POLICY RECOMMENDATIONS:

RECOMMENDED MAXIMUM SAFE INDOOR AIR TEMPERATURE

The California Department of Housing and Community Development

POLICY RECOMMENDATIONS:
RECOMMENDED MAXIMUM SAFE INDOOR AIR TEMPERATURE

This document provides the California State Legislature and interested parties Policy Recommendations on the Recommended Maximum Safe Indoor Air Temperature and related activities conducted by the California Department of Housing and Community Development (HCD) during the 2023 -2024 fiscal year.

State of California
Gavin Newsom
Governor

Tomiquia Moss
Secretary
California Business, Consumer Services and Housing Agency

Gustavo Velasquez
Director
California Department of Housing and Community Development

Zachary Olmstead
Chief Deputy Director
California Department of Housing and Community Development

Kyle Krause
Deputy Director, Division of Codes and Standards
California Department of Housing and Community Development

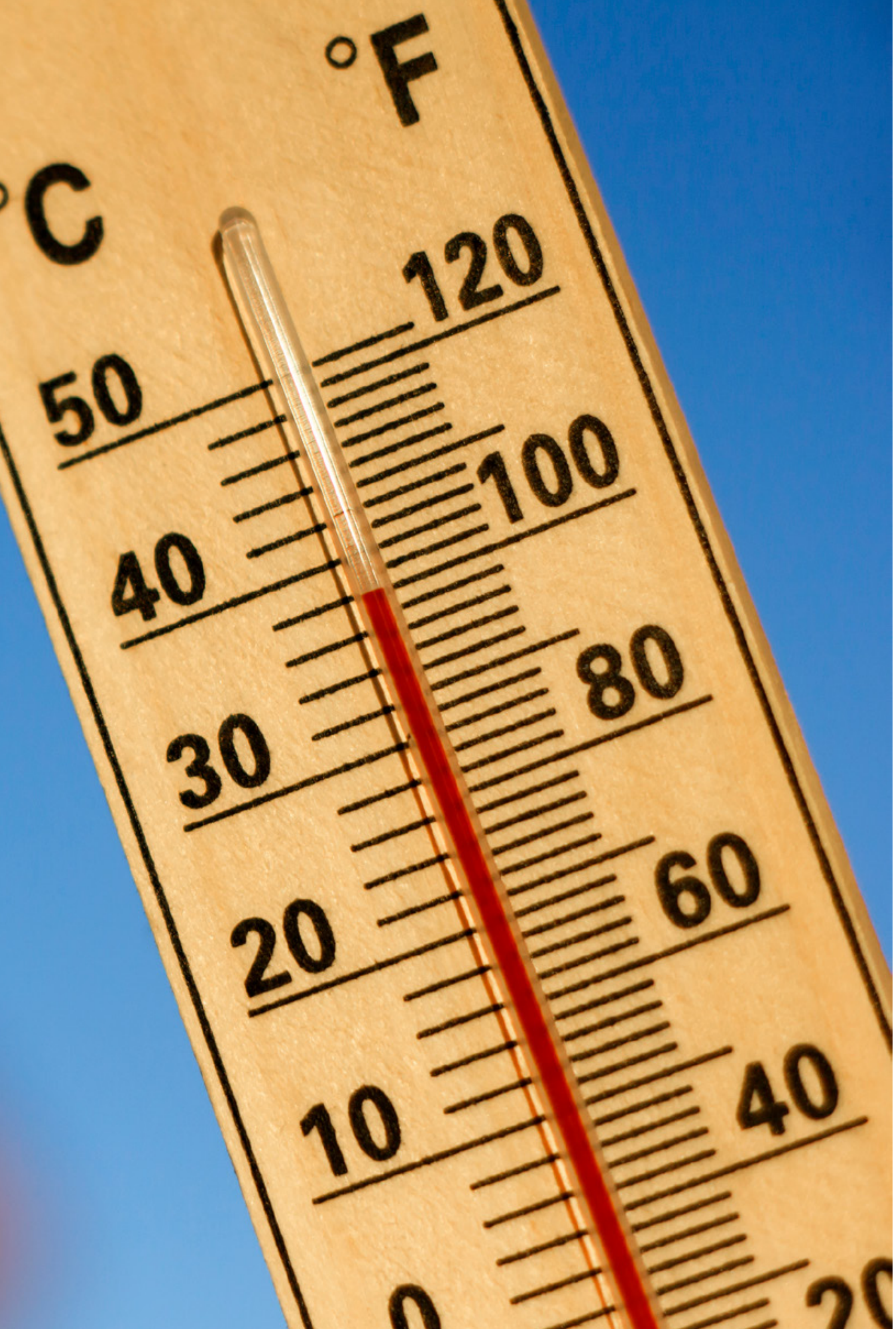


Table of Contents

Executive Summary

Background

Assembly Bill 209 (Chapter 251, Statutes of 2022), Section 31, (AB 209) requires the Department of Housing and Community Development (HCD) to develop policy recommendation(s) that are designed to ensure that residential dwelling units can maintain a recommended maximum safe indoor air temperature. These recommendations consider state climate goals, the extreme heat plan, regional temperature differences, and various methods for reducing indoor air temperatures, including, but not limited to, technical feasibility, building and site electrical system limitations, cost barriers, electric utility capacity limitations, state and federal statutory requirements, and other relevant factors. HCD contracted with the UC Berkeley Center for the Built Environment (CBE) to support the development of these policy recommendations. As specified in AB 209, HCD consulted with stakeholders including, but not limited to, the State Air Resources Board, the State Energy Resources Conservation and Development Commission, the Office of Planning and Research, the California Building Standards Commission, the Office of the State Fire Marshal, the State Department of Public Health, local building officials, local code enforcement officers, and community-based organizations, including those working in the areas of housing and health, tenant rights, and environmental justice.

In addition to input from stakeholders, the policy recommendations were developed using an extensive literature review on the impact of high indoor air temperatures on human health. Although there is not a definitive body of research to explicitly determine the maximum safe indoor air temperature for all residential dwelling units in all possible conditions, the policy recommendations are consistent with the research and standards that are currently available. The policy recommendations also include other measures such as incentives and investment, equity, and other areas of research that should be explored.

These policy recommendations are aligned with many of the goals identified in the 2022 California Extreme Heat Action Plan (EHAP).

Policy Recommendations

Maximum Safe Indoor Air Temperature

The state should consider a general maximum safe indoor air temperature of 82 degrees Fahrenheit (27.8 degrees Celsius) for residential dwelling units. Statewide methods to implement this policy recommendation may include building standards for newly constructed residential dwelling units and/or incentive programs for retrofitting existing residential dwelling units, or manufactured homes/mobilehomes (collectively “MH”).

Additional Considerations

- When air movement is provided by fans or other mechanical means within residential dwelling units, additional consideration may be provided when establishing a maximum safe indoor air temperature.
- While the proposed maximum safe indoor air temperature is meant to apply to a broad range of the population, including most elderly adults, some people have a higher risk of health impacts from heat. Conditions that are associated with higher heat susceptibility include, but are not limited to, cardiovascular disease, respiratory disease, kidney disease, and poor thermoregulation. There is not sufficient information to establish maximum safe temperatures for specific health conditions and State policy should acknowledge that individuals who require lower temperatures should not be inhibited from making accommodations to meet their needs.

Strategies Based on Unit Type

Newly constructed residential dwelling units

- Consider establishing authority and direction to HCD to research and propose for adoption building standards that require that newly constructed residential dwelling units to be designed and constructed to be able to maintain a maximum indoor air temperature of 82 degrees Fahrenheit (27.8 degrees Celsius).
- Consider incentivizing programs for passive and low energy cooling strategies focusing on the use of cool roofs, cool walls, window shading, building shading and landscaping. Evaluate the use of modeling predictions of future weather data that will better represent the conditions during the lifetime of residential dwelling units rather than historical weather data.

Existing residential dwelling units and MH

- Consider incentive programs to encourage broader adoption and use of fans or whole house ventilation systems as an effective, energy-efficient, and resilient means of keeping people cool.
- Consider incentive programs to encourage the use of room evaporative coolers in climate zones that would support evaporative cooling.
- Consider incentive programs to encourage the use of air conditioning, with current heat pump technology, where feasible and cost effective.
- Increase the heatwave resilience of the existing California residential dwelling units by incentivizing weatherization and passive and low energy cooling retrofit strategies identified in this report.

Newly constructed manufactured homes

- The U.S. Department of Housing and Urban Development (HUD) has preemptive authority for the design and construction of newly constructed manufactured homes. However, the policy recommendations may suggest the submittal of a petition to HUD’s Manufactured Housing Consensus Committee to consider the policy recommendations herein, as they may apply to newly constructed manufactured homes produced on or after a future date.

Introduction

Heat is the leading weather-related cause of death in the United States and heatwaves are increasing in frequency, duration, and intensity across the country. The California Department of Public Health (CDPH) reported 395 excess deaths in California during a 10-day heatwave in September 2022 (CDPH, 2023). A study of the July 2006 California heatwave found there were 16,166 excess emergency department visits and 1,182 excess hospitalizations statewide (Knowlton et al., 2009). The California Fourth Climate Change Assessment estimates that by 2050, heatwave events in the Central Valley could last 2 weeks longer than presently experienced (CDPH, 2018). The same report estimates that urban heat-related deaths could double or triple by the same date.

California residential building standards, based on international/uniform model codes, and state regulations in Title 25 of the California Code of Regulations, have long specified that newly constructed residential dwelling units must be able to maintain a minimum indoor air temperature, yet there is no requirement with respect to a maximum indoor air temperature. The purpose of this report is to identify a recommended maximum safe indoor air temperature for California residential dwelling units and identify strategies for maintaining dwelling indoor air temperatures at or below a safe temperature.

While there is considerable literature on the effects of heat on health, there are various approaches used to establish a maximum safe indoor air temperature. As is true for many environmental hazards, there are gaps in our understanding and there are a significant number of factors that impact how heat might affect any given person. People adapt to heat through changes in their physiology and behavior. It is also important to note that there are both short-term and long-term impacts of heat health. All these factors add to the complexity of determining what maximum indoor air temperatures are safe.

There can be significant economic and environmental costs associated with keeping residential dwelling units cool, particularly when achieved with mechanical air conditioning. These costs arise from the energy used to operate existing buildings, and in the specification of more expensive equipment and building envelope features in the design of more efficient new buildings. These policy recommendations seek to strike a balance between the benefits of keeping residential dwelling units cool and the costs of doing so. Because there is not sufficient science on the relationship between exposure to high indoor air temperatures and health to develop a rigorous cost-benefit analysis, the approach is to recommend a maximum safe indoor air temperature that is reasonably well supported by existing literature.

In addition to recommending a maximum safe indoor air temperature, this document compiles a set of strategies that can help keep California residential dwelling units at or below that temperature. These include a range of mechanical and passive cooling strategies that are appropriate for California and have been demonstrated to be effective.

The California Energy Commission (CEC) reports that, as of 2021, 65 local jurisdictions (representing just over 10 percent of all jurisdictions) had adopted policies to promote or require building electrification (CEC, 2021). Electrification of

California dwelling units includes increased use of electric heat pump appliances to replace gas furnaces and water heaters for space and water heating. Over time, this has the potential to substantially decrease the risk of residential overheating, assuming that the electric grid remains stable, and residents are able to afford to operate and maintain cooling equipment given that California utility rates are expected to continue to rise in the future (CPUC, 2021). California is aiming to: "Maximize efficiency and electrify energy use across sectors to the greatest extent possible. Provide affordable, accessible, and reliable carbon-free electricity for a highly electrified economy. Decarbonize activities that cannot be electrified by using clean fuels, efficiency, conservation, and better land use planning and infrastructure" (CCST, 2023). The California Council on Science and Technology determined 8 key challenges for California's energy transformation (CCST, 2023); relevant to this report are the challenges related to electrification (1) and grid reliability (3).

The primary tradeoffs that should be considered when establishing a maximum safe indoor air temperature for California residential dwelling units include human health, economic, and environmental impacts. Exposure to high indoor air temperatures can pose health risks across all populations. While conditions that cause acute heat stress at the individual level for healthy individuals have been studied extensively, the impacts of more moderate conditions on the health of large populations are not well understood. This knowledge gap poses a fundamental challenge to establishing maximum safe indoor air temperature guidelines. A lower maximum indoor air temperature may provide increased health benefits at increased capital, energy costs, and environmental impacts. This report provides rationale for a maximum safe indoor air temperature for California, but the recommendation is not based on a formal health risk assessment because of the lack of sufficient data to support such an analysis. As the understanding of the relationship between indoor air temperature and health improves over time the recommended maximum safe temperature limits should be reevaluated.

New Construction versus Existing Residential Dwelling Units

HCD estimates that there were 14.3 million residential dwelling units in California as of 2021, and during the period of 2020 through 2023, an average of 100,000 new dwelling units were completed each year. New residential dwelling units are generally significantly more energy efficient and over 92 percent of residential dwelling units built after 2012 have mechanical cooling of some type (CEC RASS, 2019). While this report includes a recommended maximum safe indoor air temperature for all residential dwelling units, the majority of the recommendations address the more significant risks associated with existing residential dwelling units and MH stock, particularly important in cases of substandard dwelling units that may contribute to heat vulnerability where people may be more likely to experience heat exposure.

Manufactured Homes and Mobilehomes

MH represent approximately 2 percent of total California residential dwelling units (CEC RASS, 2019). While HUD's federal manufactured home construction and safety standards largely preempt California's ability to regulate the design and construction of new manufactured homes, most of the policies recommended in this report should be considered broadly, including as they may be applied to MH.

Regional Temperature Differences

Temperature variations across the state are significant. The CEC defines 16 distinct climate zones for the purposes of California Energy Code compliance. Table 1 shows the 99th percentile temperatures for the months of May through October for each of these 16 zones. The difference between the coolest zone (Zone 1, Arcata) to the warmest zone (Zone 15, Palm Springs) averages over 40 degrees Fahrenheit. These large differences mean that the overheating risk for residential dwelling units can be very different from one location to another. The analysis of overheating risk and cooling energy use takes these regional variations into account. Some of the policy recommendations are also dependent on aspects of regional climate differences.

These regional differences in temperature also mean that individuals living in different parts of the state may have different levels of acclimatization to heat. In general, people living in warmer regions may be more resilient to heat because of physiological, behavioral, and physical environment adaptations. These adaptations are not sufficiently well understood, particularly among different subgroups of the population, to justify localized maximum safe indoor air temperature recommendations for different regions of the state.

Table 1: 99th percentile outdoor dry bulb temperatures for May through June for CA climate zones.

ZONE	CITY	MAY	JUN	JUL	AUG	SEP	OCT
1	Arcata	59	68	63	73	72	68
2	Santa Rosa	89	96	91	97	91	97
3	Oakland	83	81	81	84	80	88
4	San Jose	90	98	93	98	90	95
5	Santa Maria	81	82	78	76	85	92
6	Torrance	78	83	81	80	82	88
7	San Diego	78	77	79	79	82	86
8	Fullerton	89	91	89	90	95	97
9	Burbank	91	97	91	94	98	100
10	Riverside	93	100	98	98	101	101
11	Red Bluff	99	110	103	108	99	96
12	Sacramento	95	105	100	101	95	95
13	Fresno	98	107	103	106	100	98
14	Palmdale	95	107	102	102	99	96
15	Palm Springs	108	117	112	110	107	108
16	Blue Canyon	77	87	80	88	81	80

California Extreme Heat Action Plan (EHAP)

The 2022 California EHAP outlines a set of strategic actions to address extreme heat. These actions are organized into 4 tracks with a total of 13 goals. The recommended policies in this document are aligned with many of the actions in the EHAP including the following:

Action Track A:

Build Public Awareness and Notification

Goal 1: Build public awareness about extreme heat through targeted communications campaigns

Goal 3: Improve accuracy and accessibility of heat modeling and data to inform decision-makers

Action Track B:

Strengthen Community Services and Response

Goal 1: Invest in social resilience

Action Track C:

Increase Resilience of our Built Environment

Goal 1: Protect critical infrastructure

Goal 2: Support heat resilient and cooler communities through relevant regulations and codes

Goal 3: Invest in cool buildings and surfaces

Goal 4: Utilize science-based frameworks and tools

Action Track D:

Utilize Nature-based Solutions

Goal 1: Promote nature-based solutions to reduce extreme heat risks

AB 209 Stakeholders

AB 209 requires HCD to consult with specific state agency and non-governmental stakeholders to support the development of the policy recommendation(s). The goal was to garner participation from stakeholders in the development of policy recommendations, and to collaborate on research relevant to the scope of AB 209.

> ***AB 209 requires HCD to consult with specific state agency and non-governmental stakeholders to support the development of the policy recommendation(s). The goal was to garner participation from stakeholders in the development of policy recommendations, and to collaborate on research relevant to the scope of AB 209.***

The AB 209 stakeholders, include, but are not limited to, the State Air Resources Board, the State Energy Resources Conservation and Development Commission, the Office of Planning and Research, the California Building Standards Commission, the Office of the State Fire Marshal, the State Department of Public Health, local building officials, local code enforcement officers, and community-based organizations, including those working in the areas of housing and health, tenant rights, and environmental justice. HCD facilitated four AB 209 meetings to obtain input and held a stakeholder comment period for feedback on the draft content for the policy recommendations.

Stakeholder Feedback

Below is a summary of the general feedback HCD received from stakeholders:

- Several stakeholders expressed the importance of including MH in the development of policy recommendations.
- Stakeholders asked that existing residential dwelling units be considered as well as newly constructed residential dwelling units.
- As an option, stakeholders were supportive of passive cooling approaches that were less energy intensive and less costly to operate when compared to mechanical air conditioning.
- Clarify that the proposed maximum safe indoor air temperature should apply to existing dwelling units as well as newly constructed residential dwelling units.
- Include more discussion on the relationship between hotter temperatures and increased air pollution.
- Add more information about hydration, limiting outdoor activities to the coolest hours, and heat warning systems.
- Add more explanations and examples about behavioral and psychological adaptations.
- Change “vulnerable population” to “heat-vulnerable populations”.
- Add more information about the effects of heat on mental health, increases in interpersonal violence,

the impact of medication and alcohol on heat stress, and the limitations and challenges for people with physical disabilities in seeking cooler environments during heatwaves.

- Add a definition of “extreme heat events” and whether “heatwave” and “extreme heat event” are interchangeable terms.
- Take into consideration the limitations associated with natural ventilation/night cooling.
- Concern that fans are not effective and may in fact be dangerous to health when outdoor temperatures are high.
- Consider different thresholds for different regions of California.

Note: There were several suggestions that were outside the scope of AB 209, which are not included in the policy recommendations.

Research and Supporting Information

Maximum Safe Indoor Air Temperature Justification Summary

The proposed maximum safe indoor air temperature is consistent with applicable research and standards identified herein.

ASHRAE Standard 55-2023, Thermal Environmental Conditions for Human Occupancy (ASHRAE 55, 2023): This widely used standard defines in detail the environmental conditions required for human thermal comfort. The proposed maximum safe indoor air temperatures represent the upper range of comfort for a person wearing summer clothing at typical metabolic rates within residential buildings. Although thermal comfort is not a direct measure of health, it indicates a state of low heat stress on the body which is unlikely to significantly contribute to health-related illness.

Laboratory research: A recent study (Meade et al., 2024) on the physiological effects on elderly subjects in Canada from an 8-hour exposure to a range of thermal conditions found no significant impacts at 79 degrees Fahrenheit and significant impacts at 88 degrees Fahrenheit and above. No conditions between 79 degrees Fahrenheit and 88 degrees Fahrenheit were evaluated. The study recommends an upper limit of 79 degrees Fahrenheit, but includes the observation that “it is likely that [79 degrees Fahrenheit] is overprotective for individuals living in warmer areas (e.g., tropical or hot, dry climates), and enforcing this limit in those regions could have negative consequences because of current economic and environmental costs of mechanical cooling.”

Sleep and health: Sleep quality has direct and important impacts on health. A UK study resulted in a recommendation of 82.4 degrees Fahrenheit (28 degrees Celsius) as an 8-hour average night-time indoor air temperature threshold for most healthy persons and 78.8 degrees Fahrenheit (26 degrees Celsius) for special needs, sick and ill persons (K. J. Lomas & Li, 2023). These threshold temperatures assume that the indoor air is still, without air movement present to cool the occupant.

Susceptible Populations

While the proposed maximum safe indoor air temperatures are meant to apply to a broad range of the population, including most elderly adults, some people have a higher risk of health impacts from heat. Conditions that are associated with higher heat susceptibility include, but are not limited to, cardiovascular disease, respiratory disease, kidney disease, and poor thermoregulation. There is not sufficient information to establish maximum safe temperatures for specific conditions and State policy should acknowledge that individuals who require lower temperatures should not be inhibited from making accommodations to meet their needs.

Heat waves and Future California Climate

Global Warming and Heat Waves

The year 2023 was the warmest year since record-keeping began in 1850 (Rohde, 2024). If the current rate of global warming persists over the next decade, it could lead to irreversible impacts on natural and human systems, including sea level rise and extreme weather events such as heatwaves (IPCC, 2022; Zachariah et al., 2023). The term heatwave is defined by the IPCC as "a period of abnormally hot weather, often defined with reference to a relative temperature threshold, lasting from two days to months" (IPCC Annex II, 2022). Based on (Ostro et al., 2009), any prolonged period of high temperatures usually lasting at least 3 consecutive days, especially accompanied by high nighttime temperatures, may be deemed a heatwave. A modest increase in average temperature and/or temperature variability can lead to relatively large changes in the frequency of extreme heat events. Based on the Centers for Disease Control and Prevention (CDC), most definitions for extreme heat events refer to an extended period of time (several days or more) with unusually hot weather conditions that potentially can harm human health. The U.S. Environmental Protection Agency defines extreme heat events as "periods of summertime weather that are substantially hotter and/or more humid than typical for a given location at that time of year" (United States Environmental Protection Agency, 2006). The terms heatwave and extreme heat event are interchangeable. Heatwaves are the primary cause of weather-related mortality (Luber & McGeehin, 2008), contributing to approximately 1,000 deaths annually in the US (Khatana et al., 2022; Sarofim et al., 2016). Based on the new estimation from CDC (2024), approximately 1,220 people in the United States are killed by extreme heat every year. From 2010 to 2019, California heatwaves have caused at least 599 deaths and could be up to 3900 deaths based on a recent estimation analysis (Phillips et al., 2021) of heatwaves occurred in inland counties (Ostro et al., 2009; Trent, 2006). Future extreme heat events could kill up to 11,300 Californians annually by 2050.

Future California Climate

In California, temperature records align with global warming trends, showing a 2.5 degrees Fahrenheit (1.4 degrees Celsius) increase in annual average air temperature compared to 1880 (California Department of Water Resources, 2015; Pathak et al., 2018; Witherow, 2022). By the end of the 21st century the average temperature in California could remain at pre-industrial levels if greenhouse gas emissions are substantially reduced; if emissions continue to rise, the temperature increase could reach 8.1 degrees Fahrenheit (4.5 degrees Celsius) (Cayan et al., 2008; Kunkel, 2022). These projections are based on climate models that focus on annual average temperature changes.

However, average annual temperature rise does not fully capture the extent of heat stress because summer temperatures are rising faster than winter temperatures (California Department of Water Resources, 2015; Witherow, 2022). In addition, nighttime temperatures are rising faster than daytime temperatures, which reduces nighttime relief during heatwaves (Bumbaco et al., 2013; Gershunov et al., 2009; Guirguis et al., 2014).

The impact of global warming is not uniform across California due to its complex topography and large latitudinal extent (LaDochy et al., 2007). Since 1950, the number of daytime heatwaves has increased the fastest in Southern California (Tamrazian et al., 2008), but the number of nighttime heatwaves has increased the fastest in Northern California (Witherow, 2022). Although inland and urban regions are warming faster than coastal and rural areas (Pathak et al., 2018), coastal regions face greater adverse health impacts from rising temperatures due since they are less acclimatized and air conditioning is less common (Gershunov & Guirguis, 2012).

Review of Existing Temperature Standards and Codes

Minimum indoor air temperature thresholds are well-established in the existing state, national, and international standards and codes (World Health Organization, 2018). Maximum indoor air temperature standards are much less common (although there is currently considerable activity on this topic in many parts of the U.S. and internationally) and those that do exist vary greatly and their scientific basis is not well documented. The World Health Organization (WHO 2018) makes only a conditional recommendation that “strategies to protect populations from excess heat should be developed and implemented”, with no specific temperature guidelines provided.

U.S. Standards and Codes

Care facilities

Although currently there are no U.S. federal standards that directly address the maximum indoor safe air temperatures for residential dwelling units, Section 483 of Title 42 of the U.S. Code of Federal Regulations (42 CFR 483.10(i)(6)) specifies that long term care facilities must maintain indoor air temperatures between 71- and 81-degrees Fahrenheit. In the document State Operations Manual Appendix PP - Guidance to Surveyors for Long Term Care Facilities, further guidance is provided:

> *While facilities certified after October 1, 1990, are required to maintain an air temperature range of 71-81°F, there may be brief periods of time where that temperature falls outside of that range only during rare, brief periods of unseasonable weather. This interpretation would apply in cases where it does not adversely affect resident health and safety, and facility staff took appropriate steps to ensure resident comfort. This would enable facilities in areas of the country with relatively cold or hot climates to avoid the expense of installing equipment that would only be needed infrequently.*

Occupants of healthcare or long-term care facilities are generally considered more susceptible to heat than the general population due to age and/or underlying health conditions.

Several states, including California, Texas, Georgia, and Washington, have set state-level regulations for the highest temperatures allowed in healthcare facilities. California Title 22, Division 6, Chapter 8 (Residential Care Facilities For The Chronically Ill) Section 87303(b)(2) includes the following requirement:

> *The facility shall cool rooms to a comfortable range, between 78 degrees F (26 degrees C) and 85 degrees F (30 degrees C), or in areas of extreme heat to 30 degrees F less than the outside temperature.”degrees F less than the outside temperature.*

Local Codes for Residential Dwelling Units

At the city and county level in many states, numerous codes define indoor air maximum temperatures for residential dwelling units, summarized in Table 2, organized from highest to lowest. Local standards may be more restrictive than the applicable statewide building standards. Some local standards enable renters to require landlords to install cooling equipment if indoor air temperatures exceed these thresholds.

In most city/county, both active and passive cooling systems are considered acceptable strategies to maintain the indoor air room temperature below the established thresholds. Additionally, some cities/counties provide alternative maximum temperature thresholds for buildings that adopt specific cooling systems. For example, in Phoenix, residential buildings are required to maintain the indoor air temperature below 86 degrees Fahrenheit (30.0 degrees Celsius) with evaporative cooling systems, or below 82 degrees Fahrenheit (28.0 degrees Celsius) with air conditioning systems (City of Phoenix, 2023). Evaporative cooling systems, which rely on water evaporation, may not achieve temperatures as low as those possible with air conditioning systems. However, they are both effective and energy-efficient in dry climates, offering a more affordable alternative to air conditioning systems.

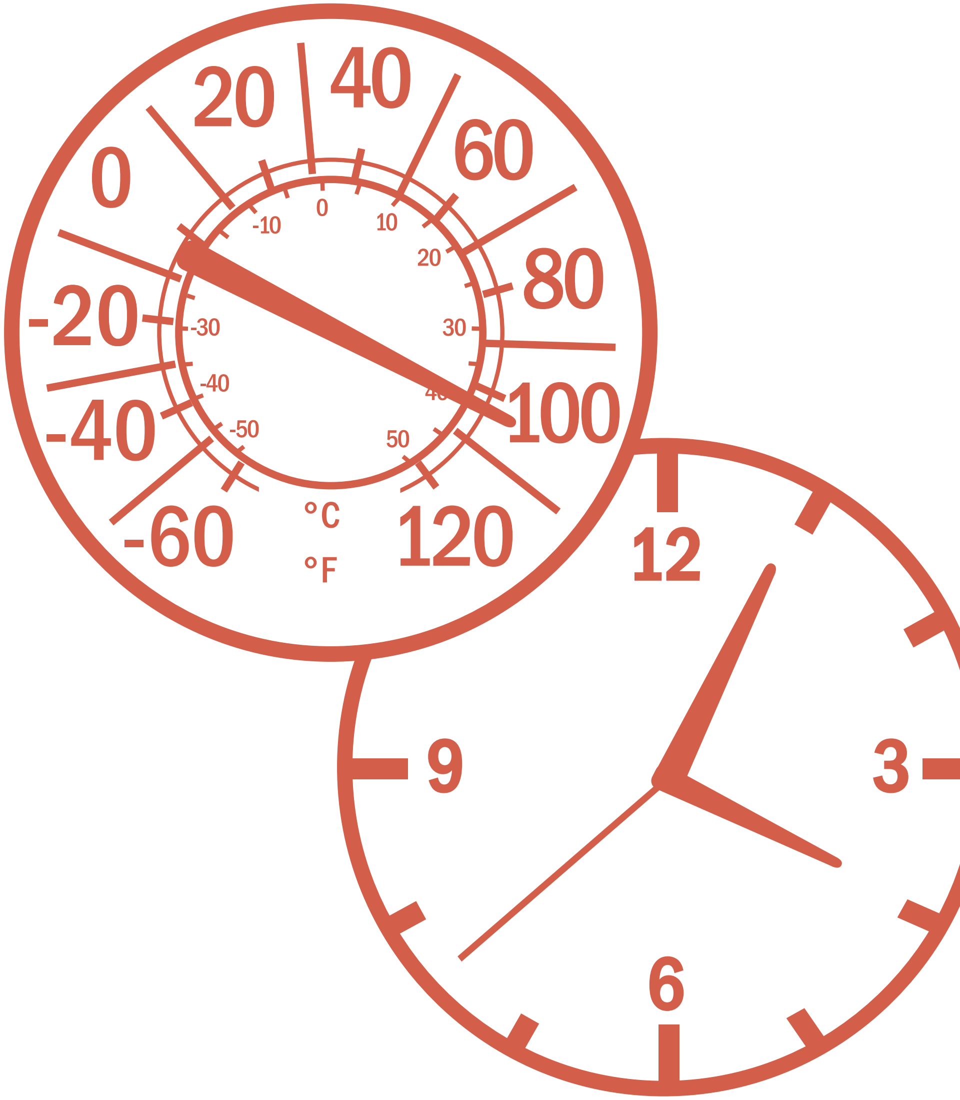
Table 2: Maximum Indoor Air Temperatures for Selected U.S. Local Codes

STATE	CITY	MAXIMUM INDOOR AIR TEMPERATURE
TX	El Paso	90 °F (32.2 °C) (City of El Paso, 2023)
TX	Dallas	85 °F (28.4 °C) (City of Dallas, 2024)
NV	Clark County	85 °F (28.4 °C) (Clark County, 2024)
AZ	Tempe	82 °F (27.8 °C) (City of Tempe, 2024)
AZ	Phoenix	82 °F (27.8 °C) (City of Phoenix, 2023)
AZ	Tucson	82 °F (27.8 °C) (City of Tucson, 2024)
TX	Houston	80 °F (26.7 °C) (City of Houston, 2022)
CA	Palm Springs	80 °F (26.7 °C) (City of Palm Springs, 2023)
LA	New Orleans	80 °F (26.7 °C) (City of New Orleans, 2024)
MD	Montgomery	80 °F (26.7 °C) (Montgomery County, 2024)
OR	Portland	78 °F (25.6 °C) (City of Portland, 2024)

For additional information see Appendix A.

Exposure Time

Although the length of time that a person is exposed to heat significantly impacts possible negative health consequences, this relationship is not well established. Some standards specify maximum lengths of time that a temperature can be exceeded. Others combine time and temperature using the concept of degree-hours, where exposure to a temperature 2 degrees above a threshold for 1 hour is considered equivalent to a 2 exposure at a temperature 1 degree above the threshold. Other standards, like Title 42 Section 483 mentioned above, acknowledge that temperatures can occasionally be above a specified threshold without specific quantitative guidance.



Heat and Human Physiology

The goal of this work is to establish health-based policy recommendations for the maximum safe indoor air temperature of California residential dwelling units. Understanding the underlying physiology of how humans are affected by heat is an important component of developing the policy recommendations.

Humans have evolved sophisticated mechanisms to maintain a nearly constant core body temperature over a wide range of environmental conditions. To maintain a constant core temperature, internal metabolic heat production needs to be in balance with heat loss to the environment. In cold environments, thermoregulation responses include reducing blood flow to the skin and to the extremities (vasoconstriction) and shivering. In hot environments, humans increase blood flow to the skin and extremities (vasodilation) and, when this is insufficient to maintain core temperature, increase their sweat production to lose more heat through evaporation. In a "neutral" thermal environment blood vessels dilate or constrict to adjust blood flow and the associated heat loss from the skin, sweating is minimal and does not result in wet skin, and no shivering takes place. In such an environment the thermal stress on the body is at a minimum and the thermoregulatory system can easily maintain a constant core temperature (homeostasis). Such conditions result in subjective sensations of thermal comfort.

Although air temperature is often used as a proxy to describe thermal environments, physiologists and building scientists use four environmental and two personal factors to more fully characterize how an environment affects the body's heat balance. The environmental factors are air temperature, mean radiant temperature, air speed, and humidity. The personal factors are activity (as it impacts metabolic rate) and clothing.

Air temperature and air speed affect human body heat loss to the surrounding air (referred to as convection). The heat loss is proportional to the temperature difference between the body's surface and the surrounding air temperature, and also to the air speed near the body. The colder the ambient temperature and the higher the air speed, the greater the heat loss. When the ambient temperature is higher than the body's surface temperature, the body instead gains heat by the same mechanisms. This convective gain is in most situations greatly exceeded by the simultaneous heat loss caused by sweat evaporation from the skin, which takes place even without the skin being perceived as wet. The use of air movement to keep people cool in hot weather goes back thousands of years, and electric fans are widely used in residential buildings because of their ability to maintain thermal comfort using far less energy than mechanical air conditioning systems.

In an indoor environment, **mean radiant temperature (MRT)** can be thought of, as a first approximation, as the average temperature of the surfaces surrounding a person. Humans exchange heat with surrounding surfaces through longwave radiation, which is driven primarily by the temperature difference between the body's surface and surrounding surfaces, the view factors to those surfaces, and the surface thermal properties. Sitting next to a cold window or in front of a warm fire are examples where radiation can play an important role. In typical residential environments when cooling is needed, MRT is very close to the air temperature when walls and windows are insulated and shaded. Exceptions include sitting next to large glass surfaces or upper story apartments with poorly insulated roofs or west-facing walls, in which ceiling or wall temperatures can become hot from solar gain.

Humidity in the air acts to reduce the rate at which sweat evaporates from the skin. Sweating is initiated either at high ambient temperatures, high activity levels, or both. When the air humidity is high, the reduced cooling effectiveness of sweating increases the thermal load on the body for a given air temperature or activity level.

Although high humidity levels during warm weather are unusual in California, if indoor relative humidity is above 60 percent, the maximum safe indoor air temperature is lower, as shown in Table 3, in next column. Some climate models predict that coastal humidity may rise due to climate change (Pierce et al., 2018).

Table 3. Impacts of humidity levels in residential dwelling units with and without mechanical air movement.

INDOOR RELATIVE HUMIDITY	WITHOUT AIR MOVEMENT (DEGREES FAHRENHEIT)	WITH AIR MOVEMENT (DEGREES FAHRENHEIT)
below 60%	82	86
60% - 69%	81	85
70% - 79%	80	84
80% - 89%	79	83
90% or above	78	82

Note: Temperatures shown represent equivalent thermal heat loads based on Standard Effective Temperature (SET) defined in ASHRAE Standard 55-2023, Thermal Environmental Conditions for Human Occupancy (ASHRAE 55, 2023).

Activity level and clothing will directly impact heat balance (for example, higher activity level results in higher internal heat production, and more clothing reduces heat loss to the environment) and therefore how a person perceives their thermal environment. In residential buildings people tend to have more flexibility in their clothing selection and can more easily adapt to heat.

Several indices have been developed to combine two or more of these environmental factors into a single number. Some of these indices are primarily intended to gauge the effect of outdoor weather; heat index and humidex combine air temperature and humidity, wind chill factor combines air temperature and air speed, and wet-bulb globe temperature (WBGT) combines all four environmental factors with the addition of solar radiation.

For indoor conditions, comfort engineers use SET which is based on a model of human response to the thermal environment. It is presented in the ASHRAE thermal comfort standard (ASHRAE 55, 2023). SET is defined as: "the temperature of a hypothetical isothermal environment at 50 percent relative humidity, average air speed less than 0.1 m/s (20 fpm), and dry-bulb air temperature equal to mean radiant temperature, in which the total heat loss from the skin of an imaginary occupant wearing clothing, standardized for the activity concerned, is the same as that from a person in the actual environment with actual clothing and activity level".

SET can be used to compare the heat load on the body between two sets of environmental conditions with different air temperature, mean radiant temperature, air speed, and/or humidity. Such combined environmental conditions surrounding the body can be described more simply as 'ambient' temperatures.

In excessively hot or hot and humid environments, heat loss from the body can be reduced below the level of heat production on the body. Over the duration of heat exposure, the cumulative imbalance between heat production and heat dissipation leads to an increase in body core temperature (Cramer & Jay, 2016; Ravanelli et al., 2015).

As the thermoregulatory system responds to a warm ambient environment, physiological changes take place in the body including: (a) Elevated heart rate. (b) Increased blood flow. (c) Increased sweating and moisture loss. (d) Elevated core temperature.

These changes, in the extreme, can lead to immediate health risks including heat cramps, heat exhaustion, heatstroke and dehydration. In turn, these effects can lead to heart, respiratory and organ complications.

Heat and Health Effects

There is conclusive evidence of links between high outdoor temperatures and human health. Outdoor temperature data is widely available and large-scale studies have been conducted that correlate outdoor temperatures and their duration to regional data on health, hospital admissions and death (Basu, 2009; Basu & Samet, 2002b; World Health Organization, 2018). Indoor air temperature data, on the other hand, is not typically available and there is significantly less research relating indoor air temperatures to health.

High temperatures have been estimated to have caused 489,075 global deaths annually throughout the 2000-2019 period (Zhao et al., 2021). This is likely an underestimate due to limitations in reporting and case attribution. Both mortality (deaths) and morbidity (illness) are expected to rise with the increase in global temperatures, estimated as 3.3 to 5.7 degrees Celsius by the year 2100 (Kiarsi et al., 2023). The effects of high temperatures are most pronounced during heatwaves, periods of peak temperature within a climate's natural variability. The length and severity of these peak events is also being influenced by changes occurring in the climate.

Heat Strain

Heat strain is the condition where the body cannot dissipate sufficient heat to maintain normal core body temperature and can lead to several heat-related disorders.

Heat Exhaustion

Extended periods of heat stress may result in heat exhaustion, with possible symptoms of dizziness and weakness, syncope, intense thirst, gastrointestinal symptoms, and dehydration (Gauer & Meyers, 2019; Hess et al., 2023). Heat exhaustion is typically associated with core temperatures between 101 and 104 degrees Fahrenheit (Hanna & Tait, 2015).

Heatstroke

If core temperature rises above 104 degrees Fahrenheit, heatstroke is likely to occur. Symptoms consist of inhibited perspiration, rapid pulse, altered mental state and potential loss of consciousness. Chronic health outcomes in relation to multiple organ system damage include cognitive impairment, acute renal failure, rhabdomyolysis, liver dysfunction with hepatic enzyme elevation, disseminated intravascular coagulation, and acid-base disturbances (Glazer, 2005; Sutton, 1909).

Heatstroke can be divided into classic and exertional forms. Classic heatstroke is caused by environmental exposure that results in core body temperature above 104 degrees Fahrenheit. This condition primarily occurs in the elderly and those with chronic illness and can develop slowly over several days. Exertional heatstroke is a condition that primarily affects younger individuals who are actively exercising and core temperature increases due to a combination of high heat generation and environmental conditions (Glazer, 2005).

Heat and Pre-Existing Health Conditions

Heat-related mortality and morbidity can generally be attributed to increased bodily strain and dehydration as the body expends additional energy to maintain core temperature. Those with pre-existing conditions such as cardiovascular disease, kidney disease, respiratory disease, diabetes, and hypertension have a higher risk for adverse outcomes. Such conditions are modulated by other risk factors such as sex, age, smoking status, activity levels, medication usage, and socioeconomic status. Heat has also been associated with elevated deaths from ischemic heart disease, stroke, COPD, lower respiratory conditions, dementias, diabetes mellitus and diarrheal disease.

Several physiological factors influence an individual's susceptibility to heat-related health issues:

Ability to sweat: A diminished ability to sweat (anhidrosis) can lead to reduced heat dissipation and ability to adapt to temperature variations (Inoue & Shibasaki, 1996). Although the number of sweat glands responsive to thermal stimuli remains constant with age, the output per gland in response to changes in body temperature or certain stimuli decreases in older individuals (Inoue & Shibasaki, 1996). Nerve damage, including from diabetes or alcoholism, can contribute to this condition.

Vasodilation and blood flow: The body dissipates heat through the skin via cutaneous vasodilation, where blood vessels in the skin expand, allowing more blood to flow near the surface and release heat to the environment (Chen et al., 2024; Inoue & Shibasaki, 1996). Changes in skin properties related to aging tend to decrease skin blood flow.

Respiration: Heat causes increased respiratory rate and bronchodilation which can exacerbate symptoms like shortness of breath and asthma.

Sensitivity and nervous system: The brain and nervous system are crucial to human thermophysiology and regulation. The hypothalamus detects changes in the body´s thermal state from changes in blood temperature and by peripheral inputs from thermosensitive receptors located in the skin and in the muscles (Nagashima, 2006). Various inflammatory and neurodegenerative conditions that interfere with the flow of information from the peripheral to central nervous system, specifically hypothalamic dysfunction, and/or motor control such as multiple sclerosis, stroke, Parkinson disease, and peripheral neuropathy can reduce the ability to respond to changes in temperature (Steinmetz, 2024).

Cardiovascular Disease

For individuals with preexisting cardiovascular conditions such as hypertension or heart failure, the physiological response to heat places additional strain on the heart and can lead to both acute and chronic illness (Ebi et al., 2021). The association between cardiovascular mortality and temperature forms a U-shaped curve where the incidence of mortality increases at low and high ambient temperatures (Arnold et al., 2022).

Heat-related cardiovascular hospitalizations appear to be dependent on location, climate, and socioeconomic status (C. Liu et al., 2015). Increased ambient temperatures in California have been associated with increased risk of hospitalization for cardiovascular disease, ischemic heart disease and ischemic stroke (Holmes et al., 2016).

Respiratory Disease

Respiratory diseases can be exacerbated by heat stress (Tham et al., 2020). The physiological mechanisms underlying this vulnerability stem from the body's effort to cool itself through increased respiration and pulmonary vasodilation. For individuals with preexisting respiratory conditions such as chronic obstructive pulmonary disease (COPD) or asthma, this response can be detrimental. The increased respiratory rate and bronchodilation can exacerbate symptoms like shortness of breath and wheezing. Respiratory diseases, specifically COPD, have been cited as a leading cause of death in relation to heat exposure as a result of inflammatory mechanisms and dehydration (McCormack et al., 2016). Increases in maximal daily indoor air temperature have been associated with worsening of COPD symptoms and with increases in the frequency of inhaler use (McCormack et al., 2016). Through the investigation of threshold relationships between temperature and heat-related hospital admissions, researchers found that outdoor temperatures above 89.1 degrees Fahrenheit (31.7 degrees Celsius) were correlated with increased respiratory hospital admissions (Lin et al., 2009).

Diabetes

Diabetes is another condition that can be exacerbated by heat exposure (Tham et al., 2020). Heat can accelerate the absorption of insulin in individuals with diabetes, potentially leading to hypoglycemia (Rönnemaa & Koivisto, 1988). In addition, people with type 2 diabetes mellitus have lower skin blood flow and sweating responses that compromise the body's ability to dissipate high heat exposures (Uejio et al., 2022). Diabetes emergency calls have been associated with high outdoor temperature (Holmes et al., 2016).

Kidney Disease

Kidneys play a major role in thermoregulatory functions. These functions include blood pressure regulation and the maintenance of fluids and essential body chemicals. Prolonged dehydration and reduced blood flow contribute to the risk of acute or chronic kidney disease (CKD) where the effects are generally acute (de Lorenzo & Liaño, 2017; J. Liu et al., 2021). Heatwaves increase the likelihood of developing kidney failure, which includes acute kidney injury (AKI) or CKD, and other outcomes such as acute renal failure, kidney stones, renal colic, abnormal kidney function, and kidney tumors (J. Liu et al., 2021).

Obesity

Obese individuals have a lower ratio of body surface area to body mass which reduces the amount of heat they can dissipate from their skin relative to the metabolic heat they generate. Fat tissue is also a better thermal insulator than muscle tissue which can reduce heat transfer from the body core to the skin. Obese individuals are also at greater risk of cardiovascular events during heatwaves (Meade et al., 2020). Obese older adults were twice as likely to die during the 2003 European heatwave compared to their non-obese counterparts (Vandentorren et al., 2006). Heatstroke has been observed to occur at a rate 3.5 times higher in obese or overweight individuals compared to those of normal weight (Henschel, 1967).

Physical Disabilities

Physical disabilities significantly impact an individual's susceptibility to indoor heat, primarily due to alterations in thermoregulatory perception and response mechanisms. Individuals with physical disabilities may experience reduced thermal perception, vaso-control of body skin temperature, and sweating efficiency (Hill et al., 2000). Medications required for treating physical disabilities can affect thermoregulatory responses. One's heat-vulnerability during heat extremes is also associated with being confined to bed, living alone, being unable to care for oneself, and not leaving the residence to cool down body temperature. Additionally using technical aids, such as wheelchairs, may affect an individuals' ability to independently manage thermal discomfort.

Medications and Alcohol

Drug use can change the body's ability to redirect blood flow to the skin to cool the body or to increase sweating, thus increasing the risk of dehydration or decreasing sweating, in turn making it harder for the body to cool off since the cutaneous vasodilation and evaporative cooling are the two primary ways for the body to lose heat. Havenith (2005) states that the "use of drugs such as alcohol may predispose subjects to heat illness by changes in physiological effector mechanisms and by changes in behavior. Many drugs affect the body fluid balance, vasoconstrictor/dilator activity and on cardiac function. These include alcohol, diuretics, anti-cholinergic drugs, vasodilators, antihistamines, muscle relaxants, atropine, tranquilizers and sedatives, beta-blockers and amphetamines.

Cognitive Disabilities

For those with cognitive disabilities, difficulties in comprehending the severity of heat stress, recognizing signs of overheating, such as early dehydration, or effectively communicating their discomfort place them at heightened risk (Ormandy & Ezratty, 2012). Furthermore, these individuals might have limited mobility, making it challenging to seek relief in cooler environments during heatwaves.

People with dementia are considered susceptible to heat due to several factors related to the pathology of their condition and its impact on thermoregulation and thermal perception. Research has also found significant variation in both tympanic and rectal temperatures in older adults with dementia, with dementia being significantly related to lower body temperatures. This variation indicates that individuals with dementia may have different thermal needs and sensitivities. Individuals with dementia often dress inappropriately for the temperature (Van Hoof et al., 2010). There is evidence that agitation of residents with dementia can increase with higher indoor air temperature (Tham et al., 2020), and that enhancing thermal comfort can significantly decrease agitation and behavioral disturbances (Tartarini et al., 2017).

Elderly

Aging impacts the skin's vasodilatory response and cutaneous blood flow, reduces sweat gland effectiveness, cardiac fitness and thermal sensitivity. These changes compromise the ability to regulate body temperature and to accurately detect temperature variations (Chen et al., 2024; Inoue & Shibasaki, 1996). The elderly population frequently has other health conditions such as cardiovascular or respiratory diseases which impact their susceptibility to heat as described above. Limited mobility among older adults may hinder their ability to seek cooler environments during extreme heat events (Basu & Samet, 2002a; Ormandy & Ezratty, 2012; Tham et al., 2020). Additionally, factors such as difficulties in operating windows and blinds contribute to their increased vulnerability (K. Lomas, 2021). A study of elderly people (average age 80.9 years) found that gait speed, chair-rise rate and balance were negatively impacted above 27.9C (Lindemann et al., 2017)

Pregnancy

Adverse pregnancy outcomes have been widely studied in relation to high ambient temperatures, including low birthweight, stillbirth, preeclampsia, and congenital abnormalities (Rekha et al., 2023). The physiological mechanisms related to high ambient temperatures can affect placental blood flow, increasing the risk of hypertensive crises and stillbirth (Rekha et al., 2023; Shashar et al., 2020). Maternal sweating and arginine vasopressin-mediated renal fluid reabsorption as thermoregulatory mechanisms in response to overheating have also been associated with preterm labor (Syed et al., 2022). Long-term, repeated exposure to high temperatures can result in several adverse pregnancy outcomes. Cumulative exposure of 5 to 15 days to outdoor temperatures above 86 degrees Fahrenheit (30 degrees Celsius) has been associated with infant congenital heart defects (Lin et al., 2018).

Infants and Young Children

Underdeveloped thermoregulatory systems, high metabolic rates and limited ability to dissipate heat make infants and young children susceptible to overheating. The inability to communicate discomfort further complicates their vulnerability (Basu & Ostro, 2008). Epidemiologic studies have shown that infants and children aged five or younger are at increased risk of mortality from high indoor air temperatures (Basu & Ostro, 2008; Tham et al., 2020). A study focusing on infant deaths in California during the warm season also found an increased risk of infant mortality as ambient temperature increased (Basu et al. 2015).

Other Impacts of Heat

Impacts on Cognitive Function and Accidents

When core temperatures reach 101.8 degrees Fahrenheit (38.8 degrees Celsius), the capacity for physical work diminishes, mental activity is impaired and accident risk increases (Walter & Carraretto, 2016). A study in China found that math test scores on a day with average temperatures above 89.6 degrees Fahrenheit (32 degrees Celsius) were slightly lower than scores on days with average temperatures between 71.6- and 75.2-degrees Fahrenheit. This effect was more pronounced in regions that are typically cooler (X. Zhang et al., 2023).

Heat is hypothesized to directly increase feelings of hostility and indirectly increase aggressive thoughts and is mediated by affect (B. G. Anderson & Bell, 2009). Higher temperatures have been associated with more penalties for aggressive behavior in professional football (Craig et al., 2016), pitchers hitting batters in professional baseball (Krenzer & Splan, 2018), and horn honking at cars not moving at green lights (Kenrick & MacFARLANE, 1986).

Impacts on Mental Health

Psychological distress can promote negative mental health and behavioral outcomes. When analyzing self-reported major depressive disorder in over 20,000 participants across 106 countries, Mason and colleagues found a strong relationship between higher body temperature and depression symptom severity (Mason et al., 2024). When assessing hospital admissions attributed to mental, behavioral, and cognitive disorders in South Australia, there was a reported 7.3% increase in admissions when outdoor ambient temperatures were above a threshold of 80.1 degrees Fahrenheit (26.7 degrees Celsius), with a statistically significant effect noted in organic illnesses, dementia, mood affective disorders, neurotic, stress related, somatoform disorders, disorders of psychological development, and senility (Hansen et al., 2008).

To date, studies investigating the relationship between high temperatures and violence are preliminary. Some suggest that hot weather induces interpersonal violence by increasing discomfort, frustration, impulsivity, and aggression, and that changes in ambient temperature can alter people's routine activities (e.g., outdoor events and social contacts), leading to increased interpersonal conflicts(Mahendran et al., 2021). Physiologically, heat can disrupt sleep and impair the function of vital neurotransmitters and hormones. Additionally, incidents of alcohol, cocaine, and drug overdoses increase as temperature increases. These factors link the climate crisis to a mental health crisis.

Among mental illnesses, schizophrenia has been identified as heat sensitive by different authors, who highlight an increase in the core symptoms of people with a schizophrenia diagnosis associated with high indoor air temperatures (Naughton et al., 2002). Additionally, it has been stated that in some cases there is an increase in summer admissions of schizophrenia patients to psychiatric facilities (Shiloh et al., 2007) and in deaths due to schizophrenia and schizotypal and delusional disorders (Hansen et al., 2008). The findings from Shiloh et al. suggest that the primary psychotic symptoms associated with schizophrenia, such as delusions and hallucinations, are influenced by temperature fluctuations. These symptoms may intensify under the stress of excessive environmental heat or potentially diminish in cooler conditions.

Impacts on Sleep

Sleep is one of the three key pillars of health (alongside exercise and nutrition) and is known to be affected by heat exposure (He et al., 2022; Romanello et al., 2022). Unusually warm night-time temperatures have been linked to an increased frequency of nights with insufficient sleep (Obradovich et al., 2017). Cumulative heat exposure and its impact on sleep will be exacerbated by climate change, as night-time temperatures are warming faster than daytime temperatures in many parts of the world (Cox et al., 2020).

Insufficient sleep is a recognized risk factor for numerous adverse physical and mental outcomes. Multiple undesirable health outcomes are associated with insufficient sleep (Luyster et al., 2012).They include reduced cognitive performance, diminished productivity, compromised immune function, adverse cardiovascular outcomes, depression, anger, and suicidal behavior (Minor et al., 2022). A review by Itani (Itani et al., 2017) highlighted nine major health outcomes linked to short sleep duration:

hypertension, cardiovascular disease, stroke, diabetes mellitus, coronary heart disease, obesity, dyslipidemia, depression, and mortality. Other studies have found a causal link between lack of sleep and Alzheimer's and cancer (Walker, 2017). Sleep loss not only degrades mental health but also reduces workplace productivity, increases absenteeism, and elevates the risk of accidents (Hillman et al., 2018). Therefore, insufficient sleep undermines independent living and places an increased burden on the health and social care system (K. J. Lomas & Li, 2023).

Temperature and Sleep Quality

Many factors affect sleep quality, including physiological, psychological, and environmental conditions. Among the key environmental factors, temperature and noise have been identified as the most influential (N. Zhang et al., 2019). In hot weather, the thermal environment during sleep becomes crucial because a lack of night-time relief from heat is considered a significant factor contributing to heat-related mortality (Murage et al., 2017; Sheridan & Kalkstein, 2004). Based on an association between high morning temperatures and deaths to heat exposure, Anderson (M. Anderson et al., 2013) stated that small diurnal temperature variations (meaning little drop in temperature at night) contribute to mortality. During the Chicago heatwave of 1995, with approximately 700 excess deaths, there were exceptionally high minimum temperatures that persisted for several days. These high minimum temperatures inhibited the normal recovery from heat stress during the nighttime hours (Kenney et al., 2014).

In the UK, an overheating criterion has been proposed based on the mean night-time bedroom temperature, with thresholds ranging between 78.8 and 84.2 degrees Fahrenheit (26 and 29 degrees Celsius), depending on bedding and comfort expectation (K. J. Lomas & Li, 2023). The allowable exceedance of the chosen threshold is limited to seven nights between May and September. Using the three adaptation categories provided in the TM59 standard and analyzing the exceedance hours, the authors recommend adopting thresholds based on population types: 78.8 degrees Fahrenheit (26 degrees Celsius) for special needs populations (sick and ill people), 80.6 degrees Fahrenheit (27 degrees Celsius) for people with disabilities, children, and elderly people, 82.4 degrees Fahrenheit (28 degrees Celsius) for most healthy people, and 84.2 degrees Fahrenheit (29 degrees Celsius) for robust and healthy young people.

Table 4. Suggested night-time temperature threshold in a proposed UK standard (K. J. Lomas & Li, 2023) (based on still air conditions).

MEAN NIGHT-TIME TEMPERATURE THRESHOLD	BEDROOM COMFORT EXPECTATION
78.8 °F (26 °C)	Very high expectation (e.g., special needs, sick and ill persons)
80.6 °F (27 °C)	High expectation (e.g., disabled, children and elderly persons)
82.4 °F (28 °C)	Medium expectation (e.g., most healthy persons)
84.2 °F (29 °C)	Moderate expectation (e.g., robust, young healthy persons)
>84.2 °F (>29 °C)	Unacceptable for any persons

Heat Combined with Poor Air Quality

Atmospheric pollution can impact the risk of heat exposure. While most studies have considered air temperature and air pollutants separately, more recent evidence has shown the amplifying effect of both exposures simultaneously on health impacts. One study, for example, using daily average exposure of heat and daily weighted concentrations of air pollutants across neighborhoods in Rotterdam, Netherlands, found a significant effect modification between maximum temperature and air quality metrics on natural-cause mortality (Willers et al., 2016).

These findings align with results from similar studies conducted in Italy and Germany (Breitner et al., 2014; Scortichini et al., 2018). A Slovenia study also found that worse cardiovascular symptoms with higher heat burden and CO2 concentration (Fink et al., 2017). A study in Jiangsu, China, provides a comprehensive picture of the interactions between high extreme temperatures and PM2.5 pollution on total mortalities (Zhou et al., 2023). The interactions were stronger in respiratory than cardiovascular mortalities. Researchers note that such risks can vary between neighborhoods due to local differences in both heat and air pollution (Willers et al., 2016).

Fine particulate matter (PM2.5) and tropospheric ozone are significant pollutants causing cardiovascular and respiratory diseases, and the relationship is influenced by heat. PM2.5 alone was responsible for 3.15 million premature deaths worldwide in 2010 and 52,000 in the United States (Giannadaki et al., 2016). Numerous recent multi-city studies report the mortality effects of ozone (Bell et al., 2004). Volatile organic compounds (VOCs) are precursors to both pollutants. PM2.5 is a secondary organic aerosol that forms through the oxidation of VOCs. Ozone is formed from photochemical reactions involving nitrogen dioxide (NO 2) and volatile organic compounds (VOCs) in the presence of sunlight, particularly ultraviolet light. Particularly relevant to this report is that these reactions increase with air temperatures (Pfannerstill et al., 2024). The percentage of days when PM2.5 exceeds a threshold level of 12 µg/m³ increases from less than 10 percent at 68 degrees Fahrenheit (20 degrees Celsius) to more than 40 percent at 68 degrees Fahrenheit (30 degrees Celsius). The temperature dependence of ozone is very strong. The ozone exceedances of the 70 ppb unhealth threshold defined by standards increase from 0 percent at 86 degrees Fahrenheit (20 degrees Celsius) to more than 70 percent at 68 degrees Fahrenheit (30 degrees Celsius) (Nussbaumer & Cohen, 2020, 2021). Sunny, hot afternoons are ideal for ozone formation, especially since hotter air tends to be more stagnant. Most tropospheric ozone originates from vehicle exhaust and emissions from factories, power plants, and refineries.

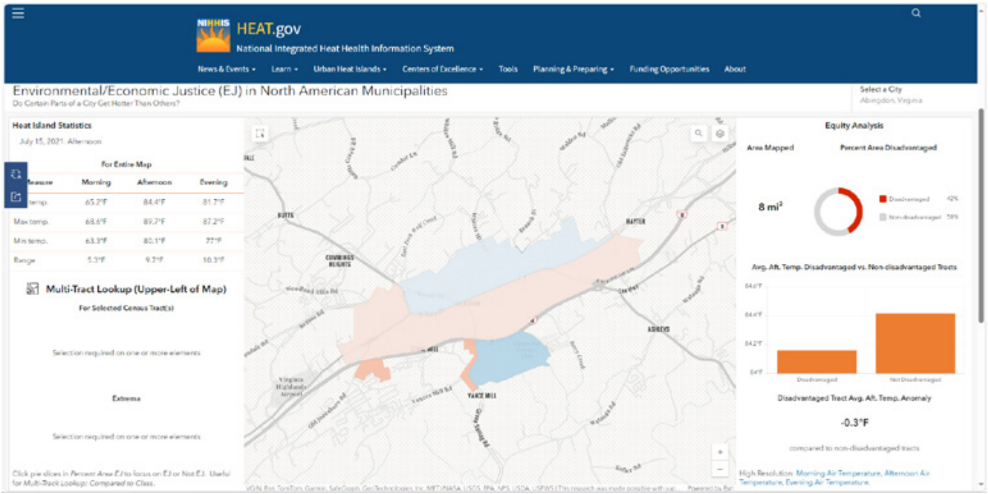
Poor air quality can also limit the use of natural ventilation to provide cooling when outside temperatures are below indoor air temperatures. This is particularly true during periods of heavy wildfire smoke.

Social equity factors Individuals with low socioeconomic status may be particularly subject to the adverse effects of extreme heat. These populations often face a combination of socioeconomic and environmental factors that amplify their personal susceptibility or circumstantial vulnerability to heat-related health risks (Basu et al., 2015; Basu & Ostro, 2008).

Lower quality dwelling units. Individuals with low socioeconomic status are more likely to reside in substandard dwelling units, which usually lacks adequate insulation or ventilation, exacerbating indoor air temperatures during heatwaves.

Limited access to cooling. One significant reason for this is that limited financial resources can further impede access to more effective cooling strategies.

Social isolation. Research has found that individuals living alone faced a doubled risk of death during heatwaves compared to those living with others (Semenza et al., 1996).



Environmental/Economic Justice (EJ) in North American Municipalities

Do Certain Parts of a City Get Hotter Than Others?

Heat Island Statistics

July 15, 2021: Afternoon

For Entire Map

easure	Morning	Afternoon	Evening
temp.	65.2°F	84.4°F	81.7°F
Max temp.	68.6°F	89.7°F	87.2°F
Min temp.	63.3°F	80.1°F	77°F
Range	5.3°F	9.3°F	10.3°F

For Selected Census Tract(s)

Selection required on one or more elements

Selection required on one or more elements

Click pie slices in *Percent Area EJ* to focus on EJ or Not EJ. Useful for *Multi-Track Lookup: Compared to Class.*

Avg. Aft. Temp. Disadvantaged vs. Non-disadvantaged Tracts

Disadvantaged Tract Avg. Aft. Temp. Anomaly

-0.3°F

compared to non-disadvantaged tracts

High Resolution: Morning Air Temperature, Afternoon Air Temperature, Evening Air Temperature.

Heat.gov serves as the premier source of information regarding heat and health for the nation. This portal seeks to improve federal, state, and local information and capacity to reduce the health, economic, and infrastructural impacts of extreme heat.

Heat.gov is the webportal for the National Integrated Heat Health Information System (NIHHIS).

The concerns for individuals who live alone during heat emergencies, particularly the elderly, is underscored when they have limited social networks and potentially debilitating health conditions (Naughton et al., 2002). This demographic faces challenges in accessing timely assistance during extreme heat events. Researchers have emphasized the importance of social support networks and access to cooling resources in mitigating the impact of high temperatures on heat-susceptible populations, particularly those living alone (Basu & Samet, 2002a).

Lack of access to health care. Additionally, it has been emphasized by researchers that disparities in healthcare access and quality may limit their ability to receive timely medical care for heat-related illnesses (Basu et al., 2015).

Higher outdoor temperatures in urban areas. Urban heat island effects can cause higher temperatures for urban populations. These areas have fewer green spaces and more concrete surfaces, which absorb and radiate heat, elevating overall temperatures (Basu & Samet, 2002b). The National Integrated Heat Health Information System provides temperature data comparing disadvantaged versus non-disadvantaged census tracts. Data for South Los Angeles shows that afternoon temperatures in disadvantaged tracts are 2 degrees Fahrenheit warmer compared to non-disadvantaged tracts (www.heat.gov/pages/heat-equity).

Adaptation To Heat

Many authors agree that there are three levels of adaptative ability: behavioral, psychological, and physiological (Brager & de Dear, 1998; Pallubinsky et al., 2023; Rahif et al., 2021). Behavioral adjustments can be personal (e.g., adjusting clothing, activity, posture, eating/drinking cold food or beverages, moving to a different location, etc.), or environmental (e.g., opening/closing windows or shades, turning on fans, etc.). Psychological adaptation recognizes that comfort and acceptability are subjective and depends on a variety of contextual factors, including whether conditions match one's expectations. This, in turn, can be influenced by whether one has personal control over thermal conditions, how constant versus variable one's past thermal experiences are, and whether the indoor climate is controlled entirely by mechanical heating or cooling or if the building is conditioned with passive strategies, making the indoor climate be more aligned with the natural rhythms of the outdoor climate.

The most important physiological adaptations are cardiovascular and sweating. Heat acclimation is characterized by increased perspiration due to the number and distribution of active sweat glands, increased peripheral blood flow, and lowered heart rate, each physiologically favorable outcomes with respect to heat (Syed et al., 2022). Significant beneficial adaptation occurs within the first few days of repeated heat exposure and reaches a plateau after 7-14 days, varying with the type of exposure (Pallubinsky et al., 2023). Following exposure to heat, the physiological adaptation does not last a long time, reducing after a few days or weeks after a reduction in heat exposure (Lee et al., 2014). In healthy adults, seasonal heat acclimatization is well documented to affect the resting core temperature, resting heart rate, sweat rate, and skin temperature (Brown et al., 2022). In a review, out of 16 studies, 11 studies reported a reduction in core temperature and an increase in sweating rate at the end of the warm season compared to early in the season.

In the context of climate change, there are signs that there may be physiological adaptation to heat occurring in the broad population (Lee et al., 2014). This effect is not well understood and will need more study to better understand the impact across different climates and populations. People living in hotter climates tend to cope better with extreme heat. The maximum temperature threshold associated with increased emergency room visits and admission rates is higher in regions with hotter weather (Kenny et al., 2019). The duration of the exposure is also important; successive days of exposure can lower the threshold for heat-related mortality. The physiological factors affecting heat-related mortality and morbidity include sex, age, and fitness.

Strategies For Avoiding Indoor Overheating

Strategies to avoid indoor overheating and maintain temperatures below the recommended maximum can be categorized into three levels: building, urban, and personal. These strategies are detailed in the following sections. Many of these strategies can and should be used in combination with other strategies.

In this section, the strategies are described functionally and critically assessed. Given the vast array of building design and construction (envelope, interiors, electrical, and mechanical) and the large variations in usage, site conditions, climates, availability of market-ready solutions, electrical panel load capacity, and social and economic issues, there is no one-size-fits-all solution to avoid indoor overheating. The effectiveness of any given solution depends on the specific context.

The following passive and active strategies may only apply to newly constructed residential dwelling units, existing residential dwelling units, or manufactured homes/mobilehomes, or a combination thereof. The method to apply these strategies will likely vary between policy/legislation, incentive programs, building standards, or other vehicles of implementation.

Building Strategies

There are several building-level strategies that can be adopted to mitigate indoor overheating by making buildings more resilient to extreme heat. In this section, two types of strategies are described: passive and active strategies. Passive strategies include those that control indoor thermal conditions by improving the performance of the building, for example the envelope, without the need for external energy. Since these strategies do not require energy, they are very effective even during power outages for all buildings and occupants, or in situations of energy poverty. In 2010, World Economic Forum defined energy poverty as the lack of access to sustainable modern energy services and products. Therefore, passive strategies can effectively improve the heat resilience of homes in underserved and heat-vulnerable communities (Sun et al., 2021). Active strategies involve using energy to control the indoor thermal environment, such as through mechanical ventilation or cooling. This section discusses the applicability of these strategies to new buildings, existing buildings, and MH.

Passive Strategies

Window ventilation and night cooling. Opening windows to enhance natural ventilation/cooling, potentially in multiple places in a household to enable cross-ventilation (from one side to the other of the home), is an effective strategy to dissipate heat accumulated during the day. Natural ventilation also increases air velocity indoors thereby enhancing convective heat loss from the occupant skin and related evaporative heat losses. Airflow between outdoors and indoors can be wind-driven and/or buoyancy-driven (driven by the difference in outdoor and indoor air temperature) and it can be enhanced with the use of fans (including whole house fans mentioned below).

Natural ventilation effectiveness depends on building characteristics and the outdoor thermal conditions. If the outdoor temperature is higher than indoors, there is no benefit in increasing air flow from outdoors to indoors. Temperature sensors are affordable and can be installed to inform occupants on when to open and close windows. The lowest temperatures happen at night toward the early morning, and this is usually the best time to have the windows open. Night cooling decreases indoor air temperature during the night hours but also during the day. Thanks to the building's thermal mass and the starting of the day with lower indoor air temperatures. To enable natural ventilation, it is important to provide occupants with easy access to operable windows, vents and skylights. The applicability of night cooling is constrained by several factors that limit its effectiveness and applicability in various contexts. When outside air is polluted (episodically like with wildfires, or frequently as when a window is close to a freeway) it is safer to close the windows and vents and use air filtration (centralized or portable). There could be other limitations to the use of night cooling such as noise pollution, the risk of insect ingress as mosquitoes and security risks related to crime. There is also evidence that nighttime temperatures are increasing more than daytime temperatures, which could reduce the effectiveness of night ventilation in the future.

Window ventilation and night cooling can be applied to new and existing single and multifamily units and MH. Some multifamily layouts, including point access blocks and single-loaded corridors, encourage natural ventilation more than other designs (Eliason, 2021).

Shading to reduce solar heat gain. This strategy aims to reduce heat gain from solar radiation transmitted through transparent parts of the building envelope, for example, windows and skylights. Windows are the primary source of daylight and access to outdoor views thanks to their transparency (Ko et al., 2022). They are fundamental for occupant well-being. However, they also significantly impact indoor overheating, since the incoming solar radiation is also thermal energy, which can raise indoor air temperatures and significantly impact thermal comfort (Arens et al., 2015). This is the reason why windows are usually integrated with shading devices or high-performance glazing technologies that are specifically designed for controlling solar radiation. The most effective ways to control undesired thermal gains from solar radiation while maintaining access to daylight and view are: (i) design and install permanent outside shadings elements as screens, louvers, porches, awnings to block or reflect solar radiation during the warmest hours of the day, thick walls that shade the glass; (ii) design and install dynamic façade technologies, for example, movable shadings as shutters, venetian blinds, and roller shades, which can be adapted either manually or through automated controls to reduce solar gains whilst still ensuring access to the outdoor views. Shading elements are more effective when installed on the exterior and can reduce solar energy from entering the building via the glass. Dynamic shading devices are ideal in one sense because they can adapt to changing indoor or outdoor conditions. This can reduce incoming solar radiation during the warmest hours of the day or the extreme heat periods, while allowing maximum access to daylight and view. However, dynamic shadings or glazing require careful operation and management to avoid undesired performance. This requires awareness from the occupant on when and how to operate the shading or window technologies most effectively. In situations where occupants cannot frequently operate windows and shadings technology the design and installation of systems that are either automated, so their operation relies on actuators and sensors, or designed to avoid incoming solar radiation in the worst time of the day by using fixed exterior shading elements or glazing with low SHGC (below 0.30). These solutions are more robust to occupant behaviors, and they can ensure effective operation and mitigation of indoor overheating. Selecting windows with low SHGC or adding windows films can substantially reduce cooling loads. Windows films are a low cost and effective solution (Sun et al., 2021) that can be applied to new and existing single and multifamily homes and MH.

Thermal mass. Thermal mass refers to the property of the material and the weight of building components to absorb, store, and release in time thermal energy. This strategy has the overall objective to create a thermal buffer in buildings to shift the heat peak load in time. In this way, the heat during the day is absorbed by the building envelope or structure mass and released later in the night when the outdoor temperature is lower. Thermal mass also has the benefit of reducing the peaks of indoor air temperatures and providing a more stable indoor environment. However, thermal mass effectiveness depends on the operation time of a building or on other strategies that can be implemented in combination, for example, night cooling, to reduce the impact of delayed heat release. In a seismic area like California, increasing the thermal mass of a building, increases the cost of the structural solutions.

There are four main ways heat can be stored in buildings. First, heat can be stored as sensible heat, therefore by using materials that have high specific heat capacity, for example, concrete floors and foundations. Secondly, heat can be stored by leveraging on latent heat, for example, by using materials that can easily change physical state (from solid to fluid and vice versa) with temperature, for example, phase change materials. Third, heat can be stored by leveraging chemical or thermochemical storage. This latter is especially useful in combination with active systems. Fourth, part of the building can be underground (for example, burrowed into hillside) and the earth play the role of thermal mass. These last three strategies are not commonly used in residential dwelling units. It is difficult to change the thermal mass of a building after construction, so this solution is mainly applicable to new buildings.

Cool coatings and materials. This strategy has the main objective of reflecting unwanted solar radiation, which hits the building envelope thereby increasing the surface temperature and the net heat transfer from outdoors to indoors through the envelope. By doing so, cooling reduction between 2–44 percent, with an average benefit of 20 percent, can be achieved (Levinson & Lee, 2023). Increase in solar reflectance can then mitigate outdoor local overheating by about 0.2 degrees Celsius for each 10 percent increase of albedo (Santamouris et al., 2012). Applying cool coatings on the roof or selecting materials that have retro-reflection (redirecting solar radiation towards the sky) are the best.

One affordable way of increasing the solar reflectance of walls and roofs is by using light colors or white materials that can reach high reflectance levels of 0.7-0.85, in comparison to a typical solar reflectance of 0.04 for traditional black asphalt roofs. A few innovative materials and coatings have also been proposed to limit the undesired effects of cool coatings: (i) temperature sensitive high solar reflectance coatings, which can change the surface reflectance depending on the outdoor temperature and maintain high solar gains in winter; (ii) incident-dependent or retro-reflective coatings, which reflect the solar reflectance depending on the angle of incidence or redirect the unwanted radiation towards the sky to avoid overheating of pedestrians. Databases with information about the solar reflectance and the infrared emittance of commercial roof products are provided by the EU Project Cool Roofs (http://coolroofcouncil.eu), and the US Cool Roof Rating Council (https://coolroofs.org).

Sky radiative cooling is the strategy where roof surfaces are cooled down by the thermal exchange with the sky. Particularly during cloudless sky nights, when the sky equivalent temperature is very low, building roofs release heat to the sky through long-wave (thermal infrared) radiation. However, sky radiative cooling can also have detrimental impacts on heating demand, and its effectiveness depends on sky cloud coverage and wind. To enhance sky radiative cooling, the ideal material properties should have a maximum reflectivity in the short-wave range (0.25–2.8 μm) to reflect solar radiation, while the emissivity should be as close as possible to unity in the atmospheric window band (8–13 μm) and zero on the rest of the sky band.

SP-4 Improved building envelopes and ductwork. Improving the insulation level and reducing air leakage in the building envelope and ductwork can reduce heat gain during the day and help reduce indoor temperature. Weatherization programs for existing buildings focus on sealing cracks or holes around doors, windows and pipes; adding insulation to roofs and/or walls; replacing broken, leaky or inefficient windows; and sealing and insulating duct work. Substandard dwelling units with poor envelopes can benefit considerably from such improvements.

Green walls. Where allowed by building standards, vegetated exterior surfaces can decrease surface temperature, shade from solar radiation and therefore reduce sensible heat gain from outdoors to indoors. The aim of this strategy is to leverage the evaporative cooling potential of greenery, thanks to their moisture content, the shading effect, and the relatively low solar absorption. Green walls and roofs also have a positive impact on outdoor thermal comfort, urban heat islands (Alexandri & Jones, 2008), and rainwater management thanks to their water retention potential. There are two types of vegetated solutions: (i) green walls, where the plants in green façades are rooted in the ground and use the façade as the structure to grow; (ii) living wall/roof systems. In living walls and roofs, the plants are rooted in pots or ground systems integrated into the façade/roof. Overall, vegetated walls require maintenance and irrigation, and typically have higher structural requirements; thus, this solution is very limited in residential buildings and dry climates in California but vines on walls and trellises (green walls) are more commonly used options.

Roof insulation, roof ventilation, and radiant barriers. Roof insulation reduces the heat transfer from the outside to the inside of the building. It is valuable both in summer and winter. Roof ventilation increases thermal dissipation through the roof, air can circulate through these gaps and remove heat through convective heat exchange. The added benefit of ventilated gaps is the control of moisture across the building envelope, preventing the growth of mold. The side effect of ventilated roofs is decreasing thermal resistance in the winter season.

A radiant barrier is a type of reflective building material installed (usually underside of the roof rafters) in the attic to reduce heat transfer between the building and the outside. The sun's radiant heat can penetrate the roof and transfer into the attic space, causing the temperature to rise. A radiant barrier reflects part of the radiant heat back toward the roof, preventing it from entering the attic and reducing the heat gain in the living space below. This helps to keep the interior of the building cooler and can lower cooling costs. Installing a radiant barrier in ceilings can contribute to improved energy efficiency, increased comfort, and potentially lower utility bills. Roof interventions are usually only cost effective in retrofits when coordinated with an end-of-life roof replacement.

Overall recommendation in terms of passive strategies. Initial actions for mitigating overheating risk are: (i) to effectively control solar radiation through shadings, ideally placed outside. Windows with low SHGC and the use of window films is suggested; (ii) to enhance night cooling by effectively opening windows and vents to maximize natural ventilation/cooling when the outdoor temperature is lower than indoor. Natural ventilation can be enhanced with the use of window and ceiling fans. If these actions are not sufficient, secondary actions may consider the retrofit of the building fabric to improve thermal insulation and thermal mass, including the use of cool or green surfaces for roof or walls. Again, these strategies should be considered in the context of building type and if the residential dwelling units are newly constructed or are existing residential dwelling units.

Active Strategies

While passive strategies are important to reduce the risk of indoor overheating and energy demand, they may not be sufficient to protect people under high temperatures, especially the heat-susceptible population. For this reason, it is important to combine or provide access to active cooling strategies in addition to passive strategies when they are not sufficient during extreme heat events. Low-energy or low-carbon active cooling technologies should be preferred to reduce the side effects of indirectly contributing to global greenhouse gas emissions. In addition, the use of active cooling should be limited to situations where thermal conditions are dangerous. Nevertheless, active cooling strategies are only valid for indoor environments when thermal adaptation and other strategies at urban levels are considered for the livability of both indoor and outdoor spaces.

Fans for cooling people. This strategy is mostly recommended because it is cost-effective and can be easily installed and used in residential buildings. Using fans alone or in coordination with air conditioning systems to cool people offers several significant enhancements compared to air conditioning alone, including improved thermal comfort, indoor air quality, air distribution, energy savings, and initial cost savings" (Raftery et al., 2023).

Whole house fans. When natural ventilation and night cooling alone are not sufficient, it is possible to enhance their effect with windows fans or whole house fans. Whole house fans are usually installed in the attic and move a large amount of air. There should be proper vents/openings that allow air to flow from outside to inside the home, then to the attics and then outside. These fans can be noisy, and they should be operated with the windows open to avoid creating too much negative pressure (the indoor pressure is lower than the outdoor pressure). They should be operated when outdoor temperatures are equal or lower than indoor air temperatures. Whole house fans cool the building by bringing in cool air and by cooling down the indoor thermal mass. This solution is not applicable when the outdoor conditions are unfavorable (for example, noise and air pollution), similarly to the situations described for “Window ventilation and night cooling”. They are cheaper to buy and operate than air conditioning. This solution can be applied to new and existing residential dwelling units.

Evaporative cooling. In evaporative cooling systems also known as evaporative coolers or swamp coolers, the air temperature is reduced by extracting latent heat through the evaporation of water in contact with the air stream. These systems are usually low-cost but require high maintenance (C. Zhang et al., 2021). Since these systems exploit the evaporation of water, evaporative cooling is effective in dry environments, in particular arid climates, where air temperature difference of 27degrees Fahrenheit (15.0 degrees Celsius) can be achieved (Watt, J., 2012). These cooling systems are usually utilized in open or semi-open spaces, where the growth in absolute humidity levels is mitigated by air movements (E. Erell, D. Pearlmutter, Y. Etzion, 2008). In residential buildings they are operated with the windows or vent slightly open to allow the extra supplied air to escape. They are less expensive to buy and operate compared to air conditioners. Some evaporative coolers are portable and can be easily placed near occupants, they can be applied to new and existing single and multifamily homes and MH, in particular the portable units.

Air conditioning. Air conditioning with heat pump systems are an effective and well proven strategy to reduce indoor temperature and humidity. During the twentieth century in the United States, heat-related mortality decreased by about 75 percent thanks to air conditioning, saving an estimated 20,000 lives each year (Barreca et al., 2016). Air conditioning is considered a good strategy for protecting heat-susceptible populations against the adverse effects of extreme weather.

The main negative aspects related to the use of air conditioning are the large energy consumption (and related installation and operation costs) and the associated greenhouse gasses emissions and the strain on the electrical grid. Moreover, air conditioning uses refrigerants that usually have a large Global Warming Potential. Air conditioning strongly relies on electricity and therefore, as a cooling strategy, is very sensitive to power outages. In an older unit, the dwelling’s electrical panel needs to have adequate electrical capacity to cover the increased electrical load. When trying this approach for an entire apartment complex, updating the capacity of the local electrical grid may be necessary, which could be extremely costly, or in some cases infeasible depending on the electrical utility provider and possible infrastructure limitations. If air conditioners are coupled with photovoltaic panels and batteries, they could be more resilient to power outages. These air conditioners coupling strategies are important for heat-susceptible populations in sub-standard dwelling units because they would experience higher indoor air temperature during power outages, which could be more frequent during heatwaves or extreme heat events, due to high peaks in energy demand and instability of the electric grid at the same time.

Typical indoor settings between 75-79 degrees Fahrenheit (24-26 degrees Celsius) are considered comfortable in air-conditioned spaces (ASHRAE 55, 2023). Higher temperatures are possible when fans are present.

Radiant cooling. Radiant cooling involves cooling either the floor or ceiling by absorbing heat radiated from the surrounding surfaces using cool water running within pipes or capillary tubes. When applied to the floor, it is named radiant floor cooling, while ceilings are typically cooled using radiant panels in residential settings. Radiant cooling is not very common in California. Humidity and infiltration need to be controlled to avoid surface condensation. In dry climates the problem is less concerning. Radiant systems tend to be more energy efficient than air conditioning systems and the additional thermal mass often allows cooling loads to be shifted to off-peak hours, reducing peak electricity demand. Radiant cooling is primarily in new construction or major retrofits as it can be expensive in retrofit applications.

Ground source cooling. The low and stable temperature of the ground below approximately 30 ft (9 m) can be exploited to release heat in the ground and cool down a working fluid through heat exchangers. In this way, this strategy can remove sensible heat from the indoor environment through heat exchange with a cooler refrigerant, which is usually water (borehole heat exchanger) or air (earth to air heat exchanger). Ground-source cooling is classified as: (i) direct or passive, and (ii) indirect or active. The first system relies exclusively on the thermal exchange between ground and the working fluid, without any additional mechanical cooling. The second system uses the ground temperature as part of a traditional compression refrigeration cycle, where the ground acts as a sink for dissipating heat. Despite ground temperature is relatively constant, the heat dissipation potential of the ground can be affected by climate change as investigated (G. Chiesa, A. Zajch, 2020). Ground-source cooling is most effective when difference of temperature between working fluid and ground is high, for example, peak load condition (C. Zhang et al., 2021). Ground source heat pumps are not very common in California (Opinion Dynamics, 2022).

Cool rooms. A cool room is a way to provide a safe place in a residential dwelling unit during extreme heat. By focusing on keeping a smaller area cool, it can be less expensive than trying to cool the entire living space and can make it more practical to provide battery backup power. The selected space should be a frequently used space, for example a living room or a bedroom, and it should be easily accessible to all occupants, including people with mobility issues. The same concepts described above may apply, just at a smaller scale.

Again, these strategies should be considered in the context of building type and if the residential dwelling units are proposed for new construction or are existing residential dwelling units.

Personal Scale

The personal scale approaches to keeping cool during hot weather are included here for purposes of including in public education and awareness efforts that could reduce health impacts of heatwaves.

Knowledge, awareness, and information

Education increases people's understanding of risk by improving their knowledge. As the perception of risk increases, adaptive actions increase at both the individual and the societal levels (Kiarsi et al., 2023; Yazar et al., 2022). People's behavior can play a key role in mitigating indoor overheating while reducing energy consumption. For example, simple actions, such as the conscious opening of doors and windows or the use of shading devices (for example, shutters and curtains) can reduce indoor overheating. In addition, other actions, such as adjusting the amount of one's clothing or drinking cold water, can mitigate the impact of overheating on human health. These adaptive behaviors and mitigation strategies are influenced by awareness and knowledge (Van Loenhout & Guha-Sapir, 2016), the general level of education (Pisello et al., 2017), socio-economic status, and household characteristics. Several studies have shown the benefits of increasing awareness and education. For example, training children to adapt drinking habits helps them resist heatwaves and overheating (Kalhoff et al., 2023).

It is key to increase awareness of occupants around: (i) the risk of overheating; and (ii) what actions can be implemented to reduce indoor overheating. This latter includes knowledge of (i) strategies at the individual level, for example, adjusting clothing, drinking water, reducing activity, etc.; (ii) strategies at the household or workplace level, for example, increasing night cooling ventilation and shading. Shading is very effective since it leverages the perceived motivation to pro-actively adapt, leading to increased empowerment of how to better adapt households to heat (Valois et al., 2020). It has been shown that providing instruction and training through health networks, liaisons, and key people in the community is effective (Kiarsi et al., 2023).

Awareness campaigns and communication activities should be tailored to the specific needs of different audiences. Heat-susceptible populations are targeted due to the severe impact of extreme heat on their health and the disadvantages of communication. This includes the elderly, children, and caregivers (The Lancet, 2015). For example, children need specific communication goals and strategies (Mangus & Canares, 2019). It is important to target a population with either a language barrier or less exposure to information and education (Sheridan, 2007). A recent survey reported that one main source of information during heatwaves is news (Palinkas et al., 2022). The following items provide specific areas that may benefit individuals if presented for awareness:

Adaptive Behavior

Reducing clothing level. Removing or optimizing clothing levels is well established and widely used strategy to reduce the thermal resistance between the body and the environment. This increasing heat losses through evaporation, conduction, radiation, or convection. It is recommended to wear easy-to-modify clothing layers that enable adjusting the level of clothing in time, with loose, light, and breathable fabrics.

Activity and exposure. Limiting activity levels to keep the metabolism and work level low is an effective way to reduce the impact of overheating since it limits the amount of internal heat produced by the body. This strategy is effective both indoors and outdoors. Reducing, eliminating or rescheduling strenuous activities until the coolest time of the day is recommended. Breaks in physical activity longer than 5 minutes can lower the body temperature. Selecting cool locations and reducing exposure to solar radiation is also a very effective strategy for limiting the risks of overheating. (Palinkas et al., 2022).

Drinking cold liquids. The CDC provides the following advice to prevent dehydration: drink more fluids; don't wait until you're thirsty; avoid sugary or alcoholic drinks (these types of beverages can lead to increased fluid loss). Ingestion of cold/icy water increases conductive heat transfer between the warm body and the cool ingested aliments (Jay et al., 2021). If the water is consumed while people are sweating, for example during exercise, its effectiveness is reduced (Jay et al., 2021). Heavy sweating removes salt and minerals from the body that need to be replaced and a sports drink can replace the salt and minerals lost from sweating. Individuals with diabetes, high blood pressure, or other chronic conditions, as well as those on a low-salt diet should consult with a doctor before drinking sports beverages or taking salt tablets.

Self-dousing. Applying water to the skin can reduce physiological heat strain and thermal discomfort and this strategy is very effective when the indoor environment is dry, and clothing does not restrain the evaporation of water directly from the skin (Morris et al., 2019). However, for dousing to be effective needs to be repeated every 5-10 minutes and is therefore not always practical. Similar strategies include immersing hands and forearms in cold water (Giesbrecht, Gordon G., Christopher Jamieson, and Farrell Cahill., 2007); immersing feet above the ankles can increase conductive heat loss and reduce thermal discomfort (DeGroot et al., 2013), even if it has not been proved capable of limiting heat strain. Noticeably, cold water below 41 degrees Fahrenheit (5 degrees Celsius) can also induce local thermal discomfort.

Household modifications. There are affordable and practical actions that can be taken in dwellings to improve the thermal environment and reduce the risk of overheating: closing windows, curtains, or blinds during the day; opening windows when outdoor temperatures are equal or lower than indoor and solar radiation is not a concern, for example, during the night; limiting the use of appliances that generate heat, such as ovens and stoves (not cooking food), and clothes dryers and select energy; operating fans and small evaporative coolers. In a literature review, clothing adjustment was shown to be the most frequent adaptive behavior across various types of indoor environments followed by fan usage, opening the windows, and the use of air conditioning (Arsad et al., 2023).

Prioritize staying in cooler spaces within the available indoor spaces. Indoor spaces have different temperatures and people should stay in the cooler areas. Spaces that are in proximity of façades, roofs, windows, and higher floors are often warmer than other internal spaces. When possible, it is recommended to avoid using indoor spaces close to roof and façade surfaces in the warmest hours of the day, unless natural ventilation can prevent undesired overheating.

Personal Comfort Systems (PCS) for cooling. PCS is a local device designed to condition the environment in proximity of an occupant according to their personal individual requirements (ASHRAE 55, 2023). Examples of PCS for cooling include fans (small desktop fans, standing fans, ceiling fans) and small misters or evaporative coolers (H. Zhang et al., 2015). Since a PCS only conditions the micro-climate in proximity to the occupant, their energy consumption is generally lower than centralized systems. Use of PCS allows higher air conditioning setpoints without compromising comfort and enable increased individual control.

Alternatives to Traditional Cooling

The following subsections describe the suitability results for each alternative and traditional cooling technology. Unless otherwise noted, the discussion around each technology applies to both single-family and multi-family dwelling units. Suitability was determined based on two factors: climate and cost. Climate suitability for evaporative coolers was based on having at least three hours per day with a wet bulb temperature suitable to allow evaporative coolers to perform effectively.

Ceiling Fans

Ceiling fans are relatively cheap to install and consume much less power compared to a window AC or a central AC system. Ceiling fans are suitable in all climate zones.

In the California residential segments investigated, the main constraints that impact the cost and likelihood of a ceiling fan installation are:

- Ceiling heights
- Installation requirements and challenges
- Power availability at ceiling fan location

The installation of ceiling fans should be at least 7 feet above the floor (with 8’-9” being optimal), 18 inches from the walls, and fan blades at a minimum of 6 inches from the ceiling. Optimal fan performance is achieved when the fan is at least 12 inches from the ceiling. A 7’-8” ceiling height is the minimum ceiling height to install ceiling fan for safety and performance. Many California jurisdictions allow for ceilings as low as 7’-0” in some residential dwelling units. Although rigorous data for dwelling unit ceiling height was not found, it was estimated that less than 10% of dwelling units have ceiling heights of less than 8 feet.

Structural conditions within ceilings may present an issue as ceiling fan retrofits may require a special hanger or blocking for safe installation. While this does not present a large burden to the cost of installation, it does require the contractor to purchase extra material and take additional time to properly install the fan.

Additionally, if there is not easily accessible power at the desired location of the ceiling fan, this could present a significant cost issue as a contractor would need to install a new branch circuit to the location of the fan. It was assumed that 90% of dwelling units have overhead lighting and power available for ceiling fan installation.

Ceiling fan factors that can affect performance, satisfaction, or comfort include:

- Fan diameter affects airflow and comfort. “Hugger fans” are fans without down rods made for shorter ceilings and can sit closer to the ceiling. However, a distance less than 12” from bottom of blades to ceiling reduces performance.
- Fan vibration can also be an issue for occupants as inexpensive fans tend to use cheaper materials and are not as well-balanced as more expensive fans. Due to the vibration, cheaper fans can also present noise issues.

While addressing these performance, satisfaction, or comfort issues may affect systems in some cases, none generally present significant additional constraints to the suitability of this technology to the residential segments.

Evaporative Coolers

Evaporative coolers reduce air temperature by adding moisture to the air through evaporation. Evaporative coolers are not suitable for marine climate zones as the humidity tends to be too high for the cooler to effectively cool the air. Dry climates where the 1% summer design wet-bulb temperatures are below 70 degrees Fahrenheit are the best climates for evaporative coolers. However, evaporative coolers can provide cooling where coincidental wet-bulb temperatures are as high as 74 degrees Fahrenheit. A UC Davis report found that evaporative coolers are generally not suitable in climate zones 1, 3, 5, 6, 7, 8, and 9. [Davis].

The suitability of three types of evaporative coolers was considered:

- Direct room type evaporative coolers
- Direct type central evaporative coolers
- Indirect type evaporative coolers

Evaporative cooler types vary in terms of cost, performance, and applications for which they are well-suited. All of the evaporative cooler styles require a connection to a waterline. Smaller, portable evaporative coolers that are standalone and do not require a connection to a waterline also exist on the market, but they require continuous occupant maintenance to refill the water reservoir.

A concern with direct type evaporative coolers is the addition of humidity to the space. While this humidity can be mitigated through open windows or a makeup air duct, there is still a risk of elevated humidity in the space. Having an accessible waterline and plumbing it to an evaporative cooler could incur significant cost and therefore make direct room evaporative coolers unlikely in a multifamily retrofit scenario.

Central evaporative coolers are much more expensive than room evaporative coolers. The cost of the unit, locating and mounting the unit, and associated ductwork required to supply air to the dwelling unit would be too high to make installation likely for either single family or multifamily dwelling units.

Indirect type evaporative coolers tend to not perform as well as direct type evaporative coolers as they circulate indoor air through a heat exchanger where the evaporative cooling takes place. For this reason and the high cost of indirect coolers, it is unlikely that indirect evaporative coolers will be widely used in multifamily or single family residential retrofit applications.

Factors that can affect performance, satisfaction, and comfort include:

- Water use
- High mineral content in local water can increase water use
- Frequent maintenance requires easy access to the unit
- Proper makeup air is required to maintain appropriate humidity levels

While addressing these performance, satisfaction, or comfort issues may affect systems in some cases, none generally present significant additional constraints to the suitability of this technology to the residential segments.

Traditional Cooling Technologies

Central Air Conditioner

Central air conditioners (CAC) work on the principle of direct heat exchange (known as DX) with a refrigerant system. Liquid refrigerant passes through an indoor coil over which a fan blows indoor air. As the air moves over the coil it cools as the refrigerant picks up the heat from the air and boils off into a vapor. That vapor then moves to the outdoor unit where a compressor compresses it thus driving up the temperature and pressure. The outdoor fan rejects the heat from the refrigerant to the atmosphere and the whole process starts over. This is one of the most prevalent cooling systems in California. It is suitable in every climate zone.

A CAC retrofit would likely only occur in systems that have existing ductwork (i.e., a furnace/fan coil system), because retrofitting ductwork into a dwelling unit would add a significant cost. Whether or not the existing ductwork is suitable for CAC would vary by dwelling unit, and undersized existing ductwork could lead to a lack of proper airflow getting to the space it is serving or excessive noise. This holds true for single and multi-family applications.

Another consideration with CAC installation is appropriate clearance around the outdoor unit. Air conditioners require two to three feet of clearance around the unit and 5 feet above. In single family applications this is generally not an issue. In multifamily applications a contractor can generally achieve this using ground space or roof space.

Factors that can affect performance, satisfaction, or comfort include:

- Adequately sized equipment, and efficient and effective distribution design
- Undersized ductwork (possible when re-using existing furnace ductwork) can lead to excessive noise or inefficiency
- Noise and maintenance

Ductless Mini-split Heat Pumps

The cooling mechanism of ductless mini-split air conditioners works on the same DX principle as the CAC. They are suitable in every climate zone. One advantage of heat pumps is that they can provide both heating and cooling.

In the California residential segments investigated, the main installation constraints of ductless mini-splits heat pumps are cost and space constraints for clearance needed to the sides and above the outdoor unit. Generally, two to three feet of clearance around the sides of these units are necessary. This usually presents no problem with single family dwelling units, and a contractor can achieve this by ground or roof space in multi-family dwelling units. However, mini-split air conditioners also require a contractor to run refrigerant lines from the outdoor unit to each indoor unit head, as well as running condensate pumps and drain lines out of the space to the outside, which adds cost.

Factors that can affect performance, satisfaction, or comfort include:

- Concerns about high initial costs and increased operation costs
- Aesthetic concerns
- For heating, decisions about whether to keep or remove an existing furnace.

Window AC

Like central AC and mini-splits, window ACs work on the same DX principle. Window ACs are suitable in every climate zone. In the California residential segments investigated, the main suitability constraints of window ACs are the window type. Window ACs generally require a double hung window. These dwelling units are not suitable for casement windows.

Factors that can affect performance, satisfaction, or comfort include:

- Ability to seal between the unit and the window to prevent leakage
- Noise

Conclusion

After consultation with an extensive group of stakeholders, HCD has concluded that the state should consider a general maximum safe indoor air temperature of 82 degrees Fahrenheit (27.8 degrees Celsius) for residential dwelling units, with different approaches for newly constructed and existing residential dwelling units. This recommendation is grounded in a thorough review of relevant technical information, literature, studies, and state and local standards, and takes into consideration the impact of high indoor air temperatures on human health.

There are unique challenges to enable many existing buildings to be able to maintain a maximum indoor air temperature including infrastructure limitations, technical feasibility, cost of retrofitting, and electrical utility capacity, so this report's recommendations should allow flexibility and encourage incentive based approaches. Newly constructed residential buildings on the other hand, are already very capable of maintaining a safe indoor air temperature, as California energy codes require high performance building envelopes (including windows, doors, and thermal insulation), and the vast majority of new buildings are equipped with air conditioning systems.

The recommended maximum safe indoor air temperature is consistent with applicable research and standards identified herein and a consensus of the participating stakeholders Factors identified in this document that support the recommended maximum safe indoor air temperature include, but are not limited to, heat and human physiology and effects, critical reference standards, adaptation; related local, state, and international standards; and passive, and active cooling strategies.

Appendix A: Existing U.S. City Code Language

El Paso, Texas. City Code of Ordinances - Title 18 - Chapter 18.10 - 18.10.060

International Residential Code, 2021 Edition, Section R303.8, Required heating, is hereby amended to read as follows: R303.10 Required heating and cooling. Interior spaces intended for human occupancy shall be provided with active or passive space-heating and cooling systems capable of maintaining an indoor air temperature between 68 F (20 C) and 90 F at a point 3 feet above the floor and 2 feet from exterior walls in all habitable spaces. The installation of portable space heaters shall not be used to achieve compliance with this section.

Dallas, Texas. City Code Compliance - Chapter 27 - Section 27-11 (e)

(1) Air Conditioning: an owner shall provide and maintain in operating condition, refrigerated air equipment capable of maintaining a room temperature of at least 15 degrees cooler than the outside temperature, but in no event higher than 85 degrees Fahrenheit in each habitable room.

Clark, Nevada. County Code Compliance - Title 22 - Chapter 22.02 - 22.02.067

All dwelling units, as defined in the International Building Code (IBC) and International Residential Code (IRC), with a permit issuance date for construction or alteration, after February 3, 2019, shall be equipped with active or passive heating/cooling systems.

(A) Dwelling units, except one and two-family dwellings, shall be designed in a manner such that an interior temperature can be maintained between 68 degrees Fahrenheit and 85 degrees Fahrenheit, by the use of active or passive heating or cooling systems. A certificate of compliance certifying that the design meets the requirements of the section and applicable building codes must be sealed and signed by a Nevada Registered Design Professional and submitted to the Clark County Department of Building and Fire Prevention as a part of the permit submittal package.

  (a) As used in this section, an active heating/cooling system refers to any heating or cooling system that requires a non-naturally occurring heating or cooling source in order to adjust the temperature in a space.

  (b) As used in this section, a passive heating/cooling system refers to any heating or cooling system that does not introduce a non-naturally occurring heating or cooling source in order to adjust the temperature in a space.

Exemptions: Dwelling units that have active heating and cooling systems installed under a permit issued prior to February 3, 2019.

Los Angeles, California. Proposed County Code amendment

The Building Standards Code for unincorporated areas in LA County should be amended to require that residential buildings possess active or passive cooling strategies capable of maintaining temperatures of less than 82 degrees Fahrenheit if there is air conditioning or 86 degrees Fahrenheit if there is evaporative cooling or no cooling unit present. For maximum effectiveness, a new maximum indoor air temperature threshold should apply to new and remodeled residential buildings immediately, with a phase-in for existing construction.

Arizona HB 2146 amends the Arizona Mobile Home Parks Residential Landlord And Tenant Act as follows:

> A person who owns or operates a mobilehome park shall not:
>
> Prohibit a tenant from installing reasonably necessary cooling methods to reduce energy costs and prevent heat-related illness and death, including temporary window-mounted ventilation or air conditioning, wall-mounted mini-split air conditioners, commercial window coverings, shutters, window film, shade awnings, skirting or other commercial cooling methods.

Tempe, Arizona. City Code - Chapter 21 - Article II - Division 2 - Section 21-34

(a) General provision. Every rental housing unit should contain safe heating and cooling facilities which are properly installed and maintained in sound condition and capable of providing adequate heating and cooling, appropriate for the climate, to assure a comfortable and healthy living environment.

(c) Cooling requirements. Every rental housing unit shall have cooling, under the tenant's control, capable of safely cooling all habitable rooms, bathrooms and flush toilet rooms located therein to a temperature no greater than eighty-eight degrees (88°) Fahrenheit, if cooled by evaporative cooling, or eighty-two degrees (82°) Fahrenheit, if cooled by air conditioning. Temperature measurements shall be taken at a distance three (3) feet above floor level in the center of the room. Required cooling shall be provided by permanently installed cooling facilities. Except that those air conditioning facilities serving more than one rental housing unit shall only be required to be designed and operating in conformance with manufacturer's specifications.

Phoenix, Arizona. City Code - Article II § 39-5 (B) (1) (b)

B. Heating, cooling and ventilation systems.

1. Heating, cooling and ventilation systems in any building or structure are to be maintained hazard-free, operational and in a state of good repair. Heating and cooling systems shall be free from hazards associated with ventilation, equipment status, mounting, electrical connections and other potential defects.

b. Cooling requirements. Every rental housing unit where such systems are installed shall have cooling capable of safely cooling all habitable rooms, bathrooms and flushing toilet rooms to a temperature no greater than 86 degrees Fahrenheit, if cooled by evaporative cooling, or 82 degrees Fahrenheit, if cooled by air conditioning. Temperature measurements shall be taken at a distance three feet above the floor in the center of the room. Required cooling shall be provided by permanently installed cooling facilities.

Tucson, Arizona. City Code - Article II - Chapter 16 - Section 16-11 (b)

(2) Cooling. Every dwelling unit, guest room, and congregate residence shall be provided, in all habitable rooms, with either mechanical cooling or an alternate cooling method, to assure a safe living environment. Cooling facilities shall be installed and maintained in a safe condition and in accordance with the manufacturer's recommendations, and shall comply with the following: a. Air conditioners shall be capable of producing ambient temperatures at or below eighty-two (82°) degrees. Measurements shall be taken at a distance of three (3) feet above the floor in the center of the room. b. Evaporative coolers shall be capable of producing ambient temperatures below eighty-six (86°) degrees. Measurements shall be taken at a distance of three (3) feet above the floor in center of the room. c. Evaporative cooling shall be maintained to be free of excessive rust, corrosion or mineral deposits that limit proper operation. Any mounting apparatus for a cooling facility must be structurally sound. d. Mechanical fans or portable evaporative cooling devices may only be used on a temporary basis as the sole source of cooling when the permanent cooling system is being repaired or replaced.

Houston, Texas. City Code - Chapter 10 - Article IX - Division 4 - Section 10-363 - (d) Utility standards. An owner of property shall:

(8) In each habitable space, if screens are not provided as required in subsection (e)(2) of this section, provide and maintain in good operating condition refrigerated air equipment capable of maintaining a maximum inside temperature 20 degrees Fahrenheit lower than the outside temperature or 80 degrees Fahrenheit, whichever is warmer;

Palm Springs, California. City code - Title 8 - Chapter 8.04 - 8.04.017

2) Add new subsection R303.11, Required air conditioning, to read as follows: R303.11, Required air conditioning, to read as follows: R303.11 Required air conditioning. Every dwelling unit shall be provided with air conditioning facilities capable of maintaining a room temperature of not more than 80 degrees Fahrenheit in all habitable rooms.

New Orleans, Louisiana. City Code - Chapter 26 - Article XIII - Division 1 - Sec. 26-656

(f) Each rental housing unit shall have a cooling system in good working order that can safely maintain a maximum temperature of 80 degrees Fahrenheit in all bedrooms, measured at a point three feet above the floor and two feet from exterior walls.

Portland, Oregon. City Code - Title 27 - Chapter 27.05 - 27.05.021

Amended by Ordinance No. 187432, effective December 4, 2015. Every dwelling unit and guest room shall be provided with heating facilities capable of maintaining a room temperature of 68 degrees Fahrenheit or 20 degrees Celsius at a point 3 feet or 91.44 centimeters above the floor in all of the City of Portland habitable rooms. The version of the Oregon Energy Efficiency Specialty Code adopted by the City in Section 24.10.040 shall regulate the design and construction of the exterior envelopes and selection of heating, ventilating and air conditioning systems and equipment.

A. The annual degree days is 4,792 for heating and is 300 for cooling. The design temperature is 23 degrees Fahrenheit for winter and 85 degrees Fahrenheit for summer.

B. Indoor design temperature shall be 68 degrees Fahrenheit for heating and 78 degrees Fahrenheit for cooling.

Reference List

Alexandri, E., & Jones, P. (2008). Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates. *Building and Environment, 43*(4), 480–493. https://doi.org/10.1016/j.buildenv.2006.10.055

Anderson, B. G., & Bell, M. L. (2009). Weather-Related Mortality: How Heat, Cold, and Heatwaves Affect Mortality in the United States. *Epidemiology, 20*(2), 205. https://doi.org/10.1097/EDE.0b013e318190ee08

Anderson, M., Carmichael, C., Murray, V., Dengel, A., & Swainson, M. (2013). Defining indoor heat thresholds for health in the UK. *Perspectives in Public Health, 133*(3), 158–164. https://doi.org/10.1177/1757913912453411

Arens, E., Hoyt, T., Zhou, X., Huang, L., Zhang, H., & Schiavon, S. (2015). Modeling the comfort effects of short-wave solar radiation indoors. *Building and Environment, 88,* 3–9. https://doi.org/10.1016/j.buildenv.2014.09.004

Arnold, L., Scheuerell, M. D., & Busch Isaksen, T. (2022). Mortality Associated with Extreme Heat in Washington State: The Historical and Projected Public Health Burden. *Atmosphere, 13*(9), Article 9. https://doi.org/10.3390/atmos13091392

Arsad, F. S., Hod, R., Ahmad, N., Baharom, M., & Ja'afar, M. H. (2023). Assessment of indoor thermal comfort temperature and related behavioural adaptations: A systematic review. *Environmental Science and Pollution Research, 30*(29), 73137–73149. https://doi.org/10.1007/s11356-023-27089-9

ASHRAE 55. (2023). *Standard 55 – Thermal Environmental Conditions for Human Occupancy* (Version 2023). American Society of Heating, Refrigerating and Air-Conditioning Engineers. https://www.ashrae.org/technical-resources/bookstore/standard-55-thermal-environmental-conditions-for-human-occupancy

Barreca, A., Clay, K., Deschenes, O., Greenstone, M., & Shapiro, J. S. (2016). Adapting to Climate Change: The Remarkable Decline in the US Temperature-Mortality Relationship over the Twentieth Century. *Journal of Political Economy, 124*(1), 105–159. https://doi.org/10.1086/684582

Basu, R. (2009). High ambient temperature and mortality: A review of epidemiologic studies from 2001 to 2008. *Environmental Health, 8*(1), 40. https://doi.org/10.1186/1476-069X-8-40

Basu, R., & Ostro, B. D. (2008). A multicounty analysis identifying the populations vulnerable to mortality associated with high ambient temperature in California. *American Journal of Epidemiology, 168*(6), 632–637. https://doi.org/10.1093/aje/kwn170

Basu, R., Pearson, D., Sie, L., & Broadwin, R. (2015). A Case-Crossover Study of Temperature and Infant Mortality in California. *Paediatric and Perinatal Epidemiology, 29*(5), 407–415. https://doi.org/10.1111/ppe.12204

Basu, R., & Samet, J. M. (2002a). An exposure assessment study of ambient heat exposure in an elderly population in Baltimore, Maryland. *Environmental Health Perspectives, 110*(12), 1219–1224.

Basu, R., & Samet, J. M. (2002b). Relation between elevated ambient temperature and mortality: A review of the epidemiologic evidence. E*pidemiologic Reviews, 24*(2), 190–202. https://doi.org/10.1093/epirev/mxf007

Bell, M. L., McDermott, A., Zeger, S. L., Samet, J. M., & Dominici, F. (2004). Ozone and short-term mortality in 95 US urban communities, 1987-2000. *JAMA, 292*(19), 2372–2378. https://doi.org/10.1001/jama.292.19.2372

Brager, G. S., & de Dear, R. J. (1998). Thermal adaptation in the built environment: A literature review. *Energy and Buildings, 27*. https://doi.org/10.1016/S0378-7788(97)00053-4

Breitner, S., Wolf, K., Devlin, R. B., Diaz-Sanchez, D., Peters, A., & Schneider, A. (2014). Short-term effects of air temperature on mortality and effect modification by air pollution in three cities of Bavaria, Germany: A time-series analysis. *Science of The Total Environment, 485–486,* 49–61. https://doi.org/10.1016/j.scitotenv.2014.03.048

Brown, H. A., Topham, T. H., Clark, B., Smallcombe, J. W., Flouris, A. D., Ioannou, L. G., Telford, R. D., Jay, O., & Périard, J. D. (2022). Seasonal Heat Acclimatisation in Healthy Adults: A Systematic Review. *Sports Medicine, 52*(9), 2111–2128. https://doi.org/10.1007/s40279-022-01677-0

Bumbaco, K. A., Dello, K. D., & Bond, N. A. (2013). History of Pacific Northwest Heatwaves: Synoptic Pattern and Trends. *Journal of Applied Meteorology and Climatology, 52*(7), 1618–1631. https://doi.org/10.1175/JAMC-D-12-094.1

CA Title 24. (2022). *2022 CALIFORNIA BUILDING CODE, TITLE 24*. https://codes.iccsafe.org/content/CABC2022P1/california-code-of-regulations-title-24

California Council on Science and Technology. (2023). *Key Challenges for California's Energy Future*. https://ccst.us/reports/key-challenges-for-californias-energy-future

California Department of Water Resources. (2015). *Hydroclimate Report Water Year 2015 – California Water Library*. https://cawaterlibrary.net/document/hydroclimate-report-water-year-2015/

CDPH. (2018). *California's Fourth Climate Change Assessment Statewide Summary Report.*

CDPH. (2023). *Excess Mortality During the September 2022 Heatwave in California*. https://www.cdph.ca.gov/Programs/OHE/CDPH%20Document%20Library/Climate-Health-Equity/CDPH-2022-Heat-Wave-Excess-Mortality-Report.pdf

CEC. (2021). *BUILD_FAQ-Electrification.pdf*. https://www.energy.ca.gov/sites/default/files/2023-01/BUILD_FAQ-Electrification_2022-01-06.pdf

CEC RASS. (2019). *2019 Residential Appliance Saturation Study.* California Energy Commission. https://www.energy.ca.gov/data-reports/surveys/2019-residential-appliance-saturation-study

Centers for Disease Control and Prevention. (2024, June 21). *Extreme Heat and Your Health.* Extreme Heat. https://www.cdc.gov/extreme-heat/about/index.html

Chen, M., Younes, J., Farahani, A. V., Kilpeläinen, S., Kosonen, R., Ghaddar, N., Ghali, K., & Melikov, A. K. (2024). Evaluating thermal response when elderly people using local cooling devices: Correlation among overall and local thermal sensation with skin temperature. *Building and Environment, 111217*. https://doi.org/10.1016/j.buildenv.2024.111217

City of Dallas. (2024). *Dallas City Code—CHAPTER 27 MINIMUM PROPERTY STANDARDS - ARTICLE III. MINIMUM STANDARDS - SEC. 27-11. MINIMUM PROPERTY STANDARDS; RESPONSIBILITIES OF OWNER.* American Legal Publishing. https://codelibrary.amlegal.com/codes/dallas/latest/dallas_tx/0-0-0-111216

City of El Paso. (2023). *El Paso, Texas—Code of Ordinances Title 18—BUILDING AND CONSTRUCTION Chapter 18.12—MECHANICAL CODE - 18.12.030—Section 309.1 Space-heating systems, amended.* https://library.municode.com/tx/el_paso/codes/code_of_ordinances?nodeId=TIT18BUCO_CH18.12MECO_18.12.020AD

City of Houston. (2022). *Houston, Texas—Code of Ordinances Chapter 10—BUILDINGS AND NEIGHBORHOOD PROTECTION ARTICLE IX. - BUILDING STANDARDS DIVISION 8. - SPECIAL HEARINGS UNDER THE FIRE CODE - Sec. 10-363. - Responsibilities of owner.* https://library.municode.com/tx/houston/codes/code_of_ordinances?nodeId=COOR_CH10BUNEPR_ARTIXBUST_DIV8SPHEUNFICO

City of New Orleans. (2024). *CODE OF THE CITY OF NEW ORLEANS, LOUISIANA - Chapter 26—BUILDINGS, BUILDING REGULATIONS AND HOUSING STANDARDSHOMES PROGRAM Sec. 26-656. - Minimum rental standards.* https://library.municode.com/la/new_orleans/codes/code_of_ordinances?nodeId=PTIICO_CH26BUBUREHOST_ARTXIIIHEHOPR_DIV1INGE_S26-656MIREST

City of Palm Springs. (2023). *City of Palm Springs, CA—City Code - Title 8 Buildings and Construction - §8.04.035 : International Property Maintenance Code—Adopted. City of Palm Springs, CA Code.* https://ecode360.com/42995774

City of Phoenix. (2023). *Phoenix City Code—Maintenance Standards—Neighborhood Preservation Ordinance.* https://phoenix.municipal.codes/CC/39

City of Portland. (2024). *City Code / Title 27 Heating and Ventilating Regulations / Chapter 27.05 Equipment -General / 27.05.021 Capacity.* https://www.portland.gov/code/27/05/021

City of Tempe. (2024). *Tempe, Arizona—City Code—Chapter 21—NUISANCES AND PROPERTY ENHANCEMENT.* https://library.municode.com/az/tempe/codes/city_code?nodeId=CH21NUPREN_ARTIIREHOCO_DIV2REHOST_S21-34THEN

City of Tucson. (2024). *City Code—Chapter 16—Neighborhood Preservation—Sec. 16-11. Buidling Interior.* https://codelibrary.amlegal.com/codes/tucson/latest/tucson_az/0-0-0-11113

Clark County. (2024). *CLARK COUNTY BUILDING ADMINISTRATIVE CODE 22.02.067 Interior Temperature in Dwelling Units.* https://webfiles.clarkcountynv.gov//Building%20&%20Fire%20Prevention/Codes/Administrative%20Code%20-%202nd%20Proof%20FINAL%2008-18-22%20(Printed%2010-2022).pdf

Cox, D. T. C., Maclean, I. M. D., Gardner, A. S., & Gaston, K. J. (2020). Global variation in diurnal asymmetry in temperature, cloud cover, specific humidity and precipitation and its association with leaf area index. *Global Change Biology, 26*(12), 7099–7111. https://doi.org/10.1111/gcb.15336

CPUC. (2021). *Utility cost and affordability of the grid of the future.*

Craig, C., Overbeek, R. W., Condon, M. V., & Rinaldo, S. B. (2016). A relationship between temperature and aggression in NFL football penalties. *Journal of Sport and Health Science, 5*(2), 205–210. https://doi.org/10.1016/j.jshs.2015.01.001

Cramer, M. N., & Jay, O. (2016). Biophysical aspects of human thermoregulation during heat stress. *Autonomic Neuroscience, 196,* 3–13. https://doi.org/10.1016/j.autneu.2016.03.001

de Lorenzo, A., & Liaño, F. (2017). High temperatures and nephrology: The climate change problem. *Nefrologia: Publicacion Oficial De La Sociedad Espanola Nefrologia, 37*(5), 492–500. https://doi.org/10.1016/j.nefro.2016.12.008

E. Erell, D. Pearlmutter, Y. Etzion. (2008). A multi-stage down-draft evaporative cool tower for semi-enclosed spaces: Aerodynamic performance. *Solar Energy, 82,* 420–429.

Ebi, K. L., Capon, A., Berry, P., Broderick, C., De Dear, R., Havenith, G., Honda, Y., Kovats, R. S., Ma, W., Malik, A., Morris, N. B., Nybo, L., Seneviratne, S. I., Vanos, J., & Jay, O. (2021). Hot weather and heat extremes: Health risks. *The Lancet, 398*(10301), 698–708. https://doi.org/10.1016/S0140-6736(21)01208-3

Eliason, M. (2021). *Unlocking Livable, Resilient, Decarbonized Housing with Point Access Blocks.* Larch Lab. https://www.larchlab.com/wp-content/uploads/2022/01/Eliason_CoV-Point-Access-Blocks-report_v1.2.pdf

Fink, R., Eržen, I., & Medved, S. (2017). Symptomatic response of the elderly with cardiovascular disease during a heatwave in Slovenia. *Central European Journal of Public Health, 25*(4), 293–298. https://doi.org/10.21101/cejph.a4469

G. Chiesa, A. Zajch. (2020). Contrasting climate-based approaches and building simulations for the investigation of Earth-to-air heat exchanger (EAHE) cooling sensitivity to building dimensions and future climate scenarios in North America. *Energy and Buildings, 227*(110410).

Gauer, R., & Meyers, B. K. (2019). Heat-Related Illnesses. *American Family Physician, 99*(8), 482–489.

Gershunov, A., Cayan, D. R., & Iacobellis, S. F. (2009). The Great 2006 Heatwave over California and Nevada: Signal of an Increasing Trend. *Journal of Climate, 22*(23), 6181–6203. https://doi.org/10.1175/2009JCLI2465.1

Gershunov, A., & Guirguis, K. (2012). California heatwaves in the present and future. *Geophysical Research Letters, 39*(18). https://doi.org/10.1029/2012GL052979

Giannadaki, D., Lelieveld, J., & Pozzer, A. (2016). Implementing the US air quality standard for PM2.5 worldwide can prevent millions of premature deaths per year. *Environmental Health, 15*(1), 88. https://doi.org/10.1186/s12940-016-0170-8

Giesbrecht, Gordon G., Christopher Jamieson, and Farrell Cahill. (2007). Cooling hyperthermic firefighters by immersing forearms and hands in 10 C and 20 C water. *Aviation Space and Environmental Medicine, 78*(6), 562–567.

Glazer, J. L. (2005). *Management of Heatstroke and Heat Exhaustion. 71*(11).

Guirguis, K., Gershunov, A., Tardy, A., & Basu, R. (2014). The Impact of Recent Heatwaves on Human Health in California. *Journal of Applied Meteorology and Climatology, 53*(1), 3–19. https://doi.org/10.1175/JAMC-D-13-0130.1

Hanna, E. G., & Tait, P. W. (2015). Limitations to Thermoregulation and Acclimatization Challenge Human Adaptation to Global Warming. *International Journal of Environmental Research and Public Health, 12*(7), Article 7. https://doi.org/10.3390/ijerph120708034

Hansen, A., Bi, P., Nitschke, M., Ryan, P., Pisaniello, D., & Tucker, G. (2008). The Effect of Heatwaves on Mental Health in a Temperate Australian City. *Environmental Health Perspectives, 116*(10), 1369–1375. https://doi.org/10.1289/ehp.11339

Havenith, G. (2005). Temperature Regulation, Heat Balance and Climatic Stress. In W. Kirch, R. Bertollini, & B. Menne (Eds.), *Extreme Weather Events and Public Health Responses* (pp. 69–80). Springer. https://doi.org/10.1007/3-540-28862-7_7

He, C., Kim, H., Hashizume, M., Lee, W., Honda, Y., Kim, S. E., Kinney, P. L., Schneider, A., Zhang, Y., Zhu, Y., Zhou, L., Chen, R., & Kan, H. (2022). The effects of night-time warming on mortality burden under future climate change scenarios: A modelling study. *The Lancet Planetary Health,* 6(8), e648–e657. https://doi.org/10.1016/S2542-5196(22)00139-5

Hess, J. J., Errett, N. A., McGregor, G., Busch Isaksen, T., Wettstein, Z. S., Wheat, S. K., & Ebi, K. L. (2023). Public Health Preparedness for Extreme Heat Events. *Annual Review of Public Health, 44*(1), 301–321. https://doi.org/10.1146/annurev-publhealth-071421-025508

Hill, L. D., Webb, L. H., & Parsons, K. C. (2000). Carers' Views of the Thermal Comfort Requirements of People with Physical Disabilities. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 44*(28), 716–719. https://doi.org/10.1177/154193120004402885

Hillman, D., Mitchell, S., Streatfeild, J., Burns, C., Bruck, D., & Pezzullo, L. (2018). *Economic cost of inadequate sleep | SLEEP | Oxford Academic*. https://academic.oup.com/sleep/article/41/8/zsy083/5025924

Holmes, S. H., Phillips, T., & Wilson, A. (2016). Overheating and passive habitability: Indoor health and heat indices. *Building Research & Information, 44*(1), 1–19. https://doi.org/10.1080/09613218.2015.1033875

Inoue, Y., & Shibasaki, M. (1996). Regional differences in age-related decrements of the cutaneous vascular and sweating responses to passive heating. *European Journal of Applied Physiology and Occupational Physiology, 74*(1), 78–84. https://doi.org/10.1007/BF00376498

IPCC (Ed.). (2022). Impacts of 1.5°C Global Warming on Natural and Human Systems. In Global Warming of 1.5°C: IPCC Special Report on Impacts of Global Warming of 1.5°C above Pre-industrial Levels in Context of Strengthening Response to Climate Change, Sustainable Development, and Efforts to Eradicate Poverty (pp. 175–312). Cambridge University Press. https://doi.org/10.1017/9781009157940.005

IPCC Annex II. (2022). *Climate Change 2022 – Impacts, Adaptation and Vulnerability*. Cambridge University Press. https://doi.org/10.1017/9781009325844

IRC. (2018). 2018 *International Residential Code (IRC)*. https://codes.iccsafe.org/content/IRC2018P6

Itani, O., Jike, M., Watanabe, N., & Kaneita, Y. (2017). Short sleep duration and health outcomes: A systematic review, meta-analysis, and meta-regression. *Sleep Medicine, 32,* 246–256. https://doi.org/10.1016/j.sleep.2016.08.006

Jay, O., Capon, A., Berry, P., Broderick, C., Dear, R. de, Havenith, G., Honda, Y., Kovats, R. S., Ma, W., Malik, A., Morris, N. B., Nybo, L., Seneviratne, S. I., Vanos, J., & Ebi, K. L. (2021). Reducing the health effects of hot weather and heat extremes: From personal cooling strategies to green cities. *The Lancet, 398*(10301), 709–724. https://doi.org/10.1016/S0140-6736(21)01209-5

Kalhoff, H., Sinningen, K., Belgardt, A., Kersting, M., & Luecke, T. (2023). Climate change and fluid status in children: Early education as one response to an emerging public health problem. *Public Health Nutrition, 26(*12), 2891–2894. https://doi.org/10.1017/S1368980023002562

Kenney, W. L., Craighead, D. H., & Alexander, L. M. (2014). Heatwaves, Aging, and Human Cardiovascular Health. *Medicine & Science in Sports & Exercise, 46*(10), 1891. https://doi.org/10.1249/MSS.0000000000000325

Kenny, G. P., Flouris, A. D., Yagouti, A., & Notley, S. R. (2019). Towards establishing evidence-based guidelines on maximum indoor temperatures during hot weather in temperate continental climates. *Temperature (Austin, Tex.), 6*(1), 11–36. https://doi.org/10.1080/23328940.2018.1456257

Kenrick, D. T., & MacFARLANE, S. W. (1986). Ambient Temperature and Horn Honking: "A Field Study of the Heat/Aggression Relationship." *Environment and Behavior, 18*(2), 179–191.

Khatana, S. A. M., Werner, R. M., & Groeneveld, P. W. (2022). Association of Extreme Heat and Cardiovascular Mortality in the United States: A County-Level Longitudinal Analysis From 2008 to 2017. *Circulation, 146*(3), 249–261. https://doi.org/10.1161/CIRCULATIONAHA.122.060746

Kiarsi, M., Amiresmaili, M., Mahmoodi, M. R., Farahmandnia, H., Nakhaee, N., Zareiyan, A., & Aghababaeian, H. (2023). Heatwaves and adaptation: A global systematic review. *Journal of Thermal Biology, 116,* 103588. https://doi.org/10.1016/j.jtherbio.2023.103588

Knowlton, K., Rotkin-Ellman, M., King, G., Margolis, H. G., Smith, D., Solomon, G., Trent, R., & English, P. (2009). The 2006 California Heatwave: Impacts on Hospitalizations and Emergency Department Visits. *Environmental Health Perspectives, 117*(1), 61–67. https://doi.org/10.1289/ehp.11594

Ko, W. H., Kent, M. G., Schiavon, S., Levitt, B., & Betti, G. (2022). A Window View Quality Assessment Framework. *LEUKOS, 18*(3), 268–293. https://doi.org/10.1080/15502724.2021.1965889

Krenzer, W. L. D., & Splan, E. D. (2018). Evaluating the heat-aggression hypothesis: The role of temporal and social factors in predicting baseball related aggression. *Aggressive Behavior, 44*(1), 83–88. https://doi.org/10.1002/ab.21726

LaDochy, S., Medina, R., & Patzert, W. (2007). Recent California climate variability: Spatial and temporal patterns in temperature trends. *Climate Research, 33*(2), 159–169. https://doi.org/10.3354/cr033159

Lee, M., Nordio, F., Zanobetti, A., Kinney, P., Vautard, R., & Schwartz, J. (2014). Acclimatization across space and time in the effects of temperature on mortality: A time-series analysis. *Environmental Health, 13*(1), 89. https://doi.org/10.1186/1476-069X-13-89

Levinson, R., & Lee, S. H. (2023). Cool Envelope Benefits in Future Typical Weather and Heatwave Conditions for Single-Family Homes in Los Angeles. https://doi.org/10.20357/B7DK6T

Lin, S., Lin, Z., Ou, Y., Soim, A., Shrestha, S., Lu, Y., Sheridan, S., Luben, T. J., Fitzgerald, E., Bell, E., Shaw, G. M., Reefhuis, J., Langlois, P. H., Romitti, P., Feldkamp, M. L., Malik, S., Pantea, C., Nayak, S., Hwang, S.-A., & Browne, M. (2018). Maternal ambient heat exposure during early pregnancy in summer and spring and congenital heart defects – A large US population-based, case-control study. *Environment International, 118,* 211–221. https://doi.org/10.1016/j.envint.2018.04.043

Lin, S., Luo, M., Walker, R. J., Liu, X., Hwang, S.-A., & Chinery, R. (2009). Extreme high temperatures and hospital admissions for respiratory and cardiovascular diseases. *Epidemiology (Cambridge, Mass.), 20*(5), 738–746. https://doi.org/10.1097/EDE.0b013e3181ad5522

Lindemann, U., Stotz, A., Beyer, N., Oksa, J., Skelton, D. A., Becker, C., Rapp, K., & Klenk, J. (2017). Effect of Indoor Temperature on Physical Performance in Older Adults during Days with Normal Temperature and Heatwaves. *International Journal of Environmental Research and Public Health, 14*(2), Article 2. https://doi.org/10.3390/ijerph14020186

Liu, C., Yavar, Z., & Sun, Q. (2015). Cardiovascular response to thermoregulatory challenges. *American Journal of Physiology-Heart and Circulatory Physiology, 309*(11), H1793–H1812. https://doi.org/10.1152/ajpheart.00199.2015

Liu, J., Varghese, B. M., Hansen, A., Borg, M. A., Zhang, Y., Driscoll, T., Morgan, G., Dear, K., Gourley, M., Capon, A., & Bi, P. (2021). Hot weather as a risk factor for kidney disease outcomes: A systematic review and meta-analysis of epidemiological evidence. *Science of The Total Environment, 801,* 149806. https://doi.org/10.1016/j.scitotenv.2021.149806

Lomas, K. (2021). Summertime overheating in dwellings in temperate climates. *Building & Cities, 2*(1), 487–494. https://doi.org/10.5334/bc.128’]

Lomas, K. J., & Li, M. (2023). An overheating criterion for bedrooms in temperate climates: Derivation and application. *Building Services Engineering Research and Technology, 44*(5), 485–517. https://doi.org/10.1177/01436244231183113

Luber, G., & McGeehin, M. (2008). Climate Change and Extreme Heat Events. *American Journal of Preventive Medicine, 35*(5), 429–435. https://doi.org/10.1016/j.amepre.2008.08.021

Luyster, F. S., Strollo, P. J., Zee, P. C., & Walsh, J. K. (2012). Sleep: A Health Imperative. *Sleep, 35*(6), 727–734. https://doi.org/10.5665/sleep.1846

Mahendran, R., Xu, R., Li, S., & Guo, Y. (2021). Interpersonal violence associated with hot weather. *The Lancet Planetary Health, 5*(9), e571–e572. https://doi.org/10.1016/S2542-5196(21)00210-2

Mangus, C. W., & Canares, T. L. (2019). Heat-Related Illness in Children in an Era of Extreme Temperatures. *Pediatrics In Review, 40*(3), 97–107. https://doi.org/10.1542/pir.2017-0322

Mason, A. E., Kasl, P., Soltani, S., Green, A., Hartogensis, W., Dilchert, S., Chowdhary, A., Pandya, L. S., Siwik, C. J., Foster, S. L., Nyer, M., Lowry, C. A., Raison, C. L., Hecht, F. M., & Smarr, B. L. (2024). Elevated body temperature is associated with depressive symptoms: Results from the TemPredict Study. *Scientific Reports, 14*(1), Article 1. https://doi.org/10.1038/s41598-024-51567-w

McCormack, M. C., Belli, A. J., Waugh, D., Matsui, E. C., Peng, R. D., Williams, D. L., Paulin, L., Saha, A., Aloe, C. M., Diette, G. B., Breysse, P. N., & Hansel, N. N. (2016). Respiratory Effects of Indoor Heat and the Interaction with Air Pollution in Chronic Obstructive Pulmonary Disease. *Annals of the American Thoracic Society, 13*(12), 2125–2131. https://doi.org/10.1513/AnnalsATS.201605-329OC

Meade, R. D., Akerman, A. P., Notley, S. R., Kirby, N. V., Sigal, R. J., & Kenny, G. P. (2024). Effects of Daylong Exposure to Indoor Overheating on Thermal and Cardiovascular Strain in Older Adults: A Randomized Crossover Trial. *Environmental Health Perspectives, 132*(2), 027003. https://doi.org/10.1289/EHP13159

Meade, R. D., Akerman, A. P., Notley, S. R., McGinn, R., Poirier, P., Gosselin, P., & Kenny, G. P. (2020). Physiological factors characterizing heat-vulnerable older adults: A narrative review. *Environment International, 144,* 105909. https://doi.org/10.1016/j.envint.2020.105909

Minor, K., Bjerre-Nielsen, A., Jonasdottir, S. S., Lehmann, S., & Obradovich, N. (2022). Rising temperatures erode human sleep globally. *One Earth, 5*(5), 534–549. https://doi.org/10.1016/j.oneear.2022.04.008

Montgomery County. (2024). *Montgomery County Code—Part II. Local Laws, Ordinances, Resolutions—Chapter 26. Housing and Building Maintenance Standards. - Sec. 26-7. Light, ventilation and heating, temperature control.* https://codelibrary.amlegal.com/codes/montgomerycounty/latest/montgomeryco_md/0-0-0-134751

Morris, N. B., Gruss, F., Lempert, S., English, T., Hospers, L., Capon, A., & Jay, O. (2019). A Preliminary Study of the Effect of Dousing and Foot Immersion on Cardiovascular and Thermal Responses to Extreme Heat. *JAMA, 322*(14), 1411. https://doi.org/10.1001/jama.2019.13051

Murage, P., Hajat, S., & Kovats, R. S. (2017). Effect of night-time temperatures on cause and age-specific mortality in London. *Environmental Epidemiology (Philadelphia, Pa.), 1*(2), e005. https://doi.org/10.1097/EE9.0000000000000005

Nagashima, K. (2006). Central mechanisms for thermoregulation in a hot environment. *Industrial Health, 44*(3), 359–367. https://doi.org/10.2486/indhealth.44.359

Naughton, M. P., Henderson, A., Mirabelli, M. C., Kaiser, R., Wilhelm, J. L., Kieszak, S. M., Rubin, C. H., & McGeehin, M. A. (2002). Heat-related mortality during a 1999 heatwave in Chicago1 1The full text of this article is available via AJPM Online at www.ajpm-online.net. *American Journal of Preventive Medicine, 22*(4), 221–227. https://doi.org/10.1016/S0749-3797(02)00421-X

Obradovich, N., Migliorini, R., Mednick, S. C., & Fowler, J. H. (2017). Nighttime temperature and human sleep loss in a changing climate. *Science Advances, 3*(5), e1601555. https://doi.org/10.1126/sciadv.1601555

Opinion Dynamics. (2022, June 27). Heat Pump Market Case Study. *Opinion Dynamics.* https://opiniondynamics.com/heat-pump-market-case-study/

Ormandy, D., & Ezratty, V. (2012). Health and thermal comfort: From WHO guidance to housing strategies. *Energy Policy, 49*, 116–121. https://doi.org/10.1016/j.enpol.2011.09.003

Palinkas, L. A., Hurlburt, M. S., Fernandez, C., De Leon, J., Yu, K., Salinas, E., Garcia, E., Johnston, J., Rahman, Md. M., Silva, S. J., & McConnell, R. S. (2022). Vulnerable, Resilient, or Both? A Qualitative Study of Adaptation Resources and Behaviors to Heatwaves and Health Outcomes of Low-Income Residents of Urban Heat Islands. *International Journal of Environmental Research and Public Health, 19*(17), 11090. https://doi.org/10.3390/ijerph191711090

Pallubinsky, H., Kramer, R. P., & van Marken Lichtenbelt, W. D. (2023). Establishing resilience in times of climate change—A perspective on humans and buildings. *Climatic Change, 176*(10), 135. https://doi.org/10.1007/s10584-023-03614-0

Pathak, T. B., Maskey, M. L., Dahlberg, J. A., Kearns, F., Bali, K. M., & Zaccaria, D. (2018). Climate Change Trends and Impacts on California Agriculture: A Detailed Review. *Agronomy, 8*(3), Article 3. https://doi.org/10.3390/agronomy8030025

Pfannerstill, E. Y., Arata, C., Zhu, Q., Schulze, B. C., Ward, R., Woods, R., Harkins, C., Schwantes, R. H., Seinfeld, J. H., Bucholtz, A., Cohen, R. C., & Goldstein, A. H. (2024). Temperature-dependent emissions dominate aerosol and ozone formation in Los Angeles. *Science, 384*(6702), 1324–1329. https://doi.org/10.1126/science.adg8204

Phillips, A., Barboza, T., Vives, R., & Greene, S. (2021, October 7). *Heatwaves are far deadlier than we think. How California neglects this climate threat.* Los Angeles Times. https://www.latimes.com/projects/california-extreme-heat-deaths-show-climate-change-risks/

Pierce, D., Kalansky, J., & Cayan, D. (2018). *Climate, Drought, and Sea Level Rise Scenarios for California's Fourth Climate Change Assessment.* https://www.semanticscholar.org/paper/CLIMATE%2C-DROUGHT%2C-AND-SEA-LEVEL-RISE-SCENARIOS-FOR-Pierce-Kalansky/a14d7f2f76e7d72cfd3023c86e02c567db0ee66c

Pisello, A. L., Rosso, F., Castaldo, V. L., Piselli, C., Fabiani, C., & Cotana, F. (2017). The role of building occupants' education in their resilience to climate-change related events. *Energy and Buildings, 154,* 217–231. https://doi.org/10.1016/j.enbuild.2017.08.024

Raftery, P., Cheung, T., Douglass-Jaimes, D., André, M., Li, J., Kent, M., Khoa, K. H., Sultan, Z., & Schiavon, S. (2023). *Fans for cooling people guidebook.* https://escholarship.org/uc/item/2qd7r5mp

Rahif, R., Amaripadath, D., & Attia, S. (2021). Review on Time-Integrated Overheating Evaluation Methods for Residential Buildings in Temperate Climates of Europe. *Energy and Buildings, 252,* 111463. https://doi.org/10.1016/j.enbuild.2021.111463

Ravanelli, N. M., Hodder, S. G., Havenith, G., & Jay, O. (2015). Heart Rate and Body Temperature Responses to Extreme Heat and Humidity With and Without Electric Fans. *JAMA, 313*(7), 724–725.

Rekha, S., Nalini, S. J., Bhuvana, S., Kanmani, S., & Vidhya, V. (2023). A Comprehensive Review on Hot Ambient Temperature and its Impacts on Adverse Pregnancy Outcomes. *Journal of Mother and Child, 27*(1), 10–20. https://doi.org/10.34763/jmotherandchild.20232701.d-22-00051

Rohde, R. (2024, January 12). *Global Temperature Report for 2023.* Berkeley Earth. https://berkeleyearth.org/global-temperature-report-for-2023/

Romanello, M., Napoli, C. D., Drummond, P., Green, C., Kennard, H., Lampard, P., Scamman, D., Arnell, N., Ayeb-Karlsson, S., Ford, L. B., Belesova, K., Bowen, K., Cai, W., Callaghan, M., Campbell-Lendrum, D., Chambers, J., Daalen, K. R. van, Dalin, C., Dasandi, N., … Costello, A. (2022). The 2022 report of the Lancet Countdown on health and climate change: Health at the mercy of fossil fuels. *The Lancet, 400*(10363), 1619–1654. https://doi.org/10.1016/S0140-6736(22)01540-9

Rönnemaa, T., & Koivisto, V. A. (1988). Combined Effect of Exercise and Ambient Temperature on Insulin Absorption and Postprandial Glycemia in Type I Patients. *Diabetes Care, 11*(10), 769–773. https://doi.org/10.2337/diacare.11.10.769

Santamouris, M., Xirafi, F., Gaitani, N., Spanou, A., Saliari, M., & Vassilakopoulou, K. (2012). Improving the Microclimate in a Dense Urban Area Using Experimental and Theoretical Techniques—The Case of Marousi, Athens. *International Journal of Ventilation, 11*(1), 1–16. https://doi.org/10.1080/14733315.2012.11683966

Sarofim, M. C., Saha, S., Hawkins, M. D., Mills, D. M., Hess, J., Horton, R., Kinney, P., Schwartz, J., & St. Juliana, A. (2016). *Temperature-Related Death and Illness.* https://ntrs.nasa.gov/citations/20160011261

Scortichini, M., De Sario, M., De'Donato, F. K., Davoli, M., Michelozzi, P., & Stafoggia, M. (2018). Short-Term Effects of Heat on Mortality and Effect Modification by Air Pollution in 25 Italian Cities. *International Journal of Environmental Research and Public Health, 15*(8), 1771. https://doi.org/10.3390/ijerph15081771

Semenza, J. C., Rubin, C. H., Falter, K. H., Selanikio, J. D., Flanders, W. D., Howe, H. L., & Wilhelm, J. L. (1996). Heat-Related Deaths during the July 1995 Heatwave in Chicago. *New England Journal of Medicine, 335*(2), 84–90. https://doi.org/10.1056/NEJM199607113350203

Shashar, S., Kloog, I., Erez, O., Shtein, A., Yitshak-Sade, M., Sarov, B., & Novack, L. (2020). Temperature and preeclampsia: Epidemiological evidence that perturbation in maternal heat homeostasis affects pregnancy outcome. *PLoS ONE, 15*(5), e0232877. https://doi.org/10.1371/journal.pone.0232877

Sheridan, S. C. (2007). A survey of public perception and response to heat warnings across four North American cities: An evaluation of municipal effectiveness. I*nternational Journal of Biometeorology, 52*(1), 3–15. https://doi.org/10.1007/s00484-006-0052-9

Sheridan, S. C., & Kalkstein, L. S. (2004). Progress in Heat Watch–Warning System Technology. *Bulletin of the American Meteorological Society, 85*(12), 1931–1942. https://doi.org/10.1175/BAMS-85-12-1931

Shiloh, R., Munitz, H., Stryjer, R., & Weizman, A. (2007). A significant correlation between ward temperature and the severity of symptoms in schizophrenia inpatients—A longitudinal study. *European Neuropsychopharmacology, 17*(6–7), 478–482. https://doi.org/10.1016/j.euroneuro.2006.12.001

Sun, K., Zhang, W., Zeng, Z., Levinson, R., Wei, M., & Hong, T. (2021). Passive cooling designs to improve heat resilience of homes in underserved and vulnerable communities. *Energy and Buildings, 252*, 111383. https://doi.org/10.1016/j.enbuild.2021.111383

Sutton, H. (1909). The influence of high temperatures on the human body, especially with regard to heat-stroke. T*he Journal of Pathology and Bacteriology, 13*(1), 62–73. https://doi.org/10.1002/path.1700130114

Syed, S., O'Sullivan, T. L., & Phillips, K. P. (2022). Extreme Heat and Pregnancy Outcomes: A Scoping Review of the Epidemiological Evidence. *International Journal of Environmental Research and Public Health, 19*(4), 2412. https://doi.org/10.3390/ijerph19042412

Tamrazian, A., LaDochy, S., Willis, J., & Patzert, W. C. (2008). Heatwaves in Southern California: Are They Becoming More Frequent and Longer Lasting? *Yearbook of the Association of Pacific Coast Geographers, 70*(1), 59–69.

Tartarini, F., Cooper, P., Fleming, R., & Batterham, M. (2017). Indoor Air Temperature and Agitation of Nursing Home Residents With Dementia. *American Journal of Alzheimer's Disease & Other Dementias®, 32*(5), 272–281. https://doi.org/10.1177/1533317517704898

Tham, S., Thompson, R., Landeg, O., Murray, K. A., & Waite, T. (2020). Indoor temperature and health: A global systematic review. *Public Health, 179,* 9–17. https://doi.org/10.1016/j.puhe.2019.09.005

The Lancet. (2015). Health professionals: Be prepared for heatwaves. *The Lancet, 386*(9990), 219. https://doi.org/10.1016/S0140-6736(15)61261-2

Trent, R. B. (2006). *Review of the July 2006 Heatwave Related Fatalities in California*. 2007, A13D-0971.

Uejio, C. K., Joiner, A. P., Gonsoroski, E., Tamerius, J. D., Jung, J., Moran, T. P., & Yancey, A. H. (2022). The association of indoor heat exposure with diabetes and respiratory 9-1-1 calls through emergency medical dispatch and services documentation. *Environmental Research, 212,* 113271. https://doi.org/10.1016/j.envres.2022.113271

United States Environmental Protection Agency. (2006). *Excessive Heat Events Guidebook 430-B-16-001*.

Valois, P., Talbot, D., Bouchard, D., Renaud, J.-S., Caron, M., Canuel, M., & Arrambourg, N. (2020). Using the theory of planned behavior to identify key beliefs underlying heat adaptation behaviors in elderly populations. *Population and Environment, 41*(4), 480–506. https://doi.org/10.1007/s11111-020-00347-5

Van Hoof, J., Kort, H. S. M., Hensen, J. L. M., Duijnstee, M. S. H., & Rutten, P. G. S. (2010). Thermal comfort and the integrated design of homes for older people with dementia. *Building and Environment, 45*(2), 358–370. https://doi.org/10.1016/j.buildenv.2009.06.013

Van Loenhout, J. A. F., & Guha-Sapir, D. (2016). How resilient is the general population to heatwaves? A knowledge survey from the ENHANCE project in Brussels and Amsterdam. *BMC Research Notes, 9(*1), 499. https://doi.org/10.1186/s13104-016-2305-y

Walker, M. (2017). *Why we sleep. The new science of sleep and dreams.* Penguin Books UK.

Walter, E. J., & Carraretto, M. (2016). The neurological and cognitive consequences of hyperthermia. *Critical Care, 20,* 199. https://doi.org/10.1186/s13054-016-1376-4

Watt, J. (2012). *Evaporative air conditioning handbook.*

Willers, S. M., Jonker, M. F., Klok, L., Keuken, M. P., Odink, J., van den Elshout, S., Sabel, C. E., Mackenbach, J. P., & Burdorf, A. (2016). High resolution exposure modelling of heat and air pollution and the impact on mortality. *Environment International, 89–90,* 102–109. https://doi.org/10.1016/j.envint.2016.01.013

Witherow, M. (2022). *2022 Report: Indicators of Climate Change in California* [Text]. https://oehha.ca.gov/climate-change/epic-2022

World Health Organization. (2018). *WHO housing and health guidelines.* World Health Organization. https://apps.who.int/iris/handle/10665/276001

World Health Organization. (2024). *Heat and Health.* Who.Int. https://www.who.int/news-room/fact-sheets/detail/climate-change-heat-and-health

Yazar, M., York, A., & Larson, K. L. (2022). Adaptation, exposure, and politics: Local extreme heat and global climate change risk perceptions in the phoenix metropolitan region, USA. *Cities, 127,* 103763. https://doi.org/10.1016/j.cities.2022.103763

Zachariah, M., Philip, S., Pinto, I., Vahlberg, M., Singh, R., Otto, F., Barnes, C., & Kimutai, J. (2023). *Extreme heat in North America, Europe and China in July 2023 made much more likely by climate change.* Imperial College London. https://doi.org/10.25561/105549

Zhang, C., Kazanci, O. B., Levinson, R., Heiselberg, P., Olesen, B. W., Chiesa, G., Sodagar, B., Ai, Z., Selkowitz, S., Zinzi, M., Mahdavi, A., Teufl, H., Kolokotroni, M., Salvati, A., Bozonnet, E., Chtioui, F., Salagnac, P., Rahif, R., Attia, S., … Zhang, G. (2021). Resilient cooling strategies – A critical review and qualitative assessment. *Energy and Buildings, 251*, 111312. https://doi.org/10.1016/j.enbuild.2021.111312

Zhang, H., Arens, E., & Zhai, Y. (2015). A review of the corrective power of personal comfort systems in non-neutral ambient environments. *Building and Environment, 91,* 15–41. https://doi.org/10.1016/j.buildenv.2015.03.013

Zhang, N., Cao, B., & Zhu, Y. (2019). Effects of pre-sleep thermal environment on human thermal state and sleep quality. *Building and Environment, 148,* 600–608. https://doi.org/10.1016/j.buildenv.2018.11.035

Zhang, X., Chen, X., & Zhang, X. (2023). Temperature and Low-Stakes Cognitive Performance. *Journal of the Association of Environmental and Resource Economists, 11*(1), 75–96. https://doi.org/10.1086/726007

Zhao, Q., Guo, Y., Ye, T., Gasparrini, A., Tong, S., Overcenco, A., Urban, A., Schneider, A., Entezari, A., Vicedo-Cabrera, A. M., Zanobetti, A., Analitis, A., Zeka, A., Tobias, A., Nunes, B., Alahmad, B., Armstrong, B., Forsberg, B., Pan, S.-C., … Li, S. (2021). Global, regional, and national burden of mortality associated with non-optimal ambient temperatures from 2000 to 2019: A three-stage modelling study. *The Lancet Planetary Health, 5*(7), e415–e425. https://doi.org/10.1016/S2542-5196(21)00081-4

Zhou, L., Wang, Y., Wang, Q., Ding, Z., Jin, H., Zhang, T., & Zhu, B. (2023). The interactive effects of extreme temperatures and PM2.5 pollution on mortalities in Jiangsu Province, China. *Scientific Reports, 13*(1), 9479. https://doi.org/10.1038/s41598-023-36635-x

California Department of Housing and Community Development

651 Bannon Street
Sacramento CA 95811

www.hcd.ca.gov

@California_HCD

CaliforniaHCD

CaliforniaHCD