The New ABNORMALS: How to Adapt Buildings to Extreme Heat and Power Outages

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Lead and Healthy Housing
Winter Conference 2022
January 13, 2022 Webinar

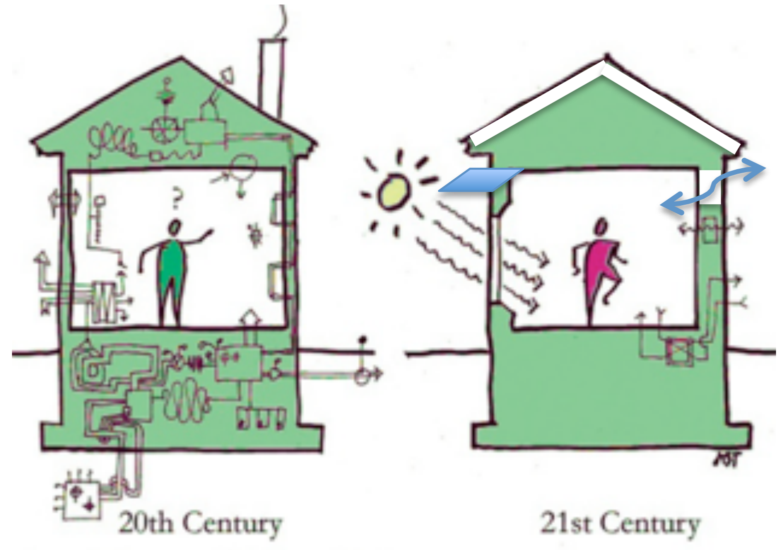
ADAPT NOW
or
DIE

TOPICS

- Introduction
- Overheating and Passive Survivability Standards and Guidelines
- Climate Adapted & Resilient Buildings: Examples
- Modeling Study Results
- Conclusions and Recommendations

How can we adapt to extreme heat?

Passive, Low Carbon Cooling



OR

Air Conditioning Death Spiral

Top Image: Adapted from Albert, Righter & Tittman Architects

A Nexus of Lead, Housing, and Climate Change:
Thomas Midgley, A One Man Environmental Disaster [1,2]

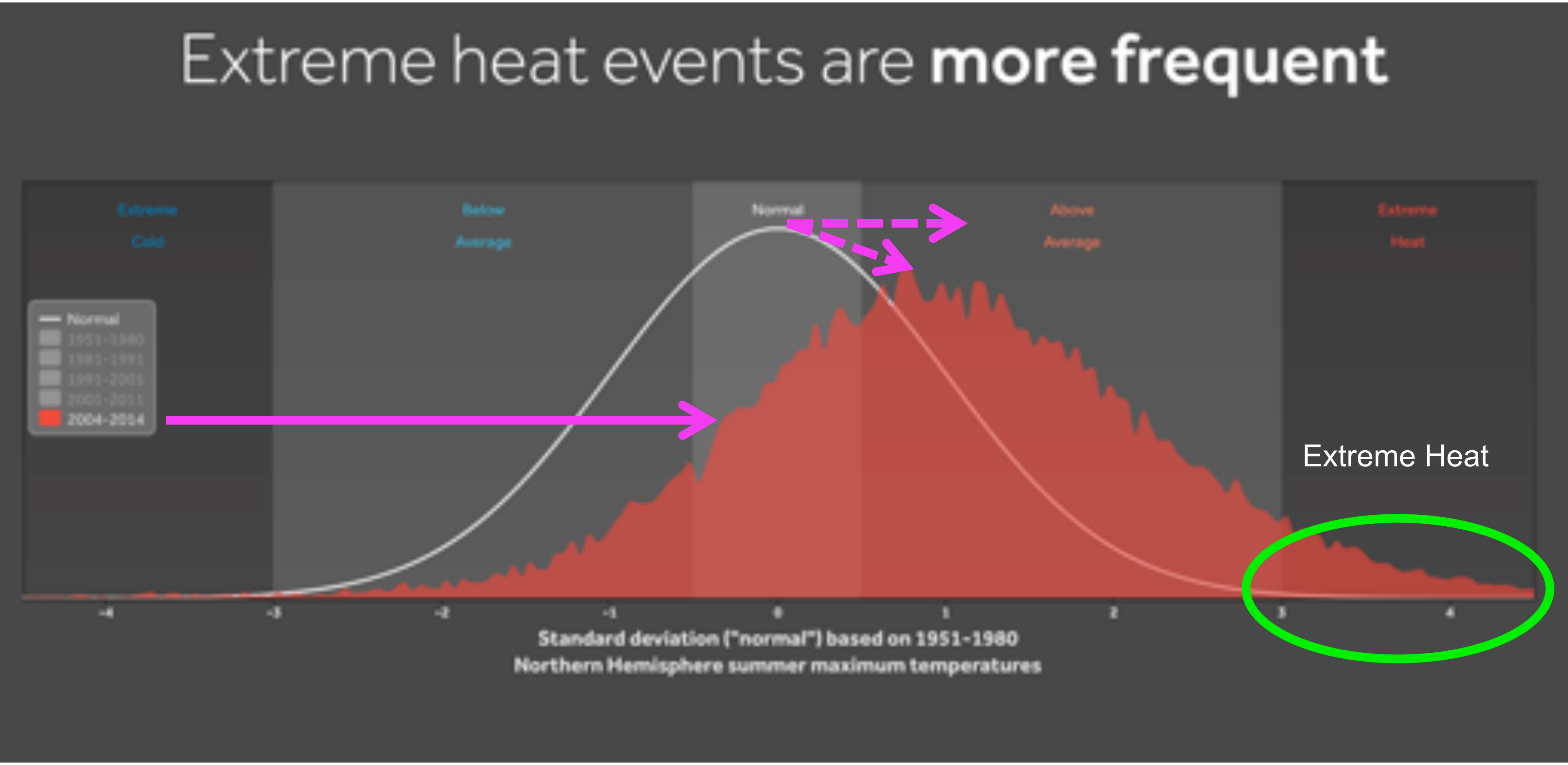
- Invented Leaded Gasoline for GM
  - ✓ Recommended it over safer alternatives so it could be patented for a huge profit
  - ✓ Suffered from lead poisoning

- Invented Freon, the first CFC in a major class of Green House Gases

- Died from strangulation by his own rope & pulley system

1. T. Phillips, 2018. Humans: A Brief History of How We F****d It All Up. (No Relation).
2. Wikipedia, 2021.

The New ABNORMALS (2014):
Major Shift to Extreme Temperatures
(& Flatter, Broader Curve) is Already Occurring



Adapted from Wx Shift, Jan. 2020. Extreme Heat. See Also: local time series chart of temperature anomalies.
https://wxshift.com/climate-change/climate-indicators/extreme-heat.

WHY
Is Extreme (Abnormal) Heat So Important ?

- Extreme heat drives health, ecosystem, and infrastructure impacts

- Health impacts of increasing heat are non-linear

- Cascading climate impacts and negative feedback loops

- Extreme heat is increasing rapidly now in many regions

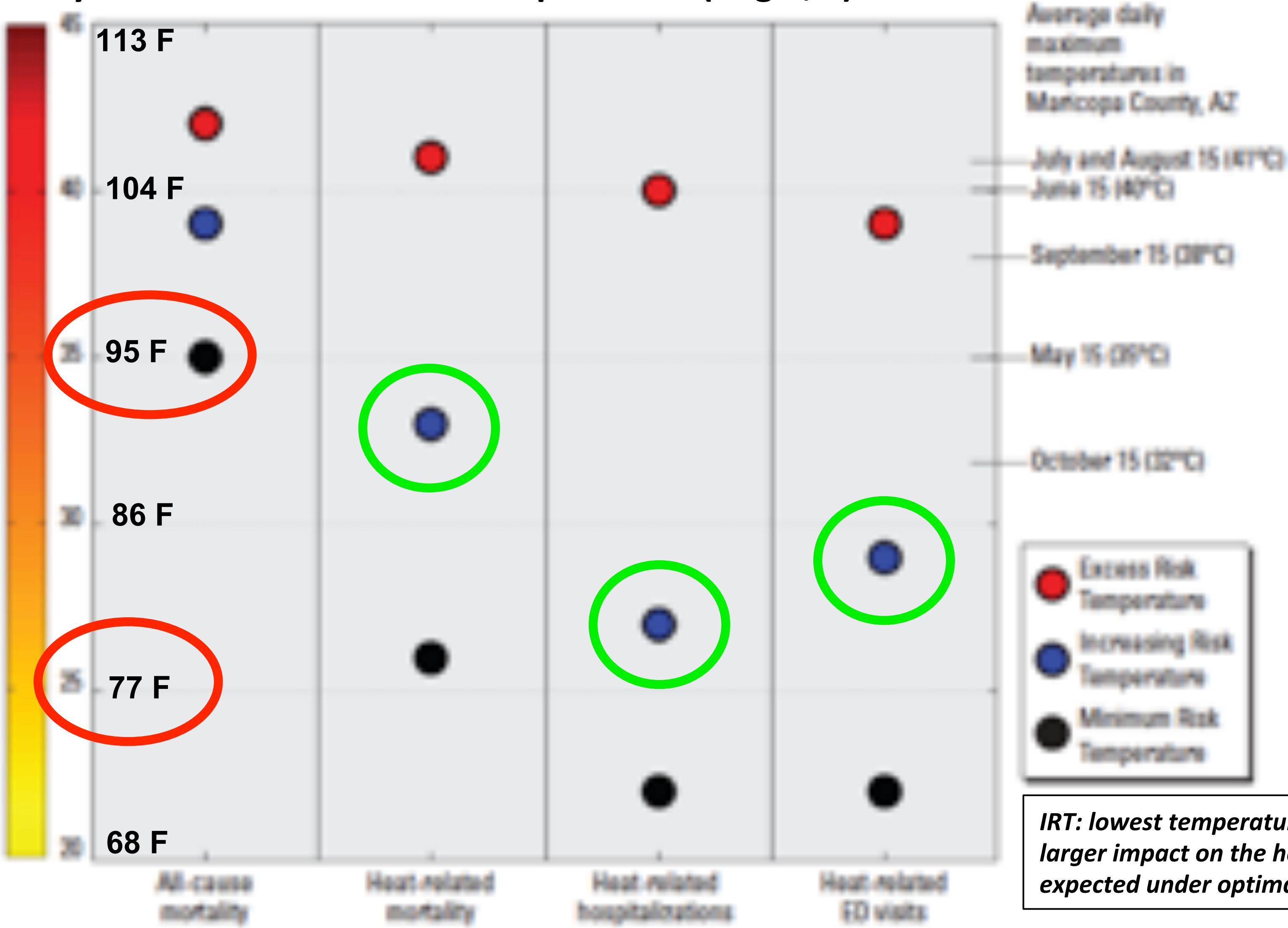
Heat & Humidity Can Kill

- ✔ #1 weather-related killer in the U.S.
- ✔ Deadly Wet Bulb Temperatures are already occurring around the world [1]
- ✔ Radiant temperature also important
- ✔ Often misdiagnosed: "The Invisible Killer"[2]

1. NOAA, 2020. Dangerous humid heat extremes occurring decades before expected.
2. Brinicombe, 2020. Heatwaves are an invisible killer – and the UK is woefully unprepared.

Heat Mortality & Morbidity: Maricopa Co., AZ

Daily Maximum OUTDOOR Temperature (deg C, F)



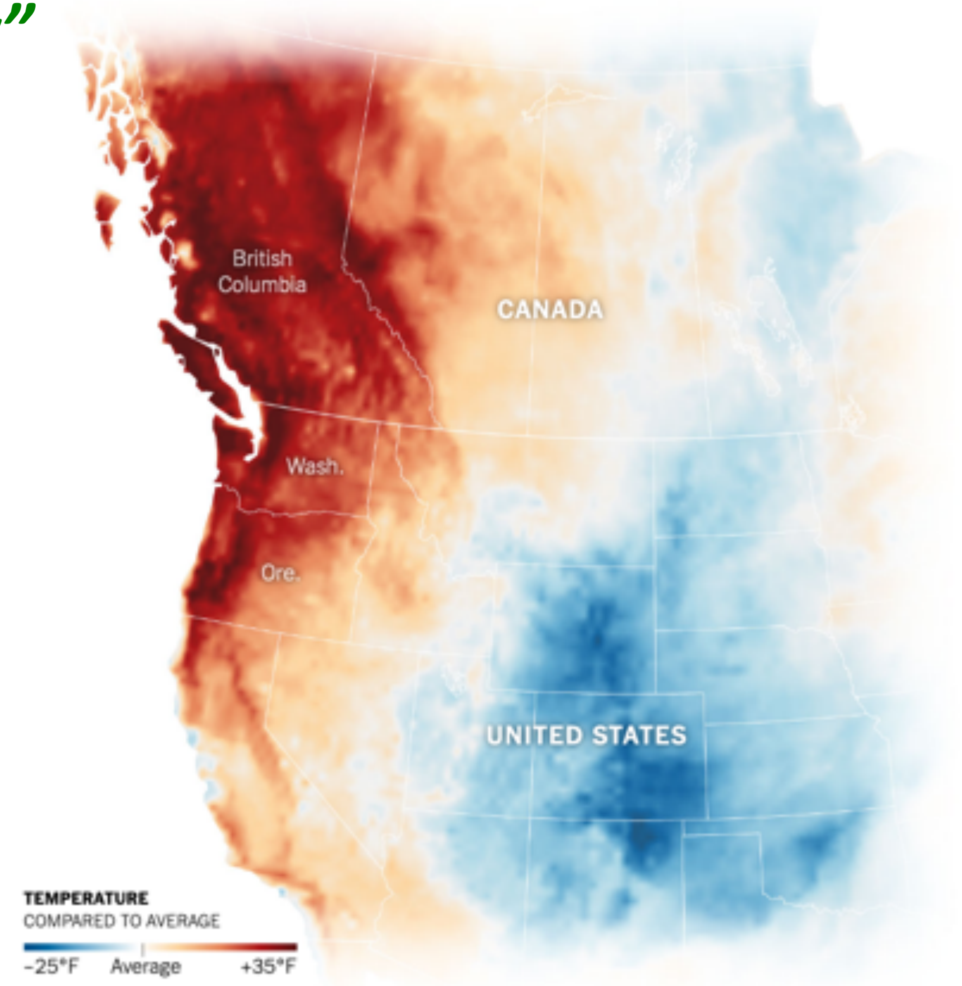
IRT: lowest temperature at which there is a larger impact on the health event than what is expected under optimal weather conditions.

Petitti et al. 2016. Multiple Trigger Points for Quantifying Heat-Health Impacts: New Evidence from a Hot Climate. https://doi.org/10.1289/ehp.1409119.

June 2021 Pacific NW Heat Dome: *"Mass Casualty"*

- **Premature deaths**
  - ✓ ~ 500 excess deaths in British Columbia [1]
  - ✓ 600 + deaths in Oregon & Washington [2]
  - ✓ Thousands hospitalized
- **Highest risks were indoors:**
  - ✓ Older persons
  - ✓ Lack of AC
- **Climate change impact [3]**
  - ✓ Heat dome more likely
  - ✓ Marine heat wave [4]
  - ✓ > 100 wildfires followed

Large areas with average temperature 30 – 35 F over "normal"

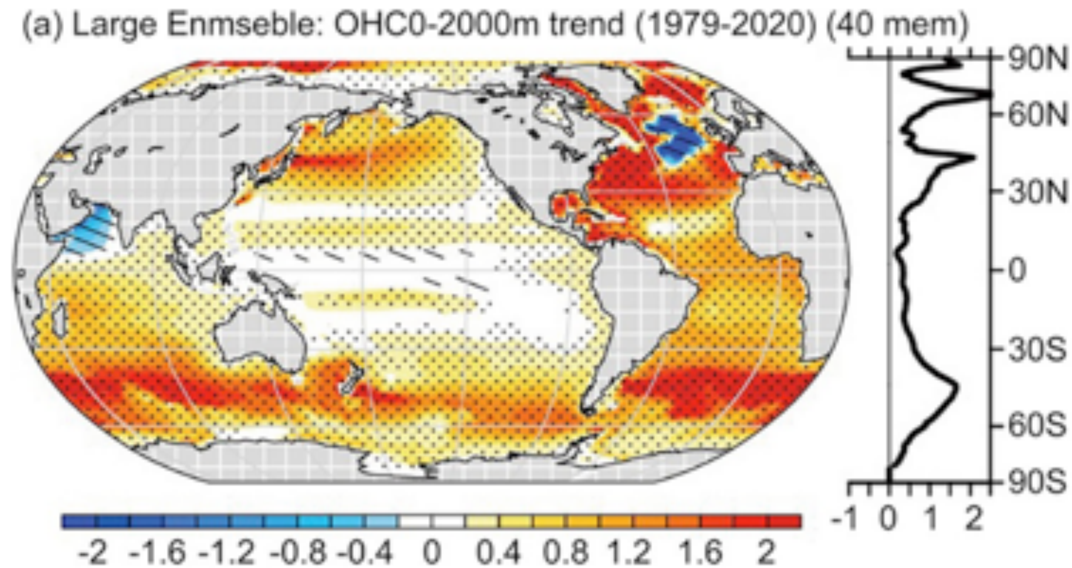


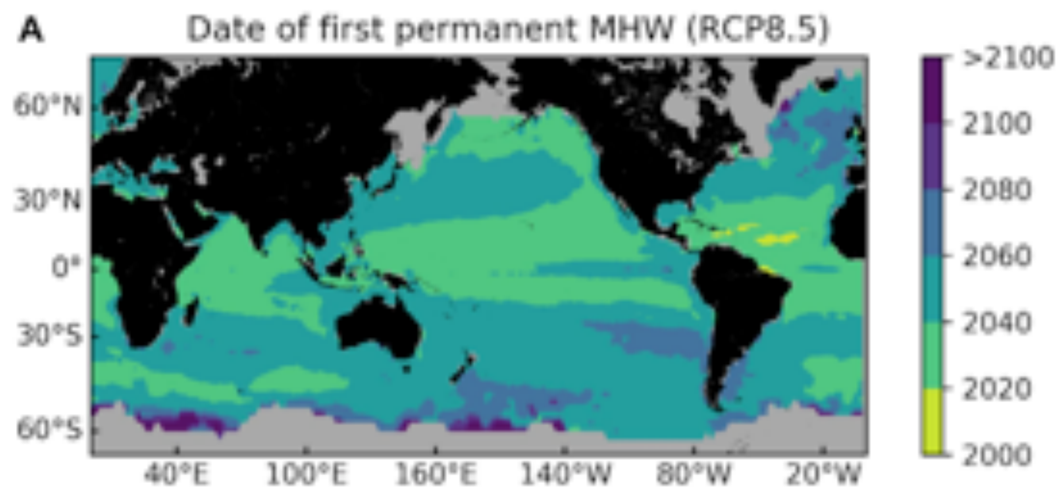
Source: Goddard Earth Observing System model, NASA · The map reflects air temperature at 2 meters (about 6.5 feet) above ground level on June 27, 2020, compared to the average temperature for the same day between 2014 and 2020.

1. KUOW, July 12, 2021. Nearly 800 people believed to have died in Northwest heat wave.
2. NY Times, Aug. 11, 2021. Hidden Toll of the Northwest Heat Wave: Hundreds of Extra Deaths.
3. Wilson, Aug. 5, 2021. The Cascading Impacts of Drought and the Role Resilience Must Play. Resilient Design Institute.
4. Cheng et al., 2022. Another Record: Ocean Warming Continues through 2021 despite La Niña Conditions.

Fastest Warming Region in U.S.: Northeast [1]

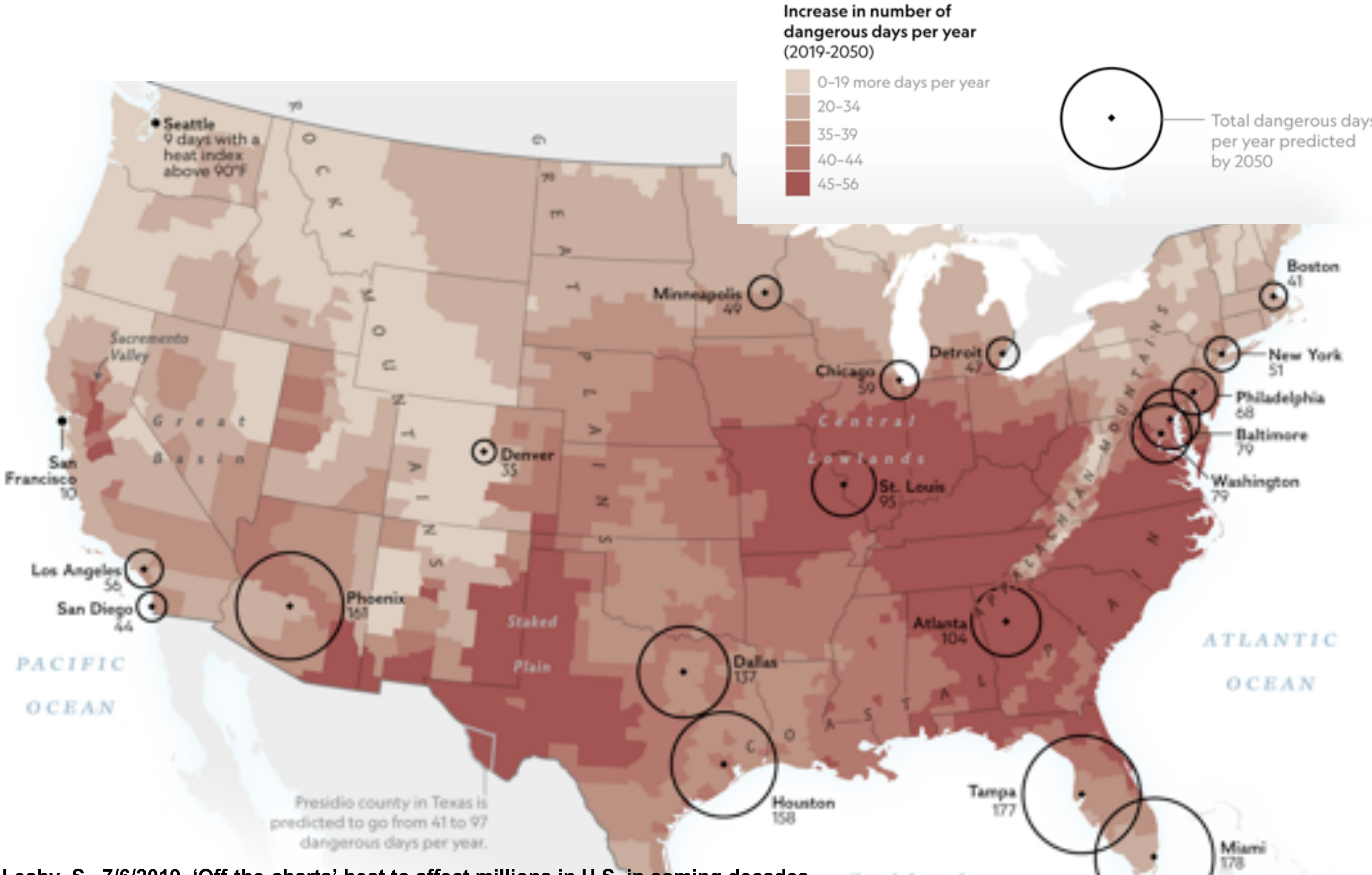
- **NE Coast is a hot spot**
- **NW Atlantic is fastest warming ocean**
- **Other ocean hot spots in the world** [2]
  - **Marine Heat Waves increasing**
  - **Near-permanent heat waves in many regions after 2060** [3]





1. Karmalkar & Horton, 2021. Phys.org, 2021. The Coastal Northeastern US is a global warming hotspot.
2. Cheng et al. 2022. Another Record: Ocean Warming Continues through 2021 despite La Niña Conditions. Phys.org, 2022.
3. Oliver et al., 2019. Projected Marine Heatwaves in the 21st Century and the Potential for Ecological Impact.

Heat Wave Increases, 2019-2050

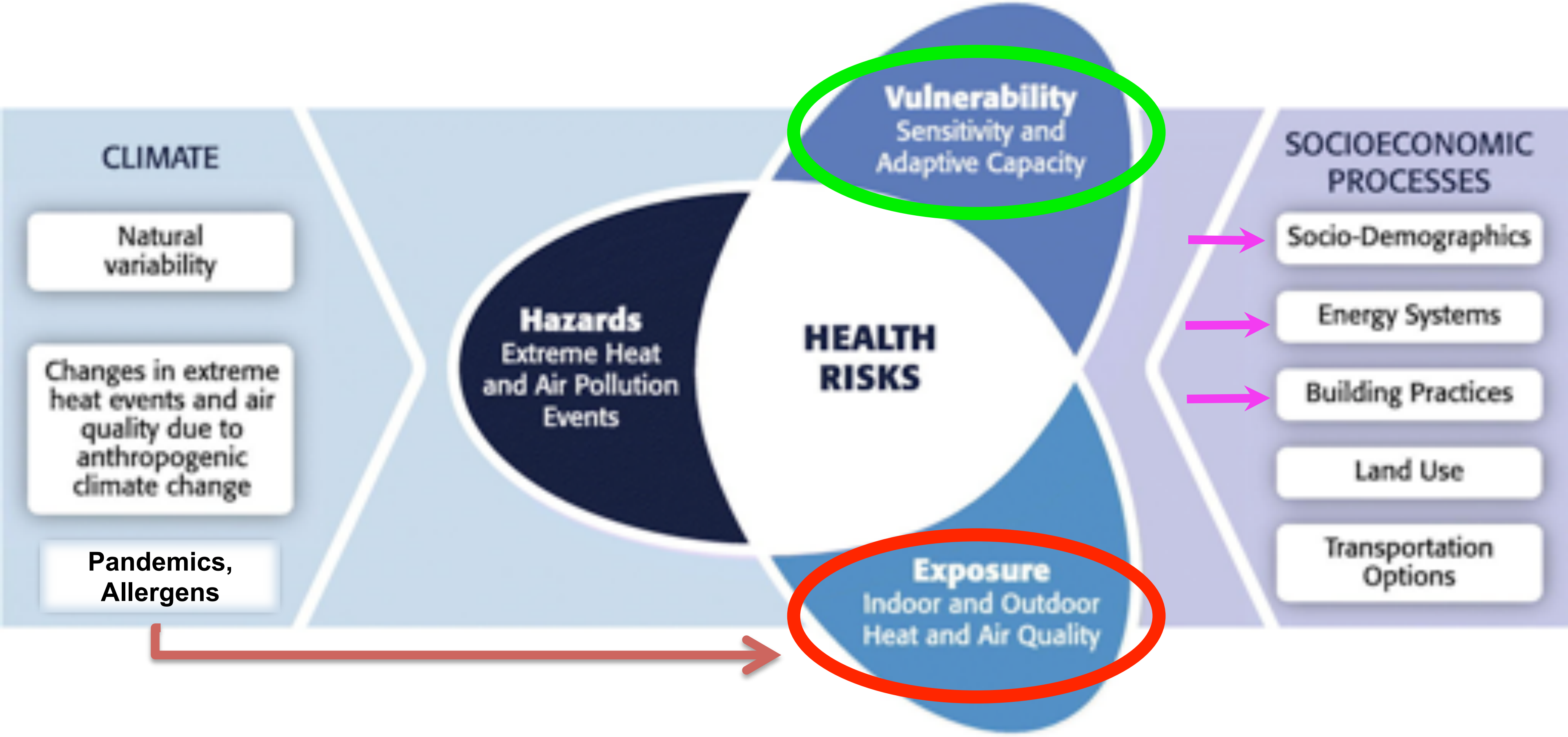


Leahy, S., 7/6/2019. 'Off-the-charts' heat to affect millions in U.S. in coming decades
Within 60 years, hot days in the U.S. could be so intense that the current heat index can't measure them.
National Geo., https://www.nationalgeographic.com/environment/2019/07/extreme-heat-to-affect-millions-of-americans/.
Interactive mapping tool: https://ucsusa.maps.arcgis.com/apps/MapSeries/index.html?appid=e4e9082a1ec343c794d27f3e12dd006d.
Dahl et al. 2019. https://iopscience.iop.org/article/10.1088/2515-7620/ab27cf.

WHY
Is Indoor Heat Exposure So Important ?

- About 90% of our time is spent indoors on average,
  and even more for some vulnerable populations
- Heat waves, COVID, wildfires, and allergens
  have forced us indoors more
- Indoor environments can become very hot,
  leading to deaths and hospitalization
- Thermal stress has significant effects on
  sleep, student performance, and worker productivity
- Energy inequity occurs in many regions,
  and has been exacerbated by increased utility and housing costs
- Our homes, schools, and other buildings must shelter us,
  and allow us to recover,
  from environmental stresses and hazards

Conceptual framework for assessing population health risks to extreme heat and air pollution

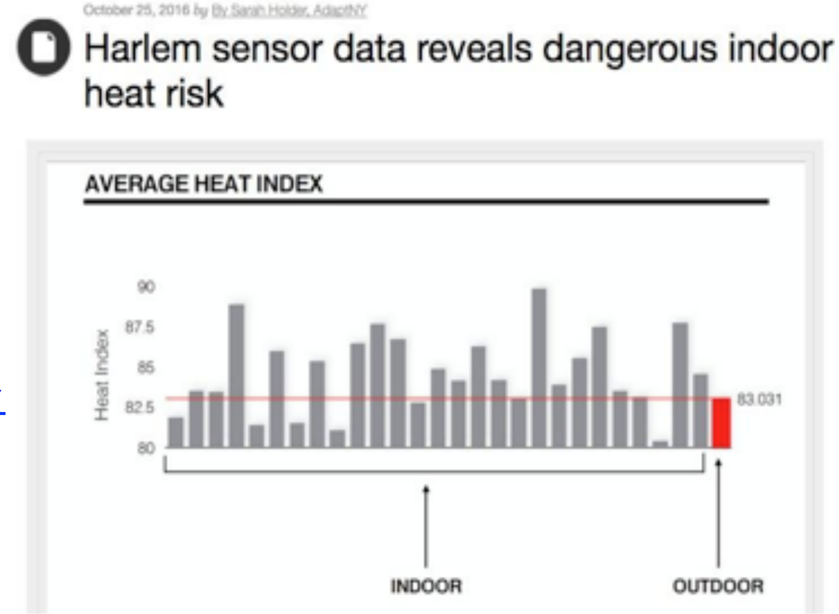


Adapted from O'Lenick, et al. 2019. Urban heat and air pollution: A framework for integrating population vulnerability and indoor exposure in health risk analyses. https://doi.org/10.1016/j.scitotenv.2019.01.002.

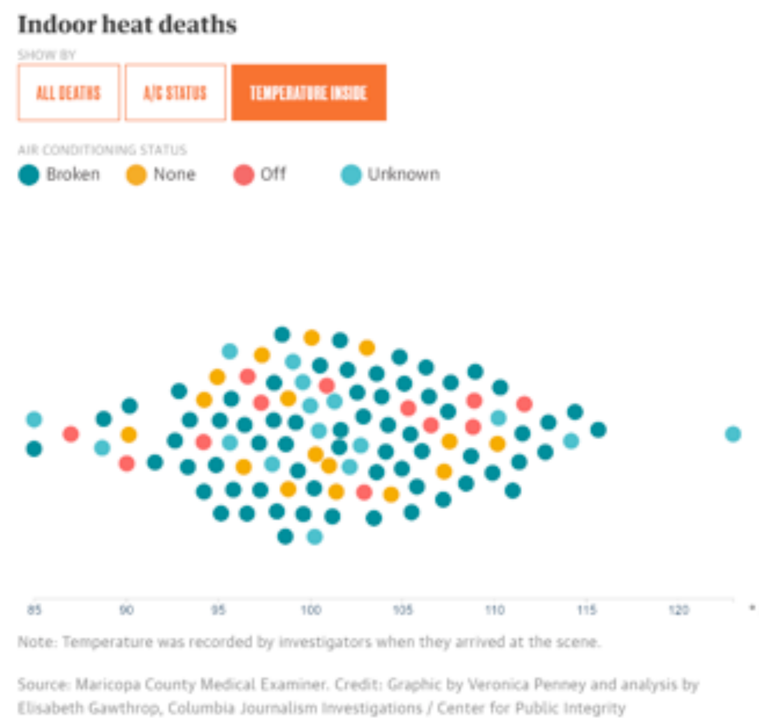
New and Existing Buildings: Already Overheating

- New CA Single Family homes:
  19% "too hot"
  (Offermann, 2005)
- NYC low income apartments:
  Heat Waves 24/7
- U.S. schools closing during heat waves
- Arizona heat deaths:
  100 indoors
  Over 100 F in half of homes

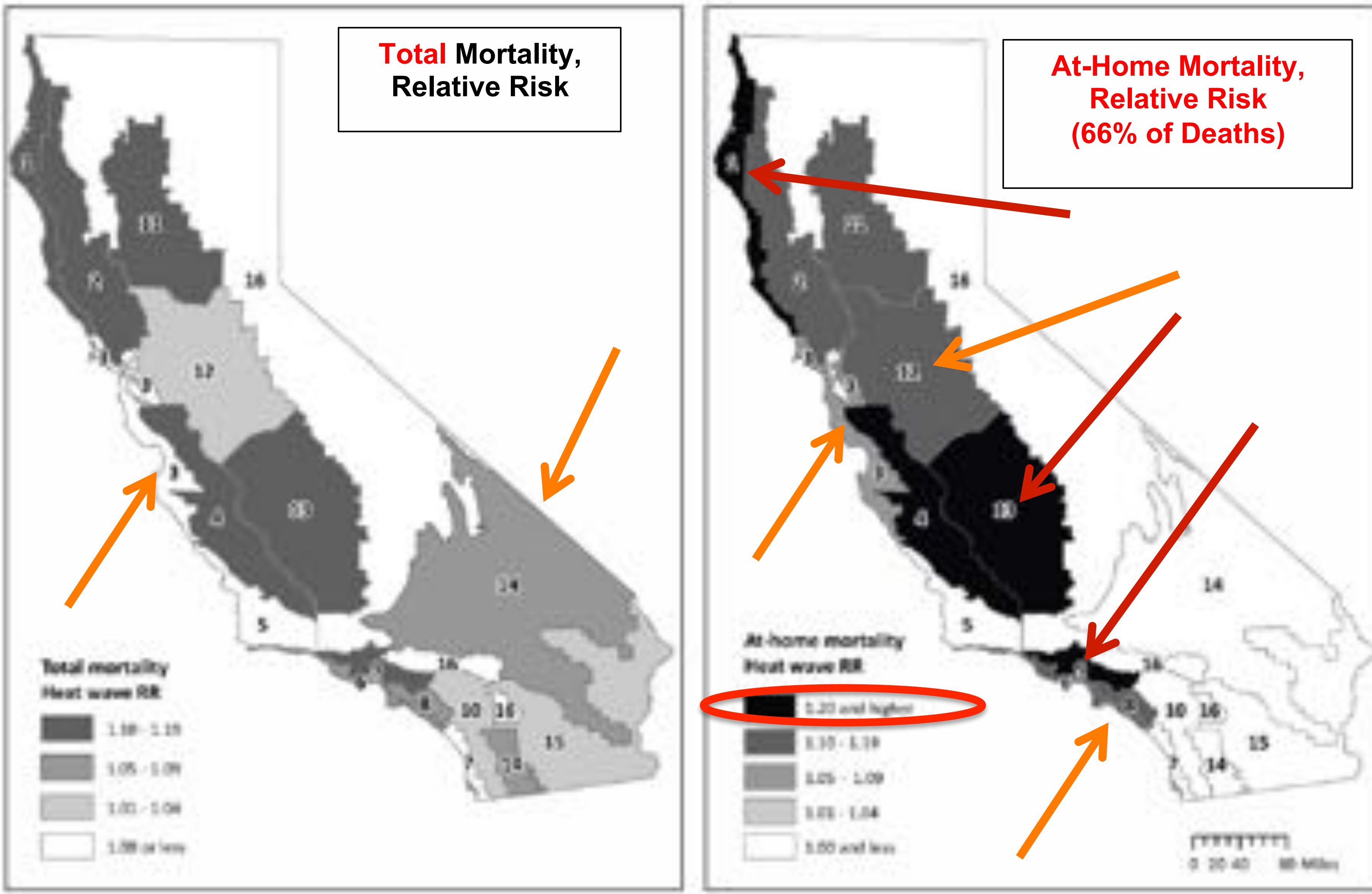
[NYC Harlem Heat Study]



[Maricopa Co. AZ, 2016-2018].



2006 California Heat Wave Mortality: Climate Zones



Adapted from: Joe et al. 2016. Mortality During a large-scale heat wave by place, demographic group, internal and external causes of death, and building standards climate zone. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4808962/.

LIABILITY
Lawsuits and Criminal Charges

- **High rise condos overheating in San Francisco**
  - 2 cases settled in recent years
- **Nursing home deaths**
  - 14 dead in Florida nursing home after Hurricane Irma: civil suits
  - After Hurricane Irma: 25% increase in nursing home deaths a week later, and a 10% increase in mortality rates after 30 days [1]
  - 2 dead in Detroit nursing home: involuntary manslaughter charges [2]
- **Liability for climate adaptation: Reviewed and workshop by Conservation Foundation (2018)** [2]

1. WUSF, 2021. Power outages that followed Hurricane Irma affected 28,000 residents of Florida's nursing homes. Skarha et al., 2021 JAMA
2. Pintas and Mullins, 2021. Extreme Summer Temperatures Leads to Possible Heat-Related Nursing Home Death, 2008.
3. Conservation Foundation, 2018. Climate Adaptation and Liability: A Legal Primer and Workshop Summary

Realtor Risk and Moldy Homes

Bordertown, a detective series on Netflix:

Father of mold victim becomes a serial revenge killer

Where
Will Indoor Heat Impacts Occur?

- All regions
- Homes and Facilities for Vulnerable Populations
- Maladapted buildings
- Urban and rural
- Maladapted power grid
- Short-term vs. Long-term health protection

WHO
Will Be Most Affected ?

Vulnerable Populations:
> 1/3 of U.S. and Growing Rapidly

	Current and projected prevalence in the U.S adults.[1]
Older adults (65 +): Many alone in home	8% in 2010, 20% in 2050
Obesity :	36%, regional hot spots
Diabetic:	8%, up to 28% by 2050
Hypertensive:	33%; 71% in elderly
Social isolation:	17% in women, 21% in men
Low income:	15%
Little / no home insulation:	21%
Pregnant women: [2,3]	3.75 million (2019); 6 - 8% are high risk

1. Holmes, Phillips, and Wilson, 2016. Overheating and passive habitability: indoor health and heat indices. See CDC for disease updates.
2. Statista, 2021.
3. UC San Francisco, 2021.

Vulnerable Populations (contd.)

- Many people have co-morbidities (multiple health conditions) and other risk factors

- Perfect (Heat) Storm:
  - Demographics (Silver Tsunami)
  - Health Risks increasing
  - Housing Crisis (costs, overcrowding, homelessness)
  - Health Care and Energy costs increasing
  - Power outages increasing
  - Climate Change ("Threat Multiplier")

Climate Ready Forests and Crops: Fit for the Future

- **Urban Forests**: UC Davis and the U.S. Forest Service are testing the resilience of several tree species from warmer, drier climates [1,2]

- **Other Plants**: similar programs in U.S. for grain crops, vegetable crops, and fruit and nut trees

- **In a rapidly changing climate, using historical climate data is "Like driving down the freeway guided by the rearview mirror."**

Examples of Recommended Trees for N. CA

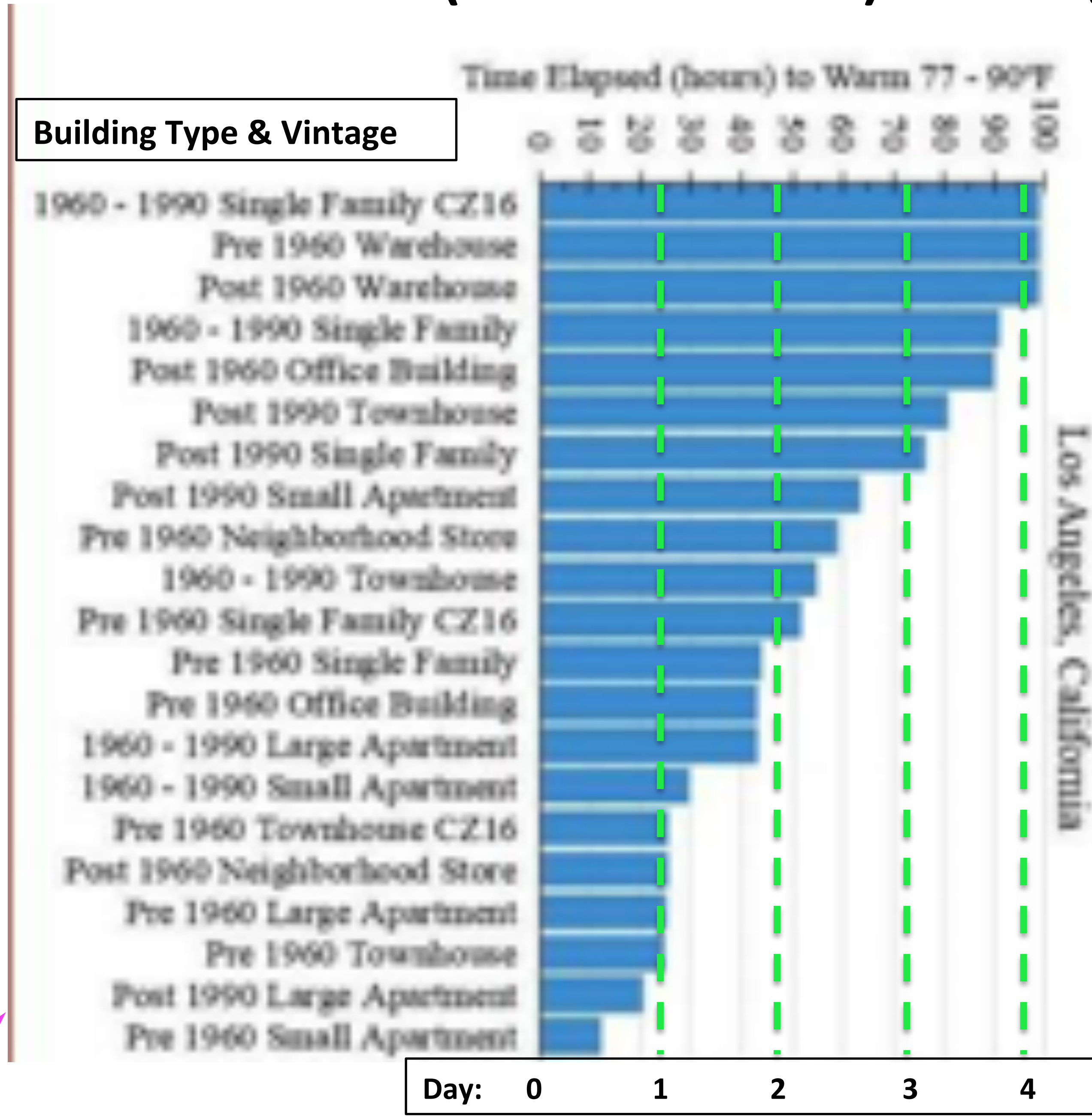
1. UC Davis, 2020. Climate Ready Trees. http://climatereadytrees.ucdavis.edu/research-updates/. Periodic updates and presentations.
2. The Introduction and Testing of Texas Tress in Sacramento Valley Landscapes Project. UC Davis Arboretum, Living Landscape Plan. https://ucanr.edu/sites/SaratogaHort/Funded_Projects/. Other drought resistant landscape projects also listed.

HOW

to Adapt Buildings to Climate Change ?

- **Assess Climate Change and Overheating Risk**
- **Standards and Guidelines**
- **Tools: do not drive by the rear view mirror**
- **Examples**
- **Opportunities**
- **Next Steps ??**

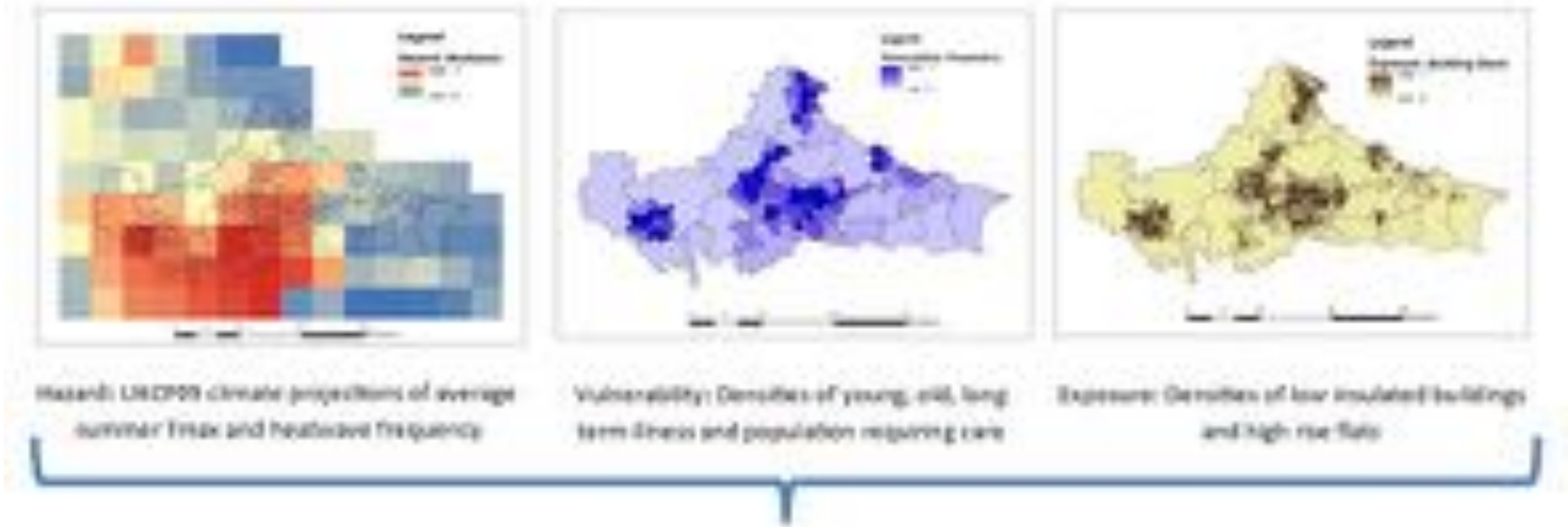
Time to Reach 90 °F (modeled hours): Los Angeles

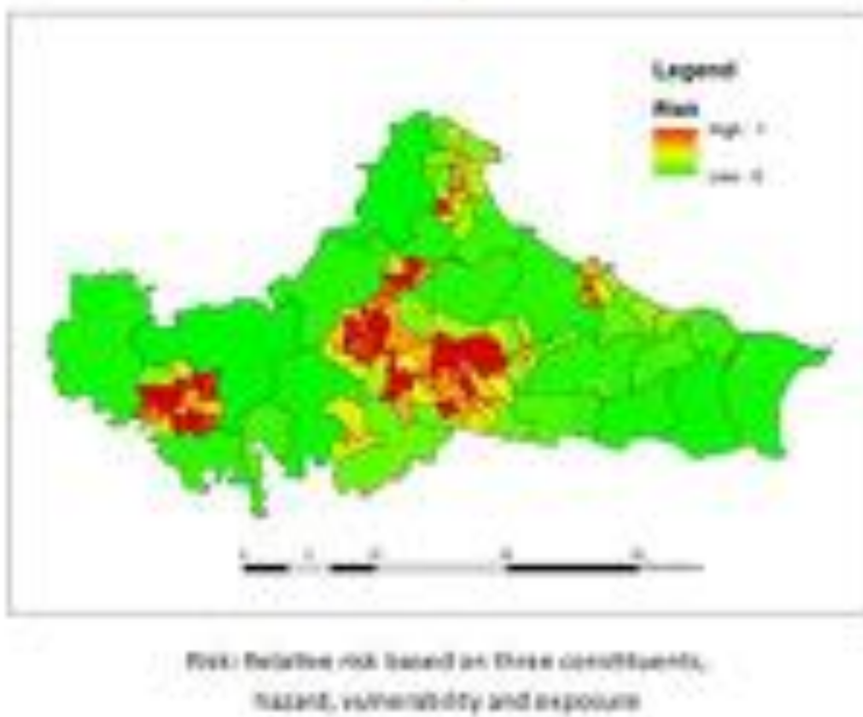


Mostly MFam, pre 90s, & pre 60s.

Mobile homes not included.

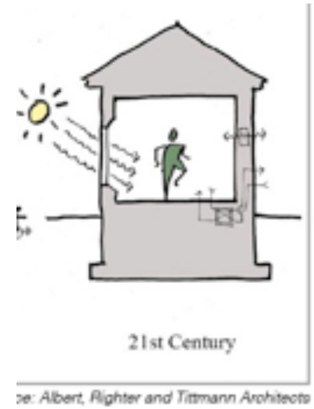
Mapping Heat, Health, and Vulnerable Buildings



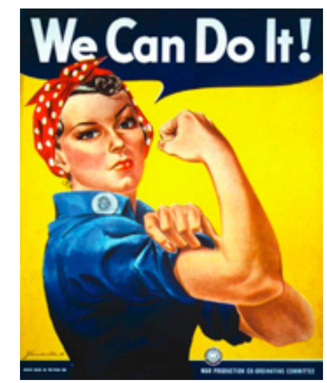


Newcastle University, 2013. Tees Valley Heat Risk Mapping. Centre for Earth Systems Engineering Research (CESER). http://www.ncl.ac.uk/ceser/researchprogramme/impactengagement/teesvalleyheatriskmapping/.
SEE ALSO: Heat mortality risk and housing mapping of London, ARCC 2017.

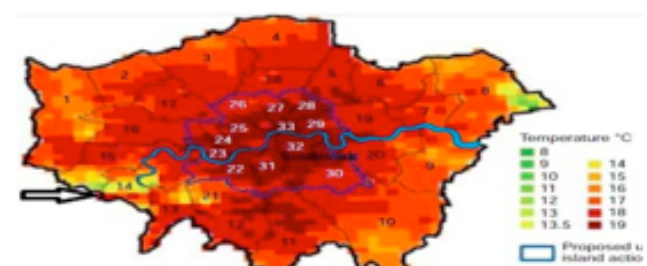
Overheating Standards and Guidelines: *International*



- **World Health Organization (1987 and 2018):**
  $\leq$ 24 C and $\geq$ 18 C (vulnerable populations). [1]
- **Passive House Program:**
  $\leq$ 10% (h/y) > 25 C, and moisture limit. [2]
- **CIBSE TM 59 Overheating Design Guide (UK):**
  - **Mechanical ventilation:** Operative Temperature $\leq$ 26 C for < 3% of occupied hours
  - **Natural Ventilation:** temperature (summer occupied hours) and annual delta T limits for bedrooms
  - **Future climate scenarios recommended:** high emissions scenarios recommended, mid & late century. [3,4]



- **CIBSE TM 49 Urban Heat Island Design Guide (UK and London Plan):** [5]
  - **Overheating risk assessment** for urban heat zones
  - **Design Summer Year** weather file
  - **Hierarchy of efficiency measures**, before mechanical cooling is allowed



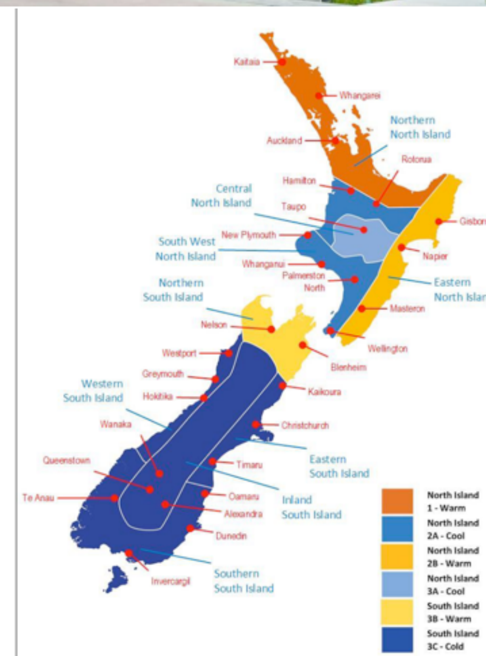
Average outdoor air temperature in London during August 2013

1. WHO, 2018. Housing and Health Guidelines.
2. Passive House Institute, 2016. Criteria for the Passive House, EnerPHit and PHI Low Energy Building Standard.
3. CIBSE, 2017. TM 59, Design methodology for the assessment of overheating in homes.
4. Diamond, S., May 22, 2017. CIBSE Overheating webinar. Inking Associates.
5. CIBSE, 2014. TM49 Design Summer Years for London. See also: ARCC Network, 2017. Designing for Future Climate.

Overheating Standards and Guidelines: *International (Part 2)*

- UK Draft **Future Homes Standard** and Building Regulations (2021) [1]
  - Overheating assessment, low carbon, and ventilation requirements
  - **Over 1 million homes** could still suffer from overheating (reviewer comments)

- New Zealand **School Design Guidelines**: Overheating
  - Varies by region
  - < 26 C: 20 – 250 hours, < 28 C: 10 – 60 hours, 32 C max
  - Design Summer Year (DSY) weather file
  - Life cycle analysis, efficiency measures, etc.



1. UK Future Homes Standards, 2021. Draft standards and consultations. News: https://www.architecture.com/knowledge-and-resources/knowledge-landing-page/the-future-homes-standard-explained.
2. B. Cruise., March 2018. AIVC Workshop. Guideline: NZ Ministry of Education, 2017. Designing Quality Learning Spaces – Indoor Air Quality and Thermal Comfort.
3. Top image: RIBA Journal;

Overheating and Adaptation Guidelines and Standards: U.S.

- **No maximum temperature limits in residential building standards or schools, at the national or state level**
  - **Some locales require AC and maximum temperature limits** [1]
  - **Some state Medicaid programs allow cooling or AC measures** [1]
  - **Many proposals have failed**
- **Nursing homes, if certified after Oct. 1, 1990: ~ 71-81 F in residences, under *federal* law** [2]
  - ***Michigan* law only applies if construction cost is $1 M or more**
- **Hospitals and care facilities**

1. GHHI, 2020. Air Conditioning, Heat Vulnerability, and Racial Equity.
2. Michigan, 2004. Federal regulation, 42 CFR Part 483. 483.15(h)(6). Leeway allowed if heating or cooling needs are rare. Somestatres require AC and heating, such as Illinois.
3. Wilson, A., 2018. The LEED credits are back up. Resilient Design Institute.

Overheating and Adaptation Guidelines and Standards: U.S., Voluntary

- **Build It Green (2019, 2021): GreenPoint Rated for CA Homes** [1]

- **Collaborative for High Performance Schools, U.S. (CHPS, 2020) Climate Adaptation and Resilience, 1-5 points** [2]
  - **Climate Vulnerability Assessment using climate change projections**
  - **Design, Maintenance, and Emergency Plans for 1 or 2 top risks**
  - **Energy Resilience: Primary power system (< 50% of load), secondary system that can be switched off**
  - **Passive Survivability/Habitability: 4+ days without power on primary system; energy efficiency and renewable backup power**

CHPS

- **LEED Pilot Credits (2018 and 2022 update): Resilient Design for new construction. Public input requested.** [3,4]

USGBC

1. Build It Green, 2020. Green Point Rated, Version 8.0. N8.2, Strategies to Address Assessment Findings
2. CHPS, 2020. US-CHPS Criteria v2.0. Sec. II C7.1 Design For Adaptation & Resilience. Net Zero Energy and daylighting are required. Low/Zero GHG is optional. 60-100 life cycle of building.
3. Wilson, 2018. The LEED credits are back up. Resilient Design Institute.
4. Melton, Dec. 2021. USGBC to Drop Its Resilience Rating System, RELi. Building Green News. Plans to integrate resilience.

Overheating and Adaptation Guidelines and Standards: Canada

- **British Columbia Housing (2019): Energy Step Code, Overheating and External Air Quality Supplement [1]**

- **Langley, BC (2021): Draft GHG, thermal resiliency (overheating), and energy equity policy) [2]**
  - ✓ Based on BC Guidelines
  - ✓ Modeling and Draft report, and public review planned.

- **National Research Council Canada, Construction Innovation (2021): [3]**
  - ✓ Overheating Risk Management Guideline and modeling results
  - ✓ Risk evaluation methodology
  - ✓ Summer reference weather files
  - ✓ Heat and cold stress metric and models

1. BC Housing, 2019. Design Guide Supplement on Overheating and Air Quality. PCIC future weather files used.
2. More info: Langley Builder Forum Series: Passive Cooling and Step Code (June 1, 2021).
3. NRC Canada. Various reports by Laouadi et al.

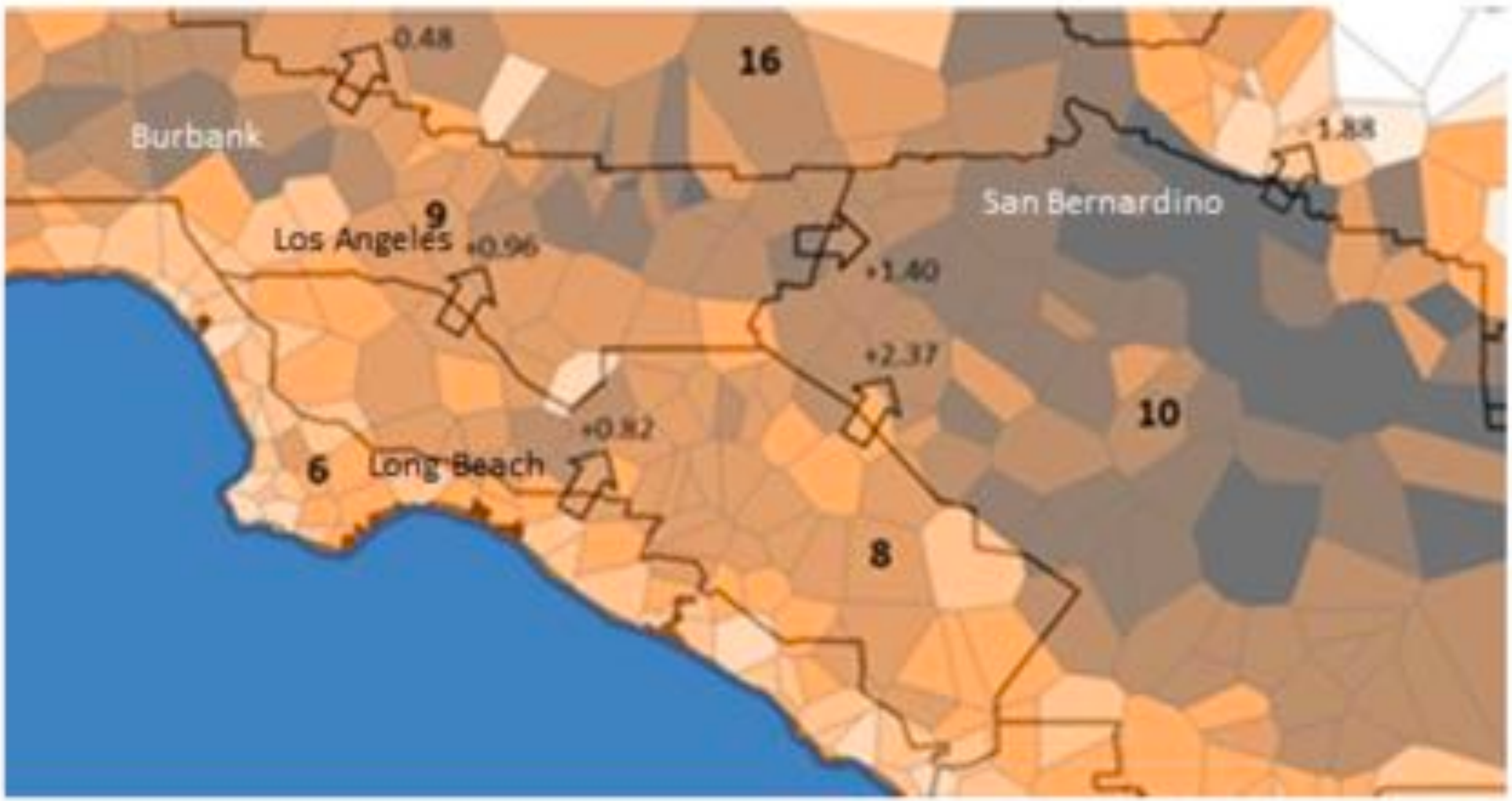
Future Weather Files:
Dynamic Downscaled Projections

- **UK Climate Projections. Probabilistic, 2.2 km resolution [1]**
- **NARRCAP. 3 hour data for the U.S., requires interpolation. [2]**
- **Altostratus 2019. California climate changes and urban heat island changes.[3]**

1. Met Office, 2021. UK Climate Projections.
2. Schuetter et al., 2014. Future Climate Impacts On Building Design.
3. Altostratus 2021

Future Weather Files:
*Dynamic Downscaled Projections **

Figure 3: Southern California microclimate zones (color coded) created by Altostratus Inc. compared to existing, coarse climate zones (numbered 6,8,9,10,16) used in current energy modeling.



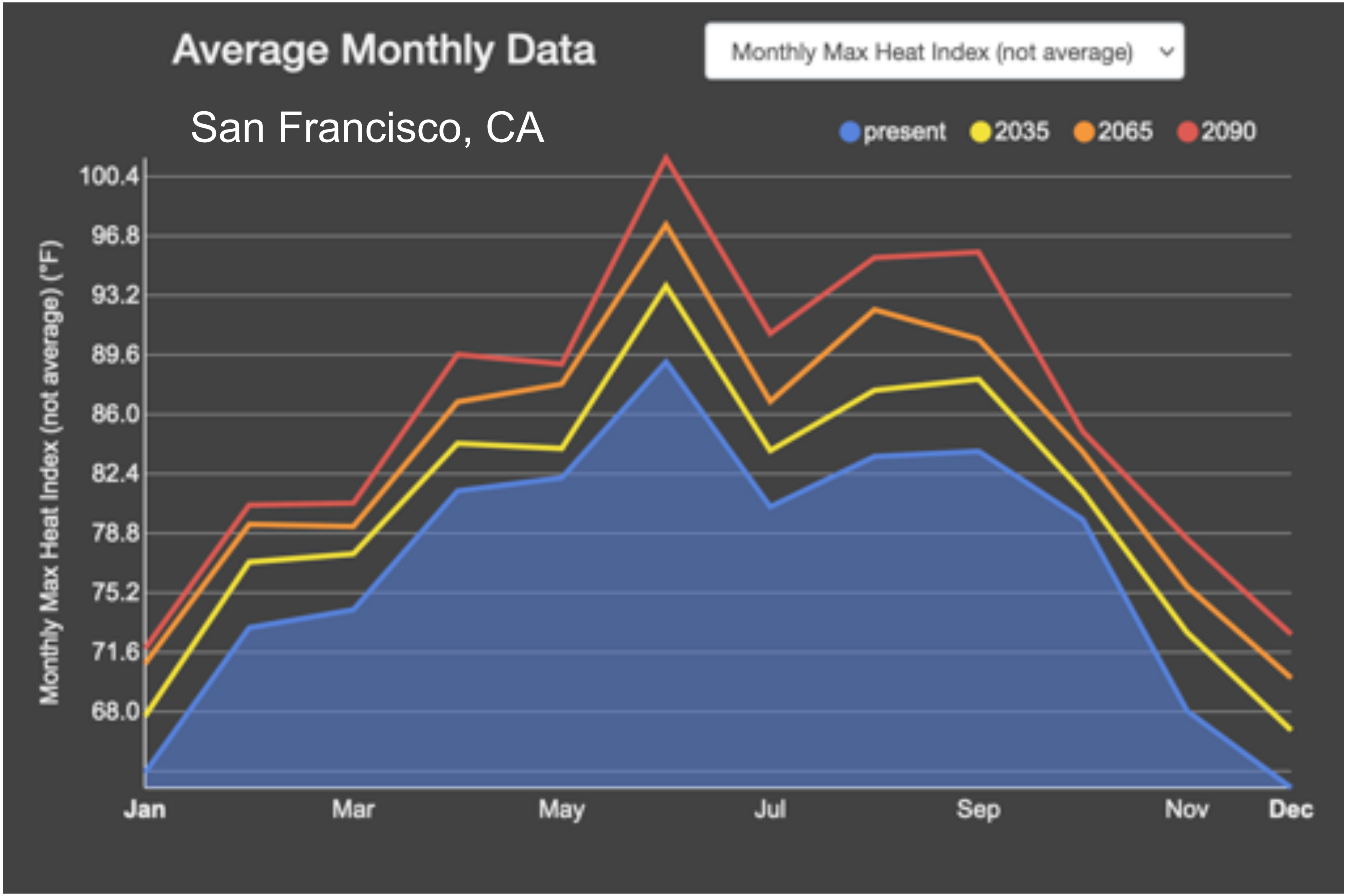
* Taha, 2019. Intraurban Enhancements to Probabilistic Climate Forecasting for the Electric System. California Energy Commission. Publication No. CEC-500-2021-003.

Future Weather Files:
Morphed, Statistical Downscaled Projections

- Climate Change World Weather File Generator. [1]
- WeatherShift. Based on maximum temperature. Fee. [2]
- MeteoNorm. Several weather variables. Monthly averages only. Urban effects for European cities. Fee. [3]
- Pacific Climate Impacts Consortium. All weather variables; all of Canada. [4]
- CSIRO, 2021. 83 locations in Australia, for building design and energy rating. [5]
- Epwshiftr R package, 2021. Uses CMIP6 climate model data.[6]

1. University of Southhampton, 2013. CCWorldWeatherGen.
2. Arup, 2021. Weathershift: Heat.
3. MeteoNorm, 2021. Version 8.
4. Pacific Climate Impacts Consortium (PCIC), 2020. Future weather files.
5. CSIRO, 2021. Predictive weather files for building energy modelling
6. Jian & Chong, 2021. epwshiftr: Create future EnergyPlus Weather files using CMIP6 data

Future Weather Files:
*Morphed, Statistical Downscaled Projections **



* **Weathershift. Heat projections. San Francisco.**

Extreme Weather Files:
Historical "Stress Test"

- **Historical Heat Waves**
- **Design Summer Year (DSY)**
  and Summer Reference Year (SRY)
- **Extreme Meteorological Year (XMY)**
- **Review of weather file types for future building simulation at Herrera et al., 2017**

Examples of Overheating Assessments and Climate Adaptation

90% by 2050 in New York City

Feasible Low Carbon Measures by Building Retrofits

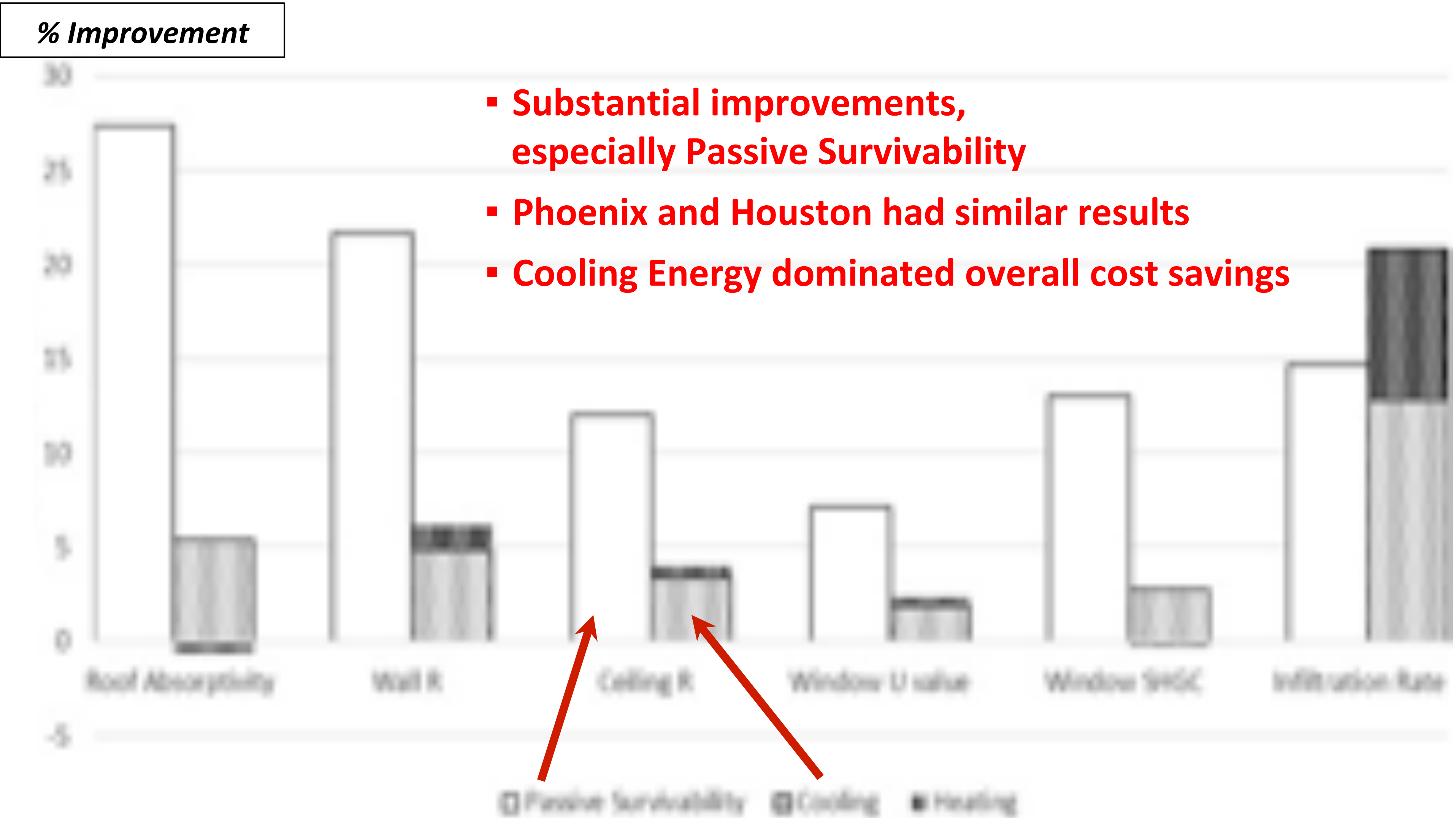
Table 4.1: Building Shell and HVAC Measures

Building Type	Airseal and isolate dwelling units, provide ERV	Airseal building, provide ERV	Lower vision glass to 50% max.	Increase insulation on opaque areas	Triple glaze all windows	Add 3' sunshades to south windows	Mini-split heat pumps	Ground source heat pumps	DHW heat pump operating in conditioned space	Heat recovery for DHW on air conditioners
1 or 2 Family House	✓			✓	✓	✓	✓		✓	✓
Row House	✓			✓	✓	✓	✓		✓	✓
Low Rise Residential	✓			✓	✓	✓	✓		✓	✓
Masonry High Rise Residential	✓			✓	✓	✓		✓	✓	✓
Window Wall High Rise Residential	✓			✓	✓	✓	✓		✓	✓
Low Rise Commercial		✓		✓	✓	✓		✓	✓	✓
Masonry High Rise Commercial		✓		✓	✓	✓		✓	✓	✓
Curtain Wall High Rise Commercial		✓	✓	✓	✓	✓		✓	✓	✓

Urban Green Council, 2013. 90 by 50. Cost estimate included.

Improvements in Passive Survivability (Degree Hours > DI 28 C) and Heating & Cooling ($): Phoenix, Older Building

- Substantial improvements, especially Passive Survivability
- Phoenix and Houston had similar results
- Cooling Energy dominated overall cost savings



Adapted from Baniassadi and Sailor, 2018.
https://doi.org/10.1016/j.buildenv.2018.01.037.

Climate Adapted, Low Income Housing in Australia

- Pathway to Climate Adapted and Healthy Low Income Housing
  - 10 housing typologies: single & multifamily, high and low rise
  - Literature review of intervention methods for heat stress
  - Climate Vulnerability and heat risk assessment
  - Thermal performance of building types was modeled for 2009 heat wave weather



Barnett et al., 2013. Pathway to Climate Adapted and Health Low Income Housing. CSIRO and NCCARF.

✔'Worst case' scenario resulted in severe heat-related health risk for 30% of the duration of the 5-day heat wave, on average.

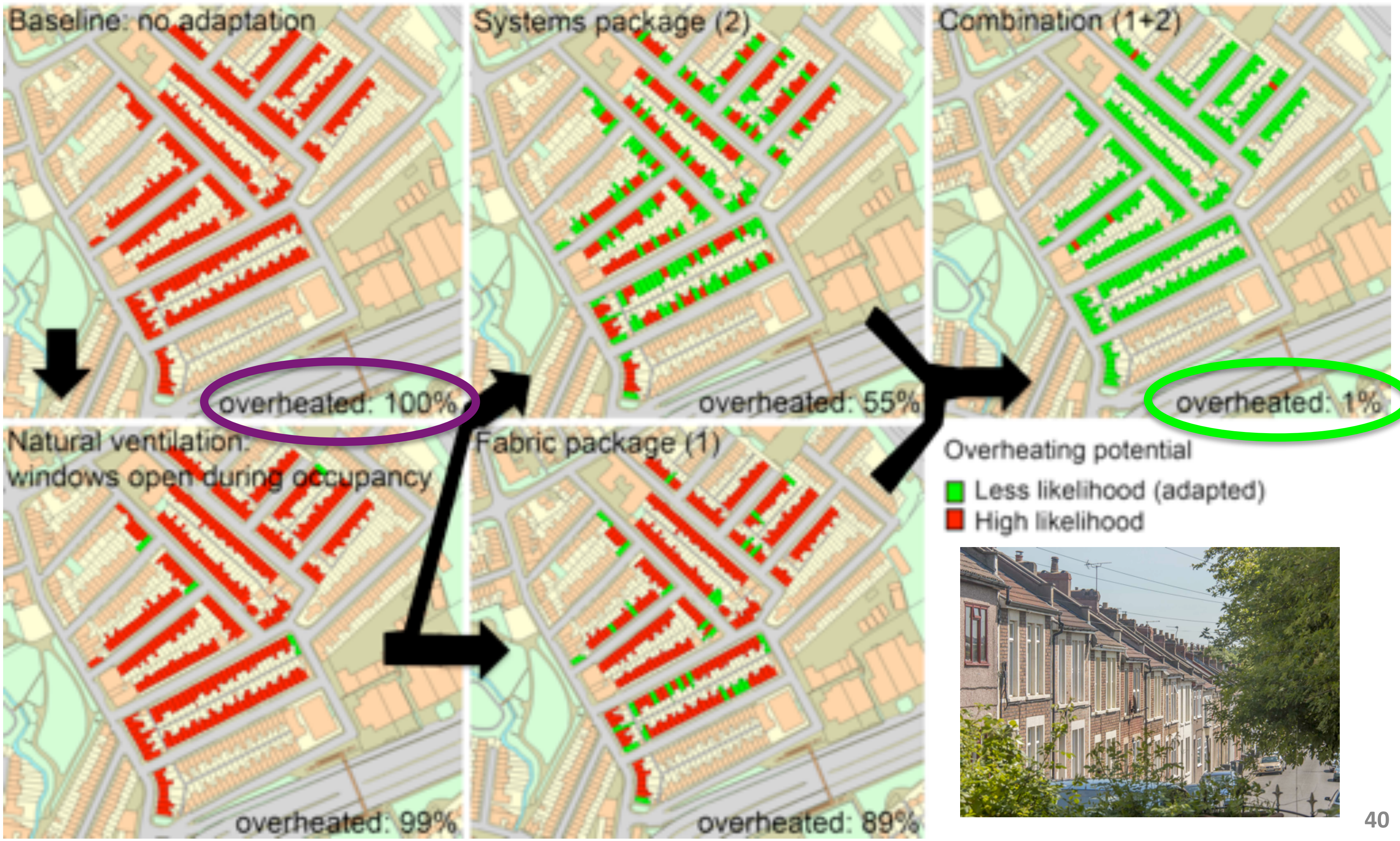
✔Risk could be reduced to 17% and 13% with the cheap retrofit and expensive retrofit, respectively.

Barnett et al., 2013. Pathway to Climate Adapted and Healthy Low Income Housing. CSIRO and NCCARF.

SNACC: Example of Overheating Risk Reduction

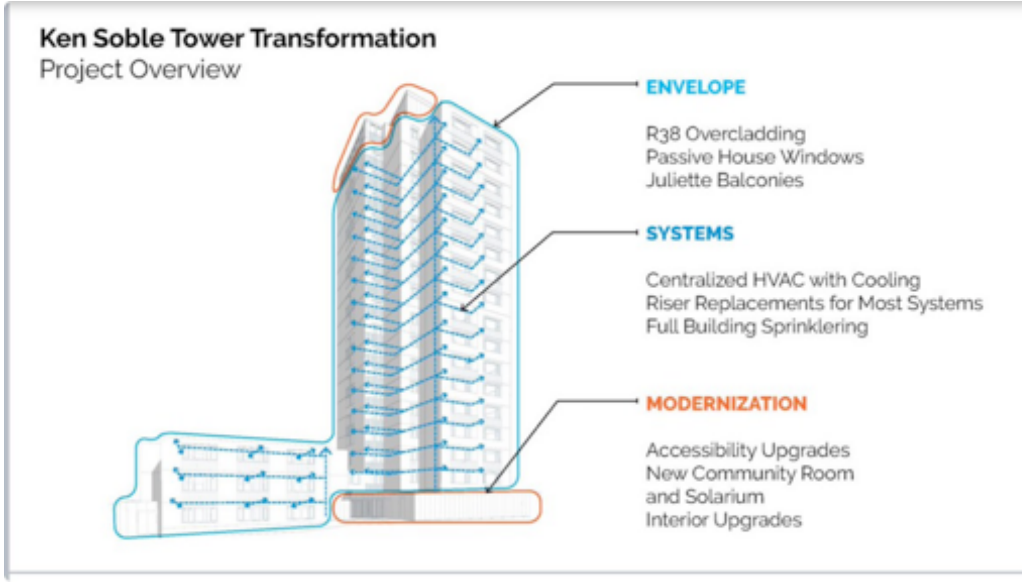
Neighbourhood scale application of the adaptation packages:

Bristol: St. Werburghs (Inner historic suburb)



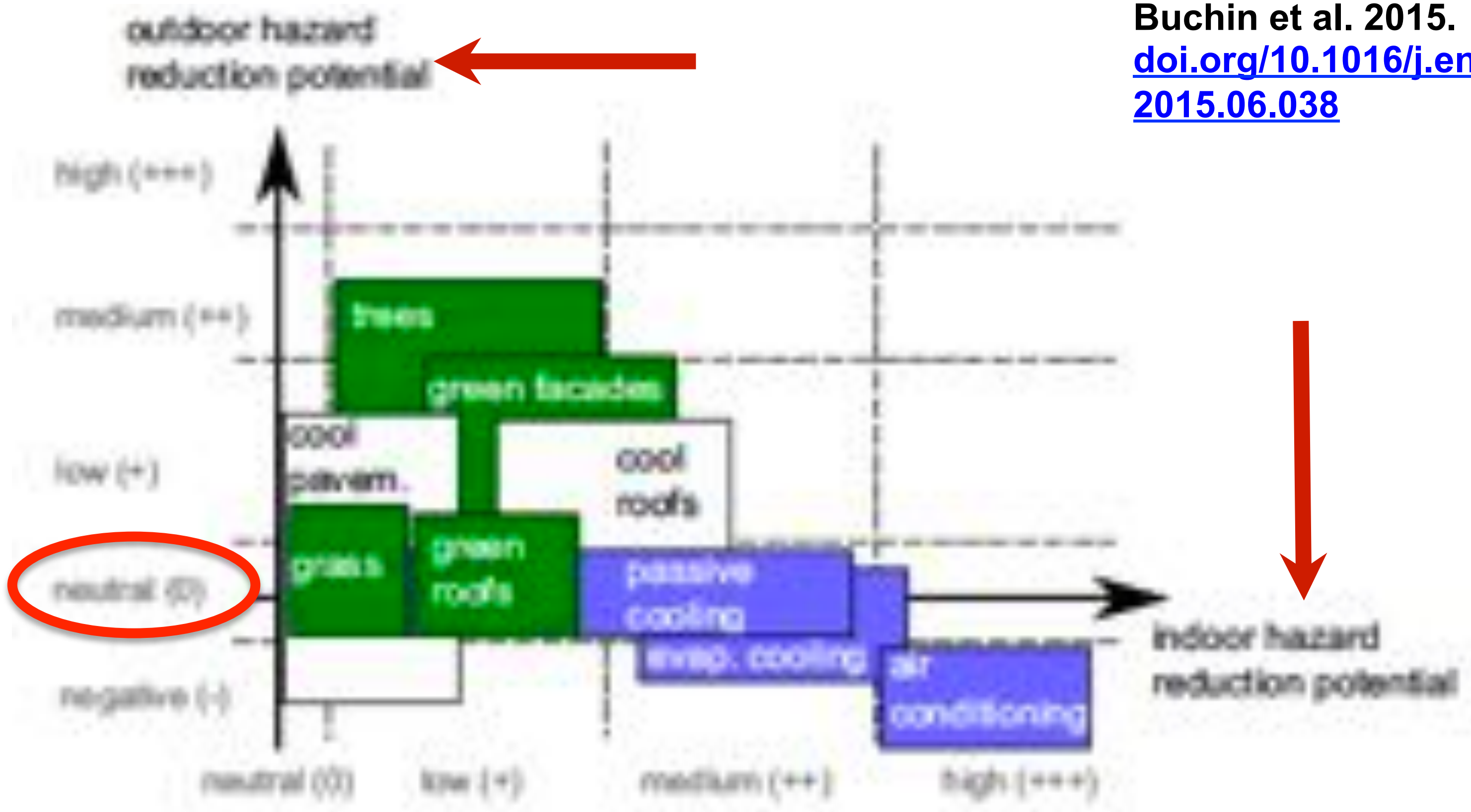
Multifamily Passive House Retrofit: Ken Soble Tower, Hamilton, Ontario [1]

- Designed for a changing climate: Using 2050 temperature projections to test thermal comfort in all seasons.
- Ultra-low energy use: 94% reduction of greenhouse gas emissions compared to the existing building.
- Passive resilience in case active systems fail:
  - ✓ Stays warm in winter for up to two days (vs. 2 hours in a typical building)
  - ✓ Safe heat levels in summer for up to four days (vs. half a day in a typical building).



1. ERA Architects. Ken Soble Tower. Completion 2020. See also: Presentation. June 10, 2020. Passive House Accelerator Happy Hour webinar.

What About:
Urban Greening and Indoor Heat Exposure?



Buchin et al. 2015.
doi.org/10.1016/j.enbuild.2015.06.038

- Few studies have looked at both indoor and outdoor heat mitigation.
- Berlin apartment study: urban greening is not necessarily effective in reducing indoor heat hazard
  - External shades were the most effective passive measure
  - But several building and neighborhood measures were needed to prevent overheating (including mechanical cooling)
  - Passive cooling measures did not have negative effects on outdoor hazard
- New U.S. studies: Mallen et al., GA Tech.; Baniassadi et al., Harvard

Designing Climate Resilient Multifamily Buildings: *British Columbia* [1]

- **Low and High Rise Multifamily: New and Existing archetypes modeled**
- **Thermal comfort assessed and mitigated**
  - ✓ ASHRAE 55 Thermal Comfort metrics,
    ≤ 200-hours above the 80% acceptability limit
    ≤ 20 hours for vulnerable populations
  - ✓ (RCP) 8.5 scenarios for 2020s, 2050s, and 2080s
  - ✓ Heating, cooling, and GHG metrics
- **Power outages modeled**
- **Incremental costs calculated: single measures & bundles**
- **Design strategies recommended for each building type**

1. RDH, 2020. Report to University of British Columbia.

Incremental Cost and Overheating Hours: Existing Low Rise, 2050s RCP 8.5

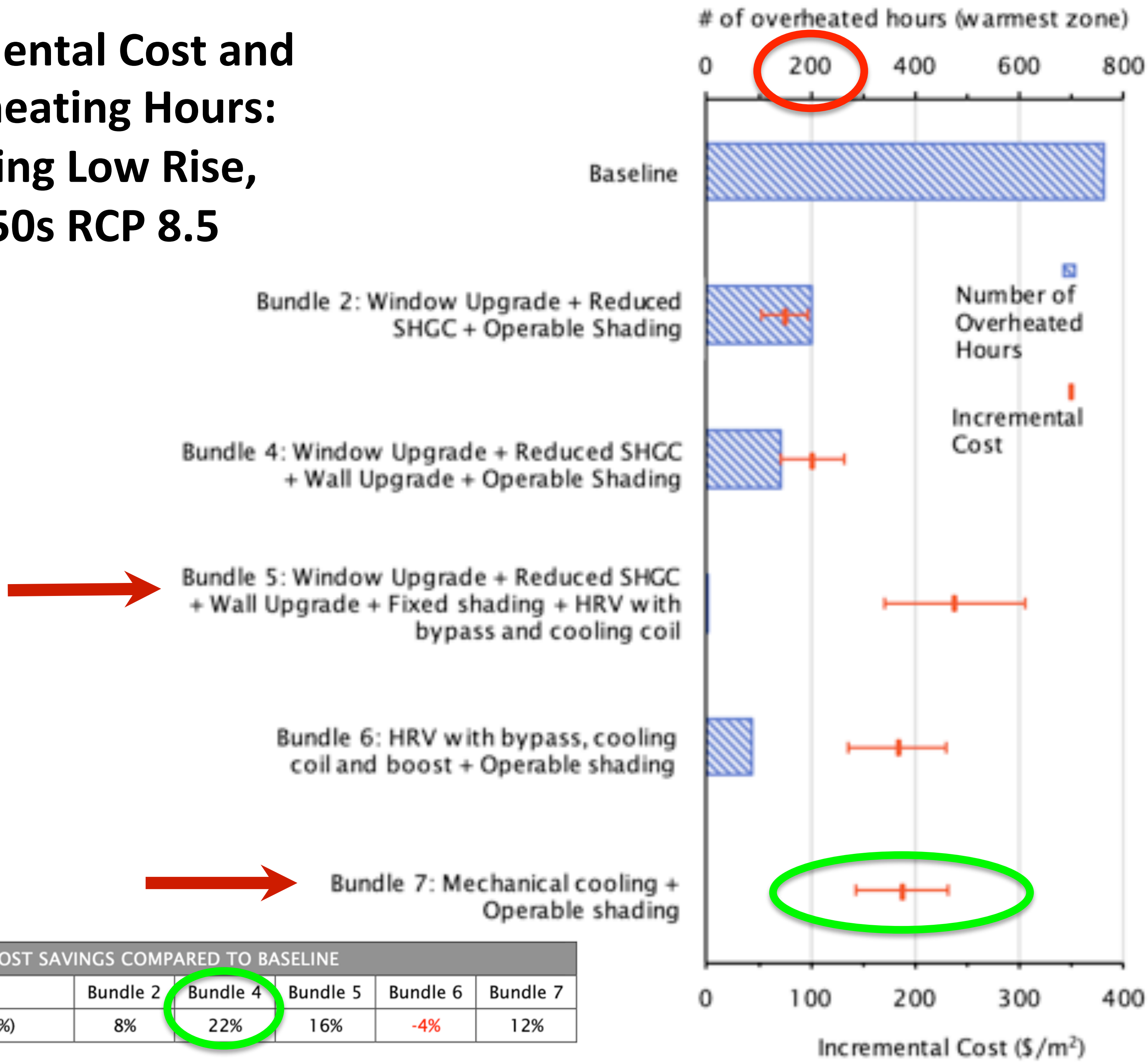


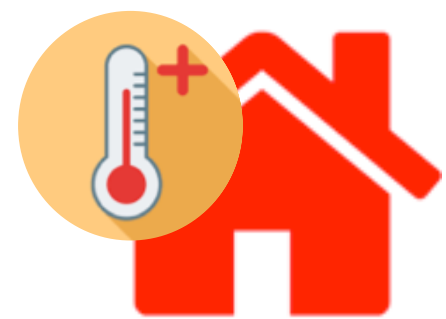
TABLE 0.5 ENERGY COST SAVINGS COMPARED TO BASELINE

	Bundle 2	Bundle 4	Bundle 5	Bundle 6	Bundle 7
Energy Cost Savings (%)	8%	22%	16%	-4%	12%

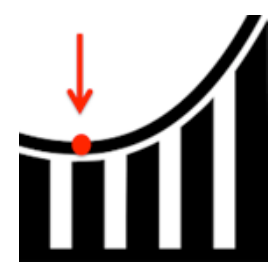
Study Objectives

- Design new single family Zero Net Energy home in Bakersfield, CA (2018 - 2019)

- Examine impacts of heat waves, future climates, and power outages on overheating and energy use



- Optimize design for energy cost (life cycle and TDV), overheating risk, and ultimately carbon emissions



Methods: Modeled Scenarios in CBECC

- CA Climate Zone 13, Fresno (CZ13)
  - *Typical historical weather, used in building standards*
- Bakersfield 2006 Heat Wave (BFL)
  - *Extreme historical case*
  - *Record night and daytime temperatures, Dry Tropical System*
- Future Climate: BFL Analogue cities *(Yuma and Phoenix, Arizona)*
  - *Reasonable worst case re: T and RH*
  - *Wind and solar angle don't match BFL*
- Power Outages for current and future climates
  - *One week in July*
  - *Near-Worst cases (no heat wave)*

- Optimized Design: all scenarios

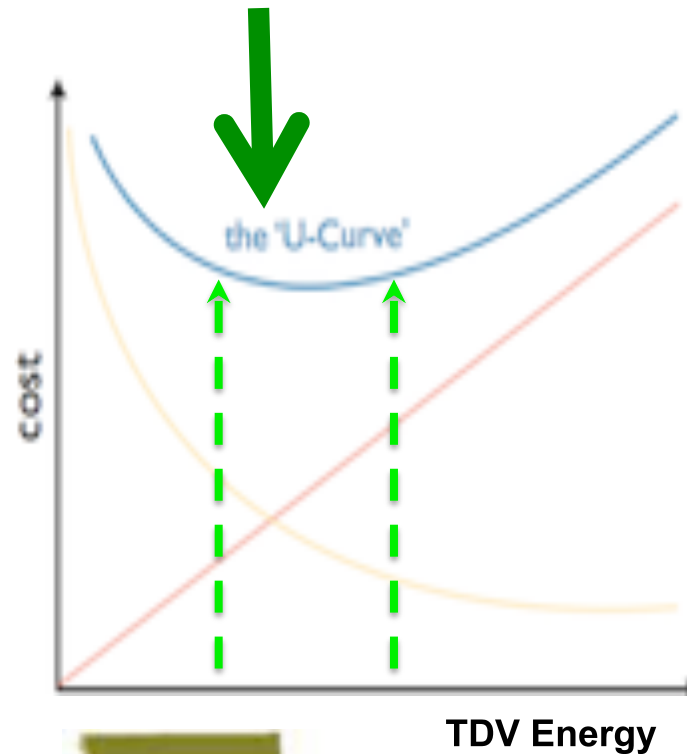
CIBSE Journal, March 2016.

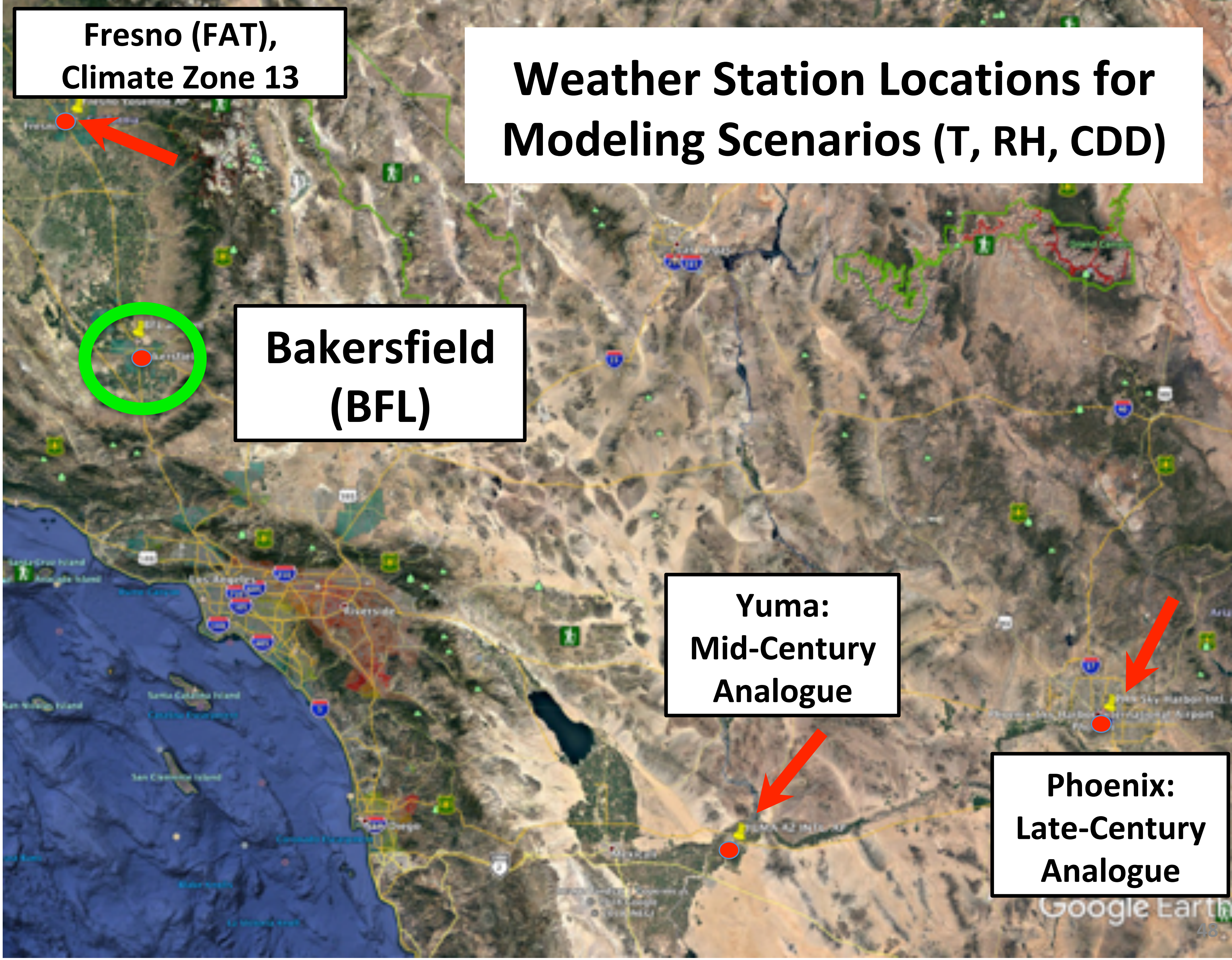
Methods

- **Building Optimization**
  - ✓ BeOpt 2.8.0 model in California Title 24 mode (NREL, free tool)
  - ✓ Optimize Cost vs.
    Time Dependent Value Energy (TDV)
  - ✓ Assess Home Cooling Energy

- **Energy and Overheating**
  - ✓ 2019 CBECC Title 24 Model
  - ✓ Fresno, Climate Zone 13, Mixed Heating and Cooling

- **Future climate in Yuma & Phoenix, AZ**
  - ✓ Similar cooling and heating demand as future Bakersfield, mid & late century, respectively
  - ✓ Cooling will increase about 50 and 100%, respectively, and heating will shrink




Weather Station Locations for Modeling Scenarios (T, RH, CDD)
Fresno (FAT), Climate Zone 13
Bakersfield (BFL)
Yuma: Mid-Century Analogue
Phoenix: Late-Century Analogue
Google Earth

BeOpt Model: Optimizing Multiple Measures

SCREEN related categories: Small groups, several options; Select top 2-3 per group.

↓

OPTIMIZE for TDV and Cooling Site Energy: No PV.

↓

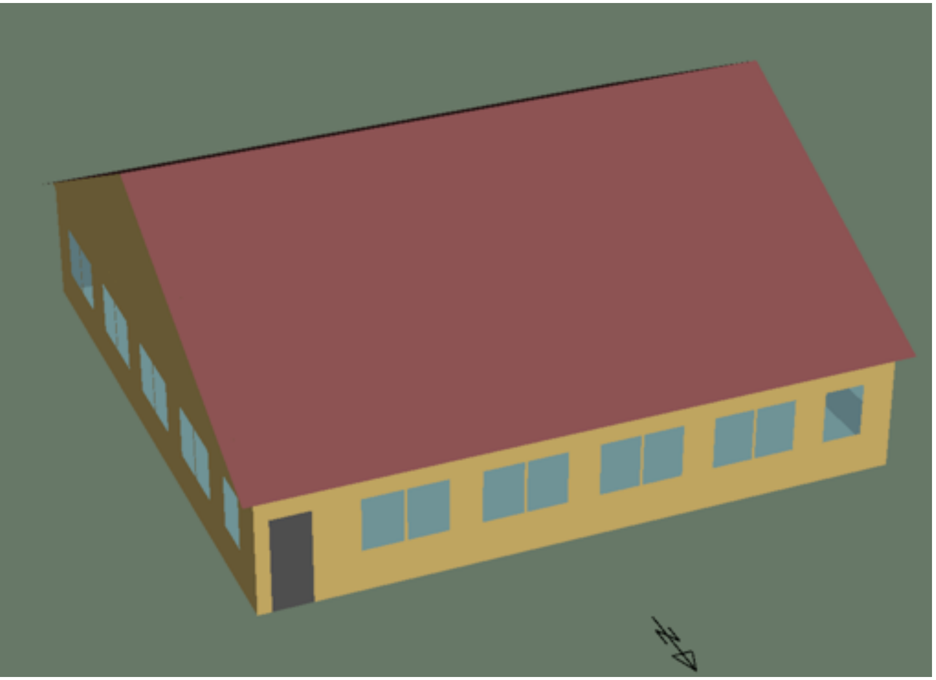
ADD PV for Site Energy need: Test a range of sizes, orientation, & tilt.

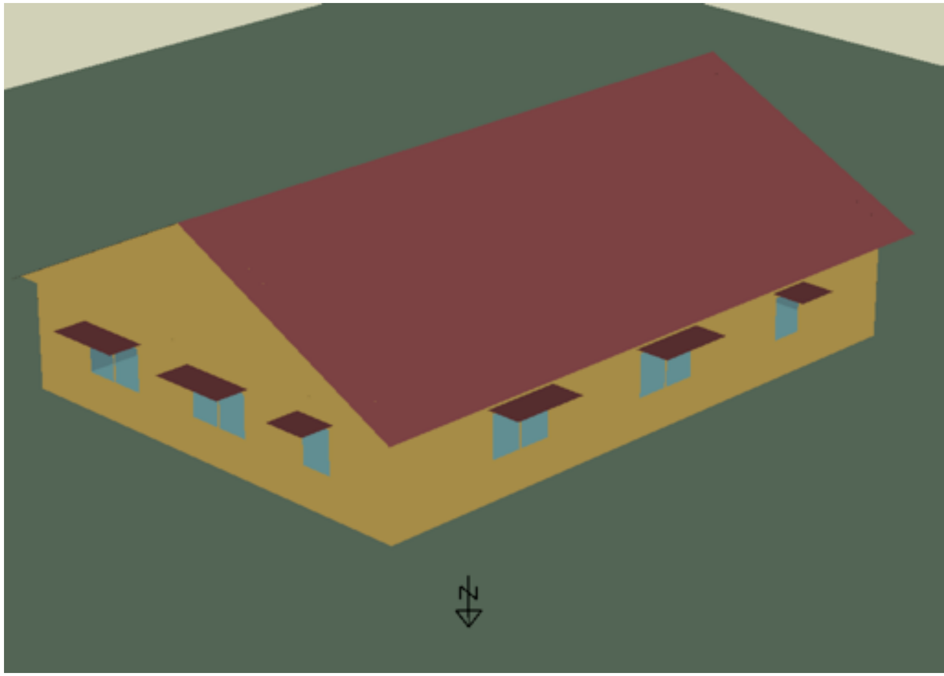
Optimization Categories	
1.	Building Site
2.	Walls
3.	Ceilings/Roofs
4.	Foundation/Floor
5.	Thermal Mass
6.	Windows/Doors/ Shading
7.	Air Flow
8.	Space Conditioning
9.	Water Heating
10.	Lighting
11.	Appliances & Fixtures & Schedules
12.	MISC: plug loads & other appliances
13.	PV

Site Design: Title 24 vs. BeOpt Low TDV

2019 T24 Reference Point:
Windows 105 SF/side, 20% CFA
HPWH, etc.

BeOpt upgrades:
Windows 50 SF/side,
Eaves, overhangs,
Insulation, air leakage,
high SEER Heat Pump, etc.

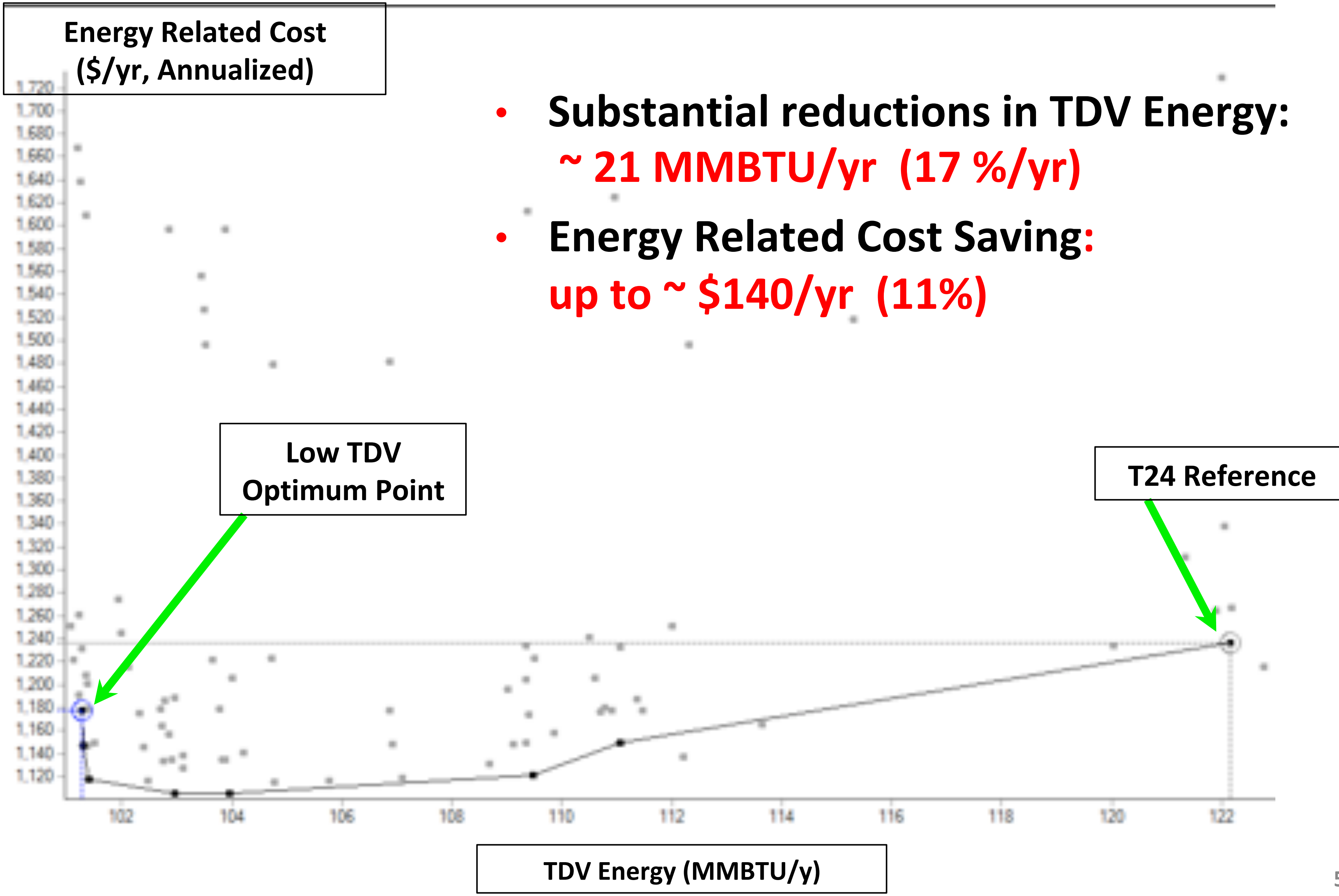




BeOpt Results: Low TDV Case

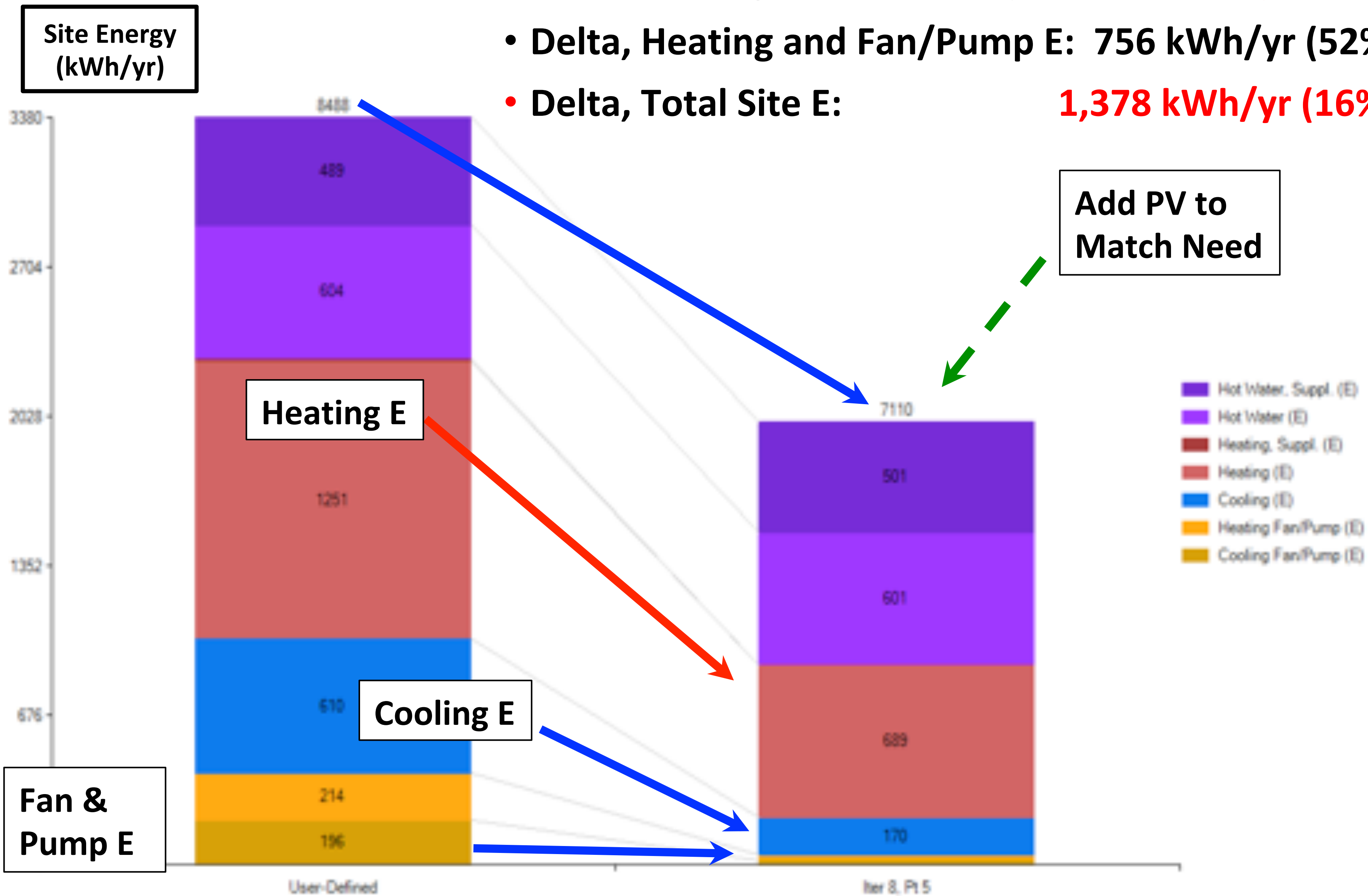
Example: Title 24, HPWH, No PV; Roof, Thermal Mass, and HVAC Options

- **Substantial reductions in TDV Energy:**
  ~ 21 MMBTU/yr (17 %/yr)
- **Energy Related Cost Saving:**
  up to ~ $140/yr (11%)



BeOpt Site Energy Results: T24 2019 Reference vs. Selected Low TDV Point

- Delta, Cooling and Fan/Pump E: **618 kWh/yr (77%)**
- Delta, Heating and Fan/Pump E: 756 kWh/yr (52%)
- Delta, Total Site E: **1,378 kWh/yr (16%)**



Energy and Overheating Results (CBECC)

Overheating: Metrics for Public Health

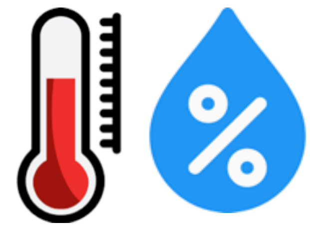
Discomfort Index

*DI = (0.5 * T dry bulb) + (0.5 * T wet bulb)* [1]

Target: ≥ 22 °C (71.6 °F) Mild[2]

≥ 24 °C (75.2 °F) Moderate [2]

≥ 28 °C (82.4 °F) Severe [2]



Wet-Bulb Globe Temperature (WBGT)

WBGT = (0.7 * T wet bulb) + (0.2 * T black globe) + (0.1 T dry bulb) [3]

Target: ≥ 18 °C (64.4 °F) Moderate

≥ 23 °C (73.4 °F) Strong

≥ 28 °C (82.4 °F) Very Strong

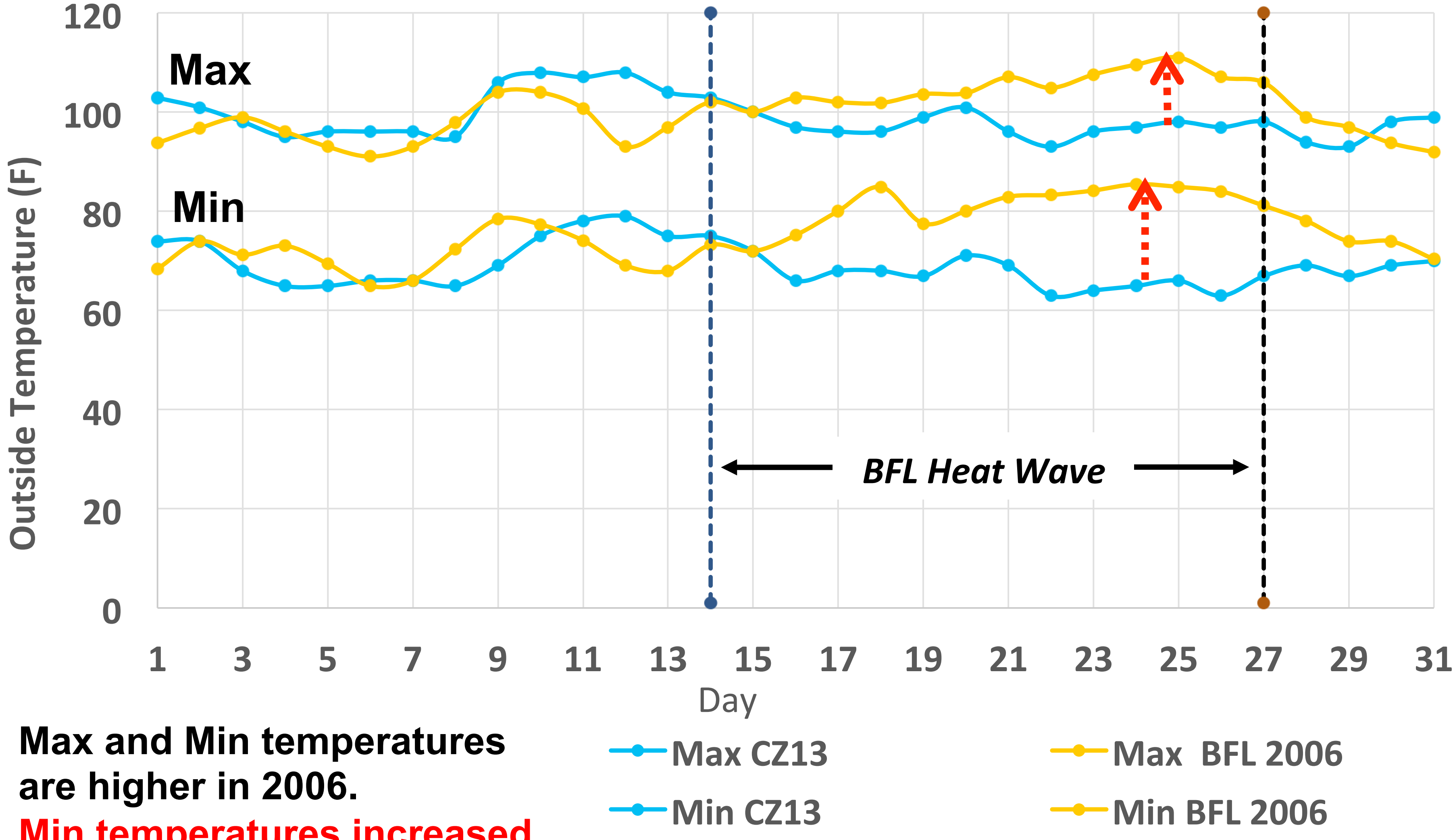
Operative Temperature

OT = (T dry bulb + T radiant)/2

Target: 78.8 °C (82.4 °F) [3]

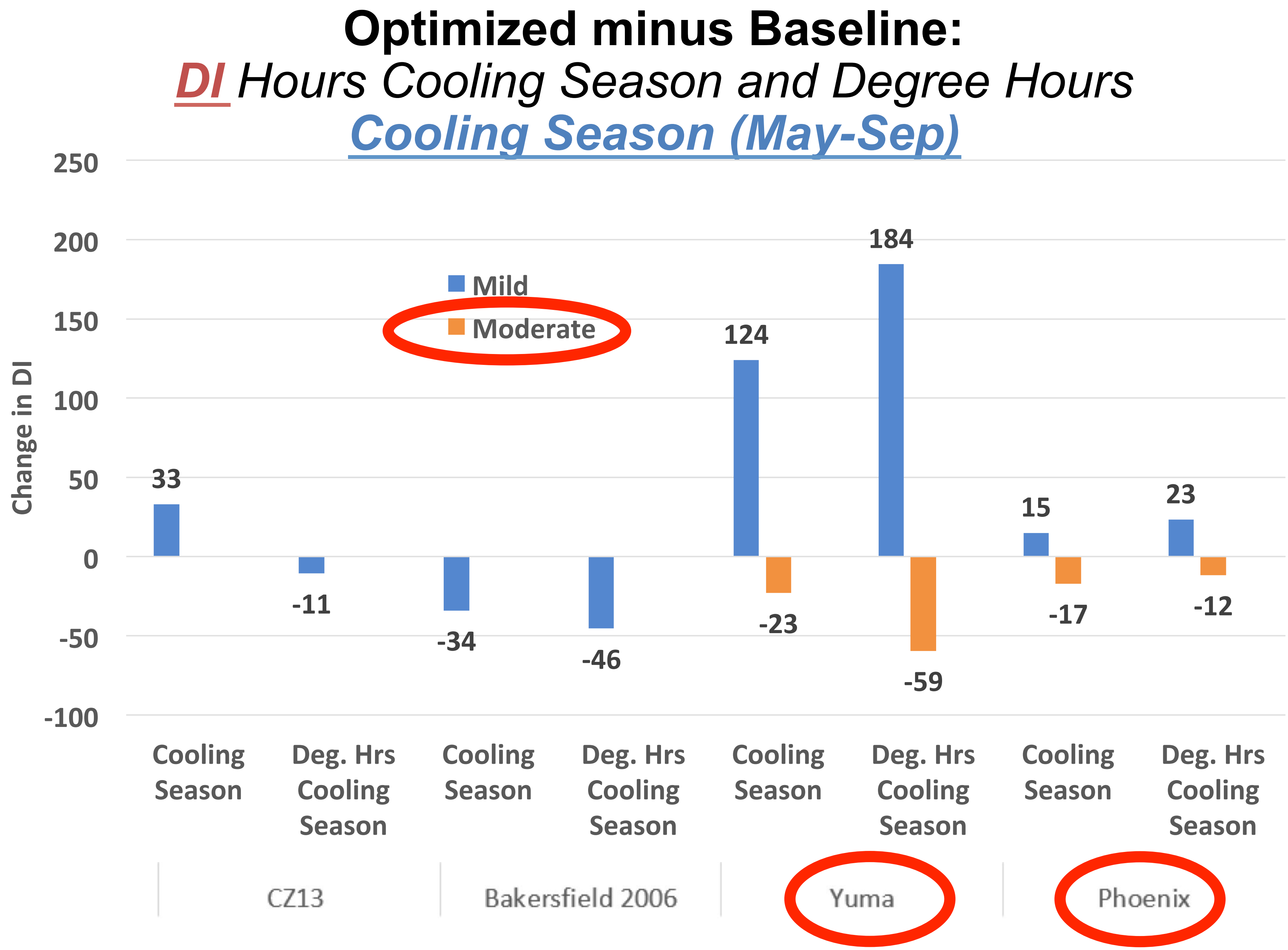
1. Baniassadi, A. and Sailor, D. (2018)
2. Epstein, Y. and Moran, D. (2006)
3. Holmes, S., Phillips, T. and Wilson, A. (2016)

The importance of weather files:
Typical Met. Year (TMY3) vs. 2006 Heat Wave



Max and Min temperatures are higher in 2006.

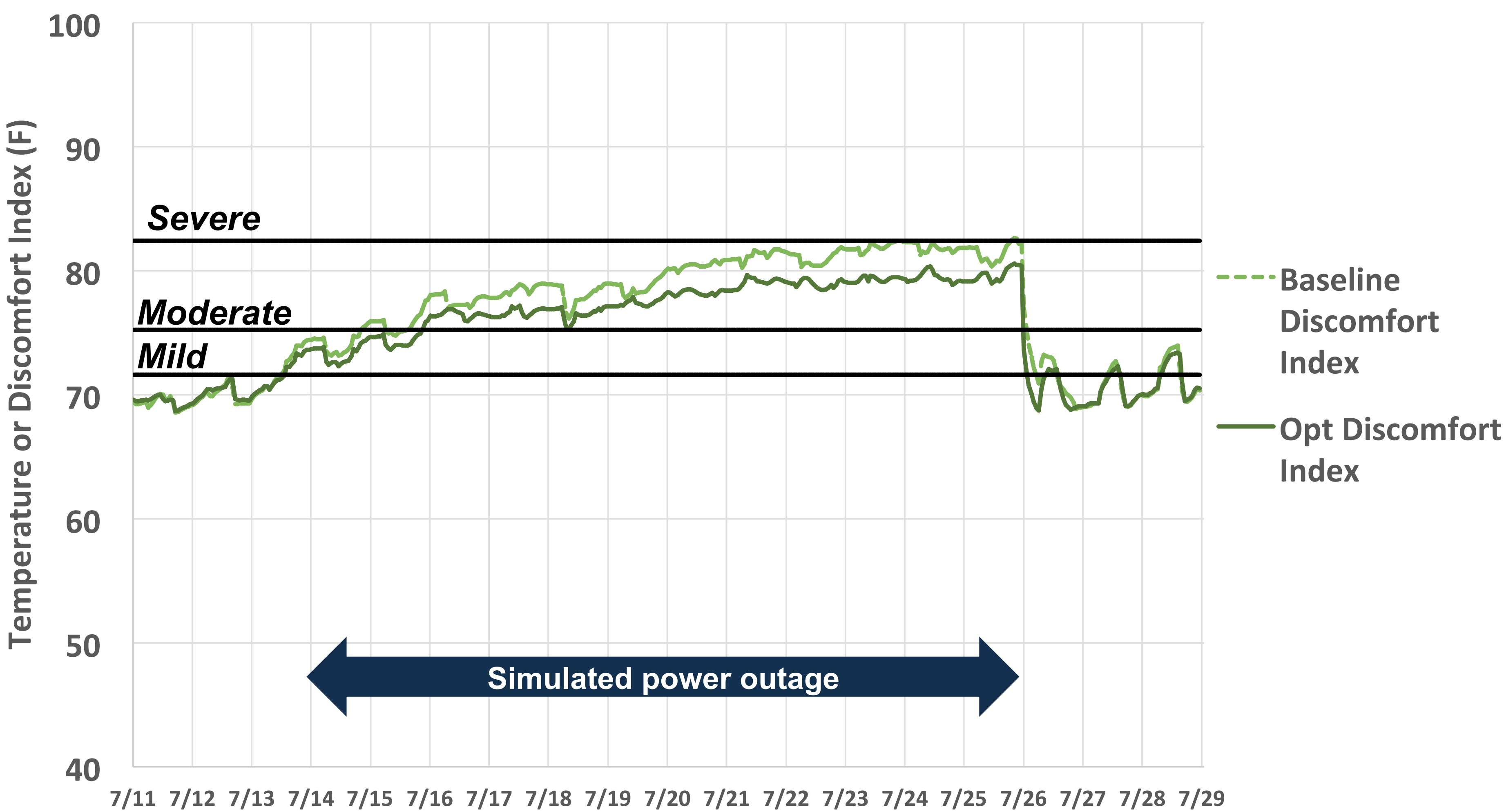
Min temperatures increased more than Max.



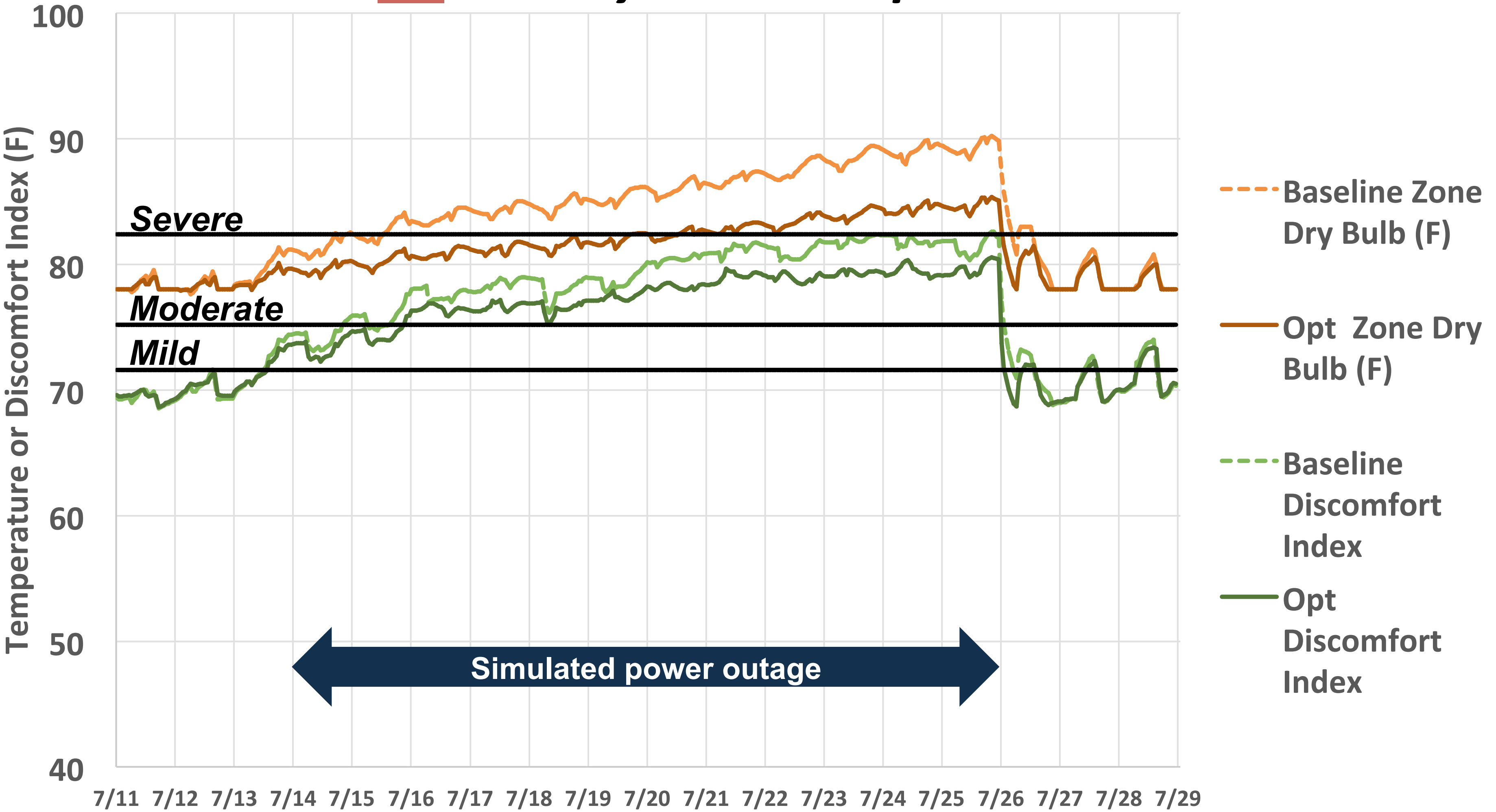
Optimized minus Baseline:
DI Hours Cooling Season and Degree Hours
Cooling Season (May-Sep)
250
200
150
100
50
0
-50
-100
Change in DI
Mild
Moderate
33
-11
-34
-46
124
-23
184
-59
15
-17
23
-12
Cooling Season
Deg. Hrs Cooling Season
Cooling Season
Deg. Hrs Cooling Season
Cooling Season
Deg. Hrs Cooling Season
Cooling Season
Deg. Hrs Cooling Season
CZ13
Bakersfield 2006
Yuma
Phoenix

Bakersfield 2006 heat wave during a power outage

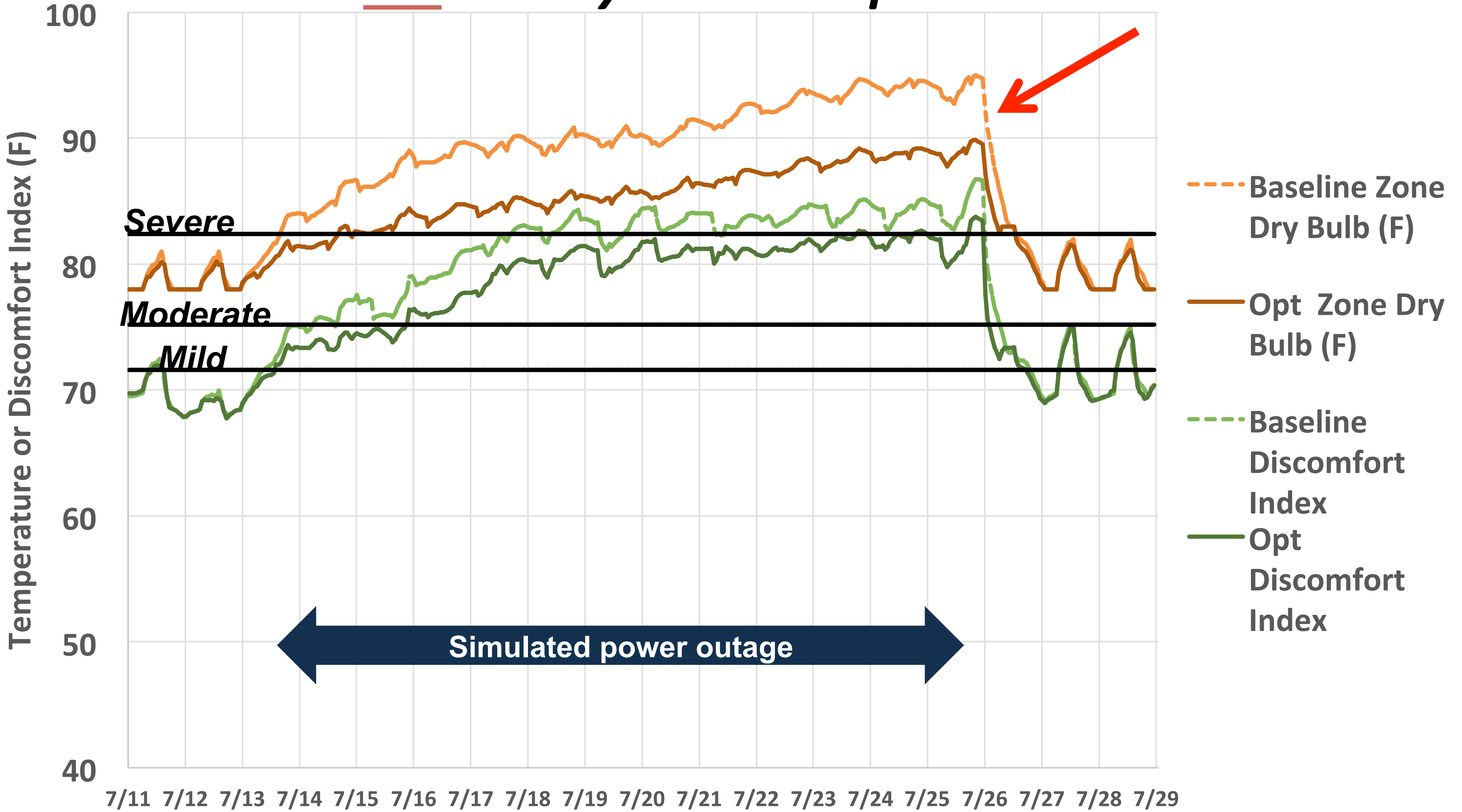
Baseline vs. Optimized: DI



Bakersfield 2006 heat wave during a power outage
Baseline vs. Optimized:
DI and Dry Bulb Temperature

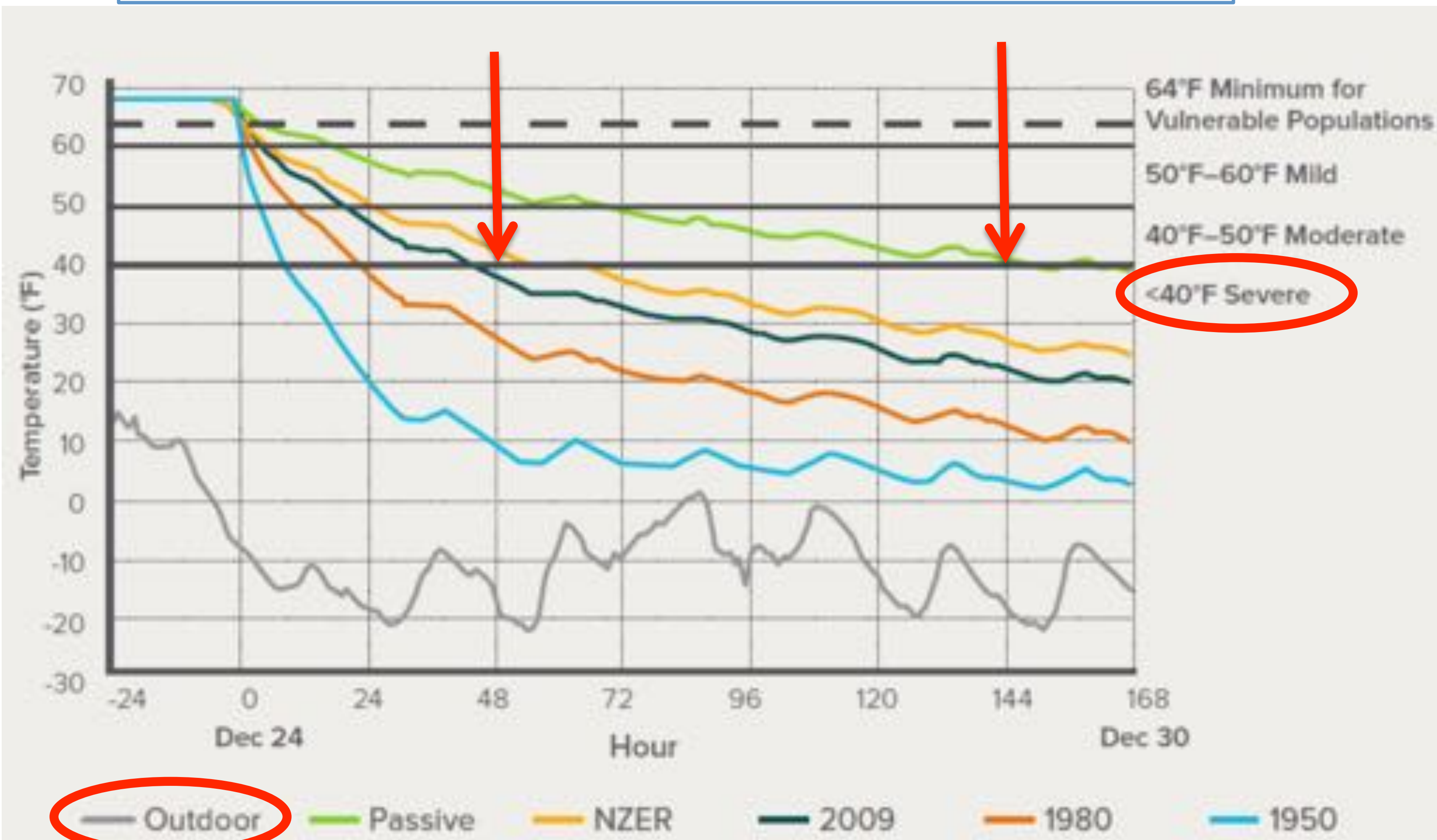


Phoenix during a power outage
Baseline vs. Optimized:
DI and Dry Bulb Temperature



Hours of Safety in Cold Wave

Time to reach Severe cold stress after power outage:
About 2 days for Net Zero Energy Ready and 2009 homes.
6 days for a Passive House (2 days for Vulnerable Populations).



RMI and Redwood Energy, 2020. Modeling of home types in Duluth, MN, during polar vortex and power outage.
https://rmi.org/insight/hours-of-safety-in-cold-weather/

CONCLUSIONS

- **Modeling and measurement tools are available to assess and mitigate overheating and energy impacts of climate change, and to keep buildings healthy and resilient (survivable)**
- **Overheating prevention is active in the UK, and is spreading in Canada and now Australia. China is very active in research on overheating issues.**
- **Federal, state, and local funding for climate action should be pursued**
- **We must integrate climate adaptation to extreme heat into all building programs & policies -- NOW.**

IR camera finds thermal leaks

ARCC, 2017. Bicester NW EcoDevelopment. Fact sheet and Master plan Final Report (2013).

RECOMMENDATIONS

Provide and promote future proof, healthy, and resilient buildings that adapt to and mitigate climate change, especially for extreme heat – at local, state & national levels

- ✔ **Assess climate vulnerability to extreme heat using future weather files, and design for full life cycle optimization and phasing. Use extreme, hot summer, or heat wave weather files if necessary.**
- ✔ **Include passive cooling measures in retrofit and new construction programs, targeting heat vulnerable populations**
- ✔ **Future proof government buildings and schools**
- ✔ **Update building standards and design guidelines now**

- ✔ **Educate, integrate, and train building, planning, & health professionals (Health in All Policies)**
- ✔ **Accelerate market demand through improved financing, incentives, demonstrations, and marketing for future proof, resilient buildings**

THANK YOU FOR YOUR ATTENTION !

Thought For the Day:

BE PREPARED

for Extreme Heat

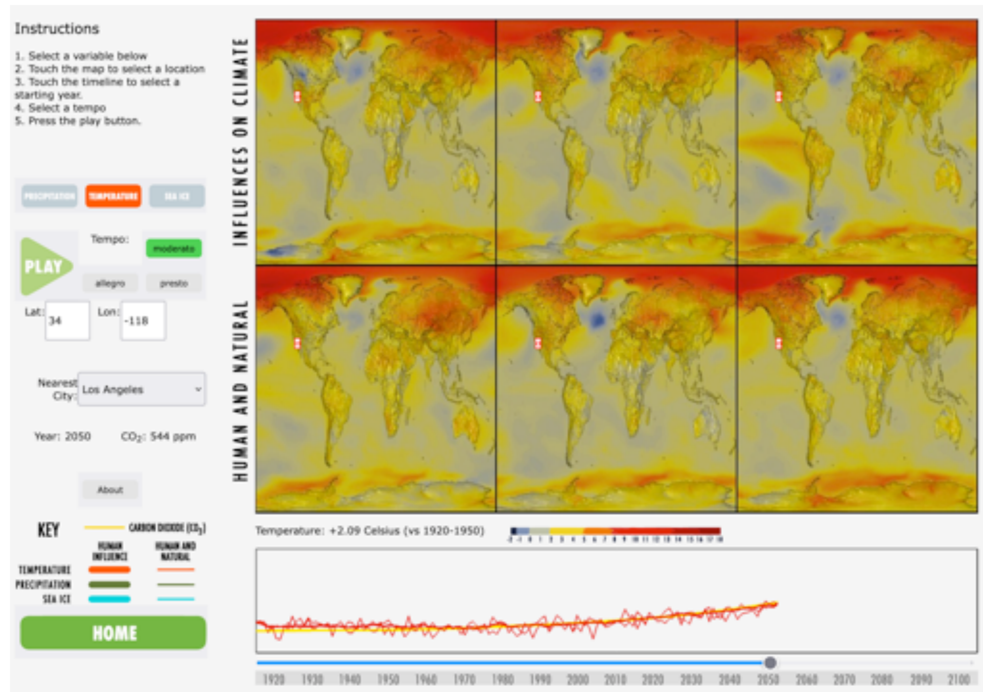
Contact Information

Tom Phillips, Healthy Building Research
tjp835@gmail.com

Emily Higbee, Redwood Energy,
higbee.emily@gmail.com

Music For the Day:

Sounds of Global Warming



UCAR, 2022. Sounding Climate Exhibit. Temperature, Precipitation, Sea Ice, CO2, 1920 – 2100. Various cities.

Video will be posted at Conference web site for 6 months.
Slides available on request.

Video from UCAR Sounding Climate Exhibit was spliced in:
Temperature & CO_2 for Los Angeles,
Allegro sound, Starting at 1980
Recorded using Zoom/Share/Advanced/Computer Audio to run
Go to:
https://listentoclimatechange.com/?utm_source=UCARSciEd+/+UCARConnect&utm_campaign=85eca77311-EMAIL_CAMPAIGN_2022_01_10_05_30&utm_medium=email&utm_term=0_ac2bdeb744-85eca77311-176688641

Tutorial for NCAR interactive exhibit
https://scied.ucar.edu/exhibits/sounding-climate
Human vs. natural effects can be shown separately