atmosphere

MDPI

Review

A Literature Review of Cooling Center, Misting Station, Cool Pavement, and Cool Roof Intervention Evaluations

Flannery Black-Ingersoll *, Julie de Lange, Leila Heidari, Abgel Negassa, Pilar Botana, M. Patricia Fabian and Madeleine K. Scammell

Department of Environmental Health, Boston University School of Public Health, Boston, MA 02118, USA; jdelange@bu.edu (J.d.L.); heidaril@bu.edu (L.H.); tabgel@bu.edu (A.N.); pbotana@bu.edu (P.B.); pfabian@bu.edu (M.P.F.); mls@bu.edu (M.K.S.)

* Correspondence: fblackin@bu.edu

Abstract: Heat islands and warming temperatures are a growing global public health concern. Although cities are implementing cooling interventions, little is known about their efficacy. We conducted a literature review of field studies measuring the impact of urban cooling interventions, focusing on cooling centers, misting stations, cool pavements, and cool or green roofs. A total of 23 articles met the inclusion criteria. Studies of cooling centers measured the potential impact, based on evaluations of population proximity and heat-vulnerable populations. Reductions in temperature were reported for misting stations and cool pavements across a range of metrics. Misting station use was evaluated with temperature changes and user questionnaires. The benefits and disadvantages of each intervention are presented, and metrics for evaluating cooling interventions are compared. Gaps in the literature include a lack of measured impacts on personal thermal comfort, limited documentation on intervention costs, the need to standardize temperature metrics, and evaluation criteria.

Keywords: heat; climate change; mitigation; adaptation; urban environment; heat island; cooling; interventions

check for updates

Citation: Black-Ingersoll, F.; de Lange, J.; Heidari, L.; Negassa, A.; Botana, P.; Fabian, M.P.; Scammell, M.K. A Literature Review of Cooling Center, Misting Station, Cool Pavement, and Cool Roof Intervention Evaluations. *Atmosphere* **2022**, *13*, 1103. https://doi.org/10.3390/atmos13071103

Academic Editors: Rohinton Emmanuel and Jack Ngarambe

Received: 10 May 2022
Accepted: 7 July 2022
Published: 13 July 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Heat islands are a result of anthropogenic activities, wherein urban areas are warmer than neighboring rural areas, due to differences between the built environments. Urban surfaces and structures experience higher temperatures, compared to the larger green spaces and greater vegetation of rural areas [1,2]. Exposure to extreme heat is of increasing concern for public health [3,4]. Considered a "silent killer", estimates of annual heat related deaths in the USA range from 600 to upwards of 6000 [5,6]. Heat contributes to all-cause cardiovascular illness, as well as lung damage, hospitalizations due to heat related illnesses [7], mental health conditions, and adverse pregnancy and birth outcomes [7,8]. Within cities, some populations are more vulnerable to heat effects, due to variability in heat exposure and the physiological ability to respond to heat. Older adults and infants are less capable of thermoregulation; people with underlying medical conditions, including respiratory and cardiovascular disease, are more vulnerable to heat-illness, and people with limited personal financial resources may be less equipped to adapt to higher temperatures [9].

Cities worldwide are implementing heat adaptation and mitigation interventions to reduce the urban heat island effect and extreme heat exposures [10]. As listed by the Environmental Protection Agency (USA EPA), these interventions may include: trees/vegetation, green and cool roofs, cool pavements, and broadly improved infrastructure that invests in 'greener' practices [11]. Cities are also investing in tackling disparities to heat exposures, some of which are the result of historic neighborhood disinvestment and discriminatory housing practices that affect low-income households and specific racial and ethnic groups (Hispanic and non-Hispanic/Black race/ethnicities) [12–17]. However, little is known about intervention efficacy or the optimal metrics to evaluate intervention impacts on temperature exposures and health.

The objective of this literature review is to understand how this set of four cooling interventions have been evaluated in the literature, the extent to which they are deemed effective, and opportunities for future research. This work is part of the Chelsea and East Boston Heat Study (C-HEAT), a collaborative research partnership between GreenRoots in Chelsea, MA (a grassroots environmental justice organization) and investigators at the Boston University School of Public Health in Boston, MA. This review was motivated by heat-vulnerable communities in Massachusetts that are interested in implementing interventions to reduce the urban heat island effect and improve public health.

2. Materials and Methods

We conducted a review of studies of four interventions often used in urban areas: cooling centers, misting stations, cool (or green) roofs, and cool pavements. The literature search included Web of Science (1990-4/6/2021) and PubMed (1990-10/2/2020), using the PRISMA guidelines for reporting systematic reviews [18]. The PubMed search used Boolean and MeSH terms; the Web of Science advanced search engine used Boolean terms and the built-in Keyword Plus tool. Specific search terms are provided in Appendix A.

Qualitative, quantitative, or mixed-method evaluations of interventions in the field were included, with and without human participants. Although lab experiments, simulations, and modeling claim evidence of cooling, studies are lacking on their ability to modify measured temperatures or thermal comfort in real world applications [19–21]. Controlled laboratory studies, models, and simulated intervention studies were excluded from this review. The PubMed and Web of Science searches and screening for eligible articles were conducted by one reviewer, while the data extraction was distributed amongst a team of six reviewers. Information extracted included: intervention location/setting, study objectives, intervention descriptions, exposure(s) and outcome(s), evaluation metrics, results/findings, intervention benefits and disadvantages, community engagement, and attention to vulnerable populations.

3. Results

Search results are detailed in the PRISMA flow diagram in Figure 1 [18]. PubMed yielded 272 articles that matched the search terms. Five were deemed eligible: two articles on cooling centers and three on cool/green roofs. Web of Science yielded 24 cool/green roof articles (three eligible), 186 cool pavement articles (five eligible), 118 misting station articles (seven eligible), and 26 cooling centers articles (two eligible).

3.1. Cool Pavements

Five studies focused on cool pavements in Los Angeles, California, USA [22], Taipei City, Taiwan [23], Acharnes, Greece [24], Ames, Iowa, USA [25], and greater Athens, Greece [26]. Each considered a different type of cool pavement, including solar reflective coating (Guard Top CoolSeal) [22], porous/permeable concrete bricks and porous asphalt [23,24], pervious concrete pavement [25], and light-yellow concrete blocks [26]. Table 1 provides a summary of the types of cool pavements assessed, evaluation metrics used, and intervention results.

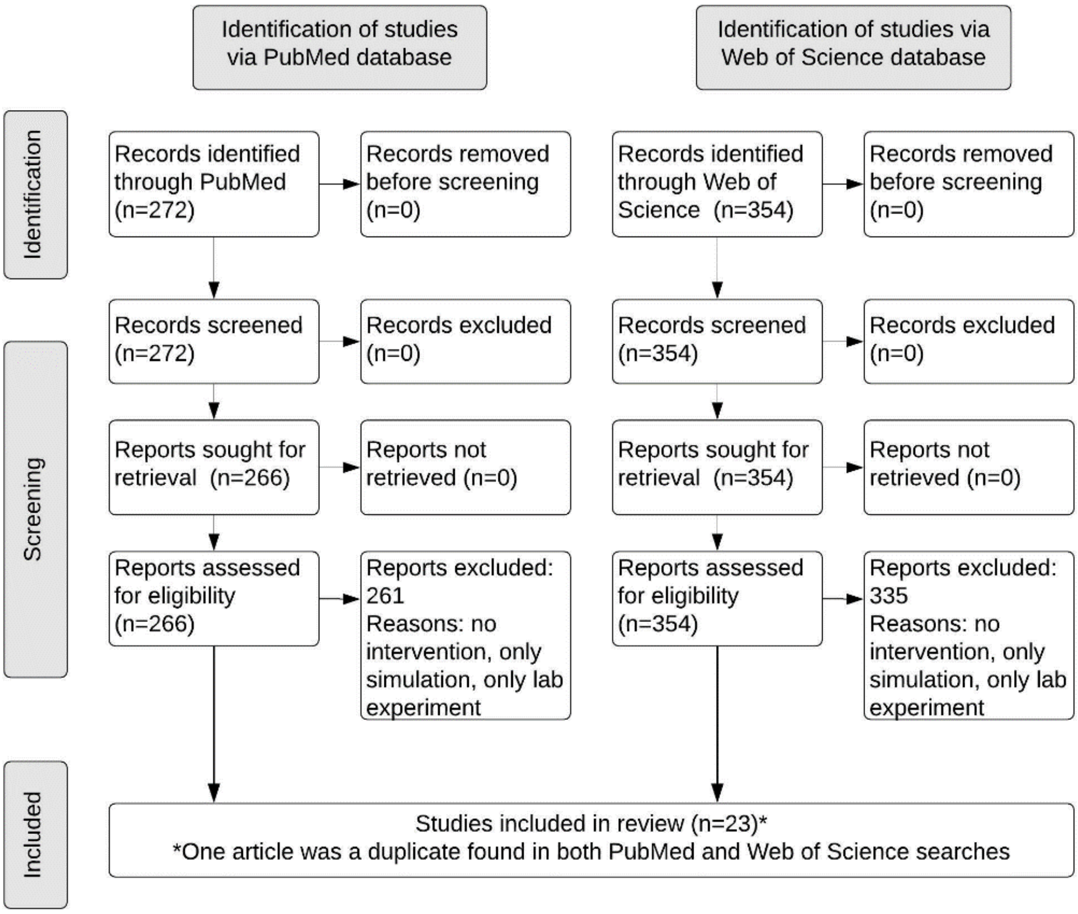

Figure 1. PRISMA flow diagram.

Table 1. Summary of evaluation metrics and results from cool pavement intervention studies.

Cool Pavement Type	Metrics	Results	Article Location & Reference
Solar-reflective Guard Top CoolSeal	Hourly measurements: radiation flux densities, ambient air temperature, surface temperature, horizontal wind speed, relative humidity	CoolSeal surface was 6 °C cooler than control at midday, mean radiant temperature was 4 °C hotter at midday	Los Angeles, CA, USA [22]
Porous concrete bricks and porous asphalt	Ten-minute measurements: surface temperature, over 12-h	Surface temperature, compared to control pavement: up to 17 °C cooler for porous asphalt and up to 14.3 °C cooler for permeable bricks	Taipei City, Taiwan [23]
Porous concrete bricks and porous asphalt	Hourly thermal images to collect surface temperature, solar reflectivity was 0.69	Compared to control, averaged 0.3K cooler ambient temperature	Acharnes, Greece [24]
Pervious concrete pavement	Daily and cumulative: heat gains, ambient air temperature data collected over the course of a summer	Lower cumulative heat gain, compared to control	Ames, IA, USA [25]
Light-yellow concrete blocks	Two days of measuring: surface temperature, ambient air temperature, wind speed, pollutant concentration, calculated cooling power comfort index; solar reflectivity exceeded 0.85	Surface temperature averaged 11.3 °C cooler than control	Athens, Greece [26]

3.1.1. Cool Pavement Evaluation Protocols

Evaluations were designed to quantify the heat differences for cool, compared to control (existing or conventional), pavements by examining surface temperature, ambient air temperature, and heat gain measurements. Two of the five studies estimated human thermal comfort via mean radiant temperature [22] and cooling power comfort index (calculated using observed mean radiant temperature and wind speed) [26]. None included study participants, and one intervention explicitly considered vulnerable populations when trying to find a study location [22].

In Los Angeles, black asphalt pavement was coated with highly reflective Guard Top CoolSeal surfacing in several neighborhoods across 10–12 street blocks each [22]. Data collection took place over the course of one summer day (30 July 2019), from 11:00:00 AM to 9:00:00 PM PDT, in the form of hourly measurements via MaRTy, including: six-directional longwave radiation flux densities, shortwave radiation flux densities (radiation flux densities calculated mean radiant temperature), ambient air temperature, surface temperature, horizonal wind speed, and relative humidity.

In Taipei City, Taiwan, investigators compared 200 m of porous concrete pavement and 200 m of porous asphalt pavement installed in a bicycle lane/pedestrian walkway in front of a high school, with regular concrete and asphalt materials during the wet months of April 2018 and May 2019, as well as the dry month of August 2018 [23]. Surface temperature was collected in 10-min intervals at nine locations between 9:00:00 AM and 9:00:00 PM.

On a sidewalk in front of a school building in Acharnes, Greece, a cool pavement of lime-cement plaster, with a solar reflectivity of 0.69, was installed to replace a conventional pavement with lower solar reflectivity; surface temperature measurements for the cool pavement and an adjacent conventional pavement were collected via hourly thermal images, taken by a FLIR B2 thermal camera device throughout the daytime on 15 June 2015 [24]. In addition to monitoring the change, they used simulation software, Envi-met, to predict temperatures based on the change.

At Iowa State University in Ames, Iowa, a parking lot was used to compare traditional concrete surfacing on top of clay soil, with pervious concrete over a limestone aggregate [25]. Using an array of temperature sensors on the two pavements, daily and cumulative heat gains, as well as ambient air temperature data, were collected throughout the entire summer.

In Athens, Greece, approximately 4500 square-meters of light-yellow concrete blocks were installed in Flisvos park in June and July 2010 [26]. The cool pavement blocks were chosen for their high reflectivity of >0.85 [26]. Surface temperature, ambient temperature, wind speed, and pollutant concentration were collected on two days pre- and post-intervention (for a total of four days) using a mobile station on a vehicle. Additionally, the cooling power comfort index was used to determine thermal comfort, including the mean ambient temperature and wind speed from eight locations ("reference points") in the calculations [26].

3.1.2. Cool Pavement Intervention Results: Surface Temperature, and Ambient Temperature

In Los Angeles, CoolSeal reduced surface temperatures, compared to unchanged asphalt, throughout the observation period. The greatest differences were recorded at midday, when CoolSeal measured approximately 6 °C lower than untreated asphalt concrete [22]. At night, the reflective pavement was between 1.6 and 1.8 °C cooler than the control. However, there was a gain in the net radiation, such that the mean radiant temperature at midday for the reflective pavement was 4.0 degrees hotter [22]. Given this increase, the authors suggest that people would not want to use hotter sidewalks and state that reflective pavement coatings may not be well-suited to all climates and cities [22].

In Taipei, during storm events, porous asphalt and permeable interlocking concrete bricks showed lower surface temperatures than regular pavements [23]. During dry periods, the surface temperatures of both intervention pavements increased more rapidly as ambient air temperature increased, and they decreased more quickly as ambient air temperature decreased [23]. Observations for 14 September 2018, between 9:00:00 AM and 9:00:00 PM, showed lower temperatures for both intervention materials, compared to the conventional pavement, with a maximum difference of 17 °C for the porous asphalt and 14.3 °C for the permeable interlocking concrete bricks. During storm events, porous asphalt and permeable interlocking concrete bricks showed lower surface temperatures than regular pavements [23].

In Acharnes, Greece, the cool pavement lowered surface temperatures and improved "outdoor conditions" [24]. The mean of the maximum summertime ambient temperatures was 0.3 K cooler for the cool pavement areas, compared to the conventional pavement. The surface temperature was reduced by 10 K [24]. Envi-met simulation predicted similar results.

In Ames, Iowa, during the peaks of five heat waves (wherein a heat wave is more than one day with maximum temperatures above 30 °C), the pervious concrete intervention pavement had lower cumulative heat gains post-heat wave peak [25]. Additionally, sensitivity analyses demonstrated that, on heating days, the intervention pavement had lower cumulative heat gains than the control or traditional concrete. The authors suggest that some of the cooling in the previous system may be attributable to the evaporation of water after rainfall.

The Athens cool pavement intervention, via the cooling power comfort index equation, determined that comfort conditions after installing the pavement dropped from extremely hot to quite/very hot (with the exception being the area monitored near the coast), and the number of visitors to the area increased [26]. While the conventional pavement mean surface temperature was 48.1 °C, the intervention pavement mean surface temperature was 36.8 °C, although comparisons of the cool and conventional pavements near the park yielded negligible differences closer to the sea.

3.2. Cooling Centers

Four studies evaluated cooling centers, also referred to as "heat refuges" located in Pittsburgh, PA [27], Portland, OR [28], Maricopa County, AZ, and Los Angeles County, CA [29,30]. Cooling centers included libraries, community centers, commercial spaces, and other public buildings with cooling systems available to city residents during extreme heat events. In each article, cooling centers included formal/designated heat refuges and informal/volunteer refuges. Formal heat refuges are buildings that are designated by the city as places for residents to cool off during heat events, whereas volunteer refuges are not formally listed by cities, but open for residents looking for air-conditioned spaces. Informal refuges often include malls, museums, movie theaters, and other commercial places that people go to escape hot weather.

3.2.1. Cooling Center Evaluation Protocols

All four studies focused on evaluating the population-level proximity, using network analysis software to examine the characteristics and number of residents with access the cooling centers as an adaptive mechanism for coping with extreme heat events [27–30]. None of the studies measured the temperatures at the cooling centers or human exposure. Access was quantified by the total proportions of the populations in the respective cities within specified travel sheds of cooling centers. A range of demographic characteristics (e.g., race, income, age, language, educational attainment, ethnicity, employment, and health insurance status) for populations with and without these sheds were assessed for equity of access, which was considered critical by authors for evaluating the efficacy of extreme heat exposure interventions.

In three of the four articles evaluating cooling centers, heat vulnerability indexes (HVIs) were developed to analyze the equity of access [27,29,30]. The Pittsburgh study identified six principal factors for their HVI: age, isolation, economic resources, cool spaces, education, language, race, ethnicity, and greenspace [27]. Los Angeles HVI variables included the percent of households: without vehicles, renting, with income below poverty, uninsured, and foreign-born. Maricopa HVI variables included the percent: Hispanic/Latino households, foreign-born, uninsured, income below poverty, construction workers, and single female householders [29]. In Portland, equity of access was characterized by census-block group data on income, race, education, age, and language [28].

3.2.2. Cooling Center Results: Accessibility and Equity

In Pittsburgh, with the demand for cooling centers per census block group weighted by the HVI, analyses of both present and future access identified the same three highest need neighborhoods, where the authors suggest that maintaining existing cooling centers and opening additional locations should be a priority [27]. In Maricopa, a greater proportion of the official cooling centers served vulnerable populations (25 of 46 official centers), compared to Los Angeles (9 of 94 official centers). However, 46% of the Los Angeles centers were in places with an already high prevalence of publicly accessible air conditioning (AC), compared to 75% in Maricopa. The researchers used the HVI and a location-allocation mapping tool to identify 10 facilities in each county that would maximize accessibility to the greatest number of people in HVI-specific populations [29]. The Portland analysis found that, at an average walking speed, census blocks with higher proportions of Black/African American populations had greater access to cooling centers, while census blocks with higher proportions of elderly or Asian populations had lower access. The range of access, which changes based on walking speed, is 3.4%, 16.9%, and 32.7% for slow, average, and fast walking speeds, respectively [28]. Further analyses of baseline heat exposure factors considered additional vulnerabilities to extreme heat events—central AC prevalence by block group and urban heat island effect—and found that, in Portland, access was limited for slower walkers, as well as Asian and elderly populations [28].

3.3. Misting Stations

Seven articles evaluated public misting stations designed to cool places and people via water droplets during extreme heat events. Misting stations were located in Osaka, Japan [31], Ancona and Rome, Italy [32–34], Singapore [35], Antofagasta, Chile [36], and Tempe, Arizona [37]. Evaluations were supported by a variety of metrics captured by sensors, indices, meteorological data, and comfort surveys administered to participants, and they measured participants' physiological responses to the misting system.

3.3.1. Misting Station Design

Two studies evaluated 'dry' misting systems, which are designed to cool users without causing dampness, which is accomplished through the particularly small water droplet sizes achieved in the systems, considered optimal for cooling off in humid climates [35]. In Singapore, the dry misting station was placed under a gazebo two meters from the participant seating and composed of two high pressure air jets, which, when aimed at a water jet, produce fine water droplets [35]. A total of 50 participants, aged 20–30, sat below the misters for a 30-min period and measurements were collected on the globe and ambient air temperature, relative humidity, and solar irradiance immediately to the front of the participants' seating [35]. The second dry mist system consisted of six nozzles, located one meter apart and fed by the fountain in a playground in Rome [32].

The two articles in Ancona and Rome, Italy, tested an overhead system fed by a local fountain. In the second iteration, the system was programmed to regulate misting based on weather conditions [33,34]. In Antofagasta, Chile, a misting station prototype with the capacity for direct and indirect misting was installed in a particularly hot location with mostly dark surfaces and little shade [36]. While the station is not referred to as a 'dry' misting system, authors emphasize that the prototype was designed to emit fine droplets of water to avoid leaving participants feeling damp after using the station [36]. The study in Osaka, Japan, set up a spray station consisting of eight nozzles attached to a fan spraying mist on the participating students in a shaded-tree area [31]. In Tempe, Arizona, USA, researchers focused on the cooling capacity of the misting stations installed in shaded, compared to sunny, areas at five restaurants with outdoor seating, where temperatures often exceed 43 °C in the summer [37].

3.3.2. Misting Station Evaluation Protocols

The thermal comfort of people using misting stations was evaluated with qualitative and quantitative data. Five articles used thermal comfort metrics to quantify the cooling capacity of misting stations. These included study participants' skin temperatures, perceived humidity, universal thermal climate index (UTCI), and the physiological equivalent temperature (PET). The UTCI and PET require data collection on ambient air temperature, relative humidity, wind speed, globe temperature, and pressure, as well as inputs for standardized personal human parameters (average height, clothing, etc.) [36,37].

In Arizona, misting stations were installed at five restaurants, and data were sampled in four conditions for 10 min in 10-s intervals each: sun, shade, sun and misting station, and shade and misting station [37]. For the study of a misting prototype conducted in Antofagasta, Chile, participants completed questionnaires on comfort after spending 10 min in the ambient environment (ambient conditions: 30 °C, windy, and cloudy) and after 2–10 min in the mist [36]. The authors used meteorological data to calculate the UTCI, with pre- and post-misting questionnaires administered to study participants [36]. The misting station interventions conducted in Rome and Ancona, Italy, assessed participants' thermal comfort via questionnaires, comparing intervention locations to non-intervention location temperature, humidity, and wind gradients [33]. The Osaka, Japan, study collected participant data via interviews, logging skin temperature, and collecting pre- and post-misting thermal comfort scoring [31].

3.3.3. Misting Station Results

In all seven evaluations, misting stations were found to successfully cool the spaces where they were installed. Two studies did not include participants, nor were there any analyses of thermal comfort [32,34]. The study in Rome was focused on developing a water spray model, using the misting station to compare simulations with measures [32]. In determining which misting station setup optimized the change in ambient air temperature, the authors reported increased cooling when the station had a greater number of misting nozzles set at lower heights, with the effectiveness decreasing at higher wind speeds [32]. In Ancona, Italy, data collected over a week in August (in 10-s intervals) for temperature and relative humidity demonstrated maximum cooling by 7.4 °C, with relative humidity increases measuring under 13% [34].

The five studies that included study participants found misting stations to have cooling effects. These included decreases in the PET and UTCI metrics in Arizona, USA [36], and Antofagasta, Chile [37]. Study participants at the University of Singapore [35], Rome and Ancona, Italy, and Osaka, Japan, reported feeling cooler after using misting stations, further evidenced by the measured decreases in skin temperature. In Antofagasta, Chile, researchers reported 15 °C cooling in both the UTCI and ambient air temperature [37]. The dry mist system tested at the University of Singapore found that, after using the misting station, 70% of study participants reported feeling cooler on the ASHRAE TSV scale (measuring thermal sensation—how warm it feels), and 50% reported feeling cooler on the Bedford TCV scale (measuring comfort—how comfortable the temperature is) [35]. The study in Rome and Ancona, Italy, found agreement in the qualitative data on perceived coolness and the quantitative measurements; misting areas dropped in temperature by approximately 8 °C [33]. In Osaka, Japan, the skin temperatures of participants dropped (nearly instantaneously) an average of approximately 1 °C, and thermal comfort changed from hot to slightly cool [34]. In Arizona, misting stations placed in the shade significantly lowered the PET (−15.5 °C, $p < 0.05$) and UTCI (−9.7 °C, $p < 0.05$) [37].

3.4. Cool Roofs

Eight cool roof intervention studies were from Hong Kong, China [38], New York City, USA [39], Ahmedabad, India [40], El Koura, Lebanon [41], Osaka and Kyoto, Japan [42], Rome and Milano, Italy [43], Acharnes, Greece [24], and Beirut, Lebanon [44]. Numerous types of cool roofs were assessed, including intensive and extensive green roofs, high-reflective and white roofs, thermocol insulated roofs, Modroofs, and garden box roofs. Intensive green roofs are roofs with a substrate depth greater than 150-mm and may include herbaceous ground cover, shrubs, and trees, whereas extensive green roofs have shallower depths and, thus, low-growing vegetation [38,39]. Highly reflective roofs and white roofs both are designed to increase the surface reflectivity by painting or installing white or highly reflective roofing materials [40]. Thermocol roofing is an insulation material installed below the current roof inside the home. Modroofs, or modular roofing, consist of waterproof roofing panels made from recycled materials [40]. Finally, garden box roofs, a variety of which were assessed in the articles reviewed here, consist of garden boxes installed on rooftops with plant, soil, and water contents [41,42,44]. All studies included a 'control roof' or comparison roof, in the form of a bare or black roof. Two of the cool roof studies considered human-effects of interventions [38,40] via qualitative data from study participants. Two studies examined the energy savings resulting from cool or green roof installation [24,39]. An overview of the parameters and results of the various cool roofs is provided in Table 2.

Table 2. Summary of evaluation metrics and results from cool roof intervention studies.

Type of Roof	Parameters	Results	Article and Location
Intensive green roof	Collected sunny and cloudy day measurements of ambient air temperature, relative humidity, black globe temperature, insolation, wind speed, and surface temperature to calculate the UTCI and PET	Compared to control in sunny weather: surface temperature cooler by 4.9 °C, ambient air temperature by 1.6 °C, UTCI by 5.5 °C, and PET by 10.9 °C	Hong Kong, China [38]
High-reflective roof, extensive green roof	Measured surface, ambient air temperature, and surface albedo at two sampling times (at night and during the day)	The surface temperature for the white and green roofs had a 30 °C lower oscillation than the control roof	New York City, USA [39]
Thermocol, solar reflective paint, airlite ventilation sheeting, modular roofing	Minutely measurements of indoor ambient air temperature and humidity	Indoor ambient air temperature significantly lower for solar reflective white paint (compared to unpainted tin) and thermocol (compared to tin/asbestos)	Ahmedabad, India [40]
Gravel, thin soil vegetated, thick soil vegetated	Minutely measurements for one year of ambient air temperature and surface temperature	Thick soil decreased ambient air temperatures by 35%, compared to a drop by 34% for thin soil	El Koura, Lebanon [41]
Hydroponic greening system for rice	Measured heat flux, surface temperature, and ambient air temperature above systems	Hydroponic ambient air temperature was 1.8 °C cooler than the comparison	Osaka and Kyoto, Japan [42]
Modified bitumen, PVC, polyolefin	Solar reflectance measured every three months for two years	Solar reflectivity diminished by 0.14 and 0.22 at the respective sites	Rome and Milano, Italy [43]
Gray roof tiles	Measured energy saved inside the building and surface temperature of tiles	Energy use was reduced by 17% in the summer months	Acharnes, Greece [24]
Garden boxes (one with mulch substrate, the other cardboard pellets)	Measured temperature under garden boxes and plant growth in the garden boxes	Mulch substrate measured a maximum temperature 2 °C cooler than control box	Beirut, Lebanon [44]

3.4.1. Cool Roof Evaluation Methods

An intensive green roof was evaluated, in comparison to a bare roof, in the humid-subtropical Hong Kong climate for 21 sunny days and 18 cloudy days in the summer of 2016 [38]. Using high-precision sensors installed at the center of each roof, ambient air temperature, relative humidity, black globe temperature, insolation, wind speed, and surface temperature data were collected and used as inputs in two indices for estimating thermal comfort: UTCI and PET. In New York City, three roof types were compared in a study from October 2008 through September 2009: a black roof, high-reflective roof, and extensive green roof, all installed on top of a three-story office building [39]. This study measured the air and surface temperatures at 1:00:00 AM and 1:00:00 PM each day, as well as the surface albedo of roofs. A study in El Koura, Lebanon, installed three roof types in 70 × 70 cm boxes on a building for one year: gravel, thin soil vegetated, and thick soil vegetated [44]. Air and surface temperature measurements were sampled minutely for a year (14 January–21 December) to compare data across the four seasons in 2016. Additionally, in Lebanon, two open garden boxes (soil/waste/mulch substrate and soil/waste/cardboard pellets) installed on one rooftop on a building in Beirut were evaluated [44], using the temperatures measured underneath the garden boxes. Plant growth was also measured. In Ahmedabad, an intervention study examined 12 non-intervention roofs (tin, asbestos, and reinforced cement), compared with four types of cool roofs (thermocol roof, solar reflective white paint, Airlite ventilation sheeting, and modular roofing) installed for assessment during the hot post-monsoon season in 16 homes located in an urban slum [40]. Temperature and humidity were measured using a sensor logging minutely data from 10:00:00 AM to 5:00:00 PM daily, and each household completed a questionnaire on socioeconomic conditions, heat stress vulnerabilities, house type, and ventilation sources. In Osaka and Kyoto, Japan, two roofs (the Osaka Gas building and a university building at Kyoto University) had hydroponic urban greening systems for growing rice installed, each system had three pools with rice plants and 10 cm of water fed by two tanks, with data collected for two summer months on two consecutive years [42]. Data were logged for heat flux, surface temperature, and ambient air temperature, as measured on the water in the pools. In another, more experimental, study, two buildings in Rome and Milano, Italy, were setup with 4 × 4 inch solar reflectance roof samples of three types of non-black waterproof materials (modified bitumen, PVC, and polyolefin) to determine which was most effective [43]. The samples weathered for two years, with solar reflectance (measured on a scale from 0 to 1) at three-month intervals for samples set at 45-degree slopes and flat slopes. Finally, in Acharnes, Greece, in a study of both cool roof and cool pavement interventions, an office building was fitted with new, gray-colored cool roof tiles and monitored for energy saved via a decrease in maximum power, surface temperature, and fluctuation of surface temperature [24].

3.4.2. Cool Roof Results: Thermal Comfort and Meteorological Data

Both studies that looked at thermal comfort reported positive meteorological and thermal comfort changes, due to cool roofs. Compared to a bare rooftop, the intensive green roof in Hong Kong found a 4.9 °C cooler surface temperature and 1.6 °C cooler ambient air temperature, with a lower UTCI by 5.5 °C and lower PET by 10.9 °C on sunny days [38]. The Ahmedabad, India, study of various roofing technologies found significantly lower indoor temperatures ($p < 0.05$) for the solar-reflective white paint roof (compared to unpainted tin roof) and thermocol ceiling (compared to tin or asbestos roofs). Questionnaires, submitted by 16 female heads-of-household, found that most homes had floors made of sand and cement; all had electric fans, but none had AC. Forty-five percent of respondents reported heat-related illnesses during the study, of which, 80% participants reported summer as the least comfortable season [40]. The preferred roof type is the thermocol roof, based on questionnaire feedback (also informed by prior knowledge that the white paint would wear over time) [40]. While this study did not directly measure UTCI, PET, or another thermal comfort index, the questionnaire included feedback on participants' experiences with indoor temperatures, as well as the baseline demographic and socioeconomic conditions of the intervention homes.

In the experimental study of two buildings in Rome and Milano, Italy, the samples of solar reflective roof types weathered for two years, with solar reflectance measured at three-month intervals. While all samples decreased solar reflectance, the two roofs with high initial solar reflectance (~0.80) dropped by 0.14 and 0.22 over the two-year study period [43]. A study in El Koura, Lebanon, installed two extensive green roofs on one rooftop, with 8 and 16 cm substrate depths, respectively [41]. The extensive green roof with 8 cm substrate depth reduced summer ambient air temperature on the rooftop by 34.07%, whereas the 16 cm substrate depth reduced summer ambient air temperatures by 35.13% [41]. Over all seasons monitored, the greatest decrease in rooftop ambient air temperatures (by approximately 44%) for the two extensive green roofs was in fall [41]. The evaluation of open garden boxes in Beirut, Lebanon, found the garden box with mulch substrate most effective at cooling, with the warmest temperature measuring 2 °C cooler than the peak temperature over the empty control box [44]. In Osaka and Kyoto, Japan, the ambient air temperature in hydroponic gardens was lower than the bare roof ambient air temperature, except on days with precipitation, and solar and net radiation negatively impacted the green roofs' abilities to mitigate urban heat. The average difference in temperatures, comparing the hydroponic to the bare roof, was 1.8 °C, with the hydroponic roof being statistically significantly cooler than the bare roof ($p < 0.05$) [42]. In the temperate climate of New York City, three roof types were compared: black roof, high-reflective roof, and extensive green roof, all installed on top of a three-story office building [39]. The roof types were evaluated based on the change in temperature oscillation. The black roof oscillated 60 °C, compared to 30 °C, for the white and green roofs. Additionally, authors found that the total energy use required for the intervention roofs vs bare roof decreased, due to both observed temperature differences and energy saving in the construction and roof replacement processes.

3.4.3. Cool Roof Results: Energy Savings

Two of the cool roof articles quantified the changes in energy used by the intervention-buildings [24,39]. In Greece, researchers found that energy use in the office building with cool roof tile decreased both in winter and summer, with a total percent energy-use reduction of 17%; they found significant changes in the summer months of July and August [24]. The study found decreased average peak surface temperature contributed to 4.79% of energy savings, and the peak power reduction necessary for cooling decreased by 10.4%. For the study of white and green roofs installed on an office building in NYC, authors determined that both roofs contribute to decreases in building energy use, with green roofs contributing to energy savings up to 110% that of white roof savings, as measured in equivalent kilograms of carbon dioxide (carbon dioxide emissions avoided due to decreased energy use demands) [39].

3.5. Summary of Metrics, Benefits, and Disadvantages in Cooling Intervention Evaluations

Table 3 presents a summary of evaluation metrics applied across the four cooling interventions, which can be used by researchers designing future cooling intervention evaluation studies. Table 4 provides descriptions of the metrics used to evaluate population accessibility and vulnerability. Table 5 provides descriptions of the comfort metrics referenced in the articles reviewed.

Table 3. Temperature metrics and derived indexes used to evaluate cool pavement, cooling center, misting station, and cool roof interventions.

Temperature Evaluation Metrics	Cool Pavements	Cooling Centers	Misting Stations	Cool Roofs	References
Surface temperature	X			X	[22–24,26,37,38,41,42,44]
Air temperature (ambient)	X		X	X	[25,26,32,35–38,40–42]
Air temperature (indoor)				X	[40]
Radiant temperature	X				[22]
Heat gain	X				[25]
Predicted temperature	X				[24,26]
Globe temperature				X	[38]
Relative humidity	X		X	X	[22,33,38,40]
Wind speed	X			X	[22,26,38]
Atmospheric pressure		X			[35]
Solar Reflectivity/irradiance	X				[24,26]
Insolation				X	[38]
Albedo				X	[39,43]
Heat flux				X	[42]
Cooling power comfort index (wind and ambient temperature)	X				[26]
Universal thermal climate index (UTCI)			X	X	[36–38]
Physiological equivalent temperature (PET)			X	X	[36–38]

Table 4. Population accessibility and vulnerability.

	Cooling Centers	Cool Roofs	References
Equitable access with heat vulnerability index (HVI)	X		[27]
Access weighted by income, race, education, age, and language	X		[28]
Access to cooling centers, no vulnerability adjustment	X		[27–30]
SES, heat stress, housing type, and ventilation vulnerability		X	[40]

Table 5. Thermal comfort metrics and definitions, as provided in the literature reviewed.

Thermal Comfort Metric	Definition
ASHRAE TSV scale	How warm a participant feels.
Bedford TCV scale	How comfortable a participant feels.
Thermal comfort questionnaire	Participants respond to questionnaire prompts with questions about comfort and cooling capacity of the intervention in question.
Physiological equivalent temperature (PET) and universal thermal climate index (UTCI)	PET [45] and UTCI [46]: require data collection on ambient air temperature, relative humidity, wind speed, globe temperature, and pressure, as well as inputs for standardized personal human-parameters (average height, clothing, etc.).
Cooling power comfort index	A calculation based on observed mean radiant temperature and wind speed.

Table 6 provides a breakdown of the benefits and disadvantages of the four interventions evaluated in the articles reviewed.

Table 6. Summary of benefits and disadvantages of each of the four cooling interventions.

Intervention	Benefits	Disadvantages
Cool pavements	• Decrease surface temperatures of paved surfaces [22–26] • Have lower cumulative heat gain [25]	• Can increase mean radiant temperatures, making it uncomfortable for persons standing on the pavement [22,26] • Can be expensive to install (varies depending on material)
Cooling centers	• Can offer heat respite for vulnerable populations, including: residents without AC at home, persons without homes, children, and elderly persons [27,29,30]	• Limit access to comforts of home (food, clean bathrooms, and other amenities) • Can be costly (e.g., movie theaters [30]) • Can be hard to access for residents with disabilities or mobility challenges [28] • May present additional heat exposures and limitations (i.e., waits for public transportation, transit costs) • Create a conflict with sustainability goals by relying on AC [47]
Misting stations	• Provide comfortable refuges from the heat [31,34,35] • Cool the ambient air temperature in the stations [32,34,36,37]	• Consume water, which may not be available in different geographic regions or during droughts • Are costly to install and upkeep
Cool roofs	• Reduce ambient and indoor temperatures [38–41] • Decrease energy demands for heating and air conditioning [24,39] • Can provide accessible green spaces	• Require upkeep and maintenance (i.e., repainting and gardening care) [43] • Are costly to install • Can add excess weight to buildings

4. Discussion

We found a limited number of articles evaluating the field implementation of cooling centers, misting stations, cool roofs, and cool pavements. Overall, the five cool pavement articles indicated that intervention pavements are effective, according to at least one observed metric. Some concerns, such as highly reflective surfaces and the experience of pedestrians, were briefly considered in two articles [22,26]. However, most of the studies gave little to no consideration of the human impacts of cool pavements. None included questionnaires or human participants, nor did they directly assess the thermal impact of cool pavements on the people using them. Additionally, while the articles all assessed variations of cool pavements, including coated, porous, etc., there was no assessment of applicability of findings to different urban climates. If water storage and release of heat is a cooling component of porous pavements, consideration for alternative approaches in areas with little precipitation is relevant [25].

The fundamental limitation in the literature on cooling centers as heat refuges is that none measure the actual usage of cooling centers by residents in the cities of interest. Key components that remain unanswered by the current evaluation strategies include: the number of people entering a facility on a given day during a heat wave; the average length of time a person uses the cooling center; thermal comfort experienced by the populations using the facilities (both pre- and post-use); motivations, facilitators, and barriers for spending time in the center; demographics of visitors (e.g., age, ethnicity, and sex,); means (walking, driving, and public transit) by which persons access the facility; and typical (and optimal) hours of cooling center operations, etc.

Inequities in access to cooling centers by race and age were documented both within and between the city/county comparisons of cooling center networks [27,29]. While the set of HVIs developed in several of the articles identified address age, race, economic, language, and transportation inequities in access to cooling centers, additional concerns arose in light of intersecting with COVID pandemic precautions [28–30]. In an article published in August of 2020, authors cautioned against the use of cooling centers, due to COVID spread, despite simultaneously noting the increased efforts in the past two decades in cities globally to address heat-related morbidity and mortality [48]. The possible spread of COVID and future pandemics threaten the accessibility and sustainability of cooling centers. Even if cooling centers open as a greater percent of the population is vaccinated, as the distribution of vaccinated populations remains inequitable, so does the safety and benefit of using opened cooling centers as refuges from extreme heat [49]. Alternative solutions proposed included monitoring vulnerable persons through phones and social media during extreme heat events. While these interventions are associated with lower death rates [48], they do nothing to ameliorate the immediate experience of extreme heat. Additionally, or alternatively, providing vulnerable homes with AC units is proposed, although the authors recognize that AC is a factor of anthropogenic heat contributing to the UHI effect [48].

The misting station interventions evaluated temporary 'pop-up' misting stations. No permanent misting stations were evaluated. The longer-term evaluation criteria for a permanent misting structure may include quantifying the number and demographics of persons who make use of the stations. In the process of developing and evaluating these solutions, analyses to determine optimal misting station locations, perhaps accounting for external factors, such as higher wind speeds, which diminish the misting station cooling capacity, are necessary [32]. Finally, the question of the length of time after using a misting station during which a person feels cooler remains unaddressed by these articles. We were unable to locate research on the health effects in the hours (or minutes) after using a misting station or cooling center.

All cool and green roofs contributed to cooling changes in ambient air or surface temperatures. Evidence of temperature changes are supported by changes in thermal comfort, which is measured as the UTCI [37] or via questionnaires [39]. Energy savings were presented in two of the cool roof interventions, wherein decreased heating and cooling demands on buildings post-cool roof installation contributed to overall reductions in the percent of energy used [24,39]. Only one article directly measured changes in indoor temperatures as a result of rooftop interventions [40]. Demonstrating decreased energy use for cooling, as a result of cool roofs lowering indoor temperatures, would support the economic benefits of cool and green roofing interventions, given that the initial installation of these interventions requires purchasing roofing renovation materials and paying for the labor of the installation of the cool or green roofs.

Limitations

There are other interventions for heat mitigation and adaptation to the effects of urban heat islands, beyond what we covered in this literature review. Cooling centers, misting stations, cool/green roofs, and cool pavement interventions were targeted based on the needs and interests of low-resource communities in the Northeastern US cities of Boston and Chelsea, MA. Other articles assessing city-specific adaptation strategies similarly emphasized the necessity of identifying the heat adaptations applicable within the context of a city's population, environment, and even regional susceptibilities and vulnerabilities [10,50–52].

Our own focus on particular methods may reflect a limited knowledge of options, as suggested by an international study of awareness of the methods for urban climate adaptation (e.g., targeting city layouts, vegetation/greenspace prevalence and spread, building and surface materials, and anthropogenic heat), finding quite a range of awareness of intervention options and effectiveness at heat adaptation between countries and across 'urban actors' (defined as citizens, politicians, urban planners/designers, and urban climate experts) [53]. Several such heat adaptation methods that are beneficial to public health are outlined in a 2021 systematic review [52]. Urban greening, for example, may include green roofs, walls, and the more conventional planting of trees and other cooling vegetation. The authors also provide a list of numerous passive thermal built environment strategies: phase change materials, solar shading, night cooling, building orientation, nocturnal radiation, and insulation [52]. Pertaining to the layout of urban areas, adopting street canyons, increasing shading, and installing surfaces with higher albedo (e.g., cool pavements) have positive health effects during urban heat events [52]. Despite limiting our heat adaptations to four intervention categories, we find that these four capture aspects of both vegetation (green roofs) and built environment (cooling centers, misting stations, cool roofs, and pavements), as they are outlined in the 2021 review of the health benefits of climate adaptation [52].

5. Conclusions

Across the set of articles found for interventions targeted for consideration—cooling centers, cool pavements, cool and green roofs, and misting stations—we found limited evaluations of, and a lack of standardized evaluation metrics for, estimating the immediate impacts on the thermal comfort or human experience of heat exposures, due to the implementation of the interventions (see Table 2 for breadth of evaluation metrics). Little or no information was provided regarding the costs of implementing the interventions considered. With the goal of providing policy and city planning guidance, intervention evaluations should include several types of cost estimates, i.e., the upfront costs of initial installation of interventions (e.g., building materials and labor required for the installation of cool roofing), as well as the short- and long-term costs for community residents. Finally, many articles were excluded in our literature search, due to a lack of in-situ data collection or implementation of the intervention. As various methods for heat mitigation and adaptation are adopted in cities across the world, standardized methods and criteria for evaluating intervention activities are critical. Through engagement with city officials and other stakeholders on an advisory team, C-HEAT will use study data from a field study of personal and home heat exposures, as well as the information evaluated in this literature review, to build and advise intervention activities.

Author Contributions: F.B.-I., M.K.S. and L.H., conceptualization; F.B.-I., J.d.L., L.H., A.N. and P.B., methodology and review; M.K.S. and M.P.F., funding acquisition, supervision; F.B.-I., J.d.L., L.H., A.N., P.B., M.P.F. and M.K.S., writing, reviewing, and editing. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Barr Foundation Climate Grant (19-08038), National Science Foundation NRT grant (DGE 1735087), National Institutes of Health training grant (NIEHS T32 ES014562), the Undergraduate Research Opportunities Program (UROP) at Boston University, and National Oceanic and Atmospheric Administration grant (NA21OAR4310313).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: We thank the Barr Foundation, Roseann Bongiovanni at GreenRoots, Inc. and members of the C-HEAT Advisory Team, including Ben Cares of the City of Chelsea and Melanie Gárate of Mystic River Watershed Association. We also thank Jonathan Levy at BUSPH.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Appendix A.1. PubMed Search Terms

The search conducted in PubMed used the following Boolean and MeSH terms:

((((“Climate Change”[Mesh] OR “Global Warming”[Mesh] OR “Climate Change” OR “Global Warming” OR “Environmental Exposure”[Mesh] OR “Environmental Exposure*”) AND (“Extreme Heat”[Mesh] OR “Extreme heat” OR “Hot Temperature”[Mesh] OR “Hot temperature*” OR “Heat” OR “Extreme Hot Weather”[Mesh] OR “Extreme Hot weather” OR “Heat exposure” OR “Heat Stress Disorders”[Mesh] OR “Heat stress Disorder*” OR “Heat Stress Syndrome*” OR “heat wave*” OR “heatwave*” OR “High heat”)) AND (“Urban Population”[Mesh] OR “Urban population” OR “Urban Populations” OR “Cities”[Mesh] OR “City” OR “Cities” OR “Urban Health”[Mesh] OR “Urban Health”))) AND (“City Planning”[Mesh] OR “City Planning” OR “Heat Mitigation” OR “heat vulnerability index” OR “Heat mitigation strateg*” OR “Cool city model” OR “UHI mitigation strategies" OR "Urban micro-climate" OR "local heat emergency plan*" OR "urban heat island" OR "Urban heat Island mitigation" OR "Cool roof" OR "Green Roof" OR "climate-resilient cities" OR "climate resilient city").

Appendix A.2. Web of Science Search Terms

Each of the four intervention types searched for in the Web of Science advanced search engine also used Boolean terms and the built-in Keyword Plus tool.

Cool roofs search criteria: KP = ((cool roofs OR green roofs OR white roofs) AND (intervention OR interventions OR mitigation OR adaptation) AND (urban OR city OR cities) AND (heat OR urban heat islands OR urban heat island OR global warming OR extreme heat OR hot weather OR heat stress OR heat wave)).

Misting centers search criteria: (KP = ((misting centers OR misting OR water spray OR spray OR showers OR hydrants OR fountains) AND (heat OR urban heat islands OR urban heat island OR global warming OR extreme heat OR hot weather OR heat stress OR heat wave OR hot OR warming OR climate change OR climate) AND (city OR urban OR cities)) OR AB = ((misting centers OR misting OR water spray OR spray OR showers OR hydrants OR fountains) AND (heat OR urban heat islands OR urban heat island OR global warming OR extreme heat OR hot weather OR heat stress OR heat wave OR hot OR warming OR climate change OR climate) AND (city OR urban OR cities))) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article) Timespan: 1990-2021. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI.

Cool pavements search criteria: (KP = ((cool OR cooling) AND (pavements OR sidewalks OR streets OR asphalt OR pavement OR roads OR road) AND (intervention OR interventions OR mitigation OR adaptation) AND (urban OR city OR cities) AND (heat OR urban heat islands OR urban heat island OR global warming OR extreme heat OR hot weather OR heat stress OR heat wave)) OR AB = ((cool OR cooling) AND (pavements OR sidewalks OR streets OR asphalt OR pavement OR roads OR road) AND (intervention OR interventions OR mitigation OR adaptation) AND (urban OR city OR cities) AND (heat OR urban heat islands OR urban heat island OR global warming OR extreme heat OR hot weather OR heat stress OR heat wave))) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article) Indexes = SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI Timespan = 1990–2021.

Cooling centers search criteria: TITLE: (cooling refuge) OR TITLE: (heat refuge) OR TITLE: (cooling center) AND TOPIC: (urban) Timespan: 1990–2021. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI.

References

1. Luber, G.; McGeehin, M. Climate Change and Extreme Heat Events. *Am. J. Prev. Med.* **2008**, *35*, 429–435. [CrossRef] [PubMed]
2. Mohajerani, A.; Bakaric, J.; Jeffrey-Bailey, T. The Urban Heat Island Effect, Its Causes, and Mitigation, with Reference to the Thermal Properties of Asphalt Concrete. *J. Environ. Manag.* **2017**, *197*, 522–538. [CrossRef] [PubMed]
3. Nwakaire, C.M.; Onn, C.C.; Yap, S.P.; Yuen, C.W.; Onodagu, P.D. Urban Heat Island Studies with Emphasis on Urban Pavements: A Review. *Sustain. Cities Soc.* **2020**, *63*, 102476. [CrossRef]
4. Yang, L.; Qian, F.; Song, D.-X.; Zheng, K.-J. Research on Urban Heat-Island Effect. *Procedia Eng.* **2016**, *169*, 11–18. [CrossRef]
5. Vaidyanathan, A.; Malilay, J.; Schramm, P.; Saha, S. Heat-Related Deaths — United States, 2004–2018. *MMWR Morb. Mortal. Wkly. Rep.* **2020**, *69*, 729–734. [CrossRef]
6. Weinberger, K.R.; Harris, D.; Spangler, K.R.; Zanobetti, A.; Wellenius, G.A. Estimating the Number of Excess Deaths Attributable to Heat in 297 United States Counties. *Environ. Epidemiol.* **2020**, *4*, e096. [CrossRef]
7. Ebi, K.L.; Capon, A.; Berry, P.; Broderick, C.; de Dear, R.; Havenith, G.; Honda, Y.; Kovats, R.S.; Ma, W.; Malik, A.; et al. Hot Weather and Heat Extremes: Health Risks. *Lancet* **2021**, *398*, 698–708. [CrossRef]
8. Wu, C.Y.H.; Zaitchik, B.F.; Swarup, S.; Gohlke, J.M. Influence of the Spatial Resolution of the Exposure Estimate in Determining the Association between Heat Waves and Adverse Health Outcomes. *Ann. Am. Assoc. Geogr.* **2019**, *109*, 875–886. [CrossRef]
9. Mitchell, B.C.; Chakraborty, J. Exploring the Relationship between Residential Segregation and Thermal Inequity in 20 U.S. Cities. *Local Environ.* **2018**, *23*, 796–813. [CrossRef]
10. Larsen, L. Urban Climate and Adaptation Strategies. *Front. Ecol. Environ.* **2015**, *13*, 486–492. [CrossRef]
11. Reduce Urban Heat Island Effect. US EPA. Available online: https://www.epa.gov/green-infrastructure/reduce-urban-heat-island-effect (accessed on 7 June 2022).

12. Eanes, A.M.; Lookingbill, T.R.; Hoffman, J.S.; Saverino, K.C.; Fong, S.S. Assessing Inequitable Urban Heat Islands and Air Pollution Disparities with Low-Cost Sensors in Richmond, Virginia. *Sustainability* **2020**, *12*, 10089. [CrossRef]
13. Fan, J.Y.; Sengupta, R. Montreal's Environmental Justice Problem with Respect to the Urban Heat Island Phenomenon. *Can. Geogr. /Le Géographe Canadien* **2021**, *66*, cag.12690. [CrossRef]
14. Hsu, A.; Sheriff, G.; Chakraborty, T.; Manya, D. Disproportionate Exposure to Urban Heat Island Intensity across Major US Cities. *Nat. Commun.* **2021**, *12*, 2721. [CrossRef]
15. Mashhoodi, B. Environmental Justice and Surface Temperature: Income, Ethnic, Gender, and Age Inequalities. *Sustain. Cities Soc.* **2021**, *68*, 102810. [CrossRef]
16. Mitchell, B.C.; Chakraborty, J.; Basu, P. Social Inequities in Urban Heat and Greenspace: Analyzing Climate Justice in Delhi, India. *Int. J. Environ. Res. Public Health* **2021**, *18*, 4800. [CrossRef] [PubMed]
17. Mitchell, B.C.; Chakraborty, J. Landscapes of Thermal Inequity: Disproportionate Exposure to Urban Heat in the Three Largest US Cities. *Environ. Res. Lett.* **2015**, *10*, 115005. [CrossRef]
18. Page, M.J.; McKenzie, J.E.; Bossuyt, P.M.; Boutron, I.; Hoffmann, T.C.; Mulrow, C.D.; Shamseer, L.; Tetzlaff, J.M.; Akl, E.A.; Brennan, S.E.; et al. The PRISMA 2020 Statement: An Updated Guideline for Reporting Systematic Reviews. *BMJ* **2021**, *372*, n71. [CrossRef] [PubMed]
19. Macintyre, H.L.; Heaviside, C. Potential Benefits of Cool Roofs in Reducing Heat-Related Mortality during Heatwaves in a European City. *Environ. Int.* **2019**, *127*, 430–441. [CrossRef]
20. He, C.; Zhao, J.; Zhang, Y.; He, L.; Yao, Y.; Ma, W.; Kinney, P.L. Cool Roof and Green Roof Adoption in a Metropolitan Area: Climate Impacts during Summer and Winter. *Environ. Sci. Technol.* **2020**, *54*, 10831–10839. [CrossRef]
21. Zhang, J.; Mohegh, A.; Li, Y.; Levinson, R.; Ban-Weiss, G. Systematic Comparison of the Influence of Cool Wall versus Cool Roof Adoption on Urban Climate in the Los Angeles Basin. *Environ. Sci. Technol.* **2018**, *52*, 11188–11197. [CrossRef] [PubMed]
22. Middel, A.; Turner, V.K.; Schneider, F.A.; Zhang, Y.; Stiller, M. Solar Reflective Pavements—A Policy Panacea to Heat Mitigation? *Environ. Res. Lett.* **2020**, *15*, 064016. [CrossRef]
23. Cheng, Y.-Y.; Lo, S.-L.; Ho, C.-C.; Lin, J.-Y.; Yu, S.L. Field Testing of Porous Pavement Performance on Runoff and Temperature Control in Taipei City. *Water* **2019**, *11*, 2635. [CrossRef]
24. Kolokotsa, D.-D.; Giannariakis, G.; Gobakis, K.; Giannarakis, G.; Synnefa, A.; Santamouris, M. Cool Roofs and Cool Pavements Application in Acharnes, Greece. *Sustain. Cities Soc.* **2018**, *37*, 466–474. [CrossRef]
25. Haselbach, L.; Boyer, M.; Kevern, J.T.; Schaefer, V.R. Cyclic Heat Island Impacts on Traditional versus Pervious Concrete Pavement Systems. *Transp. Res. Rec.* **2011**, *2240*, 107–115. [CrossRef]
26. Santamouris, M.; Gaitani, N.; Spanou, A.; Saliari, M.; Giannopoulou, K.; Vasilakopoulou, K.; Kardomateas, T. Using Cool Paving Materials to Improve Microclimate of Urban Areas – Design Realization and Results of the Flisvos Project. *Build. Environ.* **2012**, *53*, 128–136. [CrossRef]
27. Bradford, K.; Abrahams, L.; Hegglin, M.; Klima, K. A Heat Vulnerability Index and Adaptation Solutions for Pittsburgh, Pennsylvania. *Environ. Sci. Technol.* **2015**, *49*, 11303–11311. [CrossRef]
28. Voelkel, J.; Hellman, D.; Sakuma, R.; Shandas, V. Assessing Vulnerability to Urban Heat: A Study of Disproportionate Heat Exposure and Access to Refuge by Socio-Demographic Status in Portland, Oregon. *Int. J. Environ. Res. Public Health* **2018**, *15*, 640. [CrossRef]
29. Fraser, A.; Chester, M.; Eisenman, D. Strategic Locating of Refuges for Extreme Heat Events (or Heat Waves). *Urban Clim.* **2018**, *25*, 109–119. [CrossRef]
30. Fraser, A.M.; Chester, M.V.; Eisenman, D.; Hondula, D.M.; Pincetl, S.S.; English, P.; Bondank, E. Household Accessibility to Heat Refuges: Residential Air Conditioning, Public Cooled Space, and Walkability. *Environ. Plan. B Urban Anal. City Sci.* **2017**, *44*, 1036–1055. [CrossRef]
31. Farnham, C.; Emura, K.; Mizuno, T. Evaluation of Cooling Effects: Outdoor Water Mist Fan. *Build. Res. Inf.* **2015**, *43*, 334–345. [CrossRef]
32. Di Giuseppe, E.; Ulpiani, G.; Cancellieri, C.; Di Perna, C.; D'Orazio, M.; Zinzi, M. Numerical Modelling and Experimental Validation of the Microclimatic Impacts of Water Mist Cooling in Urban Areas. *Energy Build.* **2021**, *231*, 110638. [CrossRef]
33. Ulpiani, G.; Di Giuseppe, E.; Di Perna, C.; D'Orazio, M.; Zinzi, M. Thermal Comfort Improvement in Urban Spaces with Water Spray Systems: Field Measurements and Survey. *Build. Environ.* **2019**, *156*, 46–61. [CrossRef]
34. Ulpiani, G.; di Perna, C.; Zinzi, M. Mist Cooling in Urban Spaces: Understanding the Key Factors behind the Mitigation Potential. *Appl. Therm. Eng.* **2020**, *178*, 115644. [CrossRef]
35. Zheng, K.; Yuan, C.; Wong, N.H.; Cen, C. Dry Mist Systems and Its Impact on Thermal Comfort for the Tropics. *Sustain. Cities Soc.* **2019**, *51*, 101727. [CrossRef]
36. Desert, A.; Naboni, E.; Garcia, D. The Spatial Comfort and Thermal Delight of Outdoor Misting Installations in Hot and Humid Extreme Environments. *Energy Build.* **2020**, *224*, 110202. [CrossRef]
37. Vanos, J.K.; Wright, M.K.; Kaiser, A.; Middel, A.; Ambrose, H.; Hondula, D.M. Evaporative Misters for Urban Cooling and Comfort: Effectiveness and Motivations for Use. *Int. J. Biometeorol.* **2020**, *66*, 357–369. [CrossRef]
38. Lee, L.S.H.; Jim, C.Y. Urban Woodland on Intensive Green Roof Improved Outdoor Thermal Comfort in Subtropical Summer. *Int. J. Biometeorol.* **2019**, *63*, 895–909. [CrossRef]

39. Susca, T.; Gaffin, S.R.; Dell'osso, G.R. Positive Effects of Vegetation: Urban Heat Island and Green Roofs. *Environ. Pollut.* **2011**, *159*, 2119–2126. [CrossRef]
40. Vellingiri, S.; Dutta, P.; Singh, S.; Sathish, L.; Pingle, S.; Brahmbhatt, B. Combating Climate Change-Induced Heat Stress: Assessing Cool Roofs and Its Impact on the Indoor Ambient Temperature of the Households in the Urban Slums of Ahmedabad. *Indian J. Occup. Environ. Med.* **2020**, *24*, 25–29. [CrossRef]
41. Koura, J.; Manneh, R.; Belarbi, R.; El Khoury, V.; El Bahawati, M. Seasonal Variability of Temperature Profiles of Vegetative and Traditional Gravel-Ballasted Roofs: A Case Study for Lebanon. *Energy Build.* **2017**, *151*, 358–364. [CrossRef]
42. Tanaka, Y.; Kawashima, S.; Hama, T.; Nakamura, K. Thermal Mitigation of Hydroponic Green Roof Based on Heat Balance. *Urban For. Urban Green.* **2017**, *24*, 92–100. [CrossRef]
43. Paolini, R.; Zinzi, M.; Poli, T.; Carnielo, E.; Mainini, A.G. Effect of Ageing on Solar Spectral Reflectance of Roofing Membranes: Natural Exposure in Roma and Milano and the Impact on the Energy Needs of Commercial Buildings. *Energy Build.* **2014**, *84*, 333–343. [CrossRef]
44. Sisco, L.; Monzer, S.; Farajalla, N.; Bashour, I.; Saoud, I.P. Roof Top Gardens as a Means to Use Recycled Waste and A/C Condensate and Reduce Temperature Variation in Buildings. *Build. Environ.* **2017**, *117*, 127–134. [CrossRef]
45. Höppe, P. The Physiological Equivalent Temperature - a Universal Index for the Biometeorological Assessment of the Thermal Environment. *Int. J. Biometeorol.* **1999**, *43*, 71–75. [CrossRef] [PubMed]
46. Jendritzky, G.; Höppe, P. The UTCI and the ISB. *Int. J. Biometeorol.* **2017**, *61*, 23–27. [CrossRef]
47. Lundgren-Kownacki, K.; Hornyanszky, E.D.; Chu, T.A.; Olsson, J.A.; Becker, P. Challenges of Using Air Conditioning in an Increasingly Hot Climate. *Int. J. Biometeorol.* **2018**, *62*, 401–412. [CrossRef]
48. Daanen, H.; Bose-O'Reilly, S.; Brearley, M.; Flouris, D.A.; Gerrett, N.M.; Huynen, M.; Jones, H.M.; Lee, J.K.W.; Morris, N.; Norton, I.; et al. COVID-19 and Thermoregulation-Related Problems: Practical Recommendations. *Temperature* **2021**, *8*, 1–11. [CrossRef]
49. Binagwaho, A.; Mathewos, K.; Davis, S. Time for the Ethical Management of COVID-19 Vaccines. *Lancet Glob. Health* **2021**, *9*, E1169–E1171. [CrossRef]
50. Bambrick, H.J.; Capon, A.G.; Barnett, G.B.; Beaty, R.M.; Burton, A.J. Climate Change and Health in the Urban Environment: Adaptation Opportunities in Australian Cities. *Asia Pac. J. Public Health* **2011**, *23*, 67S–79S. [CrossRef]
51. Rohat, G.; Wilhelmi, O.; Flacke, J.; Monaghan, A.; Gao, J.; van Maarseveen, M.; Dao, H. Assessing Urban Heat-Related Adaptation Strategies under Multiple Futures for a Major, U.S. City. *Clim. Chang.* **2021**, *164*, 61. [CrossRef]
52. Sharifi, A.; Pathak, M.; Joshi, C.; He, B.-J. A Systematic Review of the Health Co-Benefits of Urban Climate Change Adaptation. *Sustain. Cities Soc.* **2021**, *74*, 103190. [CrossRef]
53. Lenzholzer, S.; Carsjens, G.-J.; Brown, R.D.; Tavares, S.; Vanos, J.; Kim, Y.; Lee, K. Awareness of Urban Climate Adaptation Strategies –an International Overview. *Urban Clim.* **2020**, *34*, 100705. [CrossRef]