Extreme Weather Events and Building Resilience in Home Electrification and Decarbonization

Some background/introduction and the importance of improving resilience to extreme weather in underserved populations

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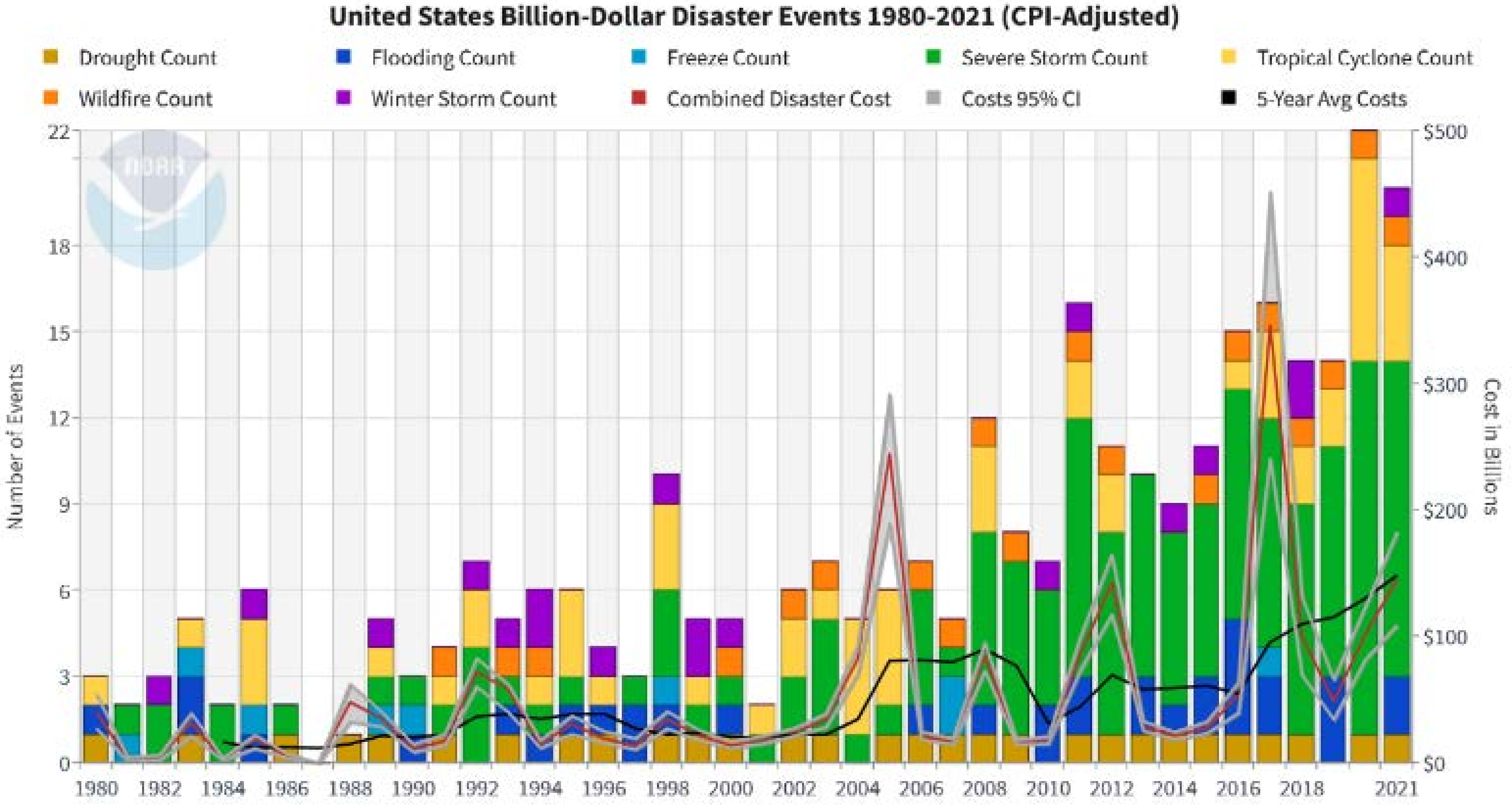
7/17/24

ENERGY TECHNOLOGIES AREA
BERKELEY LAB

Outline

- Landscape/overview
  - Extreme weather
  - Resilience & built environment, community resilience
  - Impacts with focus on extreme heat & CA
  - Equity imperative/ interactions
- Opportunities to improve resilience in the built environment
  - Cal-THRIVES example heat resilience toolkit
- Some gaps and future directions

Billion dollar natural disaster increasingly common in U.S.

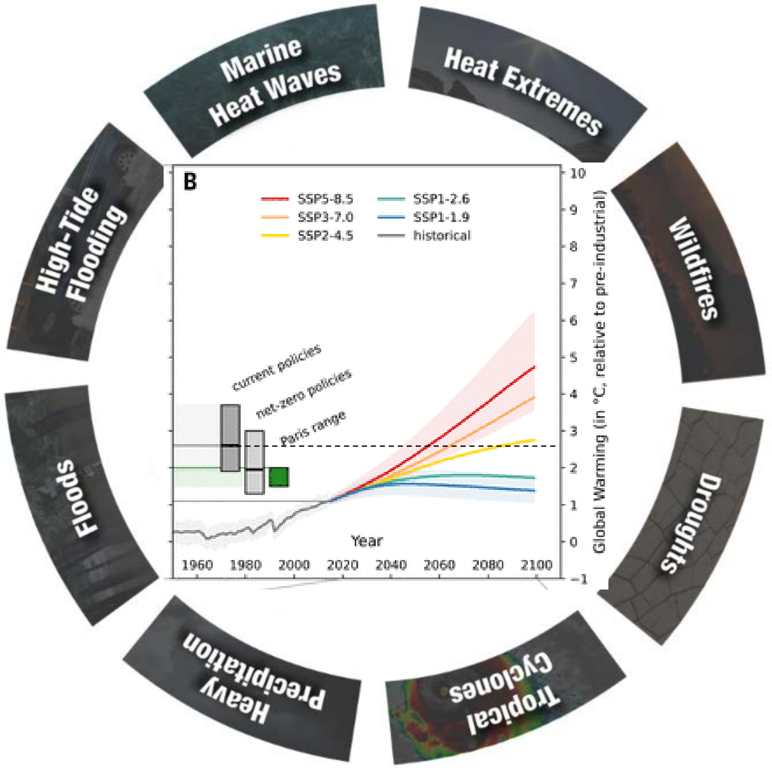



More than half the U.S. population
— almost 175 million people —
faced extreme heat on July 4, 2024


Rising Frustration in Houston After Millions Lost Power in Storm
Shores D

Extreme weather events

- Climate change-driven extreme weather: Increase in frequency, duration, and severity
- Coupling: increased precipitation & flooding, extreme heat/drought/wildfires
- Tipping points specter
  - Six tippings become likely as early as 2028 (within the Paris Agreement range of 1.5 to <2°C warming)



Extreme weather impacts

Extreme heat
Cold snaps
Wildfires
Drought
Tropical cyclones
Heavy precipitation
Floods
High-tide flooding
Marine heat waves

Some impacts

Overheating, overexposure to cold

Mortality/morbidity

Productivity, educational outcomes, mental health,…

Property/infrastructure damage

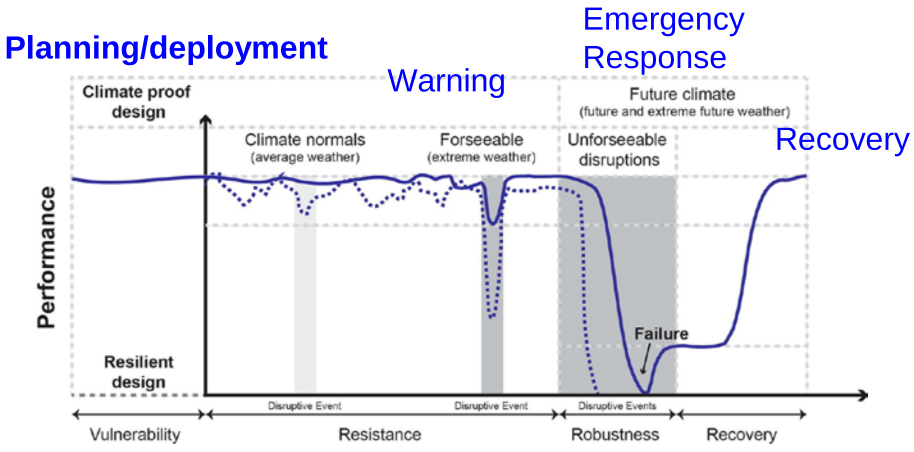
Power interruptions & resultant impacts

e.g., overheating, loss of medical supplies, food spoilage, communication disruption

…

Resilience definition

Resilience of {**building**, homes, community, …} to {**extreme weather, power outages, …**}



Attia, Levinson et al. 2021

A building or building service is resilient when it has "the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events." (NRC)

Community resilience

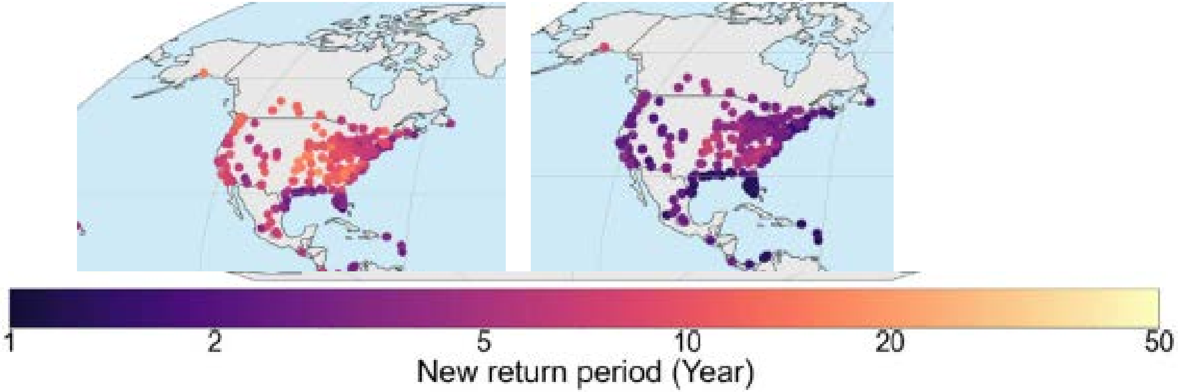
Community resilience aspects	Key considerations/ issues
Neighborhood Cooling centers	Attractiveness, features, accessibility
Community heat vulnerability	ID those at greatest risk, those most in need
Community outreach, education	Community inputs, preferences, barriers - Languages, accessibility
Emergency response e.g. buddy checks, focus on less mobile, elderly, socially isolated	Governance, resources
Metrics	Area for development e.g. SCE document

Weather extremes: heat example

- Within the next twenty years, historically infrequent to rare heat waves are expected to sharply increase in frequency (e.g. once every one-hundred years to once every two-to-four years in many locations)

1.5 °C warming

2.0 °C warming



compared to 1-in-100-year heat-mortality level of 2000

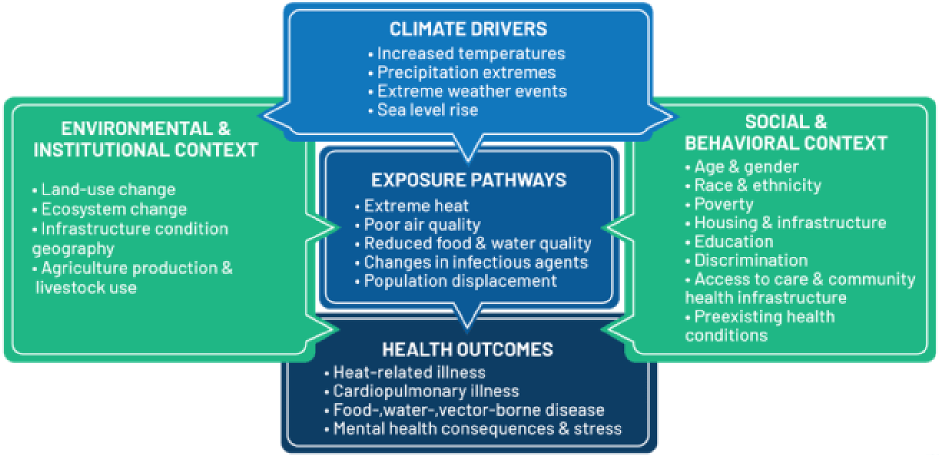
Luthi et al. Nature Communications | (2023) 14:4894 1

Climate change and climate vulnerability

- "**While climate change poses health threats for everyone, people of color, low-income people, and other marginalized or high-need groups face disproportionate risks due to underlying inequities and structural racism and discrimination.** The same factors that contribute to health inequities influence climate vulnerability" (KFF)

EPA 2021

Climate Change and Health



SOURCE: Replication of *The Climate Change and Health* figure from The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment

KFF

Heat wave impacts have disproportionate impacts on underserved, disadvantaged communities

- Extreme heat is the leading cause of weather-related deaths in the USA
  - High temps have largest direct economic impacts from Climate change, by 2050 ($50B / year, CA 5th Climate Change Assessment)
- There are heat related disparities by race/ethnicity (e.g., 56% higher death rate in heat for Blacks than Whites in CA)
- Higher rates of underlying health issues with many vulnerable populations during heat waves including elderly & very young
- Many underserved areas have older housing with older equipment or lack AC; with a higher fraction of residents unable to afford higher utility bills
- Hispanics have high participation in weather-exposed industries, such as construction and agriculture

Solution space

Strategy	Sample example(s)
EE & Electrification retrofits	DOE Enhancing Resilience Through EE 2023 study
Consolidation with EE/electrification programs: include more on resilience, resilience assessment & additional low cost resilience measures	Green and Resilient Retrofit Program (GRRP) - HUD
Updated/expanded building codes	DOE info
Improved governance, action plans, toolkits	Governance; Action plans (Heat, CA); Toolkits
Backup power – solar PV/storage	Studies, DOE RACER projects
Community resilience – technical and social	DOE RACER; SCE

Process flow to improve resilience

- Extreme weather risk assessment
- Define objectives & understand stakeholders needs and requirements
- Develop resilience plan: e.g. enumerate strategies, solutions, measures
  - Develop metrics/monitoring plan
- Implement / demonstrate or pilot
- Evaluate metrics, M&V
- Analyze, synthesize for learning/ iteration

Building codes for overheating

- No maximum temperature limits in residential building standards or schools, at the national or state level
  - Some locales require AC and maximum temperature limits
  - Some state Medicaid programs allow cooling or AC measures
  - Many school proposals have failed
  - **Residential bill pending in California (AB 209)**
- Nursing homes, if certified after Oct. 1, 1990: ~ 71-81 F in residences, under *federal* law
- Several voluntary programs; Build It Green, High Performance Schools (CHPS), LEED Pilot credits

Community-Based Guidance and Toolkits for Extreme Heat

Quantify resilience benefits of passive/ low-energy cooling solutions in three disadvantaged communities: **Fresno**, CA, **Atlanta**, GA, and **Boston**, MA

1. Assess distribution of different types of buildings
2. Interview residents
3. Model passive/low energy cooling solutions

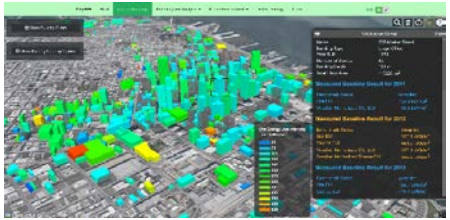
Develop cooling-solution guidance based on technical potential & preferences of the residents

Cal-THRIVES: A California Toolkit for Heat Resilience in Vulnerable Environments (Fresno, CA)

OUR TOOLKIT INCORPORATES BOTH COMMUNITY INPUTS AND BUILDING MODELING

Community engagement

Neighborhood-scale building modeling (CityBES.LBL.gov)



Heat Resilience Toolkit

Community cooling guide
Fact sheets
Modeling outputs
Heat vulnerability index tool
Online tutorials (videos, webinars)
Policy/program recommendations

We modeled 17 passive and active cooling measures in a worst-case heat wave

Cool roof

Cool walls

Ceiling fans

Window blinds

Solar-control window films

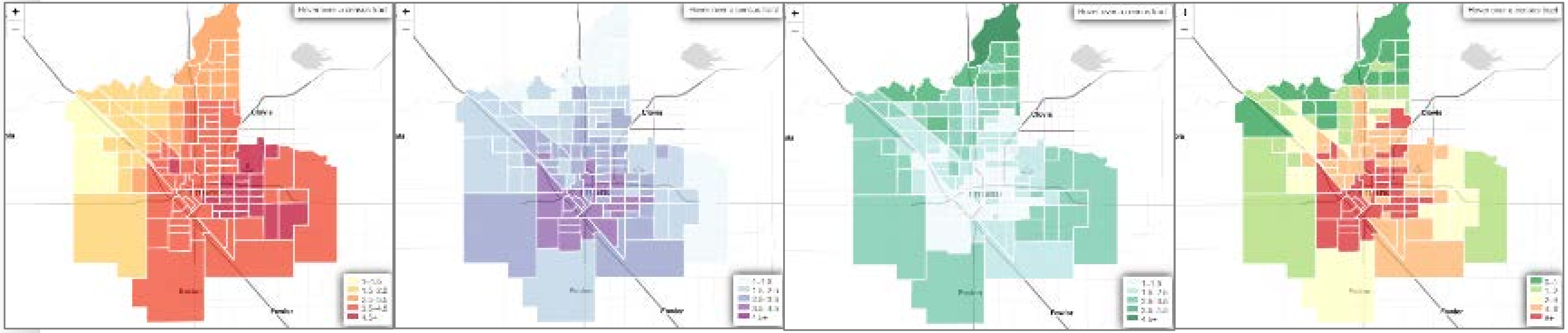
Window AC

Some Key Findings

- **Over 70% are uncomfortably hot at home often** during the summer
- **Window films, roof/ceiling insulation, and cool walls** are the among the most effective passive measures overall; **natural ventilation** on top floors is very helpful
- For active measures, **fans improve comfort and can reduce electricity bills;** homes with swamp coolers only greatly benefit from getting air conditioners

Community resilience example: Heat Vulnerability Index Tool for Fresno maps exposure, sensitivity, adaptation, and overall heat vulnerability

Exposure | **Sensitivity** | **Adaptation** | **Heat Vulnerability Index**



Exposure
- Number of hours with high heat index
- Longest number of consecutive heat-wave days
- Number of heat-wave days
- PM2.5 concentration
- Ozone concentration
- Building heat resistance indicator

Sensitivity
- Percent elderly and under 5
- Percent of pop. without high school degree
- Percent of pop. below poverty level
- Percent non-white pop.
- Percent of pop. with ambulatory disability
- Asthma hospitalization rate
- Heart attack rate
- Percent of pop. with a cognitive disability

Adaptation
- Median income
- Percent of area covered in parks

Highest vulnerability in south/central Fresno with high sensitivity and low adaptation

Cal-THRIVES.LBL.gov

For Boston, Atlanta, online dashboards report potential annual energy savings, carbon savings, and thermal comfort improvements in each community

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Who are the DataFam and what do they do on Tableau Public? **Watch a 2-minute overview →**

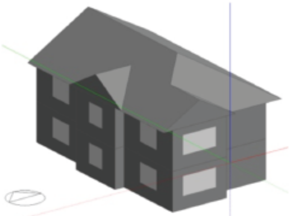
LBNL Analysis of Cooling Solutions for LMI Homes in Boston by Sang Hoon Lee

Passive/Low-Energy Cooling Strategies for LMI Homes in Boston

Audit House | Strategies | Energy Cost | Energy | Comfort | Carbon

Boston Multi-family House

- Representative multi-family double decker home from audit
  - Located in Chelsea, MA 02150
  - Built year: 1900
  - Gross floor area: 1,912 ft^2 (178 m^2)
  - Two floors (each floor has one unit)
  - Each unit has heating with boiler and cooling with split system
- The energy model was generated using DesignBuilder software for EnergyPlus simulation
- 7 strategies and 3 packages (combinations of strategies) were modeled
- Strategy technology levels include:
  - Most ambitious
  - Most accessible
- Simulations using the 2010, 2030, and 2050 fTMY weather data from https://zenodo.org/records/8335815



Screen capture from the energy simulation model

Boston
https://bit.ly/4auc6Jh

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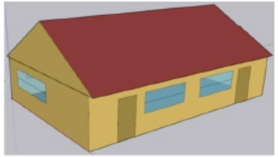
Atlanta Multi-family House

- Representative multi-family house from audit
  - Located in Atlanta, GA 30318
  - Built year: 1950
  - Gross floor area: 914 ft^2 (85 m^2)
  - 1 floor with 2 units
  - Each unit has heat pump for heating and cooling
- The energy model was generated using DesignBuilder software for EnergyPlus simulation
- 7 strategies and 3 packages (combinations of strategies) were modeled
- Strategy technology levels include:
  - Most ambitious
  - Most accessible
- Simulations using the 2010, 2030, and 2050 fTMY weather data from https://zenodo.org/records/8335815



Screen capture from the energy simulation model

Atlanta
https://bit.ly/3TPtZNc

Some key gaps & future work

- Future extreme weather assumptions (e.g, DOE funded project released a future weather dataset for every county in the U.S.)
- Metrics/Ratings/Labels development/ standardization + increased M&V activities
  - Quantifying impacts: resilience and other "non-energy" benefits
- Decision support: from EE support tools to electrification tools to resilience tools
- Building code & regulations supporting greater resilience
- Cross sector-technology integration: PV/storage role; EV storage role
- Decarbonization framework extension where possible: e.g. heat and cold resilience audits/upgrades consolidation & integration
- Role of urban form, energy sufficiency (e.g., higher density housing, more ADUs, SF to MF duplexes)

Some resources for resilience in buildings

Name	Source	Subject	Intended User
Building Codes Toolkit for Homeowners and Occupants; Building Resilient Infrastructure and Communities (BRIC)	FEMA	Building codes for resilient homes against natural hazards; BRIC supports states and local governments reduce hazard risks	Residential stakeholders, homebuilders, building engineers; BRIC: states, local governments, tribes and territories, communities
Resilient Building Codes Toolkit	HUD	Guide on resilient buildings intended to educate different stakeholders	Elected officials, all participants from code development to code enforcement
Better Buildings Solution Center	DOE	Resilience building through energy efficiency measures, grid outages, and reducing disaster risk	State and local governments, policy makers, code and standard developers, building engineers, residential and commercial stakeholders, industrial manufacturers
Achieving Hazard-Resilient Report	NOAA	Natural coastal hazards building resilience	Residential and commercial stakeholders in coastal communities
Hazard Mitigation Methodology	NIST	Build resilience against Wildland-Urban Interface (WUI)	Architects, building engineers, residential and commercial stakeholders in communities prone to WUI fires
Building Resilient Communities	NEEP	Building energy resilience through building performance standards and energy codes	Residential and commercial stakeholders, code and standard developers
Community Resilience Benchmarks	ANCR	Evaluating a jurisdiction level of resilience	Residential and commercial stakeholders, local government
Resilient Project Process Guide	AIA	Design approach for integrating resilience into building projects	Architects, homebuilders, building engineers, building owners

Thank you! Q&A

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Stakeholders

Building occupants and residents

Communities, community-based organizations

Practitioners: architects, property developers

Programs administrators/upgrade programs (regional, state, federal)

Policy makers

Standards bodies

Utilities

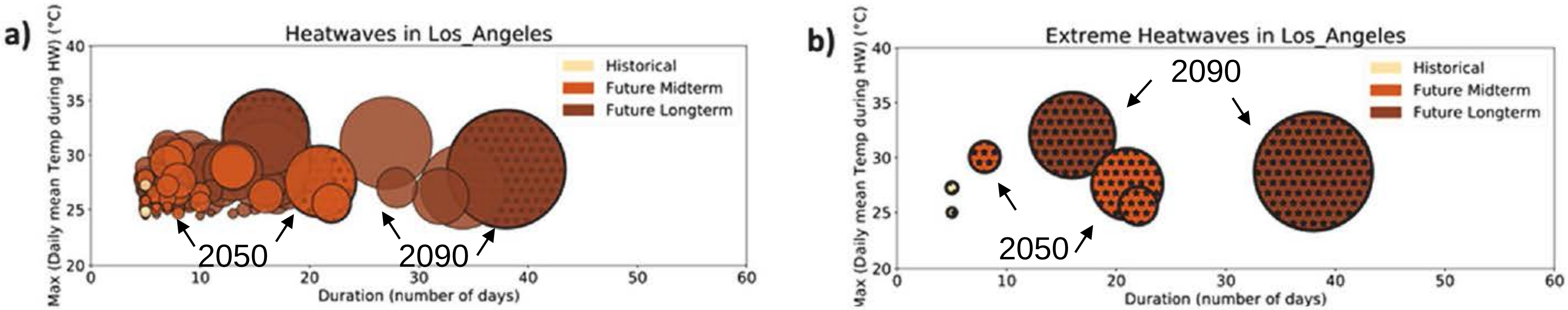
ISO/RTO, NERC

Researchers

Here, focus on **underserved and vulnerable** occupants and improving equity (exposure, outcomes)

Weather extremes: heat example [what]

- Increase in heatwave frequency, duration, severity (Los Angeles example, high emissions RCP8.5)



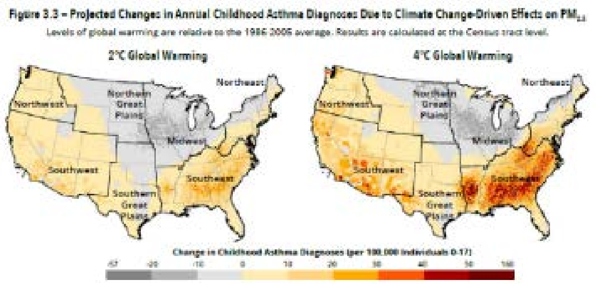
Machard, Salvati et al. Nature Scientific **Data** | *(2024) 11:531*

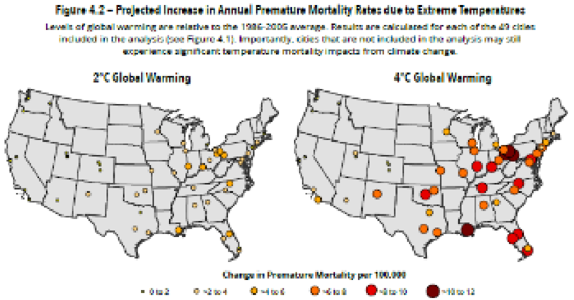
Many heat resilience metrics to characterize indoor thermal conditions

Resilience Metric	Parameters in metric	Limitations	Thresholds
UDH (unmet degree hours)	• Air temperature	• Neglects relative humidity, mean radiant temperature, air speed, clothing, and metabolic rate • Uses cooling setpoint as threshold, which could vary with different control strategies	• Cooling setpoint
HICH (heat index caution hours)	• Air temperature • Relative humidity	• Neglects mean radiant temperature of zone surfaces, indoor air speed, occupant clothing, and metabolic rate	• Caution: 27 °C • Extreme caution: 32 °C • Danger: 39 °C • Extreme danger: 52 °C
SETUDH (standard effective temperature unmet degree-hours)	• Air temperature • Relative humidity • Mean radiant temperature • Air velocity • Metabolic rate • Clothing insulation	• No comfort zone thresholds given by ISO or ASHRAE standards	• Grid-on: SET 28 °C • Grid-off: SET 30 °C
PMVEH (predicted mean vote exceedance hours)		• Fanger's PMV calculated in EnergyPlus may underestimate the cooling effect of increased air velocity	• Thermal comfort: 0.7 • Unbearable limit: 3

EPA 2021 EJ climate change:

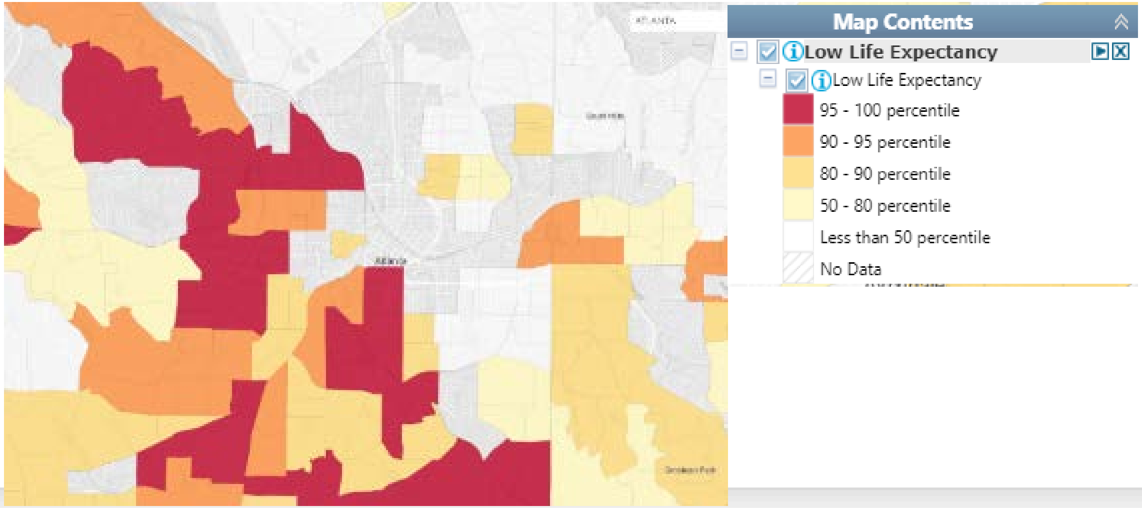
- Black individuals are projected to face higher impacts of climate change, with 40% more likely to currently live in areas with the highest projected increases in deaths related to extreme temperatures, the report found.
- Hispanics have high participation in weather-exposed industries, such as construction and agriculture





Large equity impacts and imperative

- EPA's Environmental Justice [Screening and Mapping Tool]
- Example: Atlanta & other areas with large range of life expectancy 87.6 years in Vinings; 63.6 in Bankhead (9 miles away)
- Atlanta's days above 95°F will double from 8 to 19 by 2040 (**Heat.gov tool**)



Process flow to improve resilience: heat resilience example

- **Risk assessment**: map exposure/adaption/vulnerability e.g. overheating/ cooling capacity with demographic/ health data – e.g. senior affordable housing
- Define objectives: e.g., minimize overheating exposure among most vulnerable
- Enumerate & prioritize strategies, solutions, measures: passive cooling/ shading/ cool surface, low energy active cooling, EE, then AC measures
- Develop **metrics/monitoring**: e.g. costs, energy, utility bills; thermal comfort, self-reported health/sleep, temp/AQ monitoring
- Implement / pilot/ demonstration: implement retrofits in subdivision
- Evaluate metrics, M&V
- Analyze, synthesize for learning/ iteration

KEY ISSUES: extreme weather assumptions;
Given a set of resilience investments, costs calculable
Impacts/benefits more challenging to estimate

Bluelining

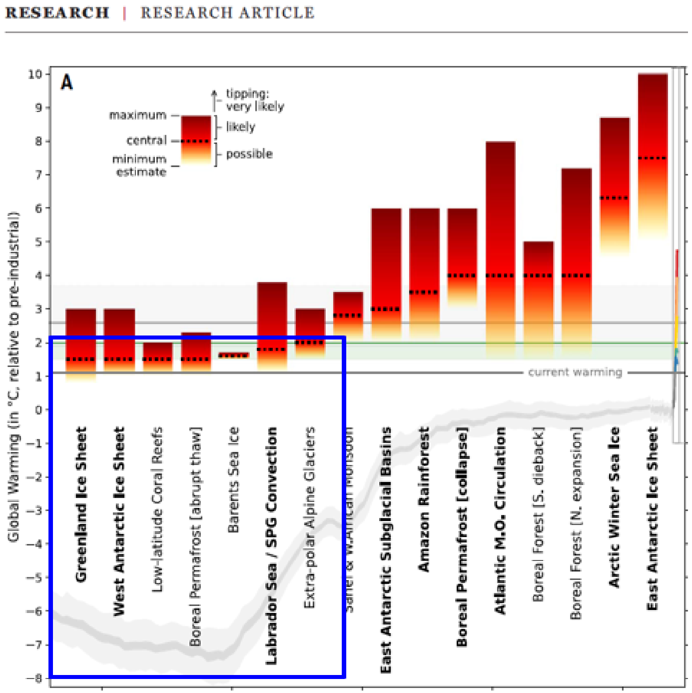
- https://greenlining.org/publications/bluelining-climate-financial-discrimination-on-the-horizon/

Tipping points

- Tipping points
  - Critical thresholds, in which a small change causes a larger, more critical change to be initiated, taking the climate system as a whole or particular systems within it from one state to a discretely different state.
  - These may also lead to cascading events in which the mutual interaction of individual climate tipping points and/or abrupt changes lead to more profound changes to the entire system

- "Six tippings become likely (with a further four possible) within the Paris Agreement range of 1.5 to <2°C warming, including collapse of the Greenland and West Antarctic ice sheets, die-off of low-latitude coral reefs, and widespread abrupt permafrost thaw"

- 1.5 °C could be reached as early as 2028



Armstrong McKay et al., Science 377, 1171 (2022)

- Q&A

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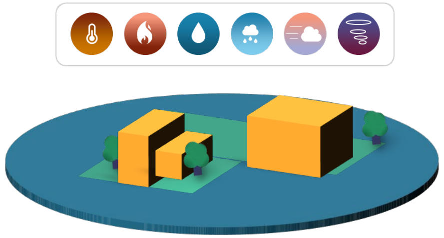
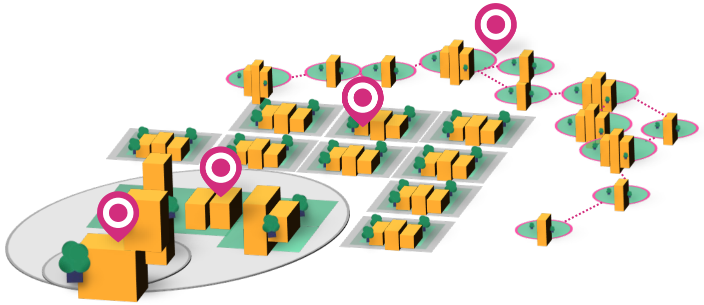
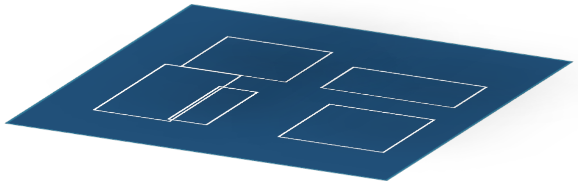
Linking Decarbonization and Resilience for Homes During Extreme Heat

Heather Rosenberg, Associate Principal

July 2024

Resilience Services

Three Service Themes

Risk and Resilience	Resilience Planning and Policy	Resilience by Design
		
Quantitative hazard and risk	Strategic planning and decision-making	Resilient design of buildings & infrastructure

Together these form an integrated set of service offerings

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Driving question

How do we keep people safe and housed in the face of a changing climate?

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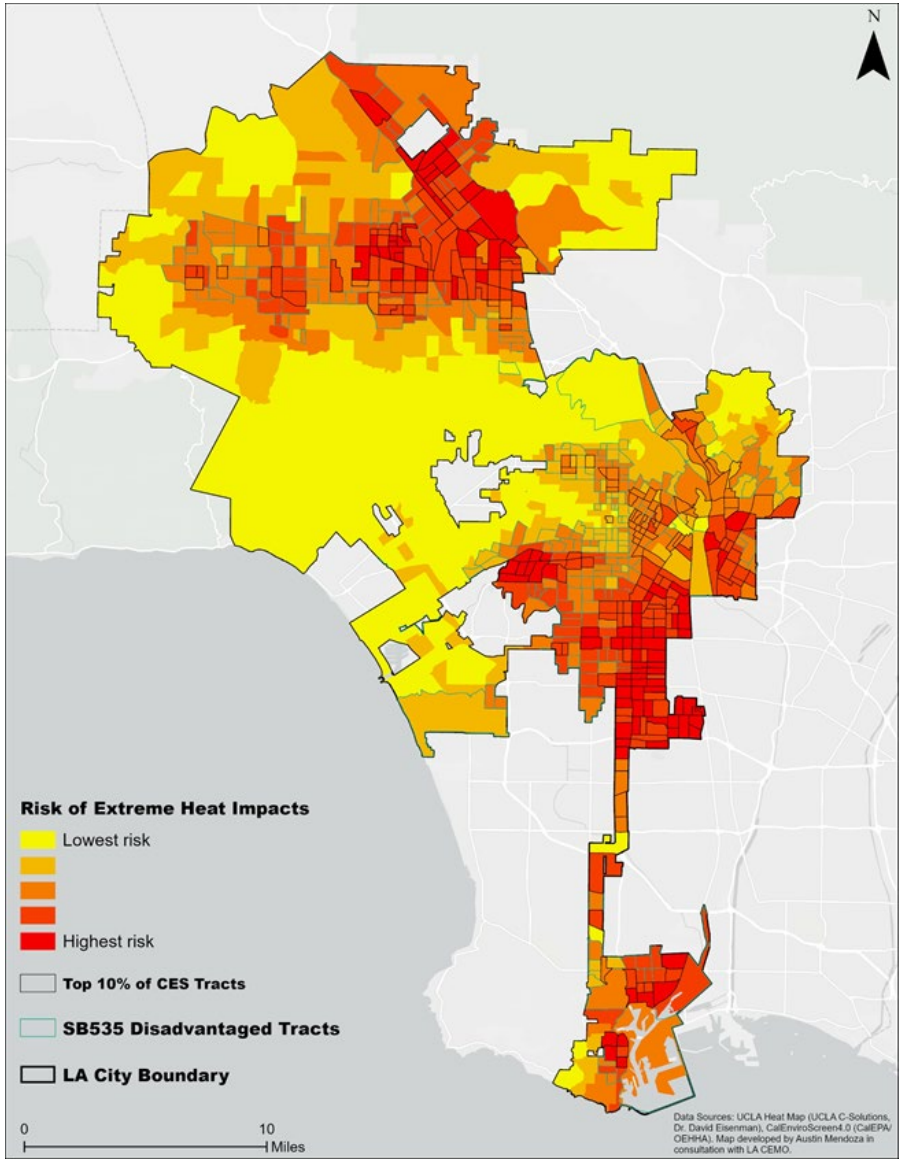
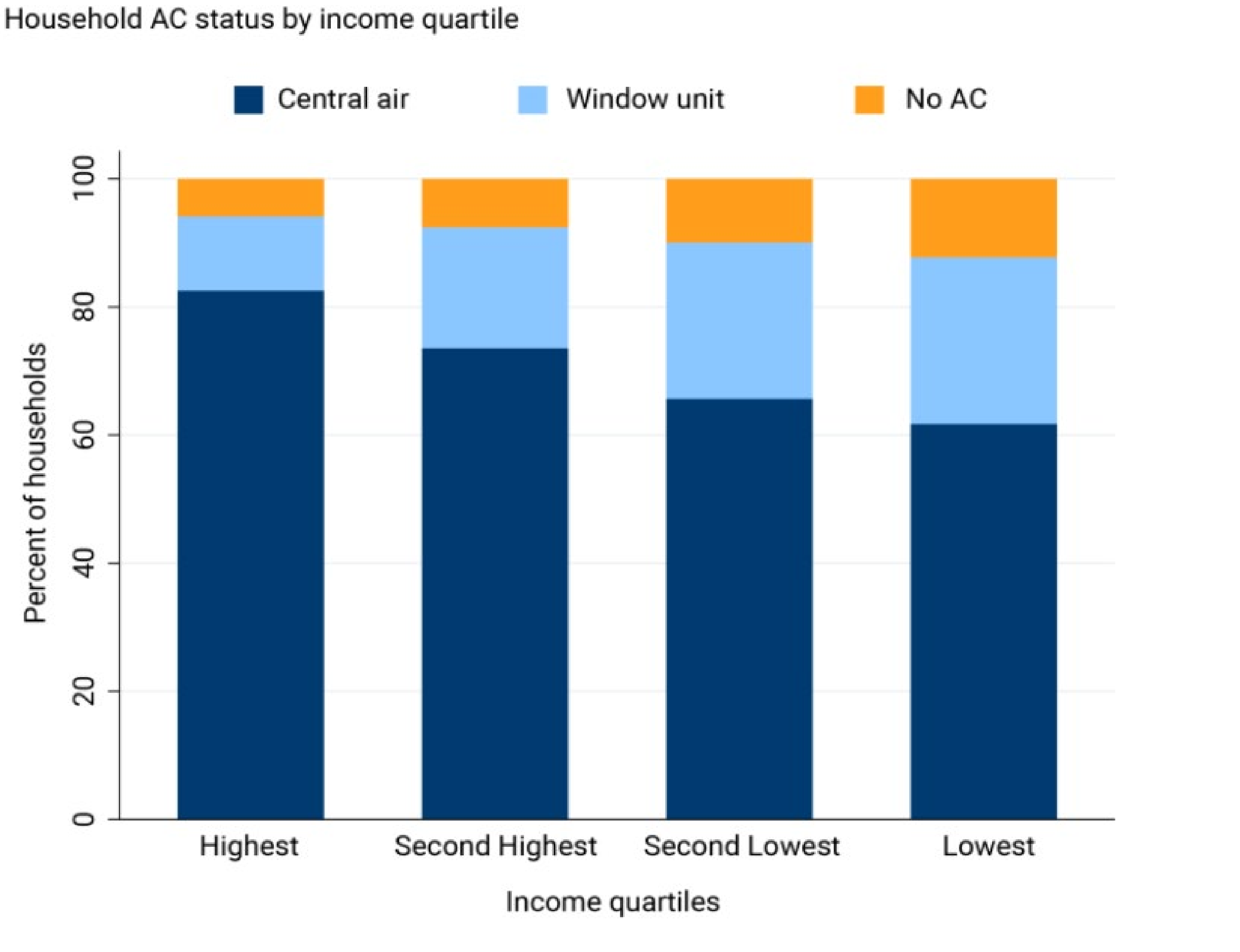
Who is at risk?

Demographic and empirical data

- City of LA Climate Emergency Mobilization Office Heat Risk Equity Map
  - Includes data on excess **Emergency Room visits**, pollution burden, and housing burden



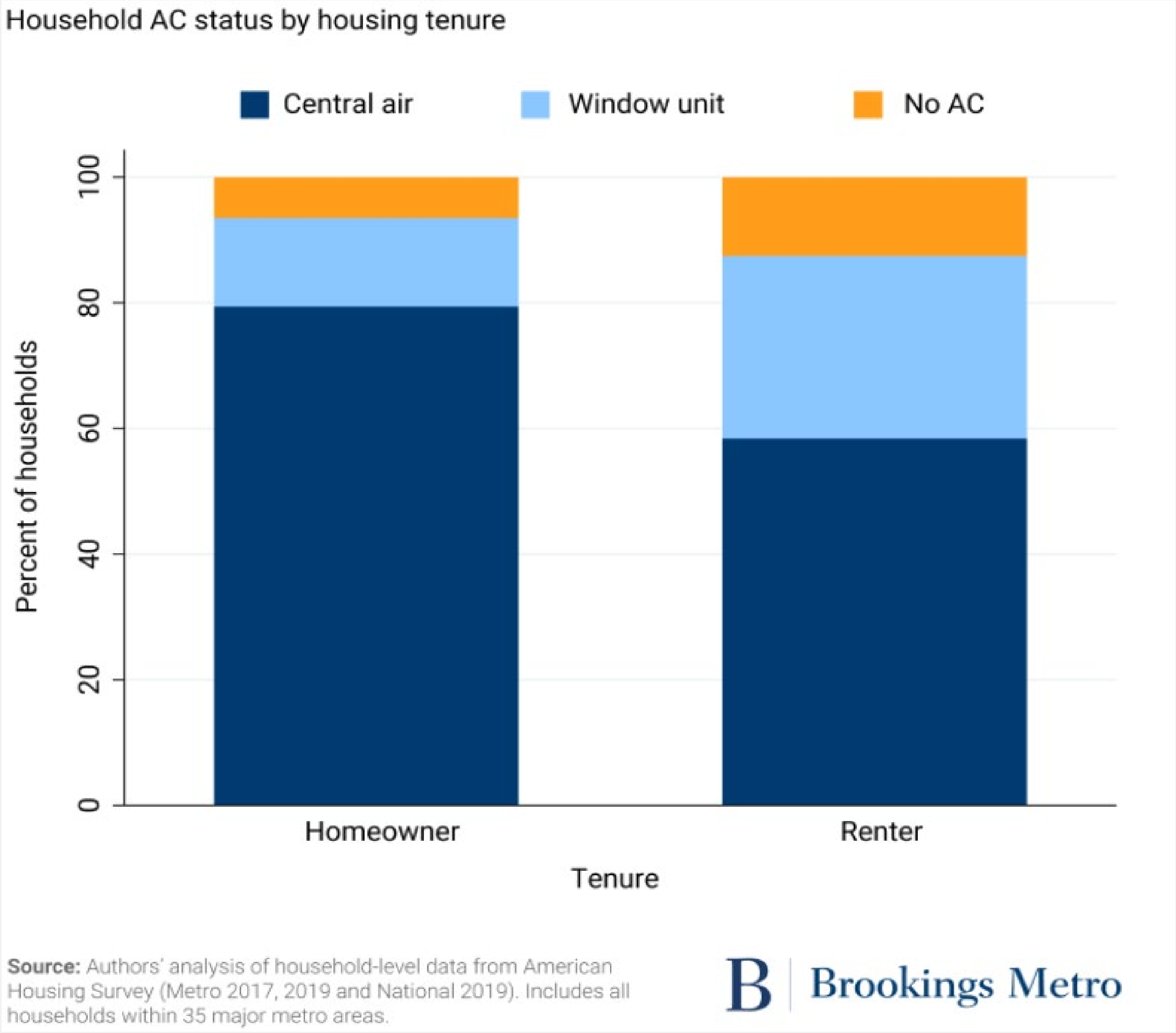
Low-income households have least access to AC



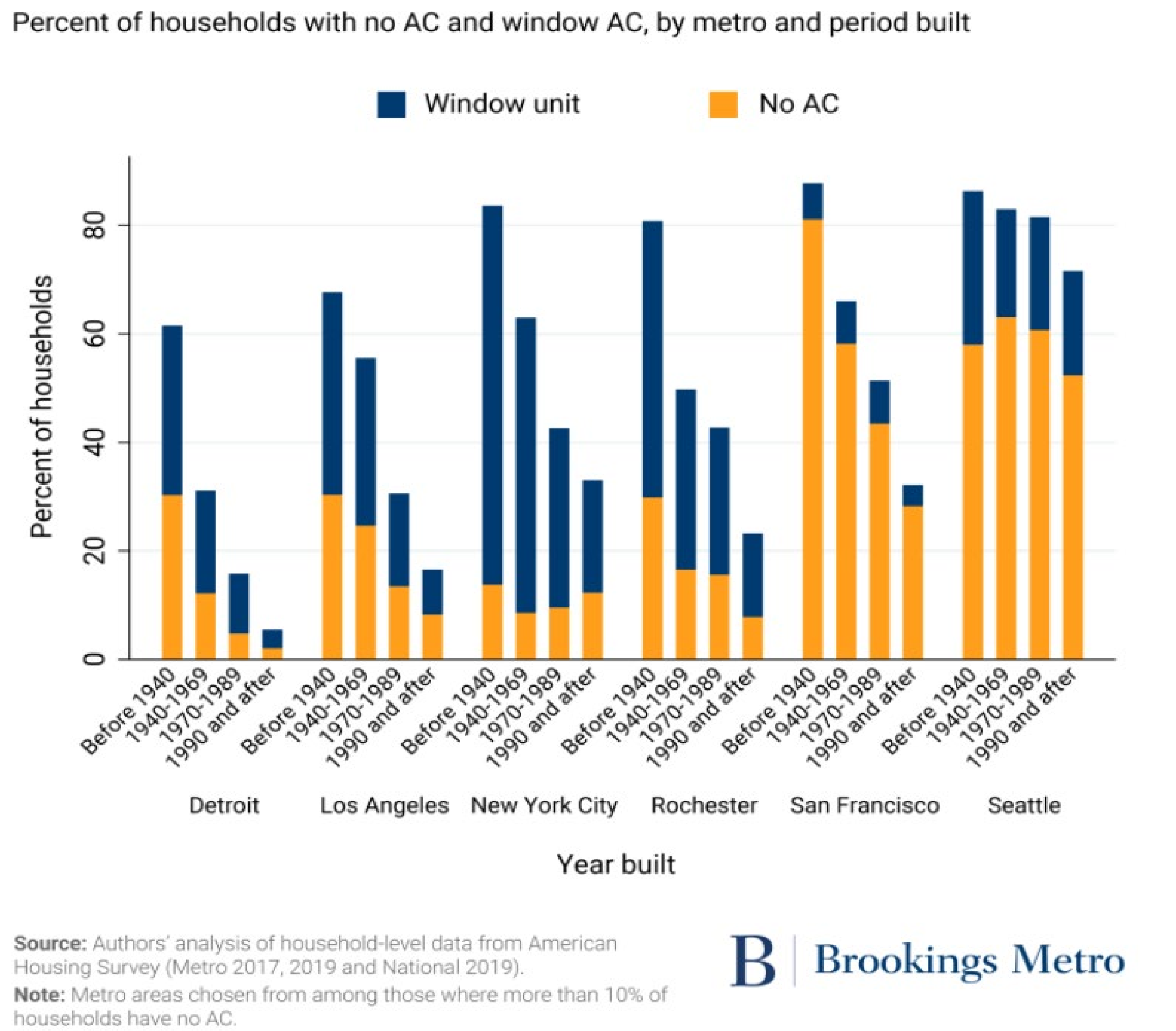
Source: Authors' analysis of household-level data from American Housing Survey (Metro 2017, 2019 and National 2019). Includes observations from 35 metro areas shown in Figure 1.

Note: Income quartiles defined within metro areas.

Renters have least access to AC



Older homes least likely to have AC



Unhoused populations face highest risk

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Right to Cooling

- Emerging state and local laws requiring landlords to provide or allow cooling
- Los Angeles considering measure establishing a safe maximum temperature for residential units
- Need for thermal safety standards

Los Angeles Times

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Community Scale Cooling

- Planning ahead to keep people cool
- Changes design requirements for wide range of facilities

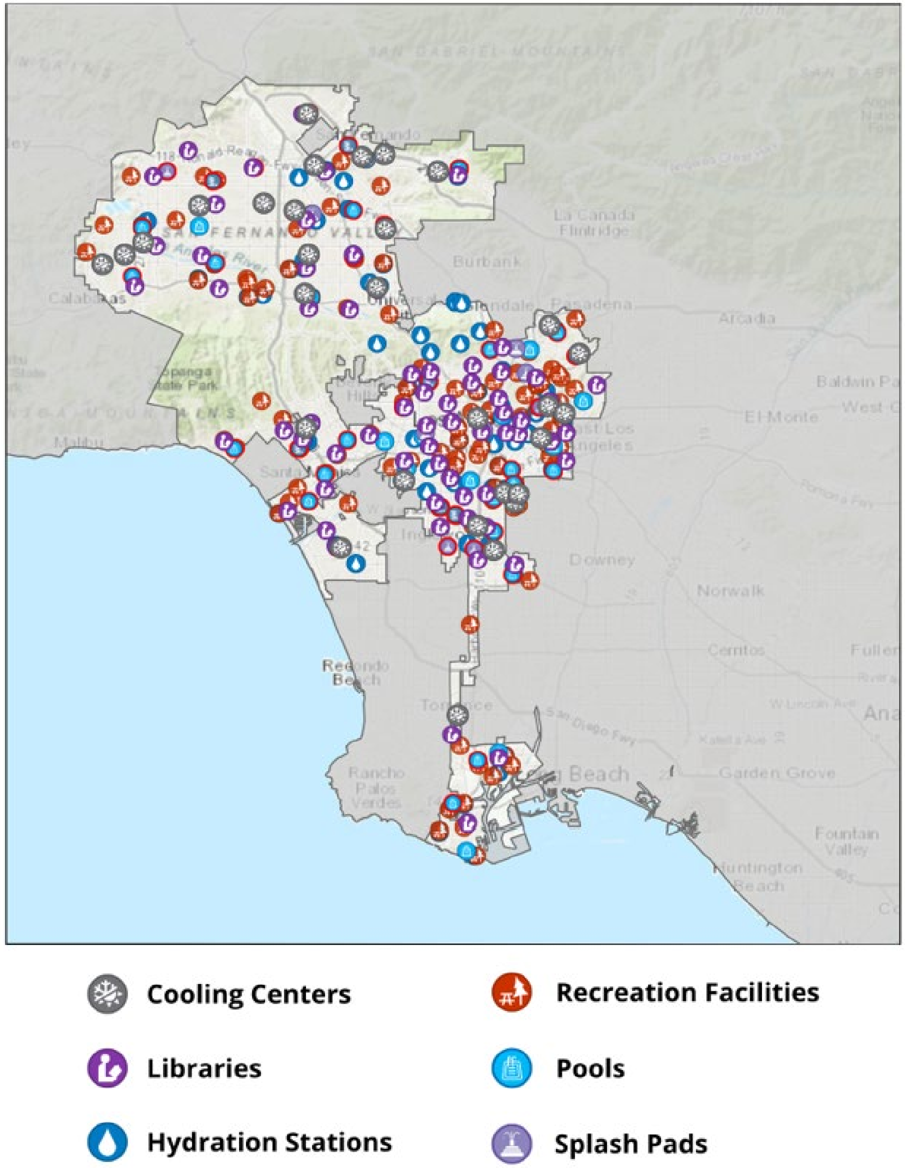

Figure 5. City of Los Angeles Cool Spots Map, developed as part of LA's heat relief campaign and available to the public online.

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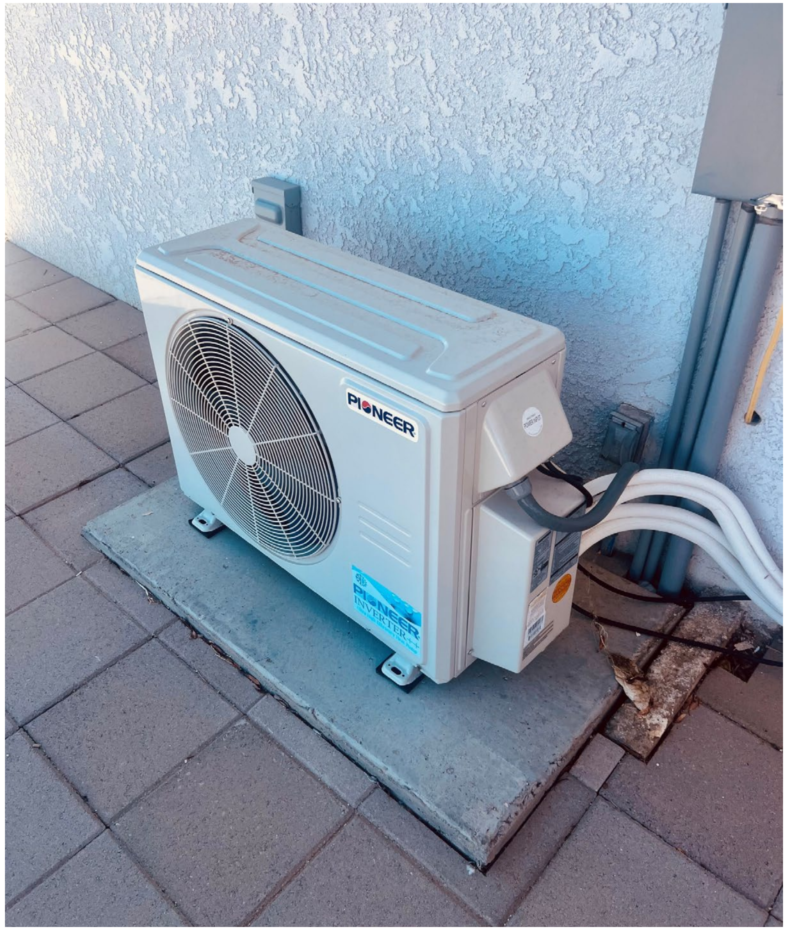
Building Decarbonization Standards

Opportunities for heat resilience

- **Heat pumps** allow for heating and cooling
- **Weatherization** can improve thermal survivability
- **Efficiency** can reduce energy bills
- **Demand response** can support grid resilience



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Building Decarbonization Standards

Challenges for heat resilience

- Challenges of **retrofitting existing** buildings, especially high rise res
- **Up-front costs** higher than possible energy savings and may be passed on to tenants
- Total **energy bills** might not be lower, esp. with adding cooling costs
- Addition of cooling treated as new amenity could drive higher rents
- Demand response **rarely included** in BPS systems

BPS and Right to Cooling policies need to be linked and to protect renters.

New York City Housing Authority (NYCHA)

Largest housing provider in US

- Commitment to climate resilience
- Design requirement of no displacement
- Leveraged large-scale energy performance contracts for 23% savings
- Planned the installation of 300,000 window heat pumps

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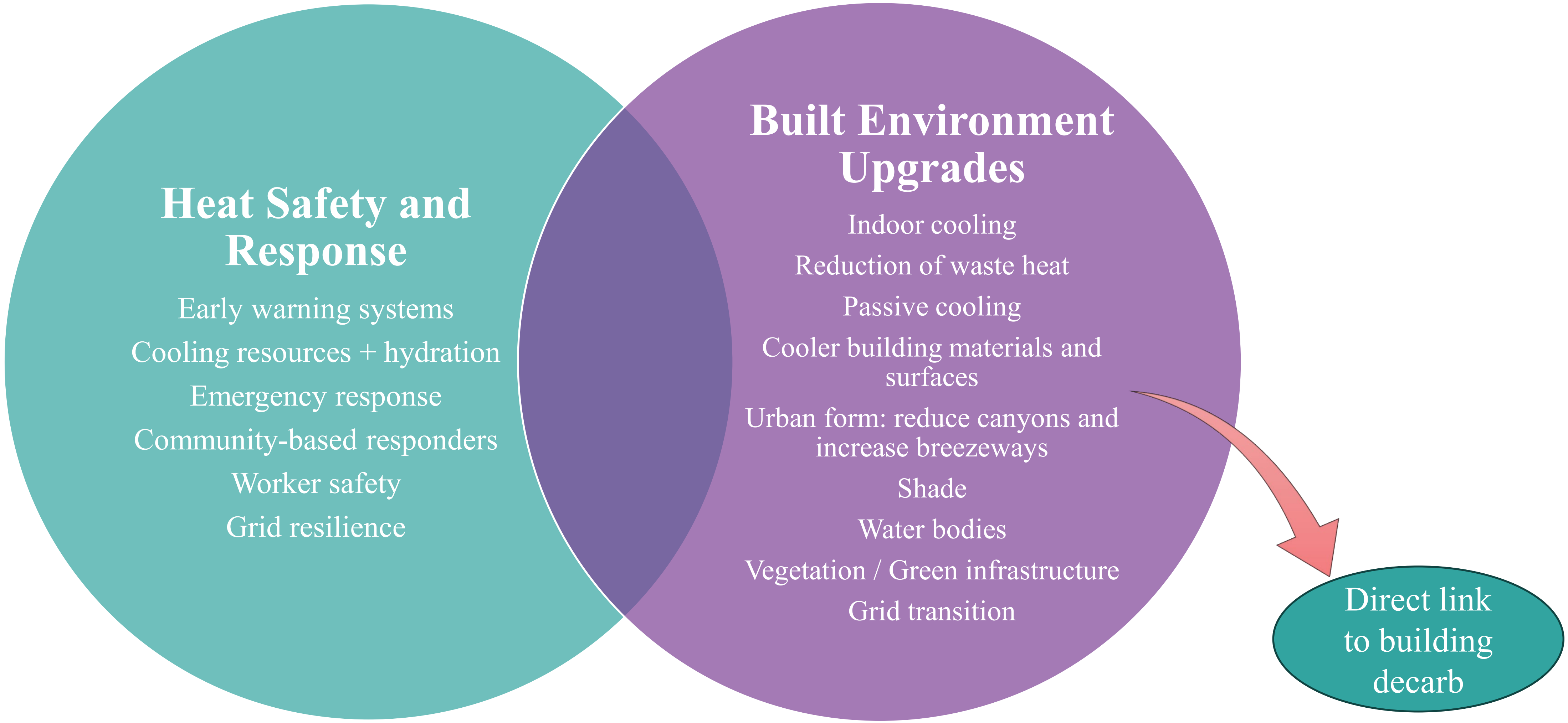
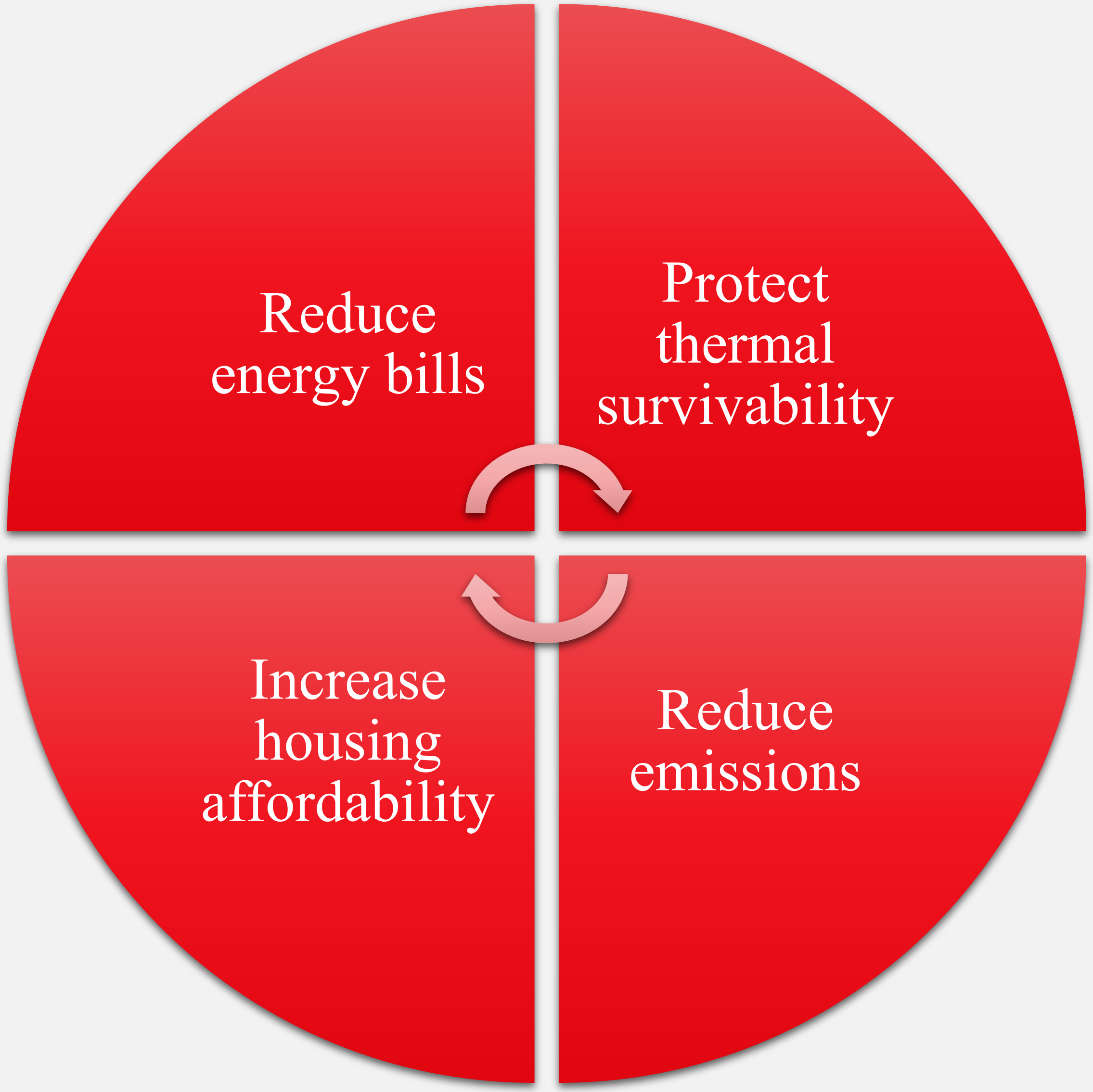
Heat Action Planning



Resilience Imperative

Keep people safe and housed in the context of a changing climate



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Addressing Heat as a Systems Issue

Resilience of the grid

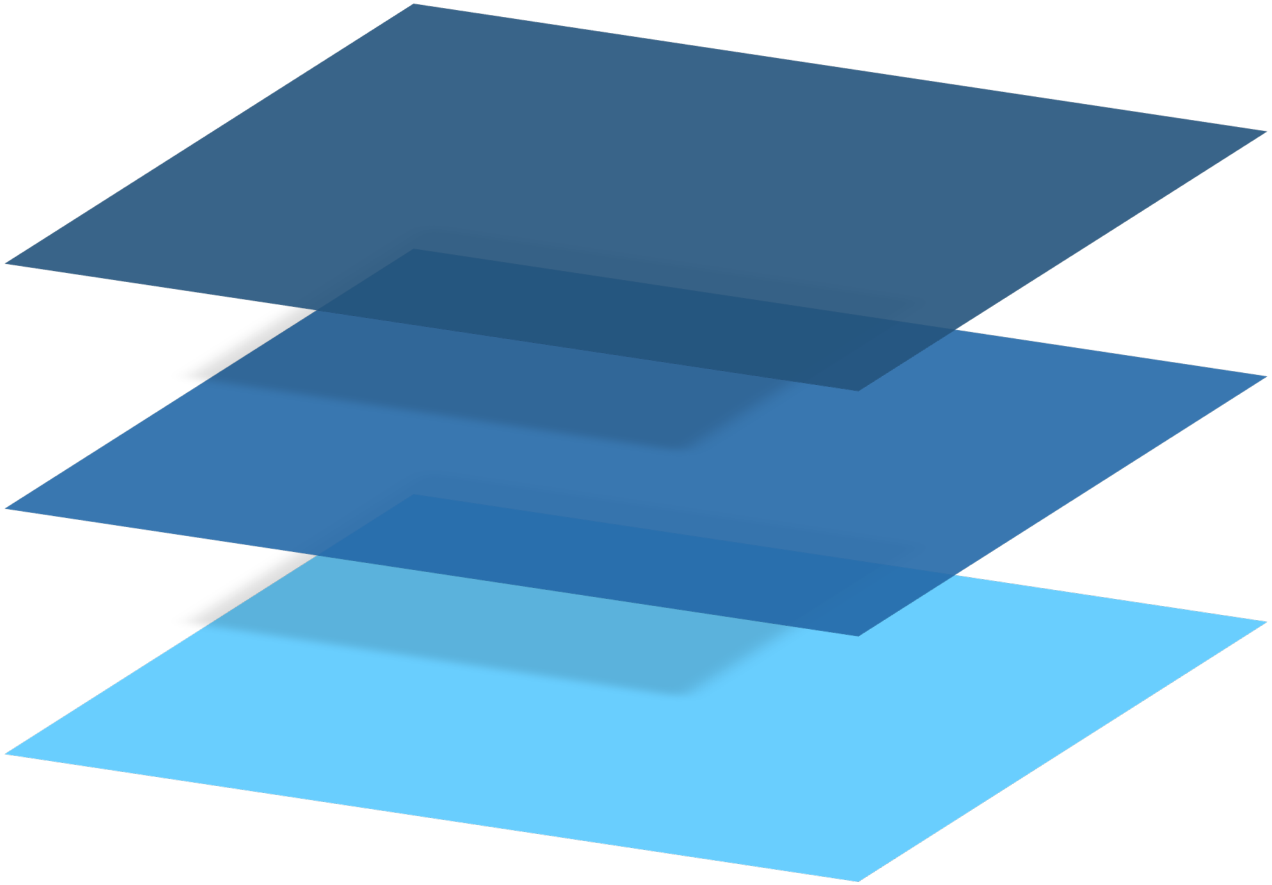
How can decarbonization and resilience strategies reduce risk of outages?

Resilience of communities

How can governments and community networks provide levels of support?

Building-scale resilience

How can buildings keep people safe longer?



Lessons Learned from Texas Power Outage

Extreme wind, flooding, power outage and heat wave

- 2.26 million utility customers without power
- Extended period of high heat and humidity
- At least 11 people dead
- Infrastructure, hospitals, water treatment and assisted living facilities impacted
- More than 200 carbon monoxide poisonings in 24 hours from improper use of generators.
- Hospitals overcrowding because they can’t release people to homes with no power

Brandon Bell | Getty Images

AP Photo/Lekan Oyekanmi

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Critical Needs

Weaving heat into technical and policy requirements

- **Thermal survivability** design requirements
- **Models** for resilience within BPS
- Lower cost **heat pumps**
- **Retrofits at scale**
- **Design standards** for cooling centers, resilience hubs and backup
- Provision and **incentives** to protect low-income households
- **Demand response** and grid hardening
- Operational **preparation** for local government

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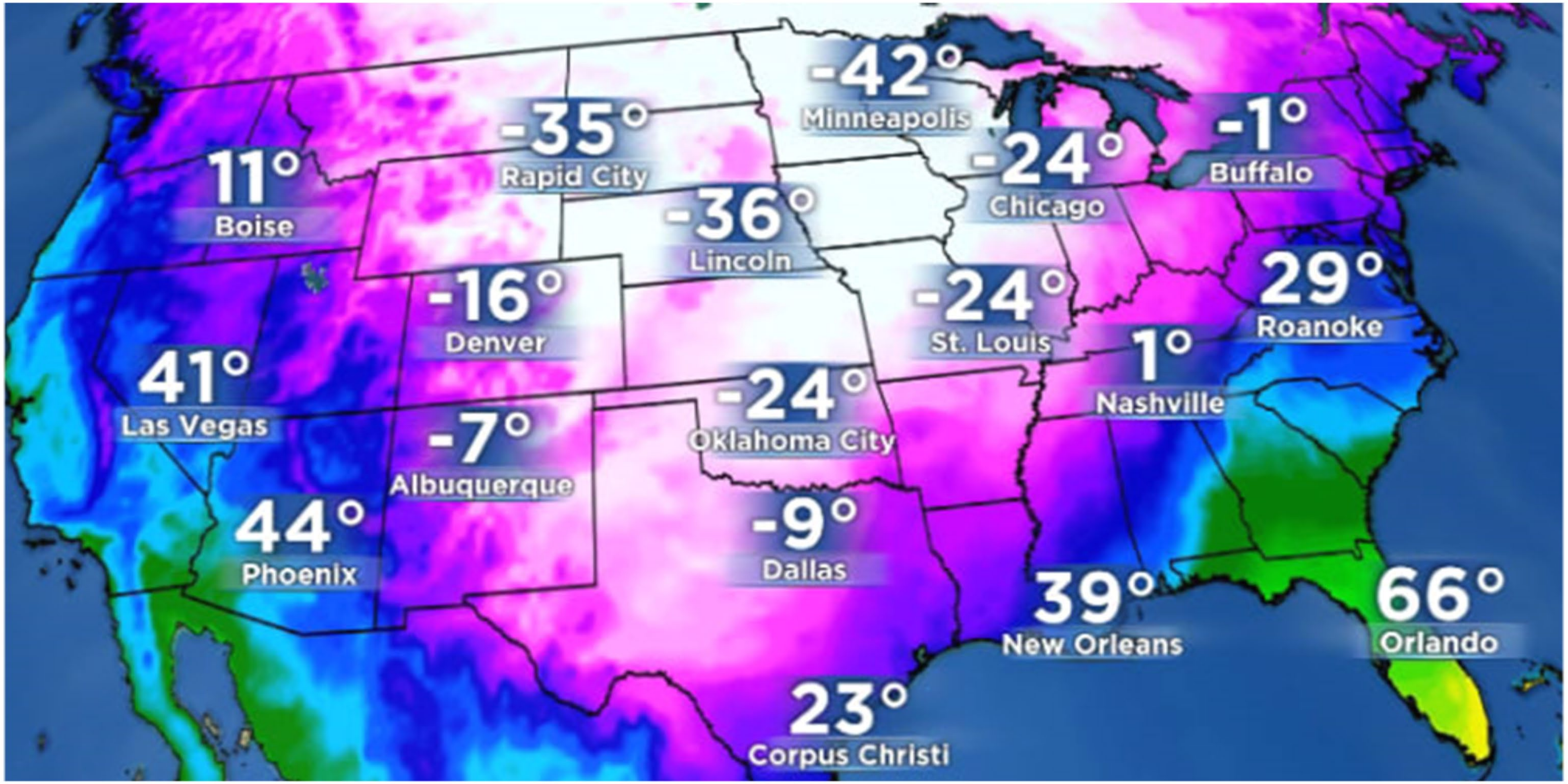
Resiliency of Decarbonized Homes to Extreme Cold

Webinar Series: Challenges and Opportunities for Home Decarbonization

Josh Quinnell, PhD

July 17, 2024



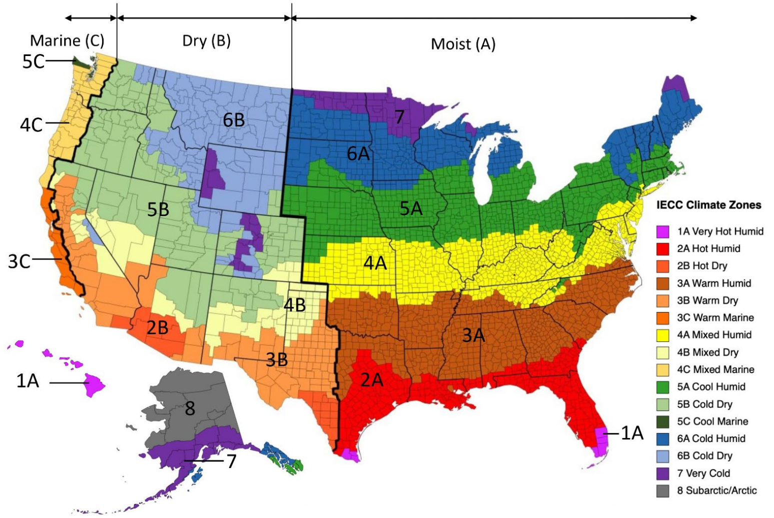
Center for Energy and Environment

Resilience to Cold Weather

- Building resilience
  - A qualitative measure of a building's response to extreme weather
  - With or without heating system?

- Extreme conditions
  - Loss of heat during cold weather
  - Temperatures below winter design conditions (a cold snap)
  - May be paired with or adjacent to winter storms

- Winter design conditions
  - Minimum outside air temperature for which a heating system must maintain a thermostat setpoint
  - A threshold representing the fraction hours above this temperature for a specific location
  - Two common values 99% and 99.6% (88hr and 35hr)



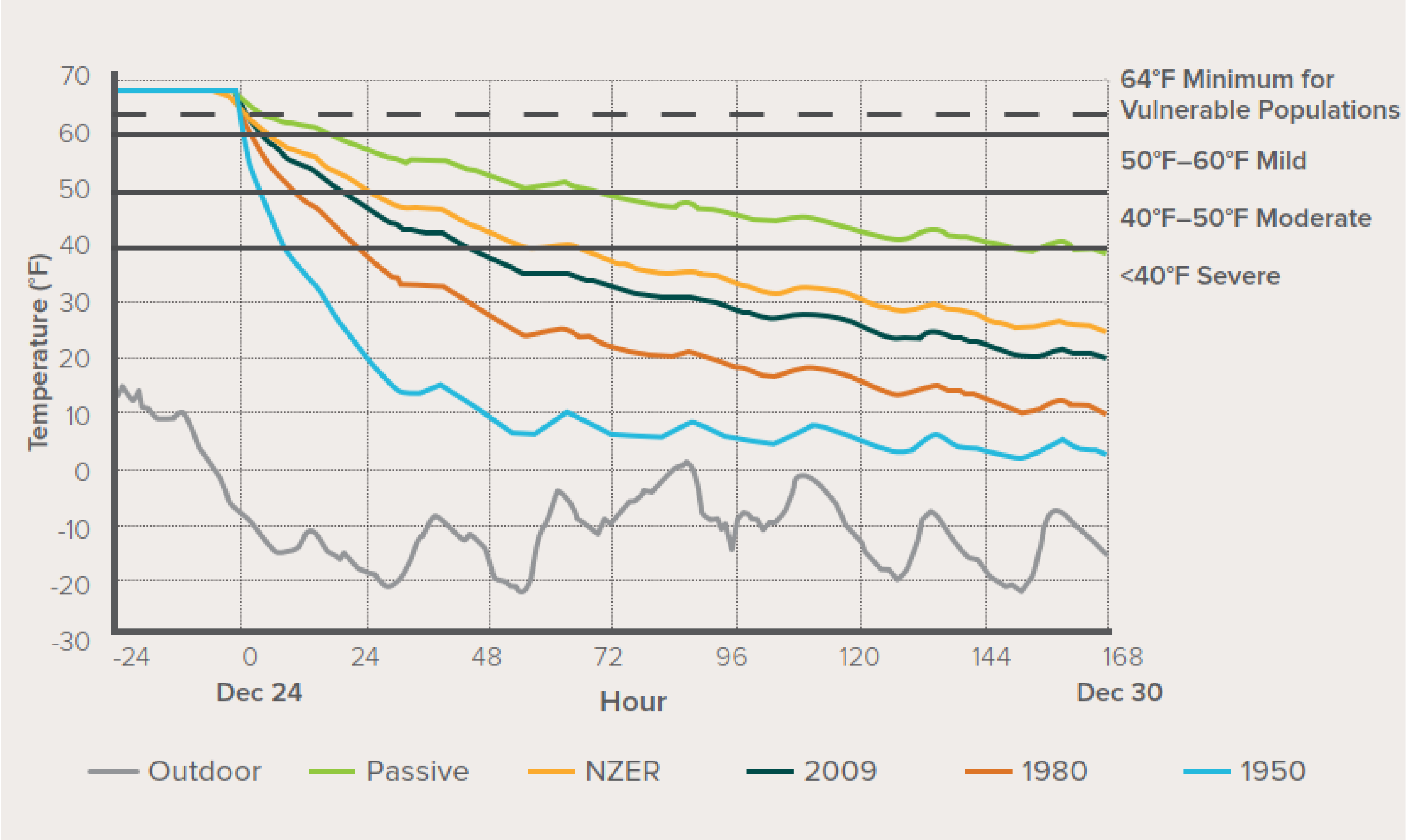
City	99% Design (°F)
Duluth, MN	-12
Minneapolis, MN	-6
Chicago, IL	3
Oklahoma City, OK	19
Dallas, TX	28

Cold Safety Thresholds

Minimum Safe Temperature for Vulnerable Populations	Minimum Safe Temperature for Healthy Populations	Mild Cold Stress for Healthy Populations	Moderate Cold Stress for Healthy Populations	Severe Cold Stress for Healthy Populations
>64	60	60–50	50–40	<40

2020, ‘A Framework for Considering Resilience in Building Envelope Design and Construction, Rocky Mountain Institute, https://rmi.org/insight/hours-of-safety-in-cold-weather/

Hours of Safety – Cold Snap in Duluth, MN



- Building resilience to cold weather is a measure of the building envelope
  - Leaky, uninsulated envelopes are not resilient
  - Tight, super insulated envelopes are more resilient

2020, 'A Framework for Considering Resilience in Building Envelope Design and Construction, Rocky Mountain Institute, https://rmi.org/insight/hours-of-safety-in-cold-weather/

What happens below design conditions?

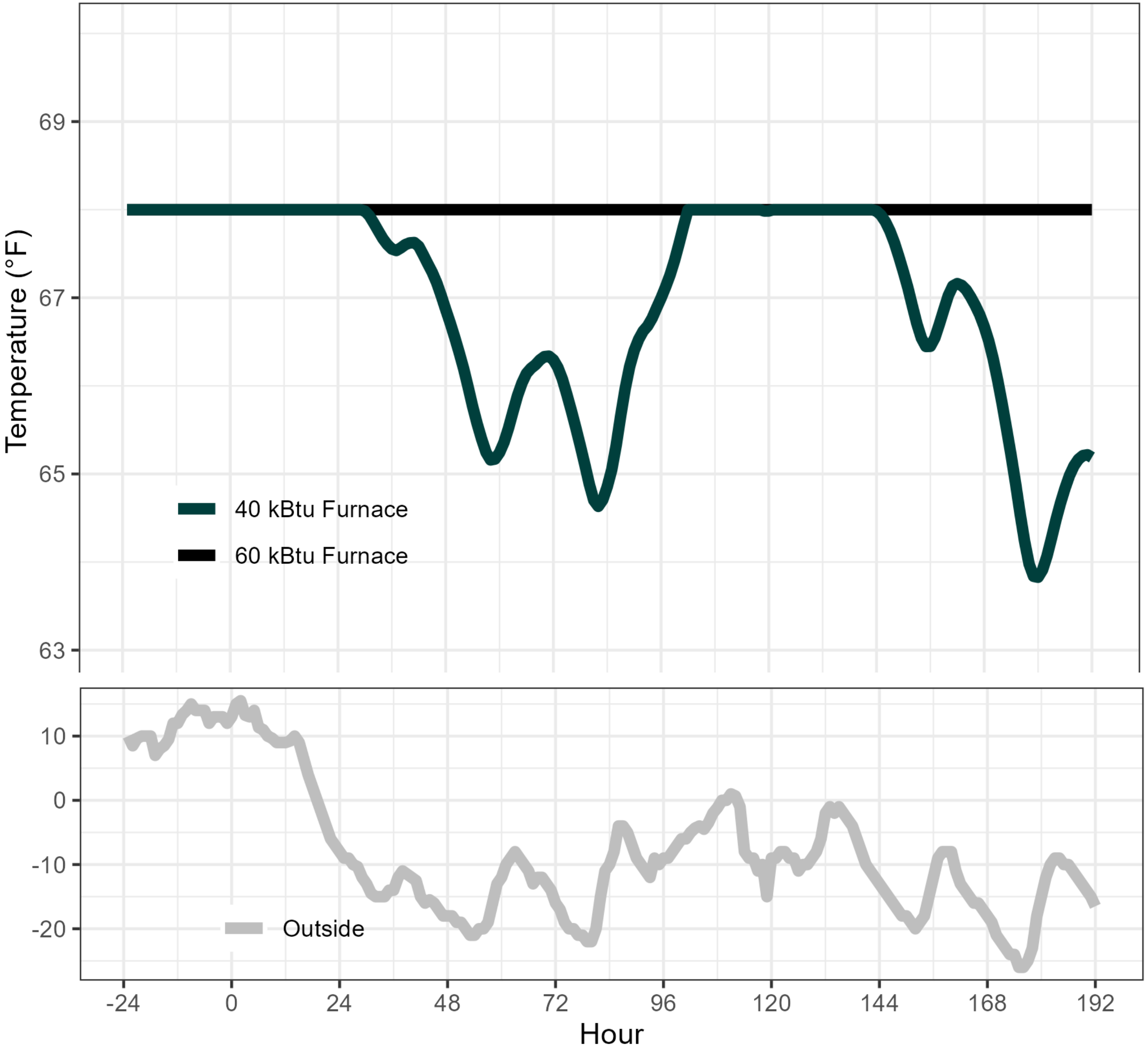
- Capacity gap
  - Heating capacity is less than load
  - Indoor temperatures fall and systems miss setpoint
  - Hours of safety now additionally depends on the magnitude of the capacity gap
- Enormous heating systems
  - “Safety factor”
  - Conservative Manual J
  - Sizing off prior equipment

Gas Furnace Capacity Gaps – Cold Snap in Duluth, MN

- 1950s house: Same weather, but with heat

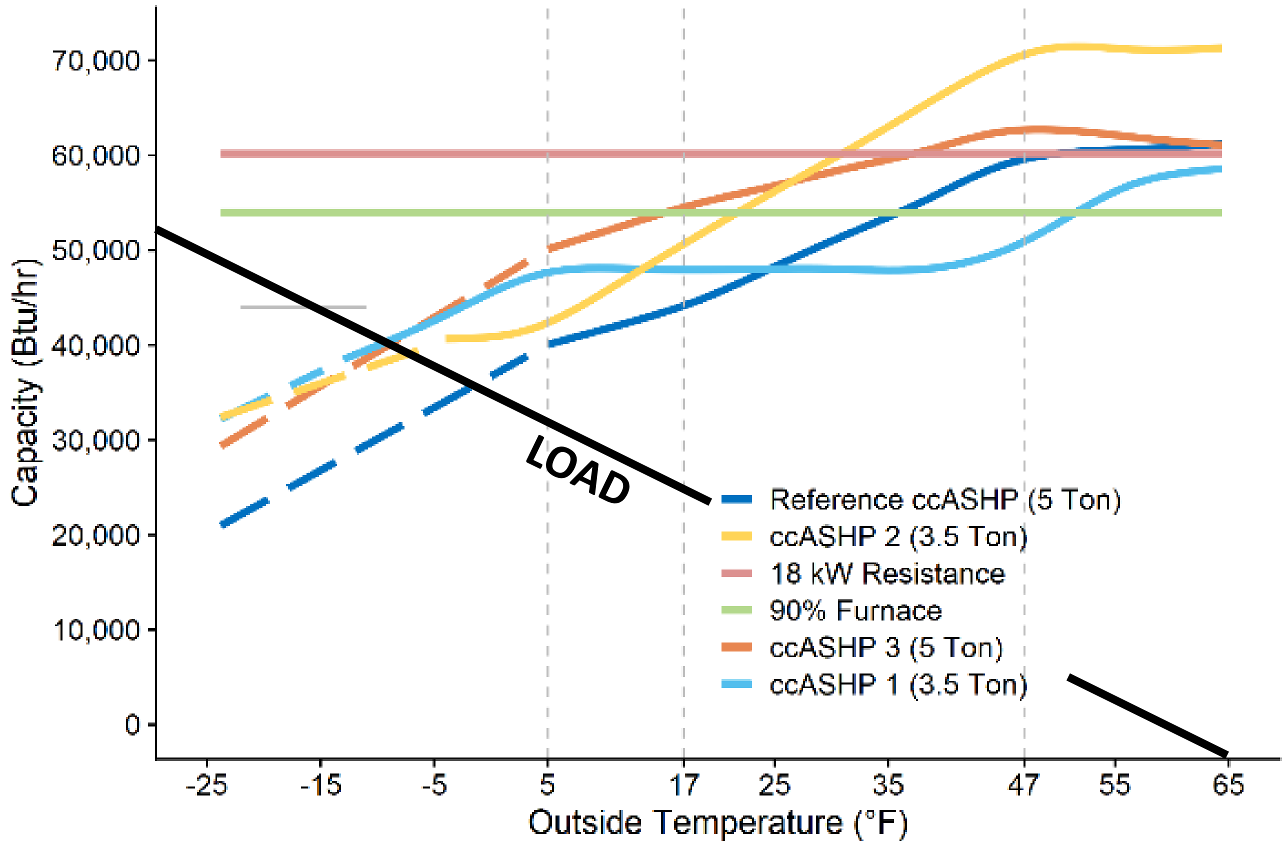
- Scenario 1
  - Oversized (60 kBtu) furnace **never misses** setpoint during cold snap

- Scenario 2
  - Right-sized (40 kBtu) furnace **occasionally misses** setpoint during cold snap



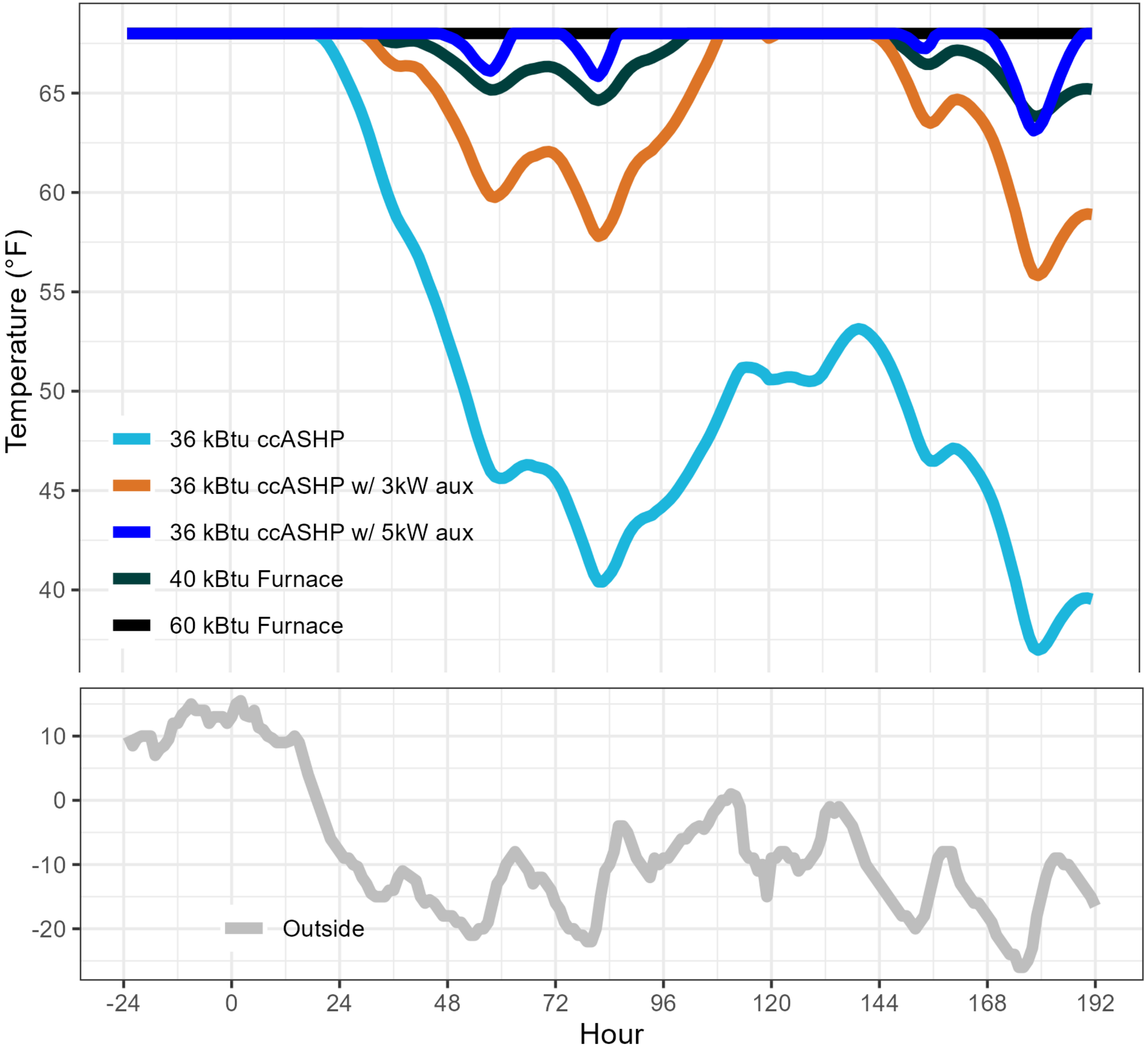
Decarbonization?

- Space heating decarbonization is the air source heat pump
- Capacity goes down with the temperature adding to a potential capacity gap
- Still a knowledge gap on performance below 0 °F
- What happens below design conditions?



ccASHP Capacity Gaps – Cold Snap in Duluth, MN

- Scenario 1
  - ccASHP sized at nameplate (36 kBtu)
  - Undersized this ccASHP loses capacity below 5 °F
  - **Can't make setpoint at design**
- Scenario 2
  - Right-sized ccASHP w/ 3 kW aux
  - Loses capacity below design condition
  - **Will miss setpoint below design**
- Scenario 3
  - ccASHP w/ 5 kW aux
  - Excess aux **occasionally misses** setpoint during cold snap



Improve the Resiliency of Decarbonized Buildings

- Better envelopes = more resilient buildings
  - Stack with all the other benefits of improved building envelopes
- Consider ASHP performance below design conditions and plan appropriately
  - Design conditions neglect infrequent cold snap events
  - Modest amounts of auxiliary electric are usually sufficient to fill the capacity gap in cold climates
    - 3-5 kW plenum heater, baseboard heater, or portable space heaters
  - In moderate climates it may be sufficient to swap to ccASHP from vsASHP
    - ccASHPs lose less-to-no capacity at the cold snap temperatures in moderate climates
  - New ccASHP products promise 100% capacity at lower temperatures
- Help fill this knowledge gap
  - Make sure contractors, policy makers, and program staff understand potential capacity gaps
  - Encourage ASHP manufactures to publish capacity data at lowest operable temperature
  - Researchers need to validate manufacturer capacity data in the field

THANK YOU!

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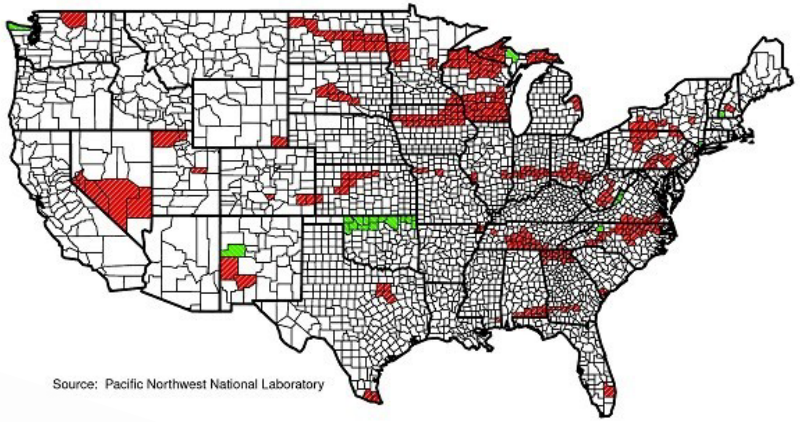
Center for Energy and Environment

Warmer Winters Everywhere?


Source: Pacific Northwest National Laboratory

Regional News

Warm Winter Is Harbinger of Winters to Come

Spokane Public Radio
Published February 19, 2015 at 11:50 AM PST

Cornell Chronicle

On thin ice: Northeast winter destined to be warmest on record, says Cornell climate center

If current trends continue for the Northeast through Feb. 28, then the meteorological winter of 2001-02 will be the region's warmest on record,...

Feb 22, 2002

ENERGY + ENVIRONMENT

Losing winter – and big chunks of New Hampshire's identity

BY: AMANDA GOKEE - JANUARY 6, 2022 5:51 AM

WEATHER

It's official: Minnesota just wrapped the warmest meteorological winter on record

WCCO NEWS

By Adam Del Rosso
Updated on: March 1, 2024 / 3:24 PM CST / CBS Minnesota

ENVIRONMENT

You're not imagining it—winters are getting warmer

Declines in snowfall will have consequences for life across the planet, from increased potential for wildfires to rising water insecurity.

By Melissa Hobson
February 28, 2024

AGRICULTURE, CLIMATE CHANGE, ENVIRONMENT, GARDENING

What the new plant hardiness zones mean for Wisconsin gardeners

The USDA recently updated its map for the first time since 2012

BY BRIDGIT BOWDEN • DECEMBER 29, 2023

GUIDES

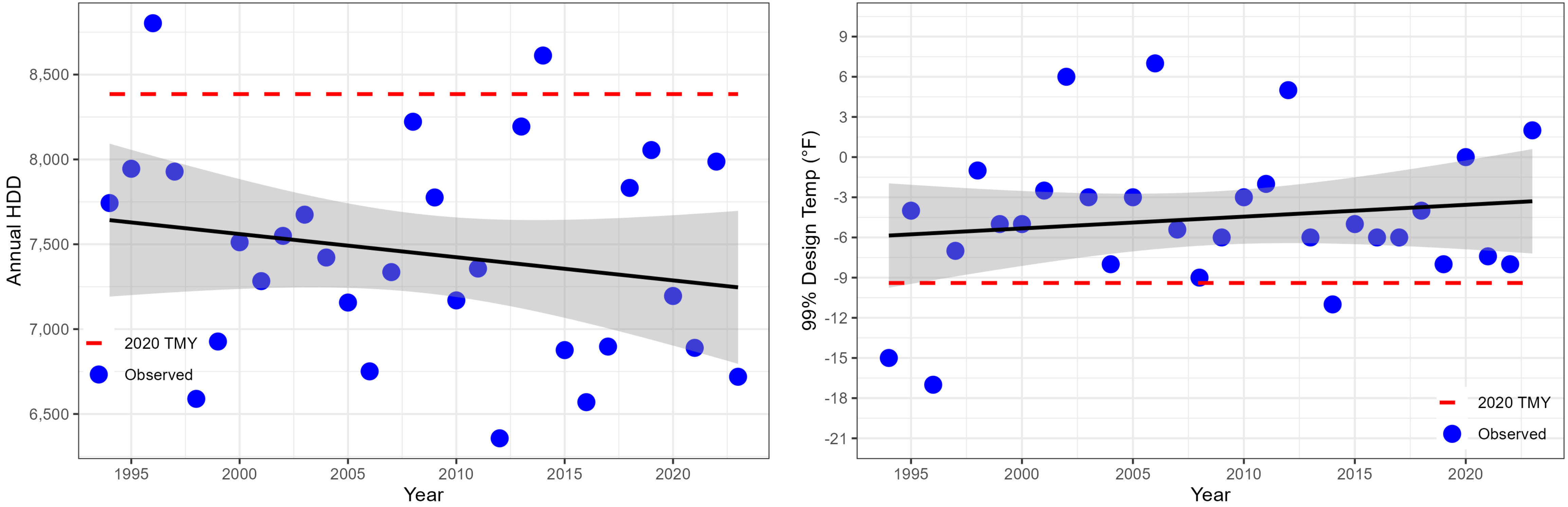
Winters get warmer with climate change. So what explains Texas' cold snap in 2021?

A warming earth has brought milder winters, but emerging science suggests that extreme cold spells in Texas could also result from climate change messing with complex weather processes.

BY ERIN DOUGLAS DEC. 14, 2021 5 AM CENTRAL SHARE REPUBLISH

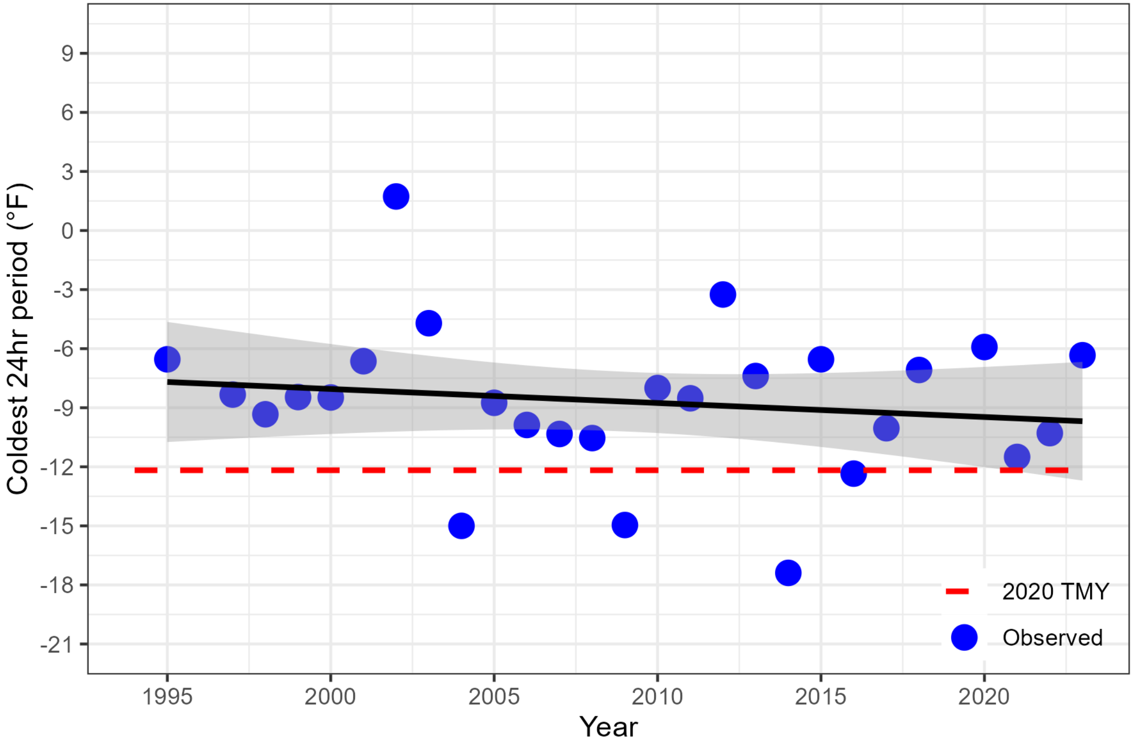
Warming winters in Minneapolis, MN

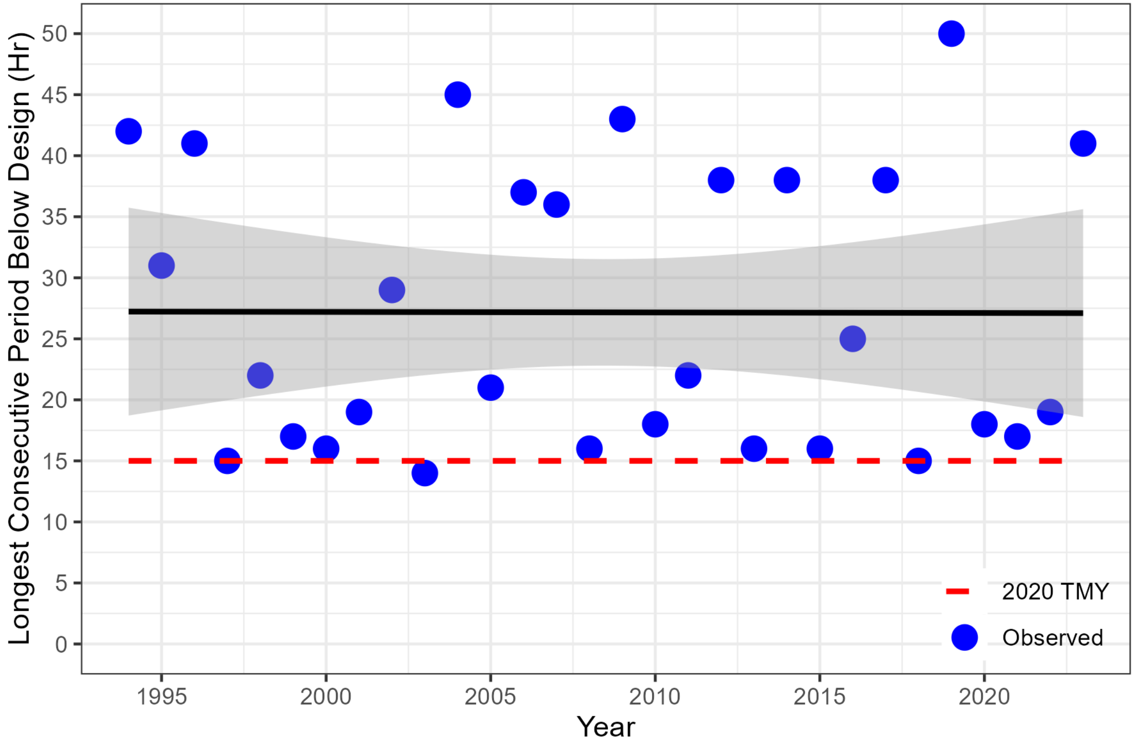
- Decreasing HDDs and increasing design temperatures



But by definition design conditions miss cold snaps!

- Coldest 24 hr and consecutive periods below design temperature constant!





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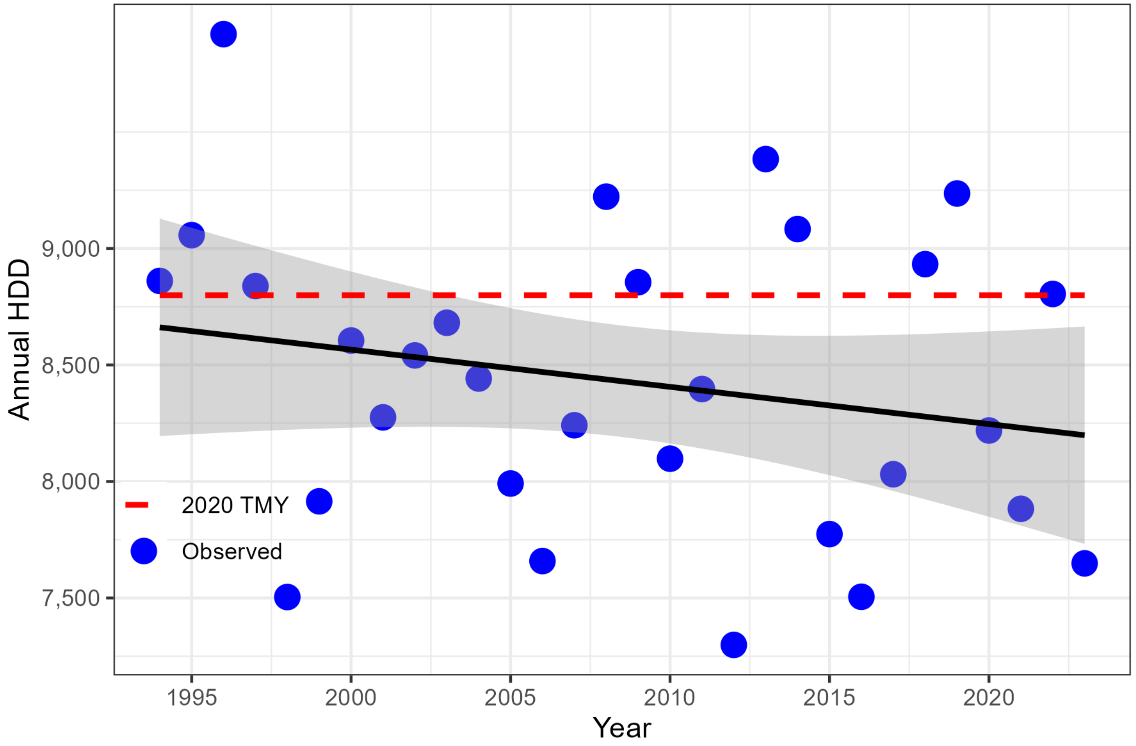
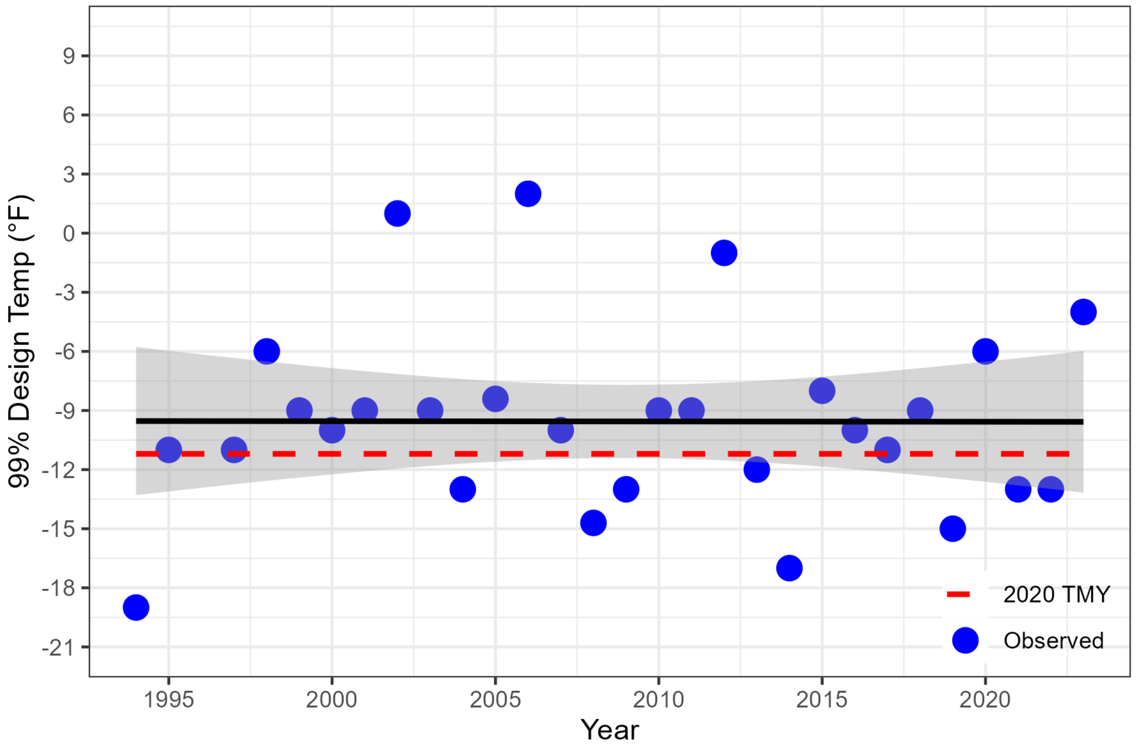
Warming isn’t uniform

St. Cloud, MN ~60mi NW of Minneapolis





Cold Snaps in different climate zones

- Cold snaps more frequent in very cold climates, more consequential in mild climates, but can be balanced by better ASHP capacity maintenance

City	99% Design (°F)	Cold Snap (°F)	Relative Load	ccASHP Capacity
Duluth, MN	-12	-27	119%	40%
Minneapolis, MN	-6	-23	123%	48%
Chicago, IL	3	-20	135%	62%
Oklahoma City, OK	19	-14	167%	74%
Dallas, TX	28	-2	175%	89%

- Oversizing ASHPs typically not viable due to equipment size and capacity loss
- Cold climate cold snaps (< -20 °F) need aux heat due to ASHP capacity loss
- Mild climate zone cold snaps (> -20 °F) can use ccASHP instead of vsASHP

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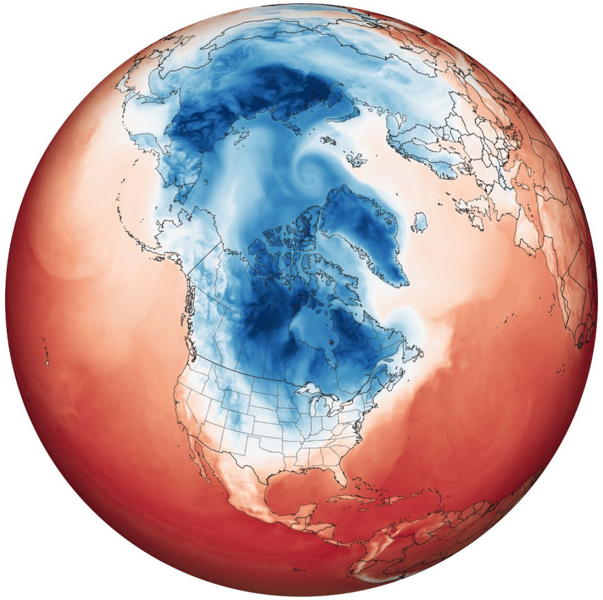

- One type of cold snap – the Polar Vortex
- SSW events cause polar vortex breakdown
  - Vortex shed off north pole and wanders across NA
  - Both the breakdown and path are unpredictable
  - Three significant events in the last decade
    - 2014, 2019, 2021 North American Cold Waves
  - Interactions with other fronts can bring high winds, blizzards, freezing rain, and ice