratives present in a governance system, but do signal which environmental agendas are included and prioritized in formal in city governance (e.g. Berke *et al* 2000, Tennoy 2010, Berke *et al* 2019).

This study characterizes priorities in urban heat governance as articulated in formal municipal planning documents. Specifically, we ask: How is the problem of urban heat framed? What solutions are included, and how do solutions relate to problem framing? What characteristics of plans or cities that the plans originate from explain variation in plan content? We answer these questions through a content analysis and compare the results of the plan analysis to major themes identified in a recent systematic review of the 539 peer reviewed articles on heat, which confirms that EHE, UHI and, increasingly, heat disparity and thermal comfort are emphasized (Stewart 2011, Rupp 2015, Horton 2016, Wilson 2020, Keith *et al* 2021). We conclude with a discussion of potential knowledge-action gaps apparent in heat plans.

2. Methods

2.1. Plan database

This study draws from a published database analysis of heat-related content in municipal plans ($n = 175$) adopted between 2006 and May 2020 in the most populous cities ($n = 50$) in the United States (2005–2020) (appendix A, for a full description of methods see Turner *et al* 2021). This sample was selected because larger cities are likely to produce one or more or our plan types of interest (Vasi 2007, Wang 2022): general, sustainability, resilience, climate, hazard, infrastructure, heat-specific, and other. An initial list of municipal plans was compiled through an online search of city names and key words. A secondary search, including calls to city offices, was conducted before starting to code plans for a specific city in case any additional plans had been adopted in the interim. We conducted a systematic document analysis drawing on the work of Bowen (2009). Weather-related 'heat statements' were identified by searching for 'heat' and a set of cognate terms in each plan document. A total of 6306 heat statements were included in our analysis. Each statement was categorized based on four overarching themes: (a) problem framing, (b) hard interventions, and (c) soft interventions data. A preliminary list of categories within these themes based on existing literature and expanded that list inductively based on plan content until no new categories were identified (saturation, see Bernard *et al* 2017). This process yielded 50 categories to which we could assign statements (appendix B). Each reference was assigned (e.g. coded) to categories

[8] For instance, the MET Heat-Health Watch response to the 2003 European heat wave, the Environmental Protection Agencies Excessive Heat Events and Urban Heat Island Guidebook (EPA 2006, 2008), the World Health Organization (WHO) Early Warning Systems (EWS, 2015) and Global Heat Health Information Network, and the National Integrated Heat Health Information System (NIHHIS, NOAA, 2016) in the United States.

[9] The United States House Science Committee held the first ever federal hearing on extreme heat, the United Kingdom MET Office published a study on the global impacts of extreme heat, and GHHIN held its inaugural forum in 2018 (Madge 2011, PBS 2021). The Adrienne Arsht-Rockefeller Foundation established the Extreme Heat Resilience Alliance (EHRA) and the United Nations' International Labor Organization internationally and efforts by community-based organizations to push heat as a priority in local and state government (EHRA, UN, Guardano *et al* 2020). As of 2022, Athens, Freetown, Miami, Phoenix, and Santiago have officially established formal roles in local government (e.g. chief heat officers), with more likely soon.

to capture how cities are understanding and framing heat and types of heat interventions are being mentioned. A single statement could be assigned to multiple categories. Before beginning the final process of assigning statements to categories, an intercoder agreement score of 75% was attained (Bernard *et al* 2017). We summed the occurrence (binary presence/absence) and frequency (total number of occurrences) of each category at the plan—and city-level to create primary (original) variables for analysis. We also included secondary variables from existing city-level sources, including population size, location, climate region, membership in environmental networks, demographics, GINI coefficient of income inequality, political affiliation, municipal spending per capita, and local climate that are known correlates to plan content or relevant to heat (e.g. summer temperature maximum) (O'Neill *et al* 2010, Pietrapertosa *et al* 2019, Berrang-Ford *et al* 2021, Meerow and Keith 2021).

2.2. Content analysis

We focused our analysis on output on plans ($n = 175$) that mention heat, summing frequency and occurrence of primary plan content variables and calculating Kendall correlation coefficients for non-normally distributed data on all primary and secondary variables to determine the relationship among coded content variables within plans and between coded content variables in plans and characteristics of the cities from which the plans originated. Non-parametric Kruskal–Wallace (KW) tests were used to determine if occurrence of primary coded variables varied significantly by plan type and region, which were independent (mutually exclusive) samples. We conducted non-parametric Mann–Whitney tests for our network memberships which were non-independent samples because plans could be from cities that were members of more than one environmental action network (C40, Urban Sustainability Directors Network, Rockefeller 100 Resilient Cities). To determine if our secondary social and environmental variables predicted plan content, we ran a series of stepwise regressions using heat problem framings dominant in science literature: general heat, EHE, UHI, thermal comfort, and disparity (a combined indicator: general vulnerability, exposure, sensitivity, adaptive capacity, and equity).

3. Results

3.1. Frequency and occurrence of coded variables

Heat was mentioned at least once in most plans ($n = 153$, 87%). On average, plans mentioned heat 43 times (min = 1, max = 250), with a larger number of plans mentioning heat fewer times. There was no clear pattern (e.g. population size, region) across cities with plans that did not mention heat. Only 33% of the plans mentioned any data source related to heat.

Among plans mentioning heat, a general heat framing ($n = 121$, 79%) with no further clarification was most pervasive (figure 2). The most common heat problem framings in the plans were UHI ($n = 116$, 76%) and EHE ($n = 116$, 76%). Other framings appearing in more than half of the plans included health ($n = 100$, 65%), ecology ($n = 95$, 62%), and energy ($n = 91$, 59%). No disparity framing appeared in more than half of the plans and equity appeared in less than one third ($n = 47$, 31%). All other framings inclusive of co-occurring environmental problems and municipal services appeared in fewer than half of the plans. Few plans included human thermal comfort framings ($n = 29$, 19%).

Soft interventions ($n = 982$) were mentioned more frequently than hard interventions ($n = 788$), which mostly included trees ($n = 525$, 67%). Trees ($n = 92$, 60%) were included in more than twice as many plans as any other hard intervention. No other hard or soft intervention was included in more than half of the plans that mentioned heat.

3.2. Relationships between plan content variables

None of the primary heat framings in the academic literature—EHE, UHI, thermal comfort, and equity—were strongly correlated with one another (appendix C). The total number of plans ($n = 30$) that mention thermal comfort was less than required for most statistical tests. EHE framings were correlated to general heat (0.626) and several other framings such as infrastructure (0.822) and energy (0.810). Plans with EHE framing were not correlated with any hard interventions, but with several soft interventions (overall soft intervention presence, 0.636). Plans with an UHI framing were not highly correlated to any other framings. Plans with UHI framing were not correlated with soft interventions, but correlated with inclusion of hard interventions (0.753), foremost trees (0.711). Plans with disparity framing variables were moderately correlated. For instance, plans that used an equity framing were correlated to inclusion of adaptive capacity (0.631) and general vulnerability (0.513) framings. None of the disparity variables correlated to any hard interventions. None of the hard interventions were correlated with any of the soft interventions, but there were numerous correlations among hard and soft intervention variables.

3.3. Explaining differences in plan content

The KW tests reveal variation in content by plan type (appendix D). Hazard plans ($n = 44$) were significantly more likely to contain almost all of the framings than non-hazard plans, especially general heat ($n = 40$, 91%, $p < 0.001$), EHE ($n = 36$, 82%, %, $p < 0.001$), and health ($n = 37$, 84%, $p < 0.001$) but not significantly more likely to include any disparity

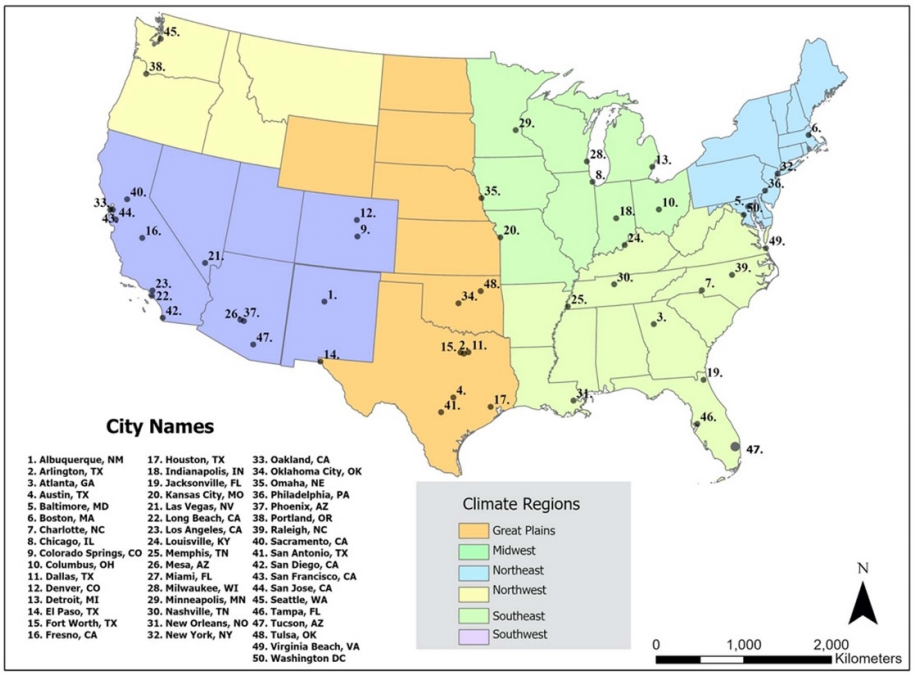

Figure 1. Cities included in analysis by climate region.

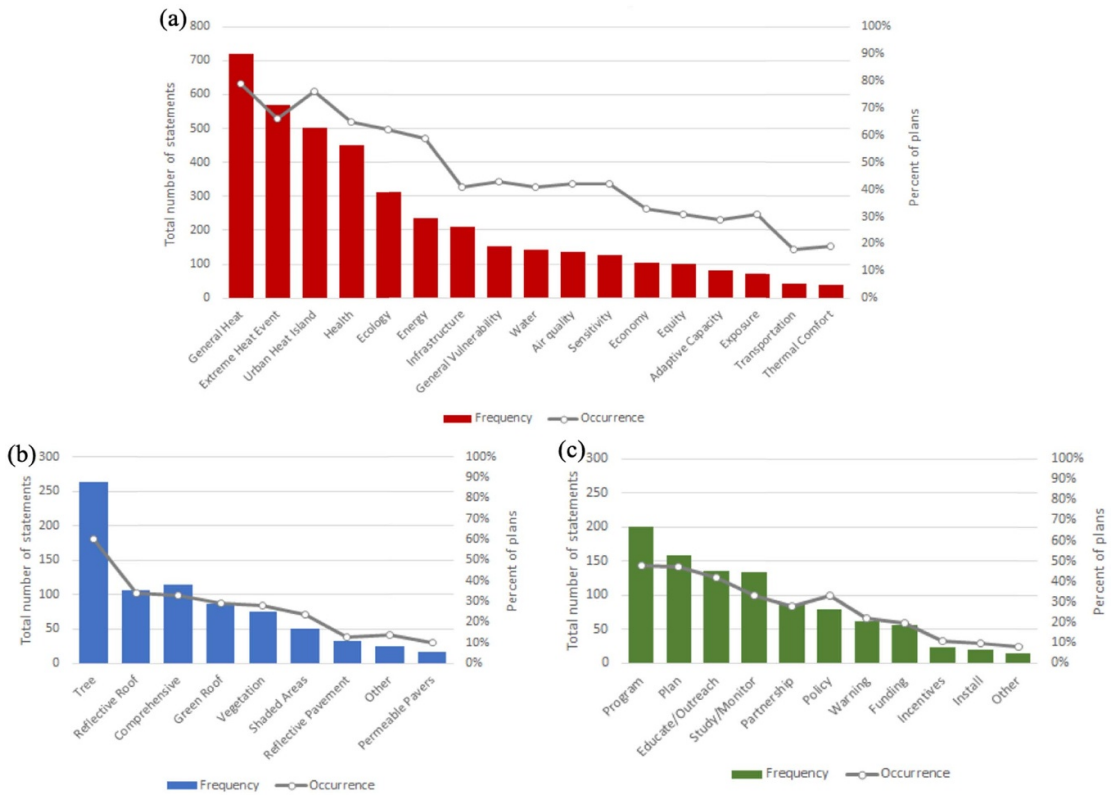

Figure 2. Plan content summary. Frequency of statements (bars) and percent occurrence in plans (lines) of primary coded variables: framings (red), hard interventions (blue), soft interventions (green).

framings (with the exception of adaptive capacity, $n = 17$, 39%, $p < 0.05$). Hazard plans were significantly less likely to include almost all of the hard interventions than non-hazard plans; none of the hard interventions were mentioned in more than one quarter of the plans. Hazard plans were significantly more likely to contain soft several interventions, compared to non-hazard plans. In contrast,

general plans ($n = 43$) were significantly less likely to include an EHE ($n = 17$, 40%, $p < 0.001$), health ($n = 15$, 35%, $p < 0.001$), and all of the disparity framings: no disparity framing appeared in more than 6 plans. General plans were more likely to include hard interventions, especially trees ($n = 32$, 74%, $p < 0.01$), but also vegetation ($n = 20$, 47%, $p < 0.001$) and shade ($n = 15$, 35%, $p < 0.01$) than non-general plans. Climate plans ($n = 32$) were more likely to contain EHE ($n = 26$, 81%, $p < 0.01$) framing, but also several disparity framings including equity ($n = 15$, 47%, $p < 0.01$) and general vulnerability ($n = 17$, 53%, $p < 0.05$). They were also significantly more likely to contain reflective roof ($n = 15$, 47%, $p < 0.001$) and reflective pavement ($n = 8$, 47%, $p < 0.001$) hard interventions. Sustainability plans ($n = 20$) were less likely to include several secondary framings and not more likely to mention any of the primary plan content variables. Finally, resilience plans ($n = 20$) were more likely to contain an infrastructure ($n = 13$, 65%, $p < 0.01$) framing and several disparity framings including equity ($n = 9$, 45%, $p < 0.05$), general vulnerability ($n = 14$, 70%, $p < 0.01$), and adaptive capacity ($n = 9$, 45%, $p < 0.05$) framings. They were more likely to contain comprehensive ($n = 11$, 55%, $p = 0.01$) hard interventions and partnerships ($n = 8$, 40%, $p < 0.05$) and incentives ($n = 6$, 30%, $p < 0.001$) soft interventions. Other and infrastructure plans were too few in number for statistical comparisons.

Region explained some differences in plan content, but never with more than 95% confidence (appendix E). Plans from the Southwest ($n = 49$) were more likely to contain an equity ($n = 14$, 29%, $p < 0.05$) framing and data ($n = 31$, 63%, $p < 0.05$). Plans from the Southeast ($n = 44$) and Great Plains ($n = 34$) were more likely to contain an UHI (SE: $n = 23$, 68%, $p < 0.05$, GP: $n = 24$, 71%, $p < 0.05$) framing. Plans from the Midwest ($n = 27$) were more likely to contain reflective pavement ($n = 9$, 33%, $p < 0.05$) hard interventions. Plans from the Northeast ($n = 22$) were less likely to reference data. Plans from the Northwest ($n = 10$) were too few in number for statistical analysis.

Results of the Mann–Whitney test revealed that cities with membership in environmental networks were more likely to include several heat content variables—mostly a wider range of framings and soft interventions as opposed to hard interventions—with some minor differences across networks (appendix F). Network membership was especially predictive of inclusion of disparity framings in plans. For instance, plans from cities with any of the networks were more likely to mention equity, especially Urban Sustainability Directors Network (USDN, $p < 0.001$) and Rockefeller 100 Resilient Cities (R100, $p < 0.01$). Plans from USDN and R100 cities were also more likely to include EHE ($p = 0.001$) and partnerships ($p < 0.001$), respectively. Plans from Climate 40 (C40) cities were more likely to include EHE ($p < 0.001$) and transportation ($p < 0.001$) framings.

In the stepwise regression models (table 1), none of the models based on secondary social and environmental variables predicted substantial percentages of variation in plan content. The models did reveal some similarities and differences in the factors that predicted inclusion of different framings. Larger population predicted inclusion of general heat, EHE, and disparity framings (all $p < 0.001$) and newer plans were modestly more likely to include general heat, UHI, and disparity framings ($p < 0.05$). Higher spending per capita predicted inclusion of a disparity framing ($p < 0.001$), which was the model with the highest overall predictive power (adjusted R^2 0.234). Other than population, no variable predicted inclusion of EHE framing. Demographic and environment variables had mixed and modest predictive power in the remaining framing models. For instance, higher percent Asian population predicted inclusion of a disparity framing ($p < 0.01$), but no other racial or demographic category predicted inclusion of any framing with more than 95% confidence. Similarly, the only environmental variables that predicted inclusion of framings with more than 95% confidence were historic summer high temperatures, which predicted inclusion of thermal comfort ($p < 0.01$), and higher mid-century ($p < 0.01$) but lower late century ($p < 0.01$) summer high temperatures, which predicted inclusion of a disparity framing.

4. Discussion

Heat was mentioned in almost all of the plans we analyzed, indicating that most cities at least include it among the environmental problems they need to address. Although a 2015 study of climate adaptation plans and other resources in the United States found that only 4% targeted extreme heat (Nordgren *et al* 2016). Just five years later, our study found that 78% of the climate plans (inclusive of mitigation and adaptation) in our study made such a reference. This result may signal that heat is a rising priority, but change over time is difficult to assess with certainty because few studies have examined heat specifically; most plan analysis focus more broadly on climate adaptation planning (e.g. O'Neill *et al* 2010, Pietrapertosa *et al* 2019, Berrang-Ford *et al* 2021). There were no clear patterns among plans that did not mention heat. However, a recent national survey found that small and mid-sized cities were less likely to have planning staff devoted to heat (Keith *et al* 2020). Our study only examined large cities, so we were unable to confirm disparities based on city-size.

Table 1. Municipal context factors explaining key frame inclusion. Stepwise regression models including coefficient estimates, 95% confidence intervals (CI), and significance level.

	Disparity		Extreme heat event		General heat		Thermal comfort		Urban heat island	
Coefficient	Estimates	CI	Estimates	CI	Estimates	CI	Estimates	CI	Estimates	CI
Intercept	1.78	−2.71–6.27	0.64	−0.50–1.78	2.37	−6.30–11.03	−0.61	−1.62–0.41	5.54	−8.99–20.08
Population	0.00 ***	0.00–0.00	0.00 ***	0.00–0.00	0.00 ***	0.00–0.00				
Age	−0.11 *	−0.21 to −0.01			−0.30 *	−0.54 to −0.07	−0.02	−0.05–0.00	−0.20 *	−0.36 to −0.04
Spending per capita	0.06 ***	0.03–0.10							−0.13	−0.27–0.00
% Asian	0.07 **	0.03–0.11								
% Black	0.31	−0.07–0.69			0.85	−0.02–1.71	0.07	−0.02–0.16		
%LatinX									−0.12	−0.26–0.02
% Native					−0.24	−0.54–0.06				
% Non White									−0.21 *	−0.39 to −0.02
%White	0	−0.00–0.00								
% Under 18					−0.37 *	−0.71 to −0.02			0.24	−0.00–0.47
% Over 65							−0.12 **	−0.20 to −0.04	−0.59 *	−1.14 to −0.05
Mid century *T*max	0.05 **	0.01–0.09								
Late century *T*max	−0.07 **	−0.12 to −0.03								
NOAA precip annual					0.13 *	0.02–0.24	−0.02 *	−0.03 to −0.00		
Summer *T*max 1971–2000							0.14 **	0.05–0.23	0.64 *	0.06–1.22
Current summer *T*max									0.05	−0.01–0.10
Observations	175		175		175		175		175	
R^2/R^2 adjusted	0.269/0.234		0.217/0.213		0.205/0.177		0.092/0.065		0.121/0.079	

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

Our results suggest that the inclusion of heat, however numerous the mentions, may not be substantive given that no framing ('general heat') was most prevalent and invocation of solutions or data were scant. This finding aligns with assertions in recent studies that heat governance is not yet well developed in cities (e.g. Gabbe *et al* 2021, Keith and Meerow 2021, Keith *et al* 2021).

Plans do not include a wide variety of interventions. Similar to other studies we found that one intervention—trees—was by far the most prevalent hard or soft intervention mentioned (Gabbe *et al* 2021, Meerow and Keith 2021). Many cities may already have forestry initiatives (e.g. Million Tree Programs), and trees are commonly associated with heat mitigation and adaptation co-benefits (e.g. Pincetl 2010, Rahman *et al* 2020, Werbin *et al* 2020, Roman *et al* 2021, Sharifi 2021, Angelo *et al* 2022). Disambiguating whether heat-specific action was a primary or co-benefit of tree-programs was beyond the scope of this study, but future studies should investigate this further, since tree placement may need to be different to effectively provide shading versus stormwater runoff control, for instance (e.g. Depietri *et al* 2012, Demuzere *et al* 2014, Haase *et al* 2014, Bodnaruk *et al* 2017, Depietri 2022). 'Plans' as a soft intervention, were the only other strategy mentioned more than half of the time. It is likely that references to plans and other soft intervention categories such as 'programs' in high level planning documents cite municipal initiatives that are more fully formulated in external documents. While a closer look at municipal heat programs and initiatives is warranted, a recent survey found that fewer than a quarter of cities had any policy on heat (Keith *et al* 2021), and a recent comprehensive report on state-level initiatives in California found that heat is rarely the central feature of policies, the consequence of which is large gaps in overall heat governance (LCI report). Moreover, we confirm that the most plans fail to frame the problem of heat with any level of specificity (Gabbe *et al* 2021). It would be difficult to formulate an effective response to a problem without more specific discussion of the causes and consequences of the problem. Taken together, these findings lend credence to the assertion that cities could be doing far more to govern heat (Keith *et al* 2021).

If heat was framed as a particular problem, the two most prevalent heat framings in our study were UHI and EHE, in alignment with peer reviewed literature recently summarized by Keith *et al* (2020). Scientific perspectives are shifting, for instance, skepticism that UHI is relevant to local planning compared to paradigms such as Local Climate Zones that take into account a variety of land morphology features (Stewart and Oke 2012, Martilli *et al* 2020, Venter *et al* 2021, Turner *et al* 2022, Wang 2022). EHE and UHI were not correlated with one another, correlated with distinct sets of interventions, and mentioned in different plan types. The EHE narrative appears to be more ubiquitous across plan types—especially Hazard plans that are required at the county level—and is associated with a variety of other problem framings, but only soft interventions. Interestingly, warning systems were among the least mentioned soft interventions in plans, perhaps because these are issued by Federal entities. UHI, on the other hand, was associated with hard interventions but not soft, and appeared in most general plans (more often than EHE). This finding supports the observation that two, distinct heat governance systems emerge—heat-as-hazard and heat-as-land-planning—that emphasize acute and chronic aspects of heat separately (Keith *et al* 2020). This finding underscores the need for integrated planning across the two domains (Keith *et al* 2021).

Our results suggest that plans do not include key framings we would expect to find in robust plans to protect people from heat. Thermal comfort, and its primary outdoor antidote, shade, were largely absent from the plans. The everyday lived experience of heat is one of the most direct ways that cities can influence urban climate by providing shade (Middel *et al* 2016). Recent work even provides cities with guidance on the relative effectiveness of different shade interventions (Rahman *et al* 2020, Middel *et al* 2021). This study focused on outdoor interventions and, potentially, plans might include indoor interventions like air conditioning as the central strategy for addressing thermal comfort. A recent study found, however, that most plans fail to link issues of housing to climate impacts in Climate Action Plans (Angelo *et al* 2022). The prioritization of heat as an acute risk (e.g. EHE, 'heatwave') and focus on mortality as a public health outcome may, inadvertently, diminished the role of heat exposure as a chronic stress in municipal responses (Bolitho and Miller 2017). Even the term 'thermal comfort,' which is widely used in the academic literature, frames thermal conditions in the positive. Terms such as 'heat stress' and 'thermal burden' better reflect the myriad problems that occur due to exposure to chronically hot conditions. The scant use of thermal comfort and shade in the plans we analyzed is somewhat unsurprising given shade is not a central means to mitigate UHI, nor is it the most effective means to save lives during EHEs if core body temperatures reach dangerous thresholds (e.g. Eisenman *et al* 2016). The gap between scholarship on thermal comfort, which is growing (Rupp *et al* 2015), and prevalence in the plans analyzed in this study, which is small, is one of the largest knowledge-action rifts we observed.

Disparity was another significant knowledge-action gap. A preponderance of evidence has

demonstrated that heat disproportionately burdens communities of color (Harlan *et al* 2006, Eisenman *et al* 2016, Hoffman *et al* 2020, Dialesandro 2021), but heat was only framed as an equity issue one third of the time. Vulnerability was more likely to be deployed as a disparity framing (Keith *et al* 2020). When an equity framing was deployed, it was more likely to co-occur with extreme heat and health framings, which aligns with other research finding that social equity is most often framed as a public health risk or impacts (Fiack *et al* 2021). This aligns with other studies reporting that equity is often missing in climate planning (Schrock *et al* 2015). Moreover, none of the disparity framings were related to any hard or soft interventions. The lack of high-level prioritization of equity or vulnerability in plans may have tangible implications for heat governance in action. Few planners reported using vulnerability assessments or mapping tools (Meerow and Keith 2021).

Economic framings were also rarely deployed. A recent national survey of municipal planners returned similar findings (Meerow and Keith 2021). Yet, decision makers have reported that evidence of economic impacts and costs of inaction are critical for spurring action (AGCI 2020). A recent report found that in the United States extreme heat is projected to cost nearly half a trillion dollars and will likely disproportionately impact sectors that employ people of color and the South and Southeastern regions (Arsht-Rockefeller report). The economics of urban heat—especially city-specific characteristics—are, therefore, an important gap in both heat scholarship and planning (The Nature Conservancy 2021).

We did not find evidence that heat content was tailored to regional differences. Rather, plan type explained differences in plan content, meaning that which plans are included among a city's 'network of plans' will have implications for which aspects of heat are governed (Berke *et al* 2019). For instance, all cities have Hazard plans, which were more likely to include an EHE framing, but far fewer cities had resilience plans, which are more likely to include a disparity framing. Indeed, the EHE framing was more prevalent than disparity in our analysis. Our finding linking resilience plans to the inclusion of disparity framings aligns with a recent study that found that resilience plans are more likely to include equity and social justice goals (Lambrou and Loukaitou-Sideris 2021). Yet, recent studies also find that inclusion of equity is typically not robustly interated into plans (Angelo *et al* 2022, Lambrou and Loukaitou-Sideris 2022). Future qualitative analysis should investigate the robustness of plan content, which we are unable to assess in our quantitative analysis.

A recent study examined city characteristics that influenced planning professional's concern about heat and assessment of the number of plans and heat strategies implemented in their city (Meerow and Keith 2021). Although both studies found mostly weak relationships, and the nature of the analysis (number of plans versus plan content) are different, a few patterns emerge. For instance, both studies found that support that general municipal resources matter: city capacity related to number of heat plans in their study and, as rough proxies for city capacity used in climate adaptation plan analysis, population and, to a lesser extent, spending per capita did predict plan content in our study (Shi *et al* 2015, Angelou 2022). Both heat planning studies found a relationship between historic experience of heat and inclusion of heat content in plans; although, this relationship was limited to thermal comfort and UHI framings in our study. Both studies found relationships with projected heat: late century projections predicted disparity framing in our study, and projected heat predicted concern and number of heat strategies in theirs. Their study found that access to heat information predicted concern and number of heat plans and strategies. Our results do not show a relationship between inclusion of data and heat plan content, but inclusion of data was rare and may not be synonymous with use of data. Unlike Meerow and Keith (2021) we found that network membership was predictive, although mostly of inclusion of a disparity framing. Both studies found only modest relationships between heat vulnerable populations and plan content and neither study found a relationship between politics and heat planning.

Future research should examine changes since 2020, strategies such as indoor cooling, and emergent strategies such as heatwave naming, ranking, or insurance. Addressing relationships between indoor and outdoor heat exposure and homeless and mobile home residents, is also needed (Kidd *et al* 2021, Phillips *et al* 2021). Expanding the study to other countries and multiple scales of governance is needed and qualitative analysis to contextualize findings.

5. Conclusions

Heat and its many consequences for urban life are a paramount concern for cities, but concrete actions in plans appear to lag behind the severity and complexity of the problem. We examined plan content as one high-level indicator of municipal intentions to govern heat and found evidence that acute and chronic aspects of the problem are not well integrated and that there are gaps in heat problem framing, especially pertaining to disparity and thermal comfort, which have downstream implications for the uneven lived experience of heat. While our analysis did not examine the full range of formal and informal institutional responses to heat, the results do contain broad

insights as action on heat increases. A need exists for greater integration across sectors impacted by heat and more robust and tailored consideration of how cities can intervene to address it.

Data availability statement

The data that support the findings of this study are available through the NSF's Natural Hazards Engineering Research Infrastructure DesignSafe Data Depot.

The data that support the findings of this study are openly available at the following URL/DOI: https://doi.org/10.17603/ds2-xc9j-3054.

Acknowledgments

This study was funded by the Luskin Center for Innovation and Graduate Division at the University of California Los Angeles and publication of the database was funded by the Natural Hazards Research Center at the University of Colorado, Boulder.

Appendix A. City and environmental network membership data (French *et al* 2018)

City data			Environmental network memberships				
City	Population 2019	Climate region	USDN	Rockefeller 100	Climate majors	C40	NLC
Albuquerque	559 374	Southwest	Yes	No	Yes	No	No
Arlington	395 477	Southeast	No	No	No	No	Yes
Atlanta	488 800	Southeast	Yes	Yes	Yes	No	Yes
Austin	950 807	Great Plains	Yes	No	Yes	Yes	Yes
Baltimore	609 302	Northeast	Yes	No	Yes	No	Yes
Boston	684 379	Northeast	Yes	Yes	Yes	Yes	Yes
Charlotte	857 425	Southeast	Yes	No	Yes	No	Yes
Chicago	2709 534	Midwest	Yes	Yes	Yes	Yes	Yes
Colorado Springs	464 871	Southwest	No	No	No	No	Yes
Columbus	878 553	Midwest	Yes	No	Yes	No	Yes
Dallas	1330 612	Great Plains	Yes	Yes	Yes	No	Yes
Denver	705 576	Southwest	Yes	No	Yes	No	Yes
Detroit	674 841	Midwest	Yes	No	Yes	No	Yes
El Paso	679 813	Southeast	Yes	Yes	No	No	Yes
Fort Worth	874 401	Great Plains	No	No	No	No	Yes
Fresno	525 010	Southwest	Yes	No	No	No	Yes
Houston	2310 432	Great Plains	Yes	Yes	Yes	Yes	Yes
Indianapolis	864 447	Midwest	Yes	No	Yes	No	Yes
Jacksonville	890 467	Southeast	No	No	No	No	Yes
Kansas City	486 404	Great Plains	Yes	No	Yes	No	Yes
Las Vegas	634 773	Southwest	No	No	Yes	No	Yes
Long Beach	466 776	Southwest	No	No	Yes	No	Yes
Los Angeles	3966 936	Southwest	Yes	Yes	Yes	Yes	Yes
Louisville	617 790	Southeast	Yes	Yes	Yes	No	Yes
Memphis	651 932	Southeast	Yes	No	Yes	No	Yes
Mesa	499 720	Southwest	No	No	No	No	Yes
Miami	454 279	Southeast	Yes	Yes	Yes	Yes	Yes
Milwaukee	594 548	Midwest	Yes	No	Yes	No	Yes
Minneapolis	420 324	Midwest	Yes	Yes	Yes	No	Yes
Nashville	663 750	Southeast	Yes	Yes	Yes	No	Yes
New Orleans	390 845	Southeast	Yes	Yes	Yes	Yes	Yes
New York	8419 316	Northeast	Yes	Yes	Yes	Yes	Yes
Oakland	425 097	Southwest	Yes	Yes	Yes	No	Yes
Oklahoma City	643 692	Great Plains	No	No	No	No	Yes
Omaha	475 862	Great Plains	No	No	No	No	Yes
Philadelphia	1579 075	Northeast	Yes	No	Yes	Yes	Yes
Phoenix	1633 017	Southwest	Yes	No	Yes	Yes	Yes
Portland	645 291	Northwest	Yes	No	Yes	Yes	Yes
Raleigh	464 485	Southeast	Yes	No	Yes	No	Yes
Sacramento	500 930	Southwest	Yes	No	No	Yes	No
San Antonio	1508 083	Great Plains	Yes	No	Yes	No	Yes
San Diego	1409 573	Southwest	Yes	No	Yes	No	Yes
San Francisco	874 961	Southwest	Yes	Yes	Yes	Yes	Yes
San Jose	1000 280	Southwest	Yes	No	Yes	No	Yes
Seattle	724 305	Northwest	Yes	Yes	Yes	Yes	Yes
Tampa	387 916	Southeast	No	No	Yes	No	Yes
Tucson	541 482	Southwest	Yes	No	Yes	No	Yes
Tulsa	402 324	Great Plains	No	Yes	No	No	Yes
Virginia Beach	450 201	Southeast	No	No	Yes	No	Yes
Washington D.C.	692 683	Northeast	Yes	Yes	Yes	Yes	Yes

Appendix B. List of 50 variables published in the original data set (Turner *et al* 2021). The following terms were used to search for heat-specific statements: heat, hot, cool, thermal, and temperature

Problem framing

- **General heat.** Statement frames the problem as heat in general.
- **Thermal comfort.** Statement frames the problem around human thermal comfort.
- **Urban heat island.** Statement frames the problem the UHI effect or elaborates on the temperature differential between the city and rural areas.
- **Extreme heat event.** Statement frames the problem around EHEs or other cognates such as heat waves or high/extreme heat days.
- **Energy.** Statement frames the problem around the impacts of heat on energy production or consumption.
- **Health.** Statement frames the problem around the impacts of heat on human health and public safety.
- **Economy.** Statement frames the problem around the impacts of heat on economic activities, including labor, costs of production, etc.
- **Infrastructure.** Statement frames the problem around the impacts of heat on hard infrastructure systems such as roads, buildings, air conditioning units, etc.
- **Transportation.** Statement frames the problem around the impacts of heat on f transportation systems (e.g. traffic, buckling roads, reduced air travel, etc).
- **Ecology.** Statement frames the problem around the impacts of heat on the natural environment. This code also includes references to greenhouse gas and other emissions, storms, precipitation, drought, wildfires, biodiversity, etc.
- **Water.** Statement frames the problem around the impacts of heat on the quantity or quality of water.
- **Air quality.** Statement frames the problem around the impacts of heat on air quality.
- **General vulnerability.** Statement frames the problem around the impacts of heat social vulnerability in general.
- **Exposure.** Statement frames the problem around the impacts of heat in terms of exposure (i.e. it refers to geographical vulnerability associated with certain places and location).
- **Sensitivity.** Statement frames the problem around the impacts of heat on demographically-sensitive groups such as elderly people or people with chronic health issues.
- **Adaptive capacity/resilience.** Statement frames the problem around the impacts of heat in terms of individual or systemic coping mechanisms (e.g. people's ability to access cool spaces or to access healthcare services if necessary during a heat wave).
- **Equity.** Statement frames the problem around the impacts of heat in terms of social equity (i.e. it refers to the uneven distribution of impacts of heat within a population). Cognates often found in these statements include: disparate, uneven, unfair, unequal, unjust, etc.

Hard intervention. A hard intervention refers to the addition, subtraction, or alteration of vegetative or built materials that change the composition and/or configuration of urban morphology.

- **Permeable pavement.** Statement mentions permeable pavement.
- **Green roof.** Statement mentions green roofs.
- **Reflective roof.** Statement mentions reflective roofs.
- **Reflective pavement.** Statement mentions reflective pavement.
  - ∗ **Reflective pavement miles.** Statement mentions a specific amount of reflective pavement.
- **Tree/canopy.** Statement mentions trees or tree canopy.
  - ∗ **Tree number.** Statement mentions a specific number of trees.
- **Vegetation.** Statement mentions vegetation.
  - ∗ **Vegetation amount.** Statement mentions a specific amount of vegetation.
- **Green wall.** Statement mentions green walls.
- **Reflective walls.** Statement mentions reflective walls.
- **Water features.** Statement mentions water features (e.g. fountains, ponds, streams, misters).
- **Shaded areas.** Statement mentions shaded areas or structures.
- **Comprehensive approaches.** Statement mentions comprehensive approaches such as complete streets or green infrastructure.
- **Other hard.** This code is reserved for hard interventions that do not align with the aforementioned action items.

Soft intervention. A soft intervention refers to a programmatic or other action aimed at addressing the cause and/or impacts of heat.

- **Policy.** Statement mentions city policies or codes.
- **Install.** Statement mentions a municipal or other initiative to install physical infrastructure or design standards to manage heat.
- **Study/monitor.** Statement mentions efforts to study or monitor heat, heat impacts, or heat management strategies.
- **Educate/outreach.** Statement mentions efforts to educate the public about heat and heat management tation strategies.

- **Partnerships.** Statement mentions partnerships with corporations, community organizations, academia, etc.
- **Warn.** Statement mentions warning systems such as text alert systems, extreme heat notices, etc.
- **Plan.** Statement mentions planning efforts related to heat. This code also includes emergency services and management.
- **Programs.** Statement mentions temporary or ongoing initiatives (e.g. cooling centers, buddy heat programs, transport to cooling centers).
- **Incentives.** Statement mentions reward-based programs such as monetary and non-monetary incentives for businesses/citizens to practice heat-friendly design and behavior.
- **Funding.** Statement mentions funding for heat-related interventions.
  - ∗ **Funding amount.** Statement mentions a specified dollar amount.
- **Ownership.** Statement mentions ownership of infrastructure related to heat management.
- **Other.** This code is reserved for soft interventions that do not align with the aforementioned action items.

Other variables

- **Maps.** Statement includes a map.
- **Figures.** Statement includes a figure.
- **Pictures.** Statement includes a picture.
- **Data sources.** Statement mentions a specific data source (e.g. NOAA).
- **Temperature.** Statement mentions temperature as a metric for studying or managing heat.

Appendix C. Kendall correlation matrix for all primary coded variables in the data set

	General-heat	Thermal comfort	Urban heat island	Extreme heat event	Equity	Energy	Health	Economy	Infrastructure	Transportation	Ecology	Water	Air quality	General-Vulnerability	Exposure	Sensitivity	Adaptive capacity/resilience	Green roof	Reflective roof	Reflective pavement	Tree/canopy	Vegetation	Shaded areas	Comprehensive approaches	Other-hard	Policy	Install	Study/monitor	Educate/outreach	Partnerships	Warn	Plan	Programs	Incentives	Funding
General-heat	1.000																																	
Thermal comfort	0.193	1.000																																
Urban heat island	0.407	0.313	1.000																															
Extreme heat event	0.626	0.149	0.330	1.000																														
Equity	0.234	−0.002	0.262	0.261	1.000																													
Energy	0.554	0.104	0.415	0.811	0.115	1.000																												
Health	0.677	0.145	0.424	0.686	0.422	0.558	1.000																											
Economy	0.414	0.063	0.159	0.372	0.035	0.385	0.695	1.000																										
Infrastructure	0.582	0.048	0.245	0.822	0.083	0.818	0.539	0.370	1.000																									
Transportation	0.476	0.167	0.258	0.477	0.022	0.483	0.449	0.386	0.587	1.000																								
Ecology	0.612	0.315	0.352	0.572	0.215	0.439	0.760	0.624	0.443	0.440	1.000																							
Water	0.501	0.077	0.379	0.568	0.185	0.532	0.589	0.439	0.434	0.365	0.532	1.000																						
Air quality	0.338	0.150	0.523	0.416	0.183	0.398	0.425	0.350	0.220	0.193	0.419	0.603	1.000																					
Gen vulnerability	0.441	0.090	0.360	0.628	0.513	0.438	0.591	0.289	0.482	0.359	0.365	0.318	0.340	1.000																				
Exposure	0.426	0.078	0.335	0.455	0.336	0.308	0.603	0.419	0.342	0.269	0.442	0.295	0.418	0.660	1.000																			
Sensitivity	0.406	0.127	0.375	0.565	0.446	0.344	0.683	0.528	0.426	0.326	0.501	0.347	0.449	0.696	0.680	1.000																		
Adaptive capacity	0.390	0.044	0.255	0.442	0.631	0.237	0.468	0.083	0.244	0.139	0.260	0.364	0.330	0.522	0.391	0.436	1.000																	
Green roof	0.233	0.018	0.502	0.139	0.087	0.360	0.233	0.142	0.169	0.284	0.212	0.066	0.213	0.156	0.172	0.092	0.079	1.000																
Reflective roof	0.311	0.132	0.543	0.177	0.169	0.343	0.273	0.057	0.175	0.276	0.180	0.024	0.183	0.198	0.219	0.153	0.174	0.732	1.000															
Reflective pavement	0.221	0.065	0.327	0.127	0.153	0.061	0.109	−0.014	0.011	0.020	0.124	0.086	0.193	0.181	0.218	0.076	0.184	0.157	0.362	1.000														
Tree/canopy	0.321	0.173	0.711	0.116	0.318	0.273	0.212	0.061	0.076	0.207	0.186	0.099	0.326	0.234	0.221	0.231	0.177	0.524	0.487	0.261	1.000													
Vegetation	0.165	0.226	0.422	0.058	0.263	0.124	0.091	−0.010	0.045	0.018	0.205	0.095	0.352	0.228	0.189	0.118	0.241	0.200	0.162	0.223	0.467	1.000												
Shaded areas	0.099	0.316	0.241	0.052	−0.021	0.063	0.013	0.004	0.000	0.144	0.145	0.056	0.138	0.016	0.037	−0.031	−0.015	0.186	0.150	0.298	0.333	0.374	1.000											
Comprehensive	0.254	0.049	0.443	0.220	0.402	0.230	0.200	0.044	0.177	0.100	0.096	0.113	0.063	0.302	0.134	0.161	0.347	0.136	0.192	0.280	0.353	0.208	0.113	1.000										
Other-hard	0.091	0.150	0.138	0.099	0.018	0.061	0.247	0.226	0.077	0.085	0.189	0.089	0.099	0.072	0.050	0.146	0.029	0.043	0.008	−0.036	0.119	0.156	0.154	−0.033	1.000									
Policy	0.241	0.053	0.481	0.167	0.153	0.205	0.242	0.062	0.174	0.196	0.253	0.146	0.183	0.166	0.132	0.151	0.087	0.514	0.479	0.217	0.473	0.232	0.279	0.179	0.162	1.000								
Install	0.281	0.048	0.095	0.255	0.090	0.183	0.405	0.385	0.118	0.036	0.213	0.166	0.247	0.306	0.492	0.347	0.150	0.094	0.078	−0.013	0.041	0.013	0.057	0.043	0.048	0.038	1.000							
Study/monitor	0.400	0.103	0.290	0.443	0.206	0.388	0.391	0.352	0.457	0.383	0.324	0.274	0.368	0.618	0.491	0.516	0.278	0.208	0.209	0.192	0.249	0.268	0.138	0.180	0.072	0.400	0.158	1.000						
Educate/outreach	0.612	0.118	0.255	0.414	0.330	0.221	0.591	0.426	0.262	0.196	0.407	0.330	0.311	0.534	0.480	0.479	0.512	0.146	0.235	0.252	0.105	0.153	0.069	0.180	0.044	0.144	0.454	0.416	1.000					
Partnerships	0.537	−0.063	0.406	0.518	0.280	0.494	0.420	0.273	0.445	0.301	0.389	0.317	0.233	0.403	0.286	0.280	0.306	0.352	0.351	0.333	0.364	0.213	0.218	0.419	0.081	0.407	0.178	0.458	0.529	1.000				
Warn	0.511	0.068	0.166	0.371	0.084	0.185	0.547	0.407	0.248	0.227	0.355	0.254	0.201	0.297	0.268	0.383	0.257	0.003	0.105	−0.085	−0.017	−0.003	0.011	−0.054	0.062	0.071	0.447	0.292	0.687	0.345	1.000			
Plan	0.482	0.124	0.299	0.644	0.363	0.476	0.685	0.563	0.536	0.375	0.556	0.441	0.454	0.669	0.528	0.672	0.556	0.204	0.172	0.181	0.179	0.216	0.133	0.203	0.123	0.245	0.331	0.605	0.519	0.450	0.391	1.000		
Programs	0.611	0.088	0.341	0.508	0.281	0.352	0.577	0.393	0.390	0.373	0.416	0.373	0.336	0.544	0.489	0.520	0.461	0.288	0.379	0.299	0.219	0.066	0.094	0.225	−0.012	0.317	0.295	0.544	0.762	0.602	0.533	0.624	1.000	
Incentives	0.262	0.108	0.423	0.108	0.017	0.308	0.144	0.059	0.229	0.346	0.079	−0.002	0.061	0.073	0.085	0.079	0.024	0.648	0.768	0.090	0.405	0.060	0.014	0.081	−0.032	0.313	−0.068	0.129	0.070	0.237	0.067	0.055	0.216	1.000
Funding	0.489	0.072	0.140	0.464	0.296	0.372	0.597	0.457	0.436	0.357	0.417	0.357	0.174	0.261	0.429	0.337	0.323	0.081	0.166	0.175	0.149	0.047	0.052	0.113	0.261	0.068	0.341	0.129	0.323	0.270	0.248	0.434	0.308	0.067

Appendix D. Total/percent content and KW test for plan type

	Hazard ($n = 44$)				General ($n = 43$)				Climate ($n = 32$)				Sustainability ($n = 20$)				Resilience ($n = 20$)			
Framing	n	%	Dir.	Sig.	n	%	Dir.	Sig.	n	%	Dir.	Sig.	n	%	Dir.	Sig.	n	%	Dir.	Sig.
General heat	40	91%	+	***	27	63%	+	**	19	59%	Na	Na	13	65%	Na	Na	15	75%	Na	Na
Thermal comfort	12	27%	+	*	5	12%	Na	Na	7	22%	Na	Na	2	10%	Na	Na	1	5%	Na	Na
Urban heat island	24	55%	+	*	32	74%	Na	Na	26	81%	Na	Na	11	55%	Na	Na	15	75%	Na	Na
Extreme heat event	36	82%	+	***	17	40%	(−)	***	26	81%	+	**	8	40%	Na	Na	15	75%	Na	Na
Equity	11	25%	Na	Na	6	14%	(−)	**	15	47%	+	**	5	25%	Na	Na	9	45%	+	*
Energy	29	66%	Na	Na	20	47%	Na	Na	21	66%	+	*	7	35%	Na	Na	12	60%	Na	Na
Health	37	84%	+	***	15	35%	(−)	***	21	66%	Na	Na	9	45%	Na	Na	15	75%	Na	Na
Economy	25	57%	+	***	8	19%	Na	Na	8	25%	Na	Na	1	5%	(−)	**	7	35%	Na	Na
Infrastructure	26	59%	+	***	6	14%	(−)	**	12	38%	Na	Na	5	25%	Na	Na	13	65%	+	**
Transportation	11	25%	+	*	6	14%	Na	Na	5	16%	Na	Na	0	0%	(−)	*	5	25%	Na	Na
Ecology	35	80%	+	***	21	49%	Na	Na	20	63%	Na	Na	6	30%	(−)	**	10	50%	Na	Na
Water	23	52%	+	**	12	28%	Na	Na	12	38%	Na	Na	3	15%	−	*	9	45%	Na	Na
Air quality	17	39%	Na	Na	17	40%	Na	Na	14	44%	Na	Na	6	30%	Na	Na	9	45%	Na	Na
General-vulnerability	22	50%	Na	Na	6	14%	(−)	**	17	53%	+	*	6	30%	Na	Na	14	70%	+	**
Exposure	20	45%	Na	Na	2	5%	(−)	***	13	41%	+	*	5	25%	Na	Na	7	35%	Na	Na
Sensitivity	31	70%	Na	Na	5	12%	(−)	***	13	41%	Na	Na	5	25%	Na	Na	10	50%	Na	Na
Adaptive capacity	17	39%	+	*	4	9%	(−)	**	11	34%	Na	Na	3	15%	Na	Na	9	45%	+	*

(Continued.)

(Continued.)

Hard interventions	Hazard ($n = 44$)				General ($n = 43$)				Climate ($n = 32$)				Sustainability ($n = 20$)				Resilience ($n = 20$)			
	n	%	Dir.	Sig.	*n*	%	Dir.	Sig.	*n*	%	Dir.	Sig.	*n*	%	Dir.	Sig.	*n*	%	Dir.	Sig.
Green roof	6	14%	+	**	11	26%	Na	Na	11	34%	Na	Na	9	45%	Na	Na	7	35%	Na	Na
Reflective roof	9	20%	+	*	11	26%	Na	Na	15	47%	+	***	9	45%	Na	Na	8	40%	Na	Na
Reflective pavement	2	5%	Na	Na	4	9%	Na	Na	8	25%	+	***	2	10%	Na	Na	4	20%	Na	Na
Tree/canopy	10	23%	(−)	***	32	74%	+	**	21	66%	Na	Na	12	60%	Na	Na	12	60%	Na	Na
Vegetation	3	7%	(−)	***	20	47%	+	***	10	31%	Na	Na	4	20%	Na	Na	5	25%	Na	Na
Shaded areas	4	9%	(−)	**	15	35%	+	**	8	25%	Na	Na	2	10%	Na	Na	3	15%	Na	Na
Comprehensive	4	9%	(−)	***	15	35%	Na	Na	12	38%	Na	Na	4	20%	Na	Na	11	55%	+	**
Other-hard	5	11%	Na	Na	7	16%	Na	Na	3	9%	Na	Na	5	25%	Na	Na	1	5%	Na	Na
Soft interventions	*n*	%	Dir.	Sig.	*n*	%	Dir.	Sig.	*n*	%	Dir.	Sig.	*n*	%	Dir.	Sig.	*n*	%	Dir.	Sig.
Policy	9	20%	Na	Na	13	30%	Na	Na	12	38%	Na	Na	6	30%	Na	Na	8	40%	Na	Na
Install	7	16%	Na	Na	1	2%	Na	Na	5	16%	Na	Na	2	10%	Na	Na	1	5%	Na	Na
Study/monitor	11	25%	Na	Na	6	14%	(−)	**	13	41%	Na	Na	7	35%	Na	Na	11	55%	Na	Na
Educate/outreach	30	68%	+	**	8	19%	(−)	***	10	31%	Na	Na	6	30%	Na	Na	11	55%	Na	Na
Partnerships	9	20%	Na	Na	7	16%	Na	Na	12	38%	+	*	7	35%	Na	Na	8	40%	+	*
Warn	20	45%	+	*	4	9%	Na	Na	5	16%	Na	Na	1	5%	Na	Na	3	15%	Na	Na
Plan	23	52%	Na	Na	14	33%	+	*	17	53%	+	*	5	25%	Na	Na	10	50%	Na	Na
Programs	29	66%	+	***	12	28%	+	**	14	44%	Na	Na	8	40%	Na	Na	11	55%	Na	Na
Incentives	2	5%	Na	Na	1	2%	Na	Na	5	16%	Na	Na	2	10%	Na	Na	6	30%	+	***
Funding	11	25%	Na	Na	4	9%	Na	Na	8	25%	Na	Na	1	5%	Na	Na	5	25%	Na	Na
Data sourcs	31	70%	+	***	5	12%	−	***	9	28%	Na	Na	3	15%	Na	Na	6	30%	Na	Na

*$p<0.05$, **$p<0.01$ ***$p<0.001$.

Appendix E. Total/percent content and KW test for region

	Midwest ($n = 27$)				Northeast ($n = 22$)				Great Plains ($n = 34$)				Northwest ($n = 10$)				Southeast ($n = 34$)				Southwest ($n = 49$)			
Framing	*n*	%	Dir.	Sig.	*n*	%	Dir.	Sig.	*n*	%	Dir.	Sig.	*n*	%	Dir.	Sig.	*n*	%	Dir.	Sig.	*n*	%	Dir.	Sig.
General-heat	17	63%	Na	Na	15	68%	Na	Na	28	82%	Na	Na	5	50%	Na	Na	23	68%	Na	Na	33	67%	Na	Na
Thermal comfort	3	11%	Na	Na	2	9%	Na	Na	8	24%	Na	Na	1	10%	Na	Na	4	12%	Na	Na	11	22%	Na	Na
Urban heat island	19	70%	Na	Na	15	68%	Na	Na	24	71%	(−)	*	5	50%	Na	Na	23	68%	+	*	30	61%	Na	Na
Extreme heat event	16	59%	Na	Na	14	64%	Na	Na	20	59%	Na	Na	6	60%	Na	Na	16	47%	Na	Na	29	59%	Na	Na
Equity	9	33%	Na	Na	7	32%	Na	Na	9	26%	Na	Na	3	30%	Na	Na	5	15%	Na	Na	14	29%	+	*
Energy	14	52%	Na	Na	13	59%	Na	Na	21	62%	Na	Na	3	30%	Na	Na	17	50%	Na	Na	23	47%	Na	Na
Health	17	63%	Na	Na	13	59%	Na	Na	19	56%	Na	Na	6	60%	Na	Na	17	50%	Na	Na	28	57%	Na	Na
Economy	8	30%	Na	Na	8	36%	Na	Na	15	44%	Na	Na	2	20%	Na	Na	6	18%	Na	Na	11	22%	Na	Na
Infrastructure	15	56%	Na	Na	9	41%	Na	Na	15	44%	+	*	2	20%	Na	Na	9	26%	Na	Na	12	24%	Na	Na
Transportation	4	15%	Na	Na	7	32%	Na	Na	9	26%	Na	Na	0	0%	Na	Na	2	6%	Na	Na	5	10%	Na	Na
Ecology	14	52%	Na	Na	14	64%	Na	Na	19	56%	Na	Na	5	50%	Na	Na	11	32%	Na	Na	32	65%	Na	Na
Water	9	33%	Na	Na	7	32%	Na	Na	8	24%	Na	Na	5	50%	Na	Na	5	15%	Na	Na	19	39%	Na	Na
Air quality	12	44%	Na	Na	10	45%	Na	Na	16	47%	Na	Na	3	30%	Na	Na	8	24%	Na	Na	15	31%	Na	Na
General-vulnerability	15	56%	Na	Na	14	64%	Na	Na	11	32%	Na	Na	2	20%	Na	Na	7	21%	Na	Na	17	35%	Na	Na
Exposure	6	22%	Na	Na	10	45%	Na	Na	12	35%	Na	Na	2	20%	Na	Na	4	12%	Na	Na	13	27%	Na	Na
Sensitivity	12	44%	Na	Na	11	50%	Na	Na	15	44%	Na	Na	3	30%	Na	Na	8	24%	Na	Na	15	31%	Na	Na
Adaptive capacity	6	22%	Na	Na	9	41%	Na	Na	11	32%	Na	Na	2	20%	Na	Na	3	9%	Na	Na	13	27%	Na	Na

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	Midwest ($n = 27$)				Northeast ($n = 22$)				Great Plains ($n = 34$)				Northwest ($n = 10$)				Southeast ($n = 34$)				Southwest ($n = 49$)			
Hard interventions	*n*	%	Dir.	Sig.	*n*	%	Dir.	Sig.	*n*	%	Dir.	Sig.	*n*	%	Dir.	Sig.	*n*	%	Dir.	Sig.				
Green roof	6	22%	Na	Na	6	27%	Na	Na	13	38%	Na	Na	1	10%	Na	Na	8	24%	Na	Na	11	22%	Na	Na
Reflective roof	5	19%	Na	Na	11	50%	Na	Na	9	26%	Na	Na	0	0%	Na	Na	11	32%	Na	Na	16	33%	Na	Na
Reflective pavement	2	7%	+	*	0	0%	Na	Na	5	15%	Na	Na	0	0%	Na	Na	0	0%	Na	Na	7	14%	Na	Na
Tree/canopy	14	52%	Na	Na	13	59%	Na	Na	18	53%	Na	Na	3	30%	Na	Na	22	65%	Na	Na	22	45%	Na	Na
Vegetation	9	33%	Na	Na	8	36%	Na	Na	9	26%	Na	Na	2	20%	Na	Na	5	15%	Na	Na	10	20%	Na	Na
Shaded areas	5	19%	Na	Na	3	14%	Na	Na	6	18%	Na	Na	0	0%	Na	Na	6	18%	Na	Na	16	33%	Na	Na
Comprehensive	7	26%	Na	Na	8	36%	Na	Na	12	35%	(−)	*	2	20%	Na	Na	8	24%	Na	Na	13	27%	Na	Na
Other-hard	4	15%	Na	Na	2	9%	Na	Na	6	18%	Na	Na	0	0%	Na	Na	5	15%	Na	Na	4	8%	Na	Na
Policy	3	11%	Na	Na	6	27%	Na	Na	12	35%	Na	Na	3	30%	Na	Na	10	29%	Na	Na	16	33%	Na	Na
Soft interventions	*n*	%	Dir.	Sig.	*n*	%	Dir.	Sig.	*n*	%	Dir.	Sig.	*n*	%	Dir.	Sig.	*n*	%	Dir.	Sig.				
Install	2	7%	Na	Na	3	14%	Na	Na	6	18%	Na	Na	0	0%	Na	Na	0	0%	Na	Na	5	10%	Na	Na
Study/monitor	9	33%	Na	Na	17	77%	Na	Na	12	35%	Na	Na	2	20%	Na	Na	5	15%	Na	Na	10	20%	Na	Na
Educate/outreach	11	41%	Na	Na	11	50%	Na	Na	13	38%	+	*	2	20%	Na	Na	8	24%	Na	Na	20	41%	+	*
Partnerships	5	19%	Na	Na	11	50%	Na	Na	10	29%	Na	Na	2	20%	Na	Na	4	12%	Na	Na	11	22%	Na	Na
Warn	5	19%	Na	Na	7	32%	Na	Na	7	21%	Na	Na	1	10%	Na	Na	6	18%	Na	Na	8	16%	Na	Na
Plan	10	37%	Na	Na	12	55%	Na	Na	19	56%	Na	Na	3	30%	Na	Na	7	21%	Na	Na	21	43%	Na	Na
Programs	10	37%	Na	Na	12	55%	Na	Na	18	53%	Na	Na	4	40%	Na	Na	10	29%	Na	Na	20	41%	Na	Na
Incentives	0	0%	Na	Na	4	18%	Na	Na	2	6%	Na	Na	0	0%	Na	Na	6	18%	Na	Na	5	10%	Na	Na
Funding	3	11%	Na	Na	5	23%	Na	Na	9	26%	+	*	1	10%	Na	Na	6	18%	+	*	8	16%	Na	Na
Data sources	9	33%	Na	Na	2	9%	−	*	8	24%	Na	Na	1	10%	Na	Na	7	21%	Na	Na	31	63%	+	*

*$p<0.05$, **$p<0.01$ ***$p<0.001$.

Appendix F. Total/percent content and KW test for network membership

	USDN ($n = 145$)				R100 ($n = 73$)				C40 ($n = 61$)				Climate mayors ($n = 148$)			
Framing	*N*	%	Dir.	Sig.	*N*	%	Dir.	Sig.	*N*	%	Dir.	Sig.	*N*	%	Dir.	Sig.
General-heat	100	69%	Na	Na	51	70%	Na	Na	42	69%	Na	Na	99	67%	Na	Na
Thermal comfort	27	19%	Na	Na	13	18%	Na	Na	11	18%	Na	Na	26	18%	Na	Na
Urban heat island	101	70%	+	*	52	71%	Na	Na	46	75%	Na	Na	103	70%	+	*
Extreme heat event	91	63%	+	**	47	64%	Na	Na	45	74%	+	***	89	60%	Na	Na
Equity	46	32%	+	***	27	37%	+	**	22	36%	+	*	44	30%	+	*
Energy	76	52%	Na	Na	38	52%	Na	Na	37	61%	Na	Na	78	53%	Na	Na
Health	87	60%	Na	Na	43	59%	Na	Na	40	66%	Na	Na	86	58%	Na	Na
Economy	42	29%	Na	Na	18	25%	Na	Na	22	36%	Na	Na	41	28%	Na	Na
Infrastructure	53	37%	Na	Na	29	40%	Na	Na	28	46%	+	*	54	36%	Na	Na
Transportation	23	16%	Na	Na	13	18%	Na	Na	18	30%	+	***	24	16%	Na	Na
Ecology	82	57%	Na	Na	38	52%	Na	Na	39	64%	Na	Na	83	56%	Na	Na
Water	54	37%	Na	Na	28	38%	Na	Na	30	49%	+	**	53	36%	Na	Na
Air quality	56	39%	Na	Na	29	40%	Na	Na	26	43%	Na	Na	54	36%	Na	Na
General-vulnerability	62	43%	+	**	31	42%	Na	Na	31	51%	+	**	62	42%	+	**
Exposure	42	29%	Na	Na	20	27%	Na	Na	19	31%	Na	Na	42	28%	Na	Na
Sensitivity	58	40%	+	*	31	42%	Na	Na	27	44%	Na	Na	56	38%	Na	Na
Adaptive capacity	41	28%	+	*	24	33%	+	*	22	36%	+	*	39	26%	Na	Na

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	USDN ($n = 145$)				R100 ($n = 73$)				C40 ($n = 61$)				Climate mayors ($n = 148$)			
Hard interventions	*n*	%	Dir.	Sig.	*n*	%	Dir.	Sig.	*n*	%	Dir.	Sig.	*n*	%	Dir.	Sig.
Green roof	37	26%	Na	Na	20	27%	Na	Na	19	31%	Na	Na	39	26%	Na	Na
Reflective roof	46	32%	Na	Na	26	36%	Na	Na	23	38%	Na	Na	46	31%	Na	Na
Reflective pavement	15	10%	Na	Na	11	15%	Na	Na	8	13%	Na	Na	18	12%	Na	Na
Tree/canopy	81	56%	Na	Na	43	59%	Na	Na	33	54%	Na	Na	84	57%	+	**
Vegetation	38	26%	Na	Na	21	29%	Na	Na	15	25%	Na	Na	37	25%	Na	Na
Shaded areas	30	21%	Na	Na	18	25%	Na	Na	13	21%	Na	Na	30	20%	Na	Na
Comprehensive	48	33%	+	**	27	37%	+	**	22	36%	Na	Na	44	30%	Na	Na
Other-hard	17	12%	Na	Na	11	15%	Na	Na	8	13%	Na	Na	17	11%	Na	Na
Soft interventions	*n*	%	Dir.	Sig.	*n*	%	Dir.	Sig.	*n*	%	Dir.	Sig.	*n*	%	Dir.	Sig.
Policy	45	31%	Na	Na	21	29%	Na	Na	24	39%	+	*	44	30%	Na	Na
Install	13	9%	Na	Na	6	8%	Na	Na	5	8%	Na	Na	13	9%	Na	Na
Study/monitor	46	32%	+	*	25	34%	Na	Na	25	41%	+	**	45	30%	Na	Na
Educate/outreach	58	40%	Na	Na	32	44%	Na	Na	27	44%	Na	Na	57	39%	Na	Na
Partnerships	38	26%	Na	Na	26	36%	+	***	24	39%	+	***	38	26%	Na	Na
Warn	26	18%	Na	Na	14	19%	Na	Na	15	25%	Na	Na	28	19%	Na	Na
Plan	64	44%	Na	Na	36	49%	Na	Na	32	52%	+	*	62	42%	Na	Na
Programs	66	46%	Na	Na	35	48%	Na	Na	33	54%	+	*	65	44%	Na	Na
Incentives	17	12%	+	*	12	16%	+	**	9	15%	Na	Na	17	11%	Na	Na
Funding	26	18%	Na	Na	18	25%	+	*	13	21%	Na	Na	27	18%	Na	Na
Data sources	47	32%	Na	Na	25	34%	Na	Na	21	34%	Na	Na	51	34%	Na	Na

*$p<0.05$, **$p<0.01$ ***$p<0.001$.

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