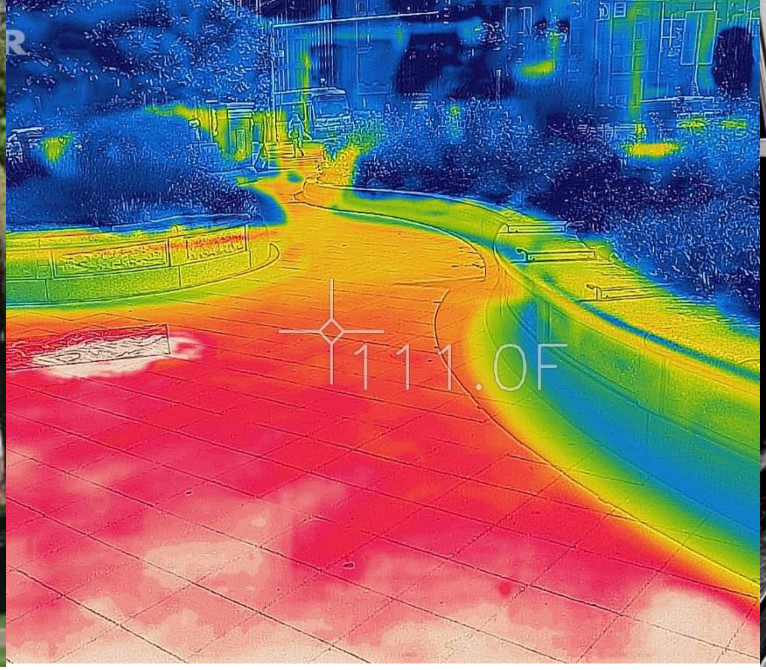


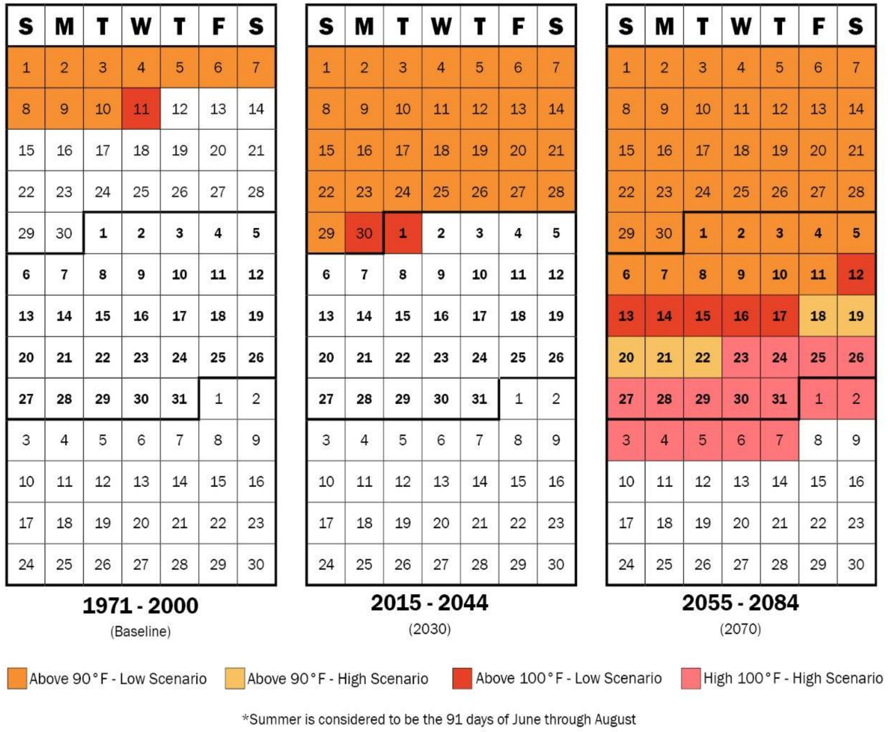
Climate Change & Urban Heat in Cambridge

City of Cambridge
June 26, 2019

Climate Resilience Zoning Task Force

KLEINFELDER
Bright People. Right Solutions.

Increasing Heat: Warmer Averages, Greater Extremes, More Heat Waves

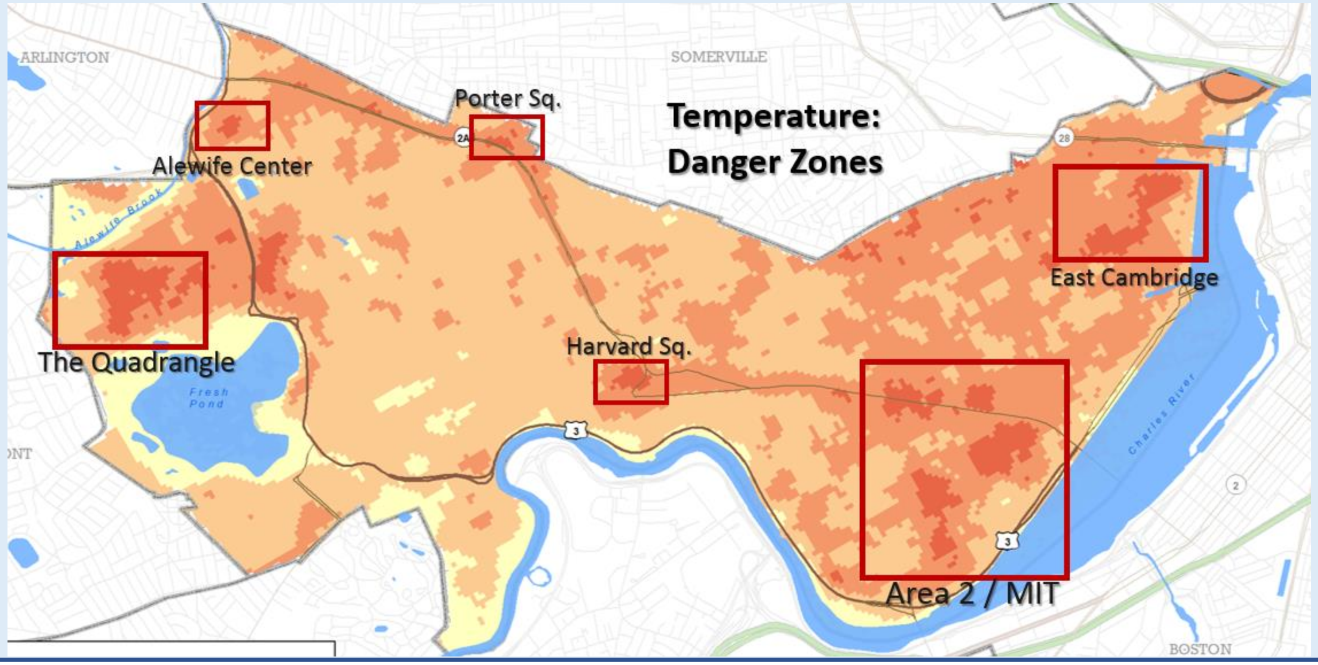


By 2030, the number of days above 90^{o} F could triple

- Stress on human health
- Stress on infrastructure

Urban Heat Island Effect Magnifies Ambient Temperature

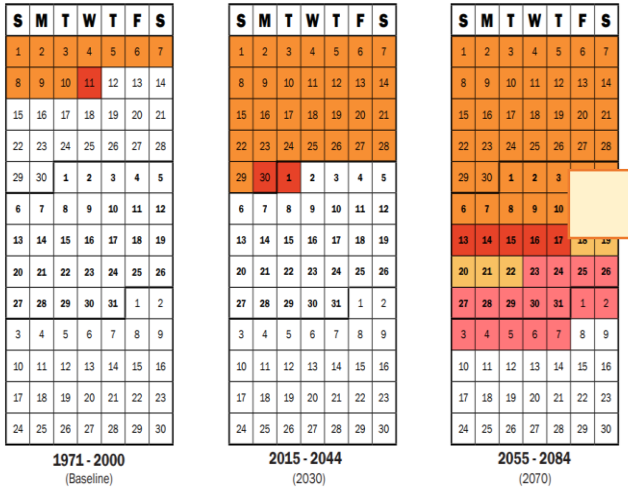
- Darker impervious surfaces – pavement & roofs -- absorb heat
- Areas with large amounts of impervious surface and lacking tree canopy tend to be heat islands

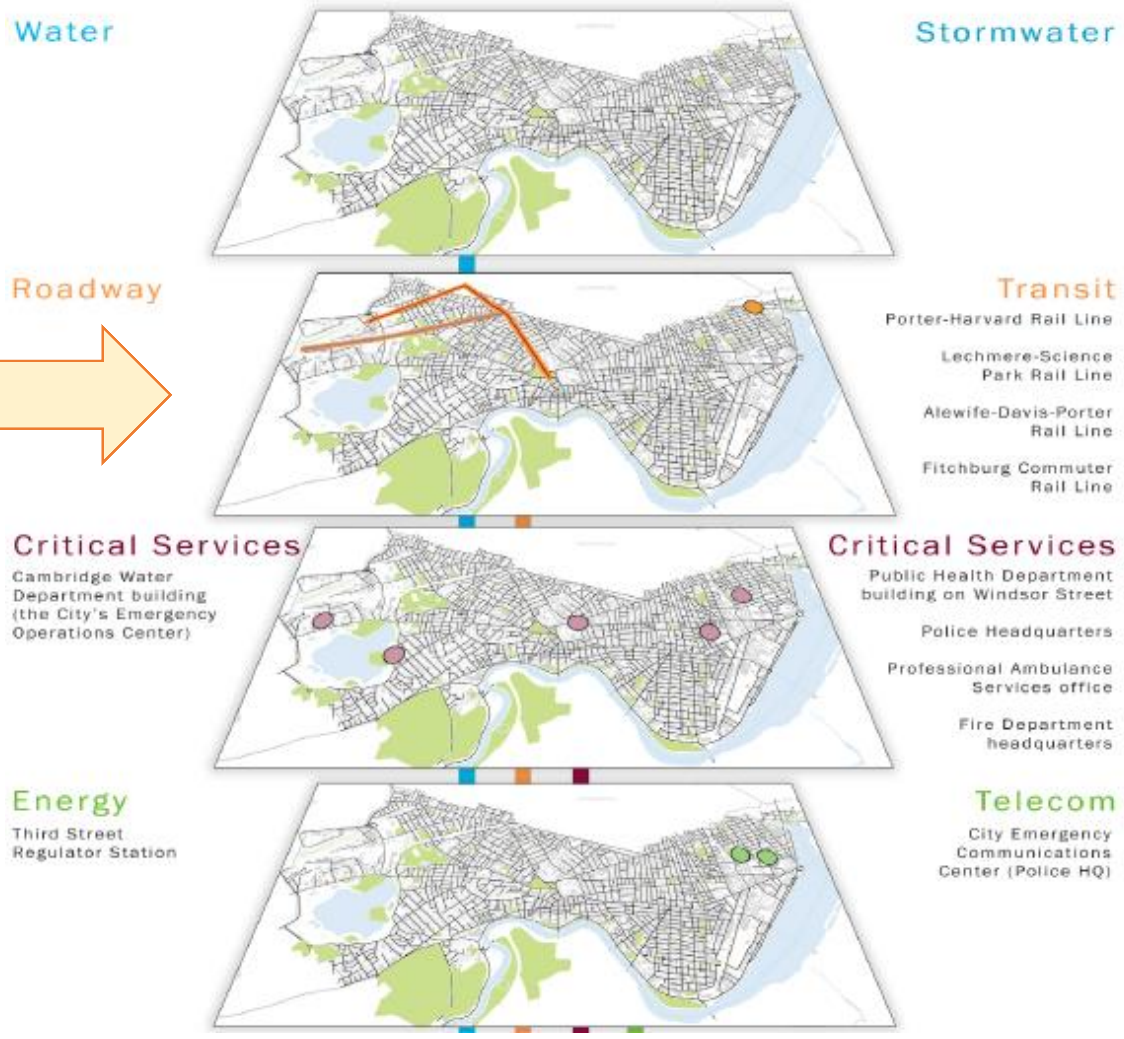


How Can Municipalities Plan for Greater Resiliency to High Temperatures?

Objectives:

1. Identify vulnerabilities to increasing heat if no changes made
2. Understand better how Cambridge's urban form influences temperatures and how it could be modified





Source: CCVA Part 1,November 2015, *http://www.cambridgema.gov/CDD/Projects/Climate/climatechangeresilianceandadaptation.aspx*

Translating Heat Index to Human Health Impacts

NOAA National Weather Service: Heat Index

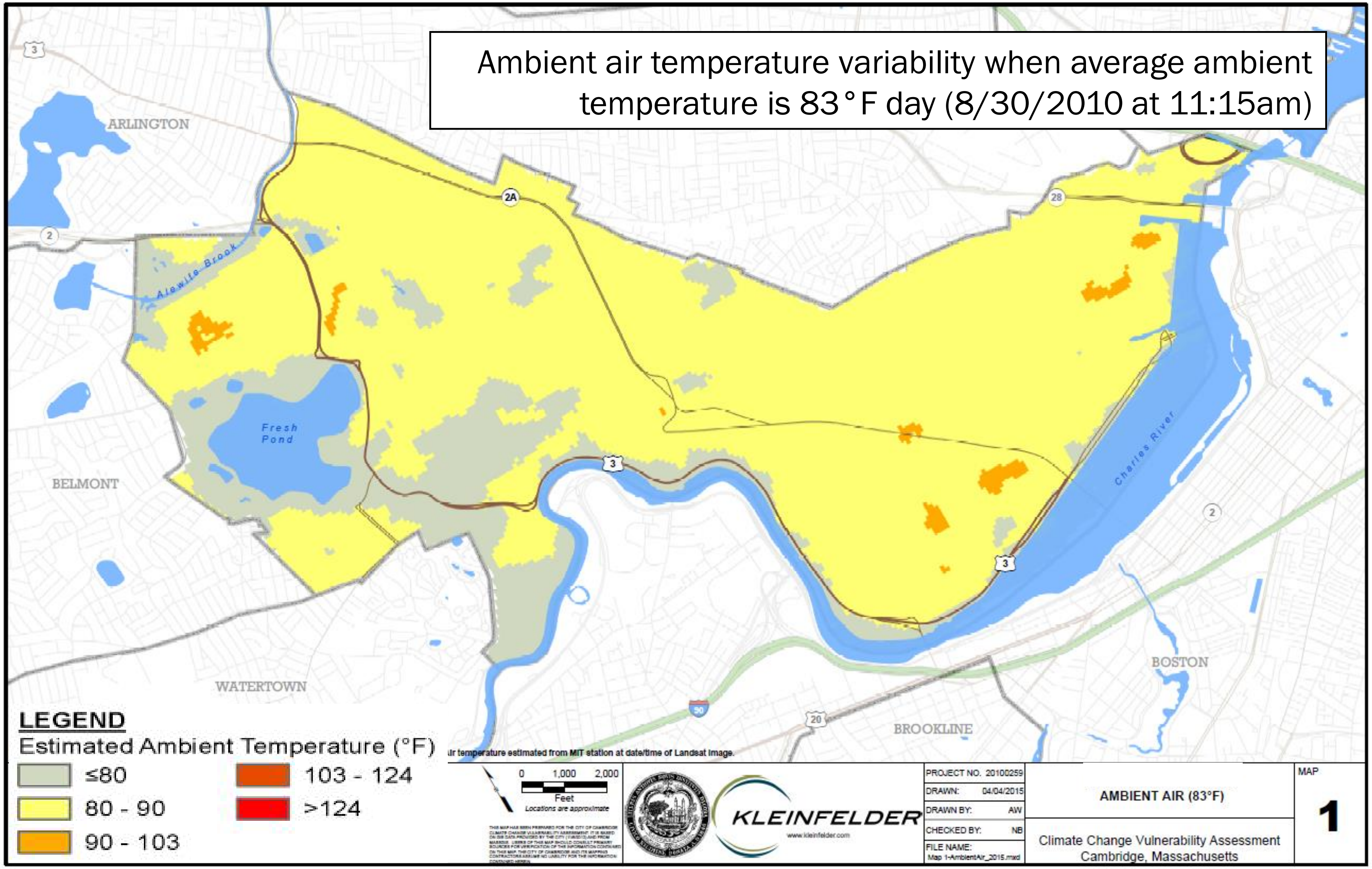
TEMPERATURE (°F)

Relative Humidity (%)	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Caution	**Fatigue**
Extreme Caution	**Heat exhaustion possible**
Danger	**Heat exhaustion likely; heat stroke possible**
Extreme Danger	**Heat stroke likely (death or permanent damage)**

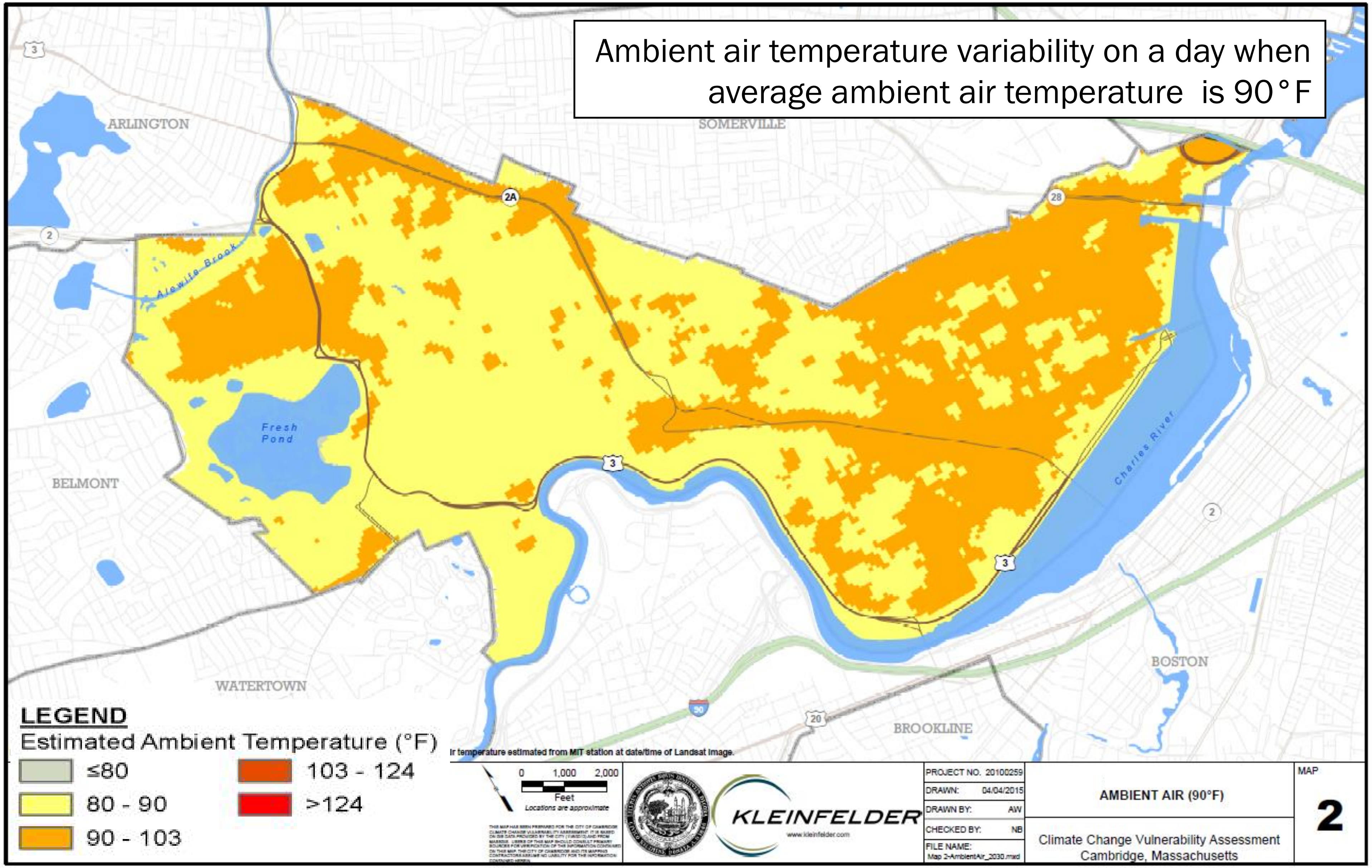
Humidity Exacerbates Heat Impact on Human Health

Ambient Air Temperatures with UHI Effect - 83°F day

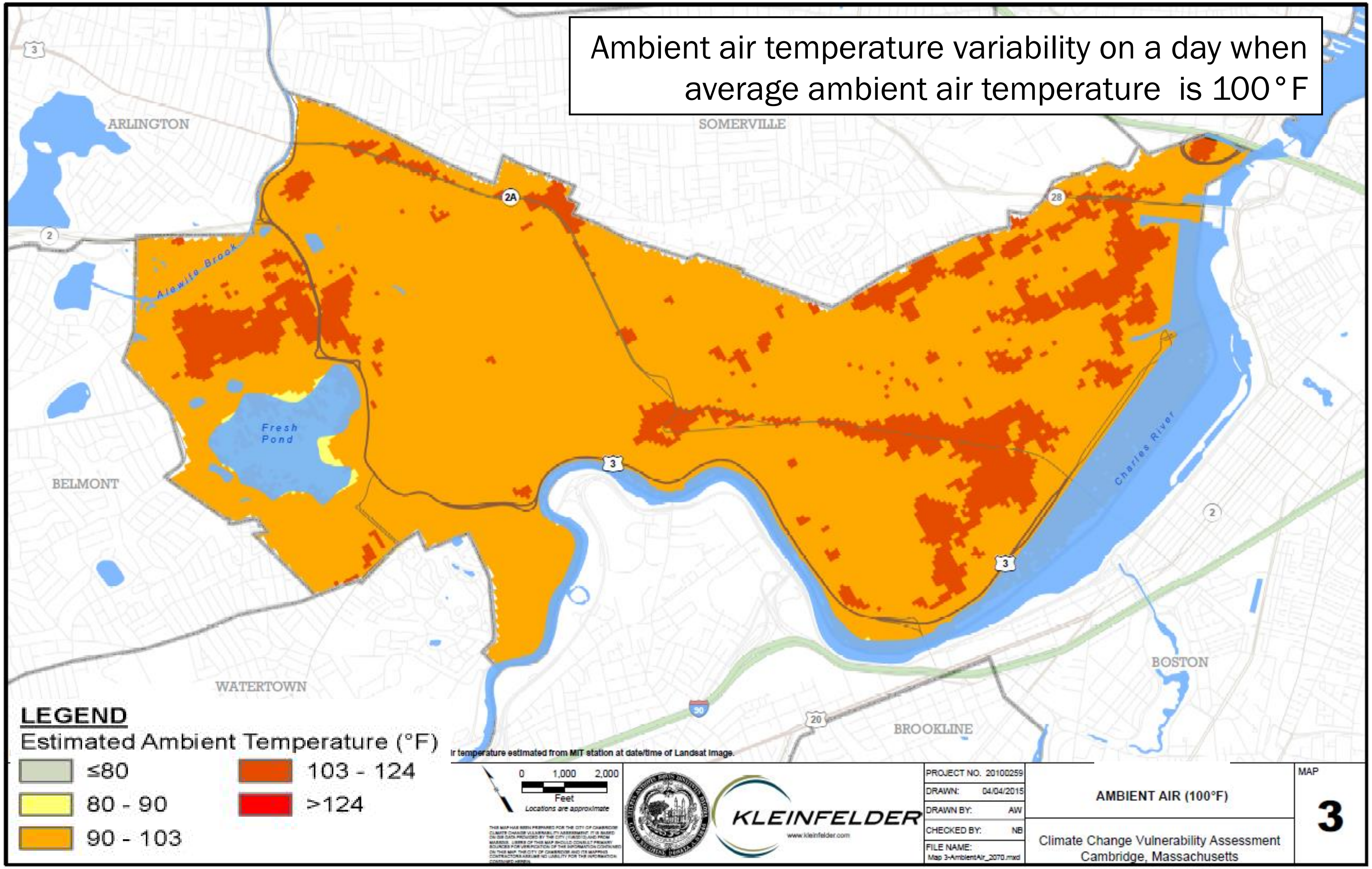


Colors keyed to NOAA Heat Index

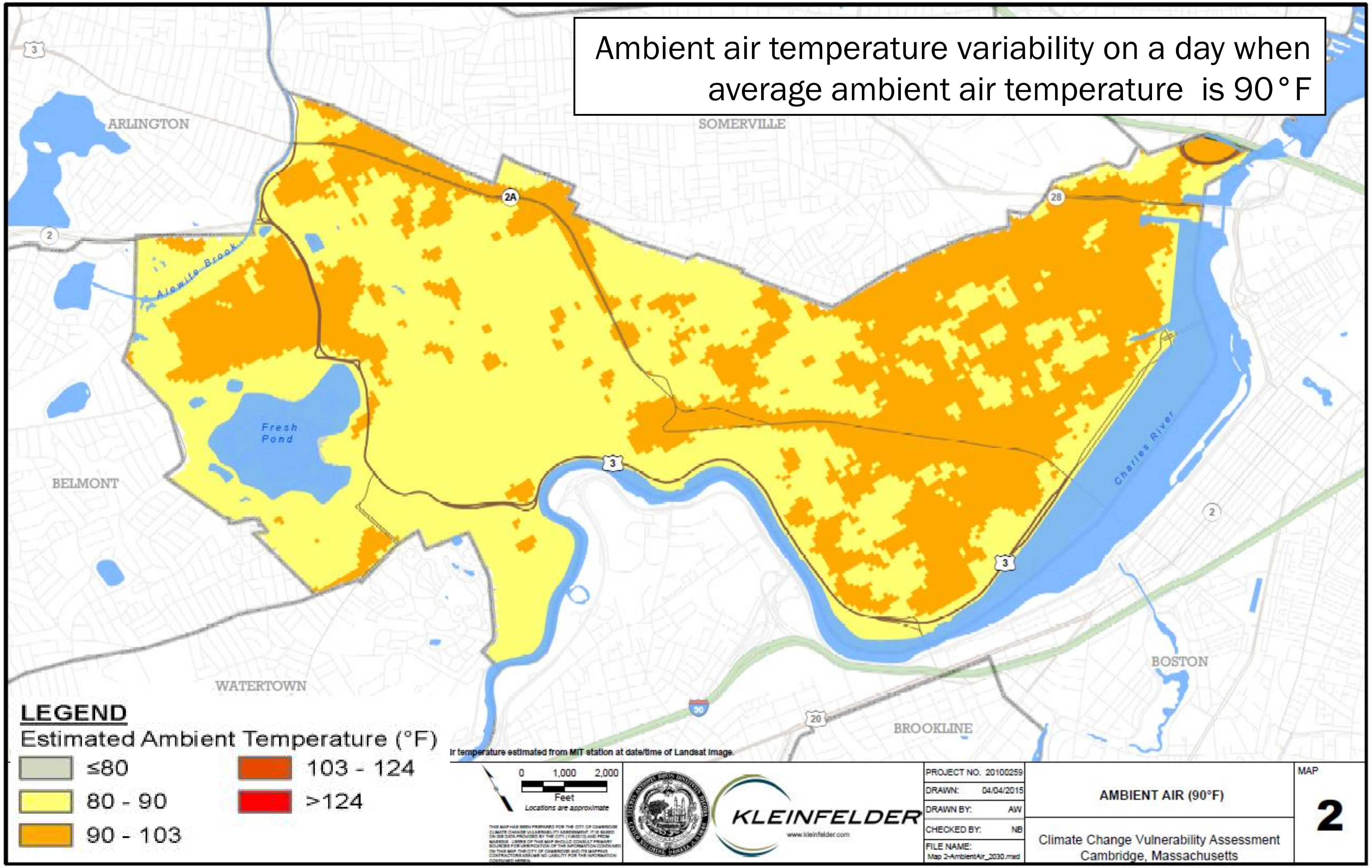
Ambient Air Temperature with UHI Effect – 90°F Day



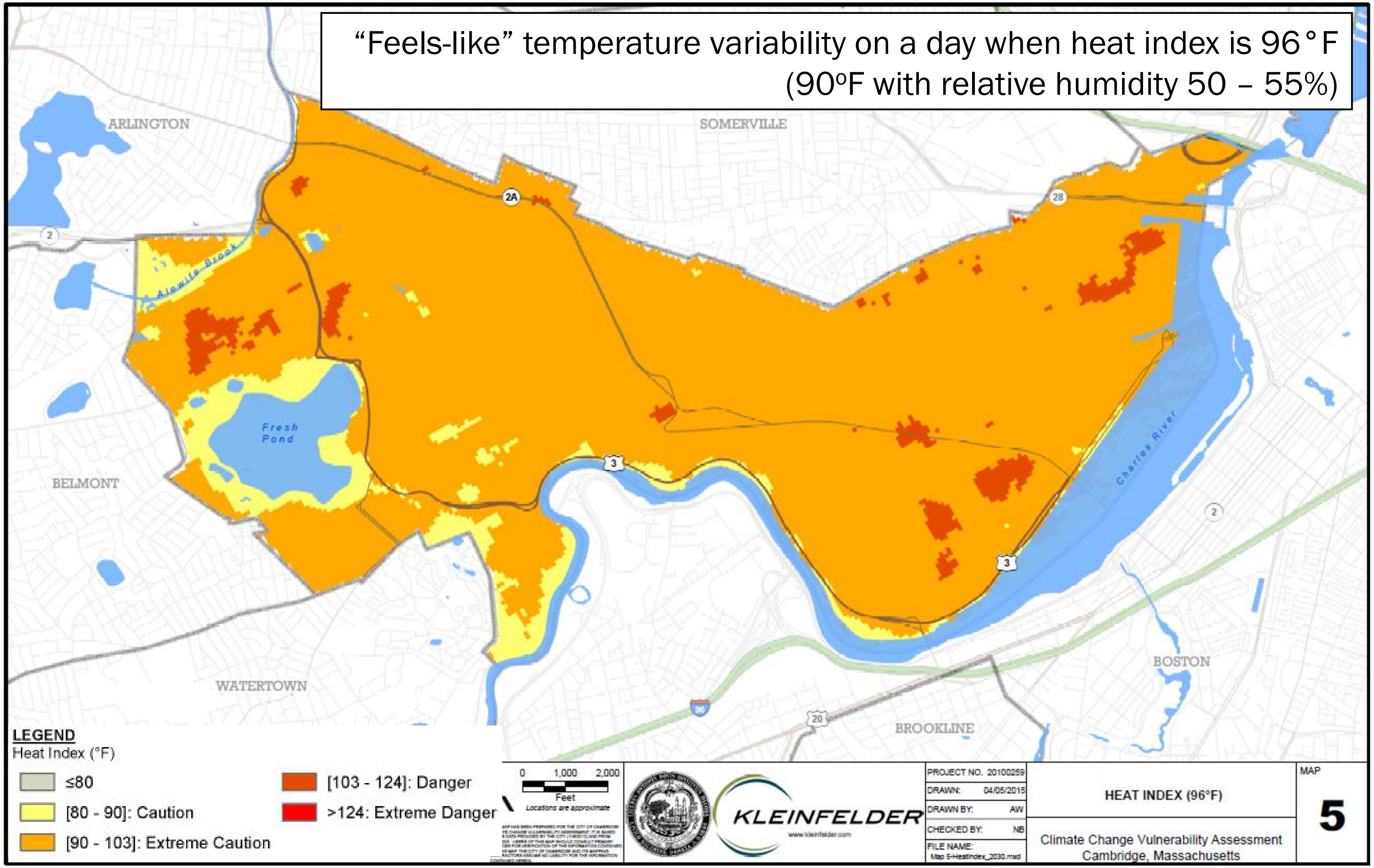
Ambient Air Temperature with UHI Effect - 100°F Day



Ambient Air Temperature with UHI Effect – 90°F Day -*Redux*



Heat Index Temperature with UHI Effect – 90^{o}F with relative humidity 50 – 55%



Energy Use in Buildings Shifting – More Cooling, Less Heating

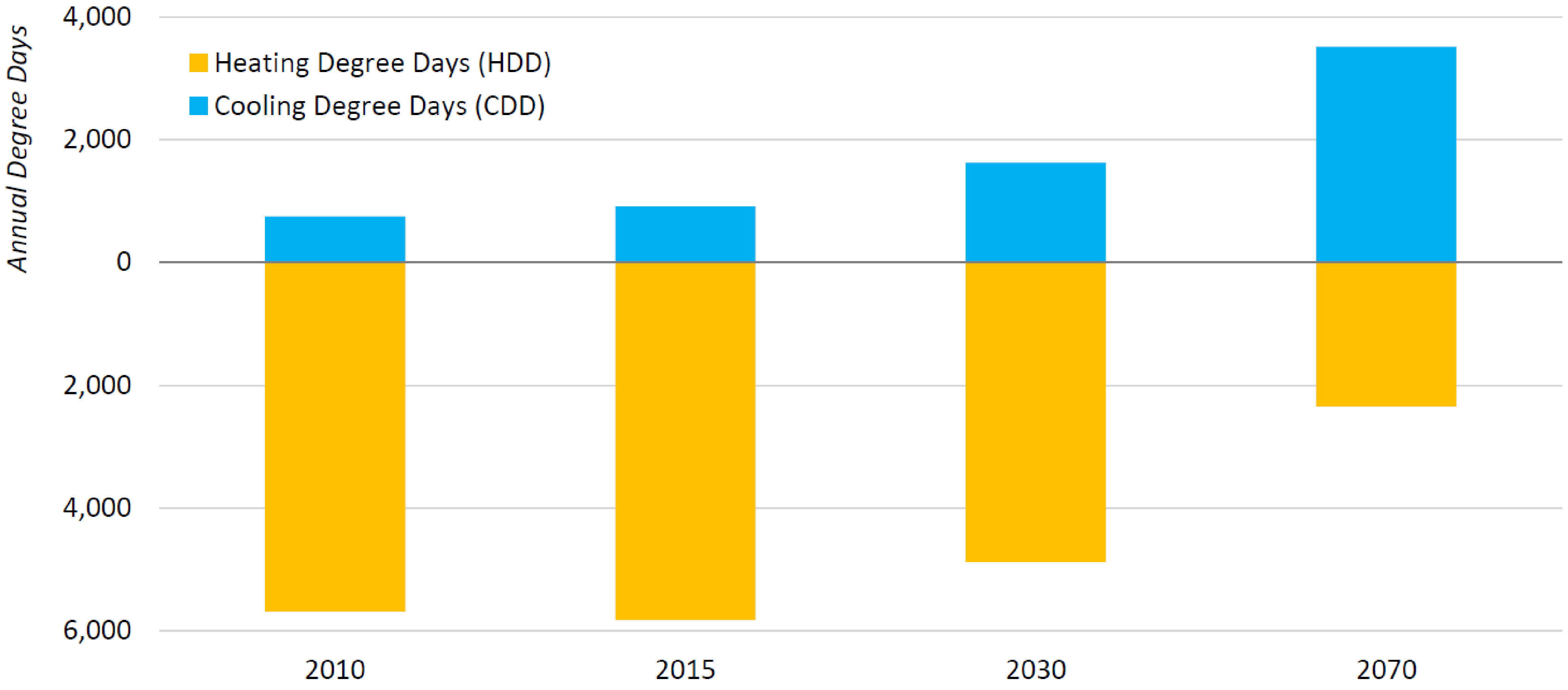


Figure 4 – Historic and projected annual heating and cooling degree days[24]

Warming Trend Is Already Affecting Municipal Building Energy Use

Weather Normalized Energy Usage for BEUDO buildings

DEGREE DAYS	2017 Observed Value	2018 Observed Value	% Difference	Normal Value
HEATING TOTAL	5,310	5,391	2%	5,681
COOLING TOTAL	880	1,132	29%	747

Normal is the average for 1981-2010

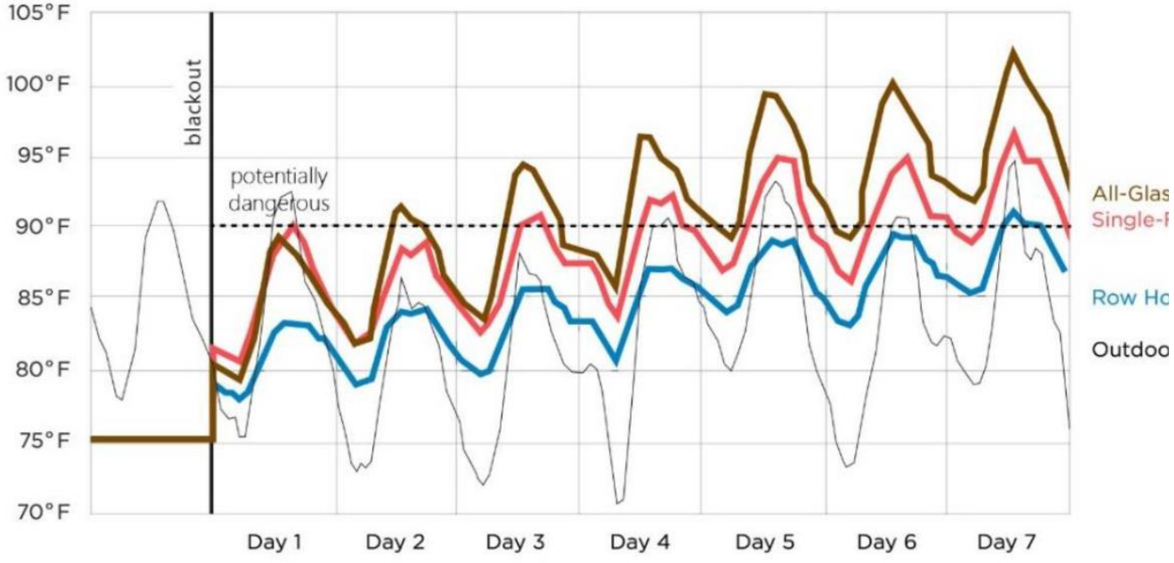
Number of heating degree days was very similar in calendar years 2017 and 2018.
Number of cooling degree days saw a 29% increase in 2018.

Total for BEUDO buildings Weather Normalized Site Energy Use (kBtu) **increased 4%**

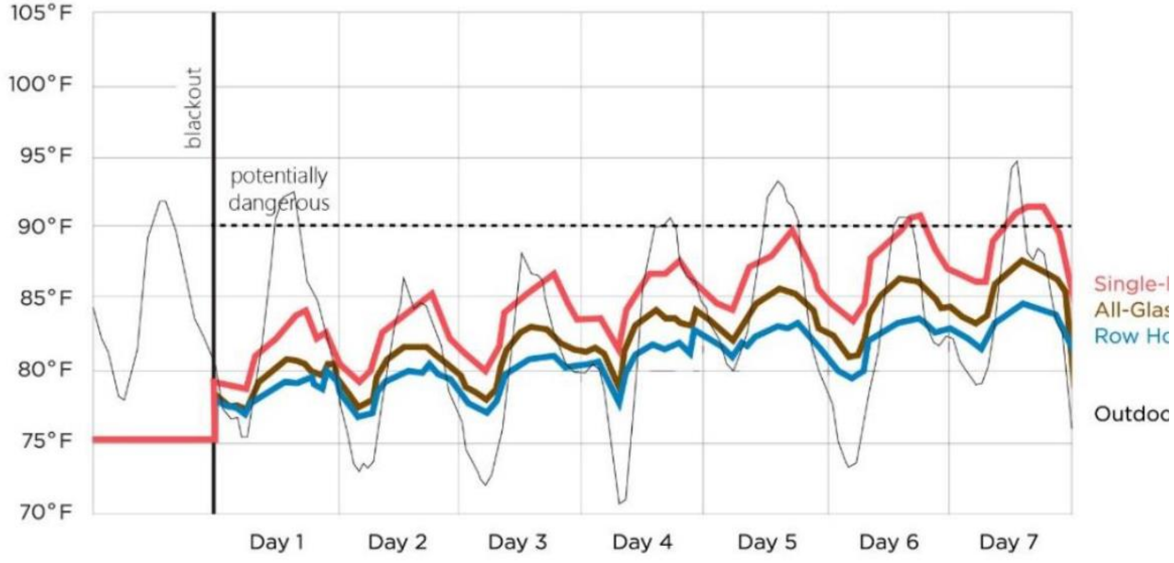
NOAA data also shows for Boston area that Cooling Degree Days have increased by 1.5 times since 2000 compared to to 1970-2000 period.

Indoor Temperatures During a Summer Blackout

Typical Building

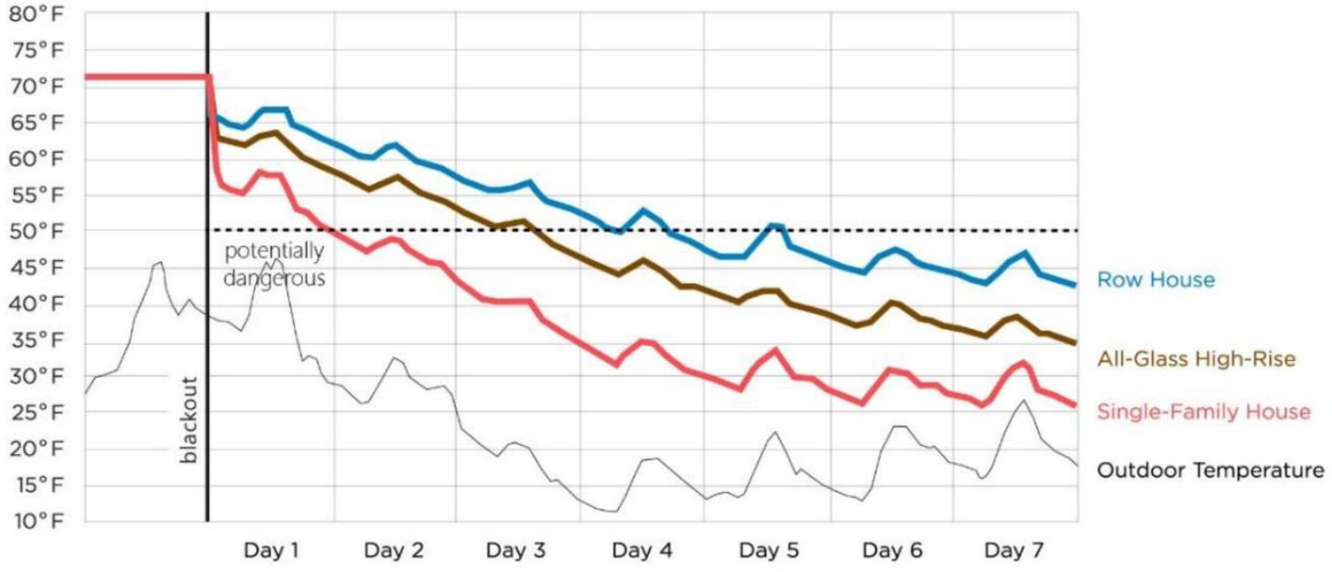


High-Performing Building

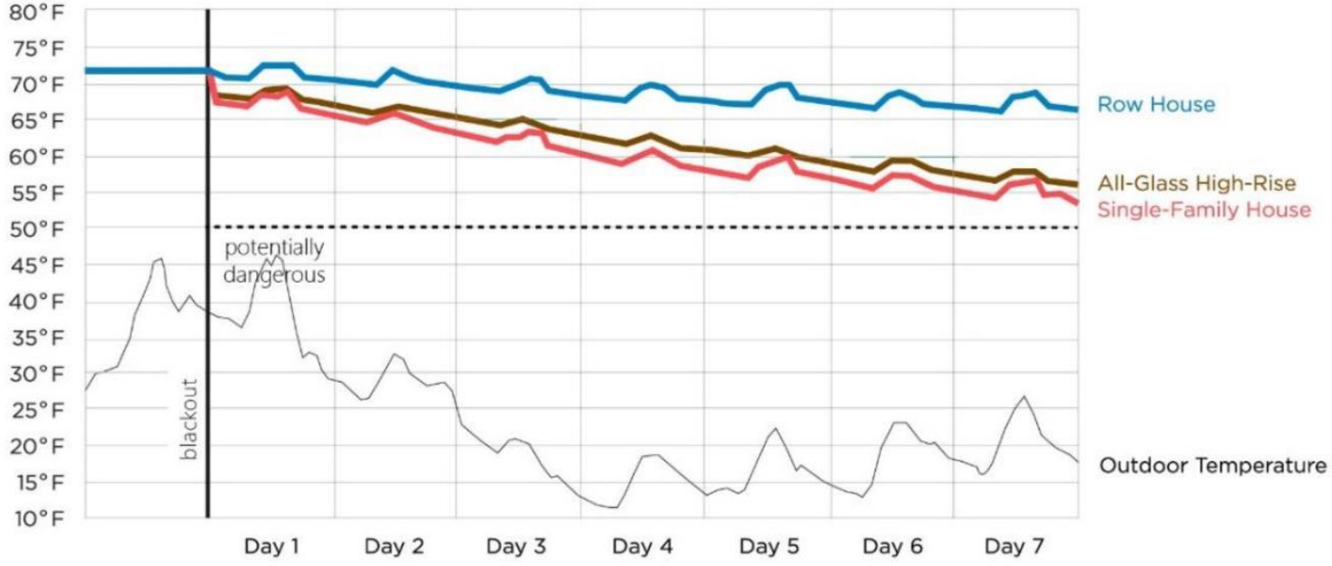


Indoor Temperatures During a Winter Blackout

Typical Building



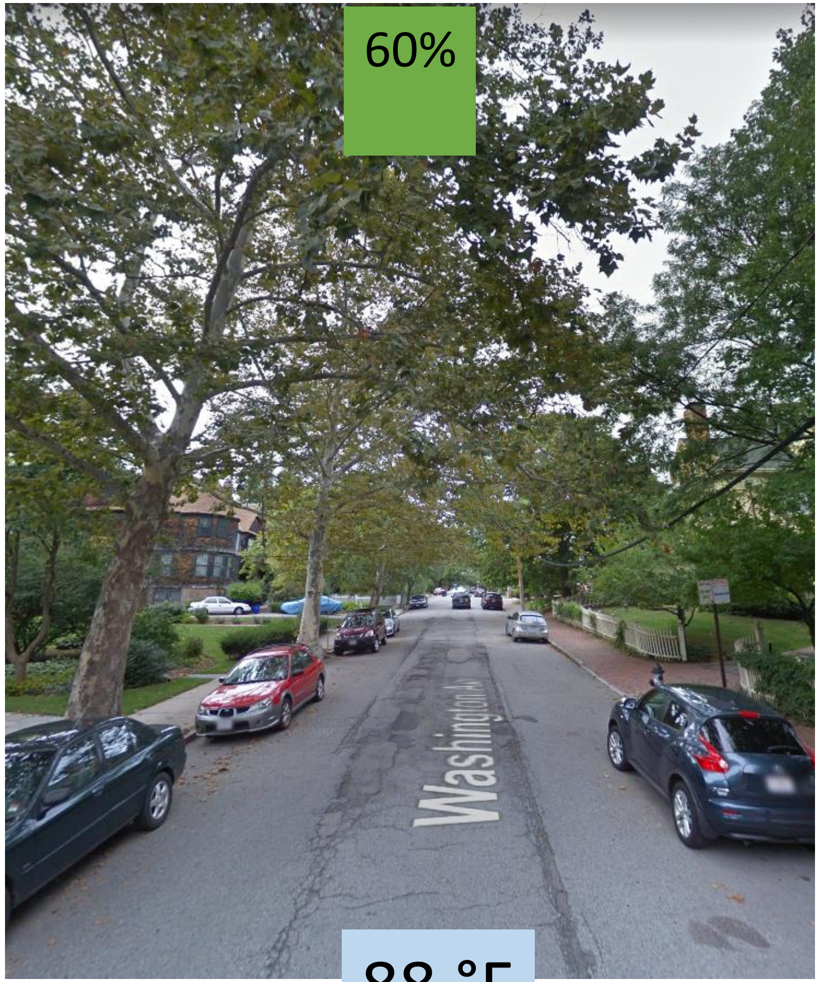
High-Performing Building



Cooling Impact Relative to Streetscape
(90 degree day)

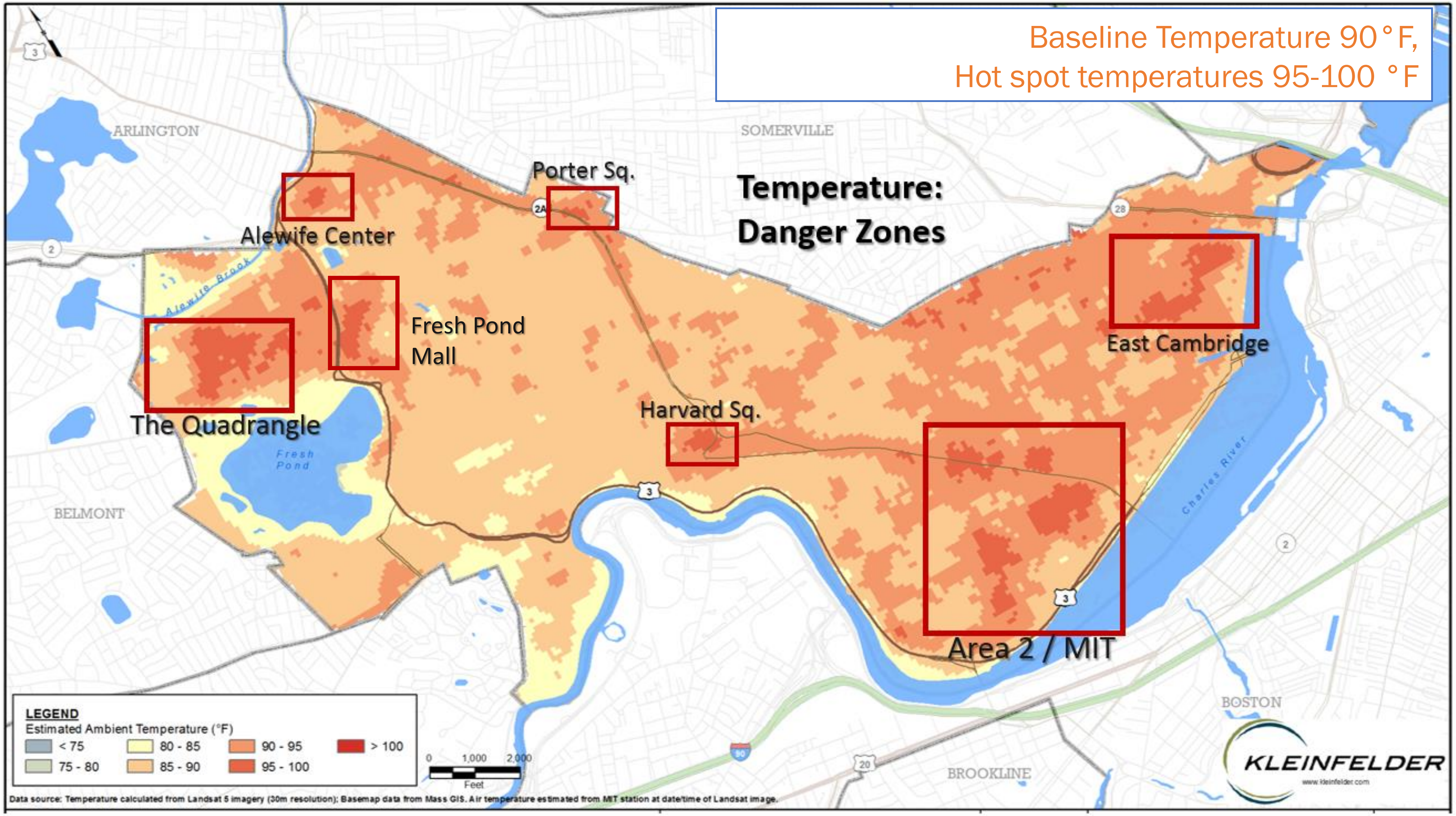
A.

B.



C.

Preparing for and Adapting to Increasing Heat Vulnerability



Resilience Strategies

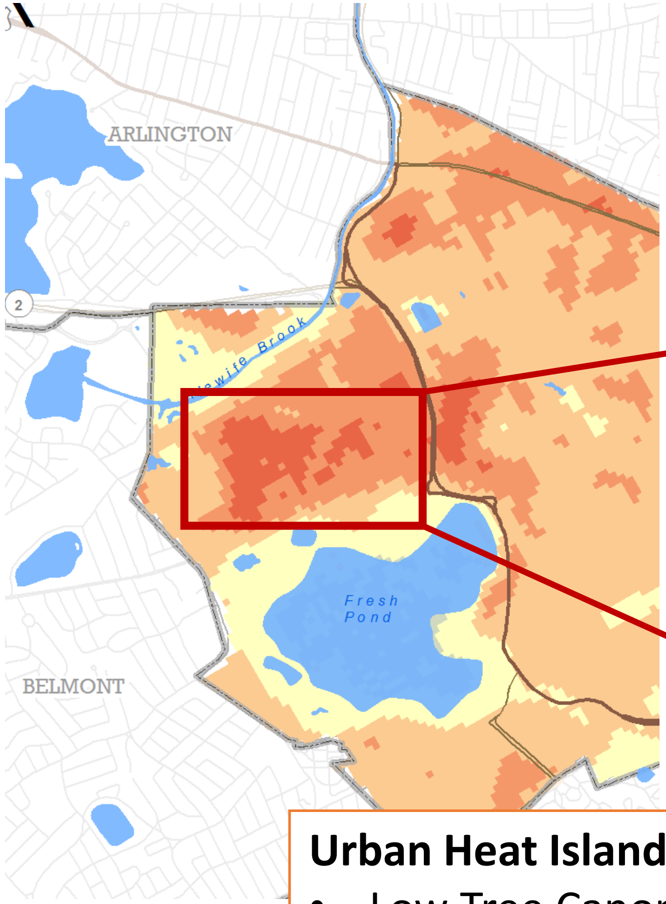
- (A) **A Prepared Community**: Strategies to strengthen community, social, and economic resilience.
- (B) **Adapted Buildings:** Strategies to protect buildings against projected climate change impacts.
- (C) **Resilient Infrastructure:** Strategies to ensure continued service or a speedy recovery from community-wide infrastructure systems.
- (D) **Resilient ecosystems:** An enhanced living environment integrating air quality, waterways, green infrastructure, and the urban forest as a system resilient to climate impacts.

Resiliency Planning Objectives for Heat

Cooling impact of:

- Converting impervious surfaces to vegetation
- White roofs
- Expanding urban forest canopy

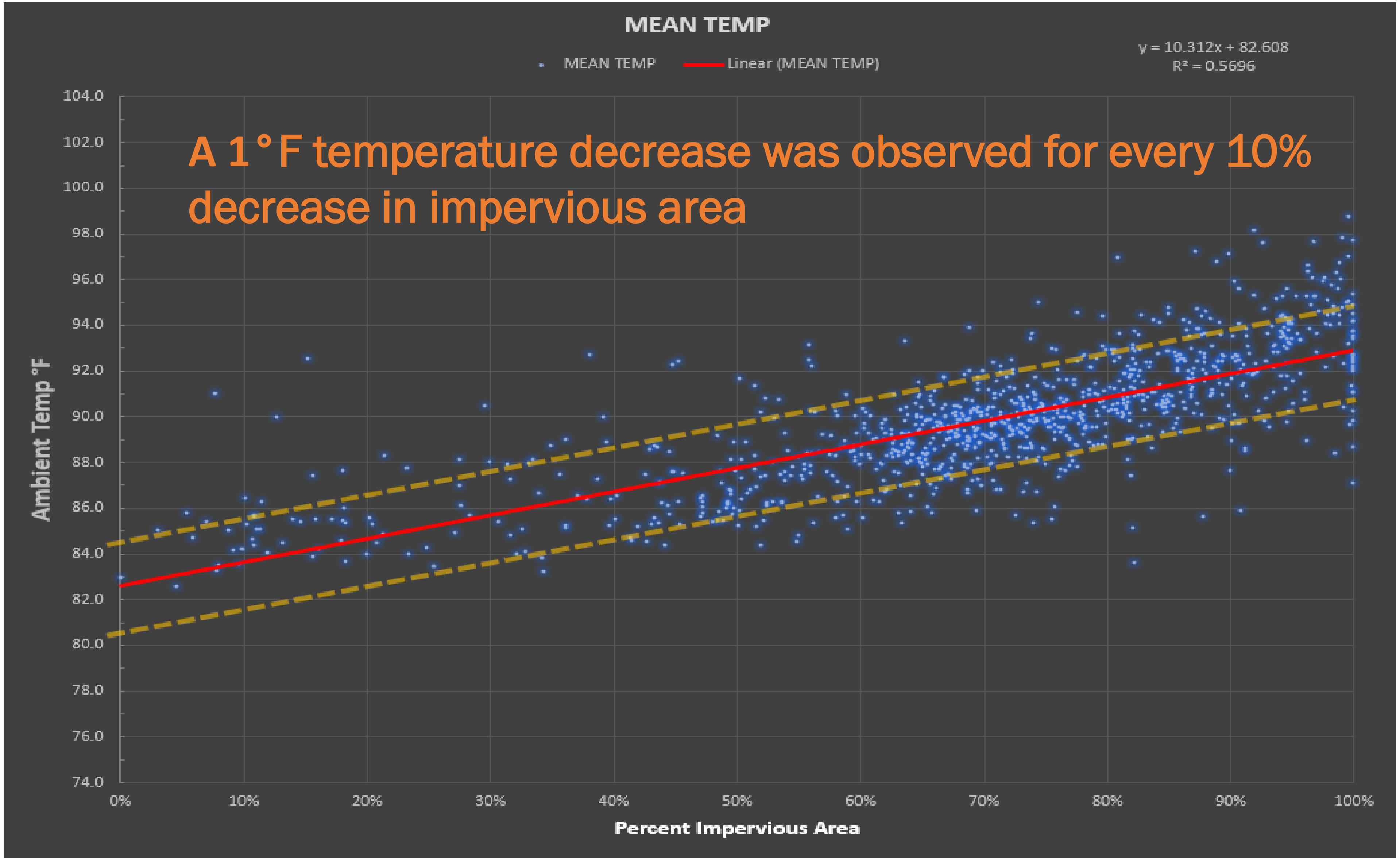
Other Factors Contributing to UHI Effects



Urban Heat Island:

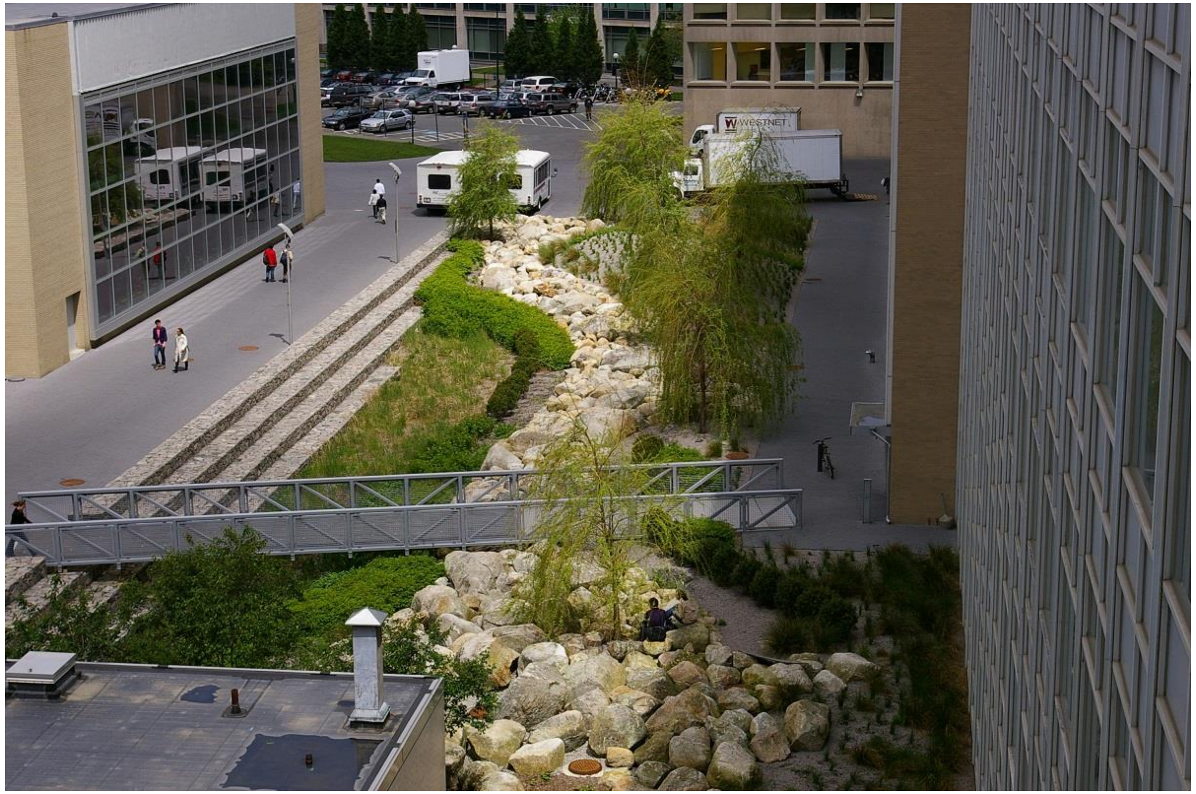
- Low Tree Canopy %
- High % Impervious Surface
- Large Square footage of roofs
- Dark roofing surfaces (Low SRI)

Relating Ambient Temperature and Percent Impervious Area



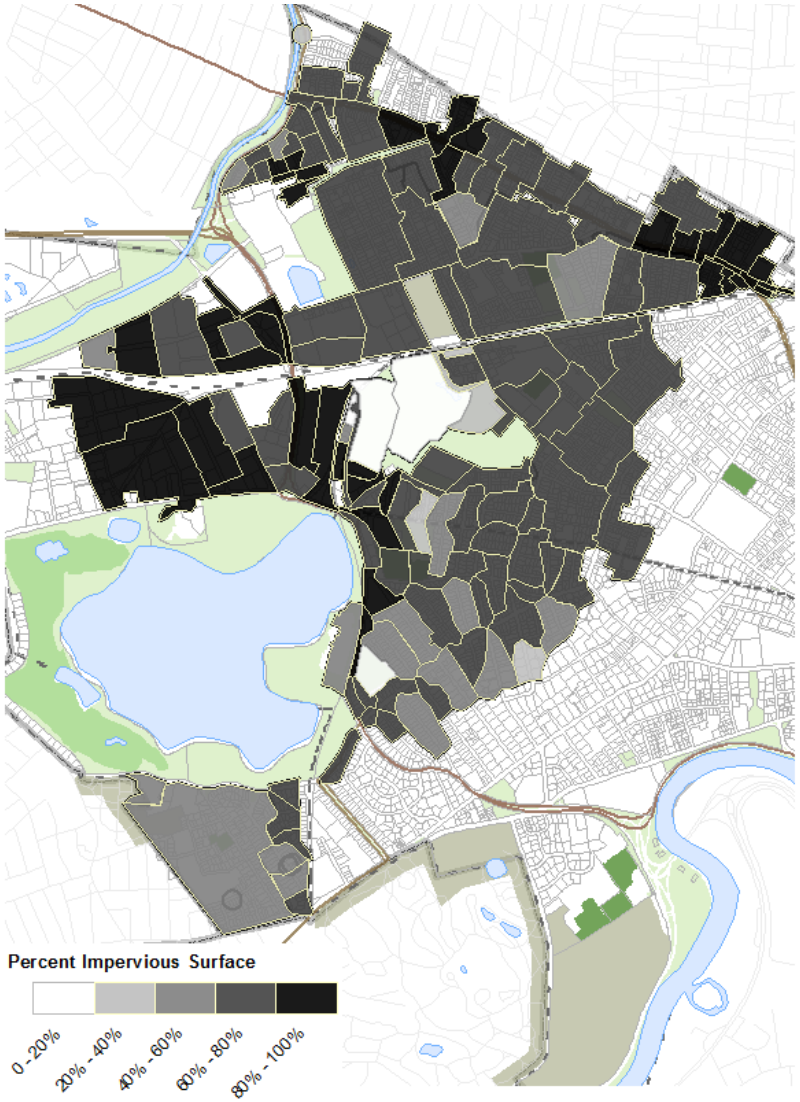
Green Infrastructure Effectively Reduces Impervious Area

Infiltration under lawn area

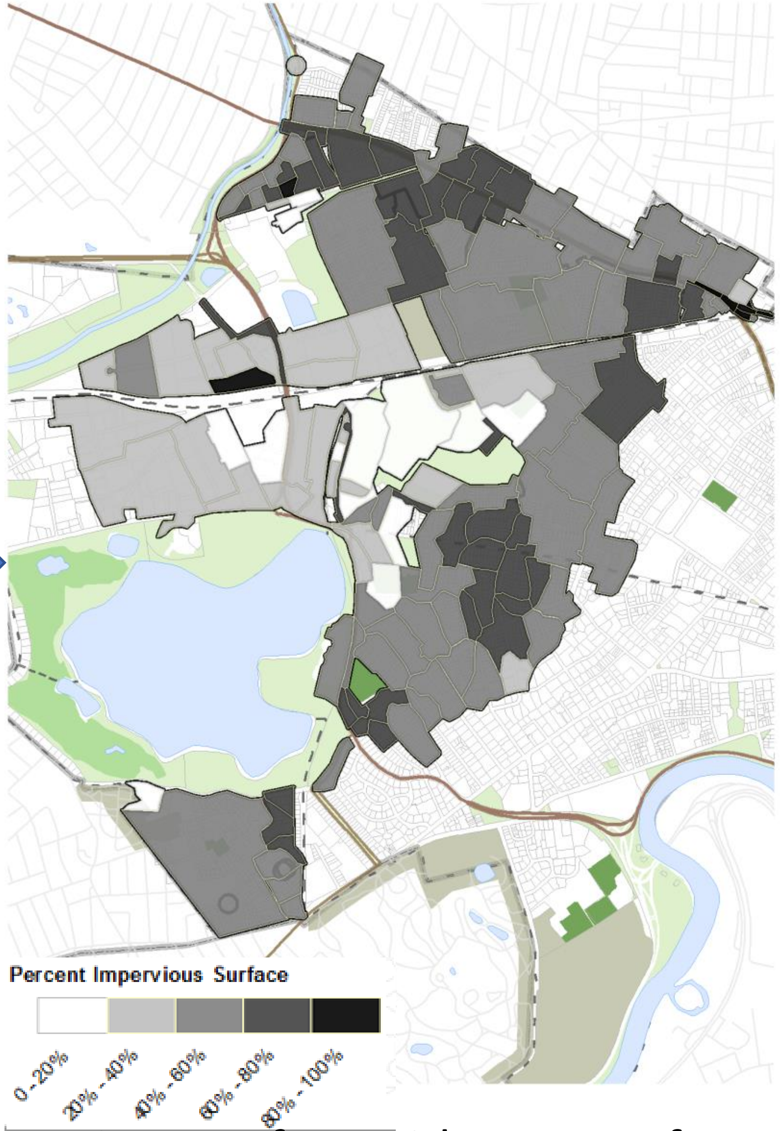


Rain Garden at Stata Center, MIT

Green Infrastructure Effectively Reduces Impervious Area

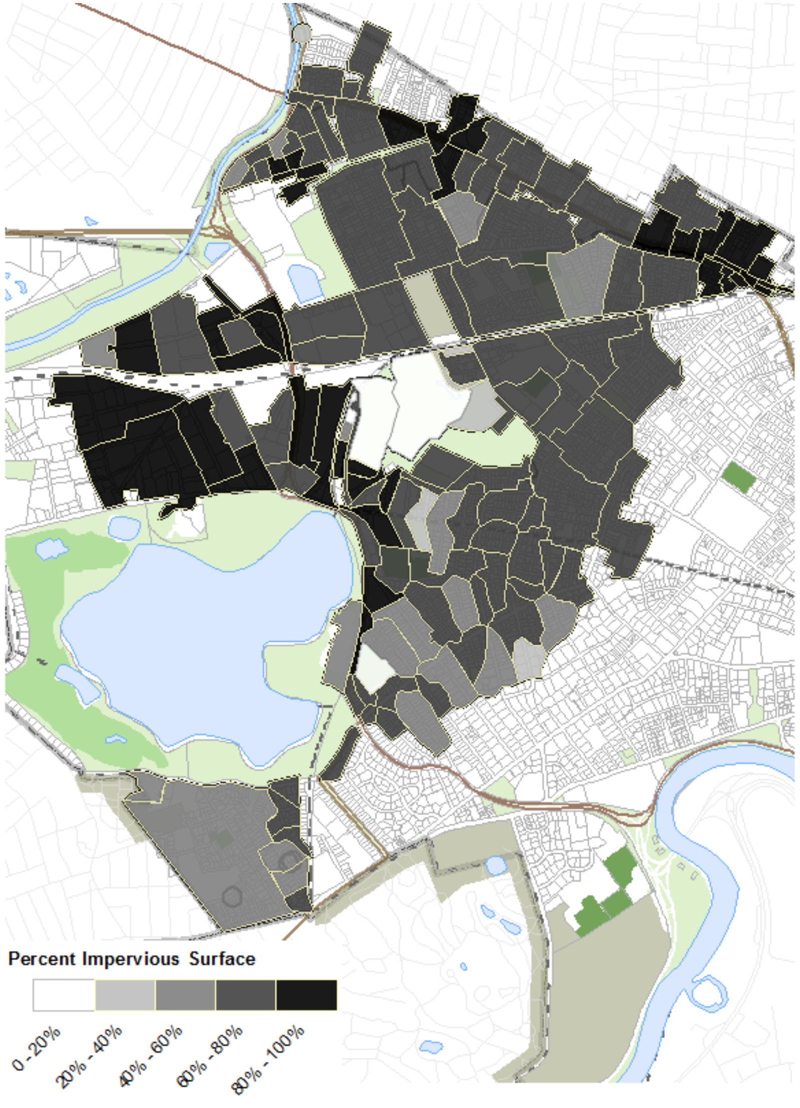


Existing Impervious Surface by Catchment



Proposed Impervious Surface with Green Infrastructure at MEP

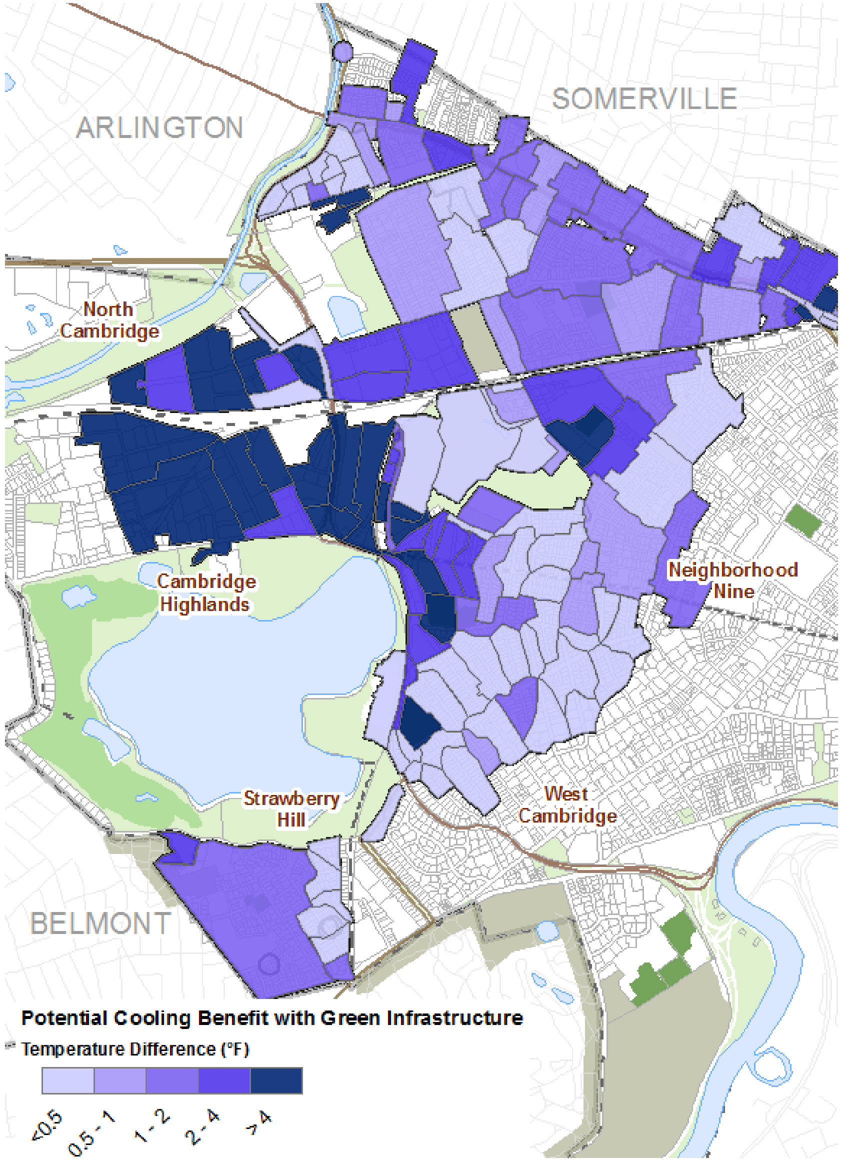
Cooling Benefits of Increased Green Best Management Practices (BMP)



Existing Impervious Surface by Catchment

Green BMPs:

- Bioswales
- Green roofs
- Porous pavement

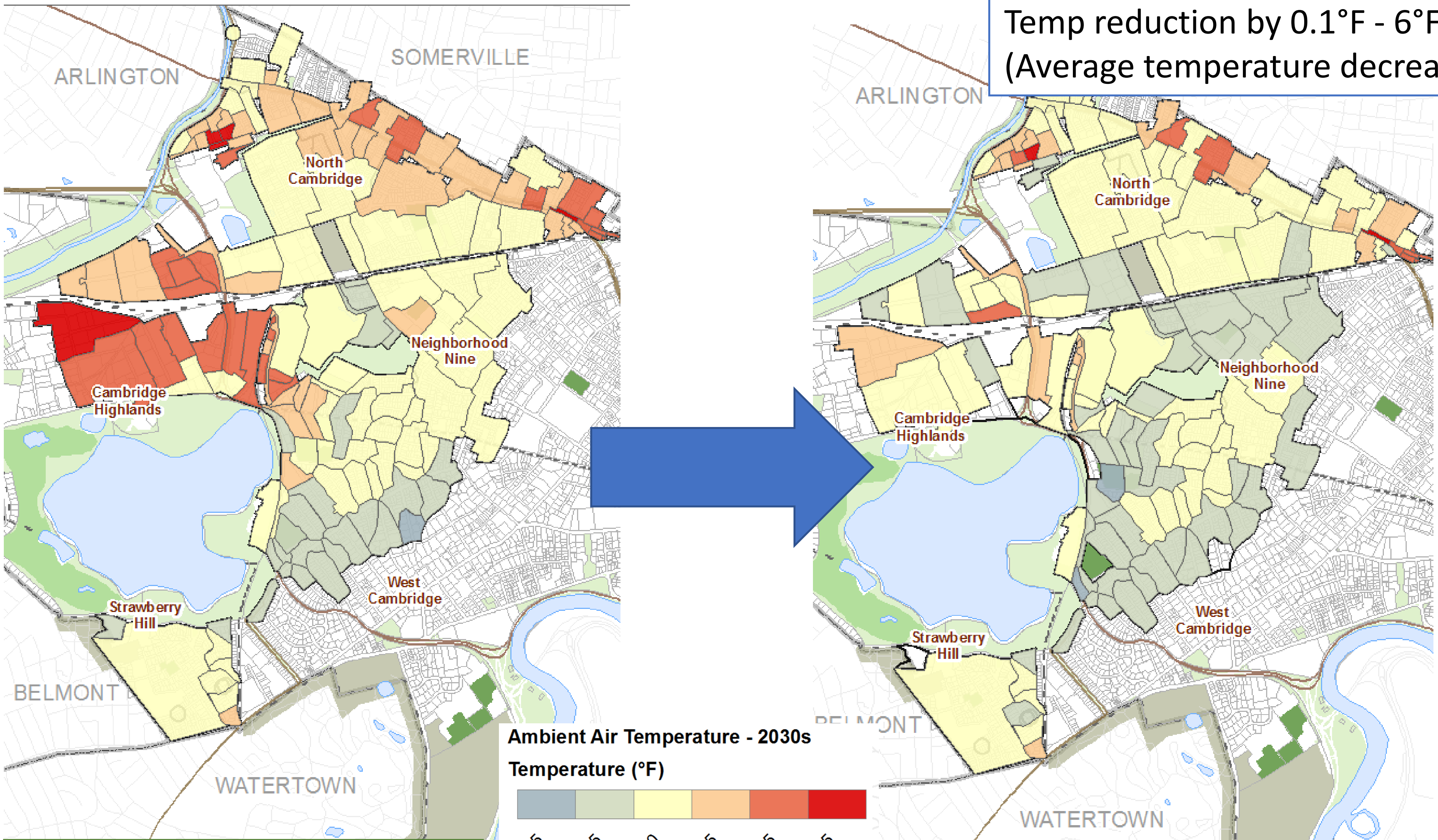


Cooling Benefit is determined by the *difference* in impervious area %

*Based on Max. Extent Practicable (MEP)

Impact of Green BMPs on UHI

Temp reduction by 0.1°F - 6°F
(Average temperature decrease 1.7°F)



Temperature 90˚F

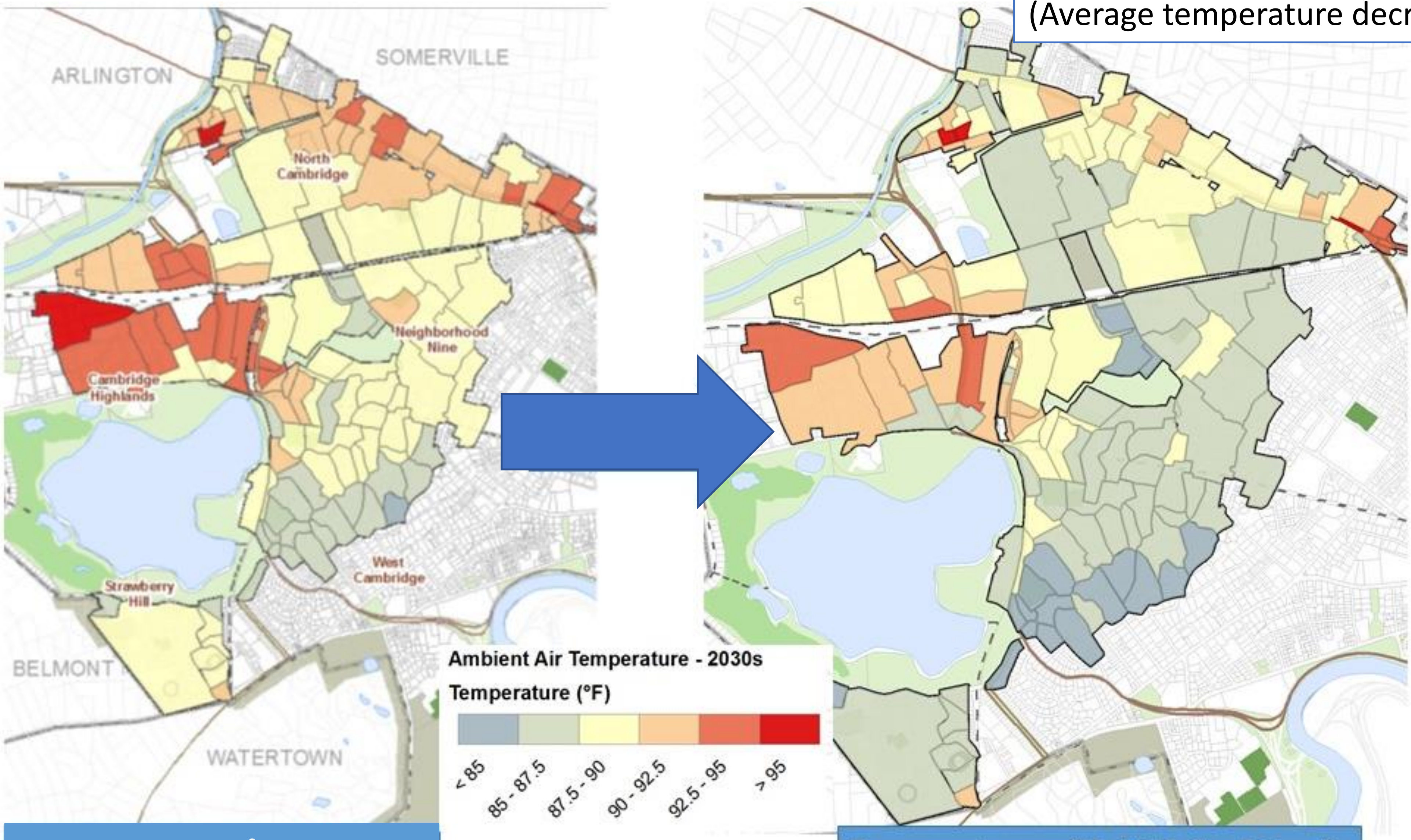
Temperature with Green BMPs at MEP

Impact of White Roofs on UHI

Max. temp reduction by 4.5°F
(Average temperature decrease 2.4°F)

Impact of White Roofs on UHI

Max. temp reduction by 4.5°F
(Average temperature decrease 2.4°F)



Temperature 90˚F

Temperature with 50% Cool Roofs

What are Some Preliminary Findings?

- **Green BMPs may reduce ambient temperature by 0.1°F - 6°F**, as a function of reduction of impervious areas, with an average temperature decrease of 1.7°F (area-weighted average across all catchments).

- **White roofs yielded a 2.4°F cooling benefit** with a 50% level of implementation across existing buildings (area weighted average)

- White roofs are more effective in cooling, but do not have the additional benefits of **water quality improvement and flood reduction** for smaller storms.

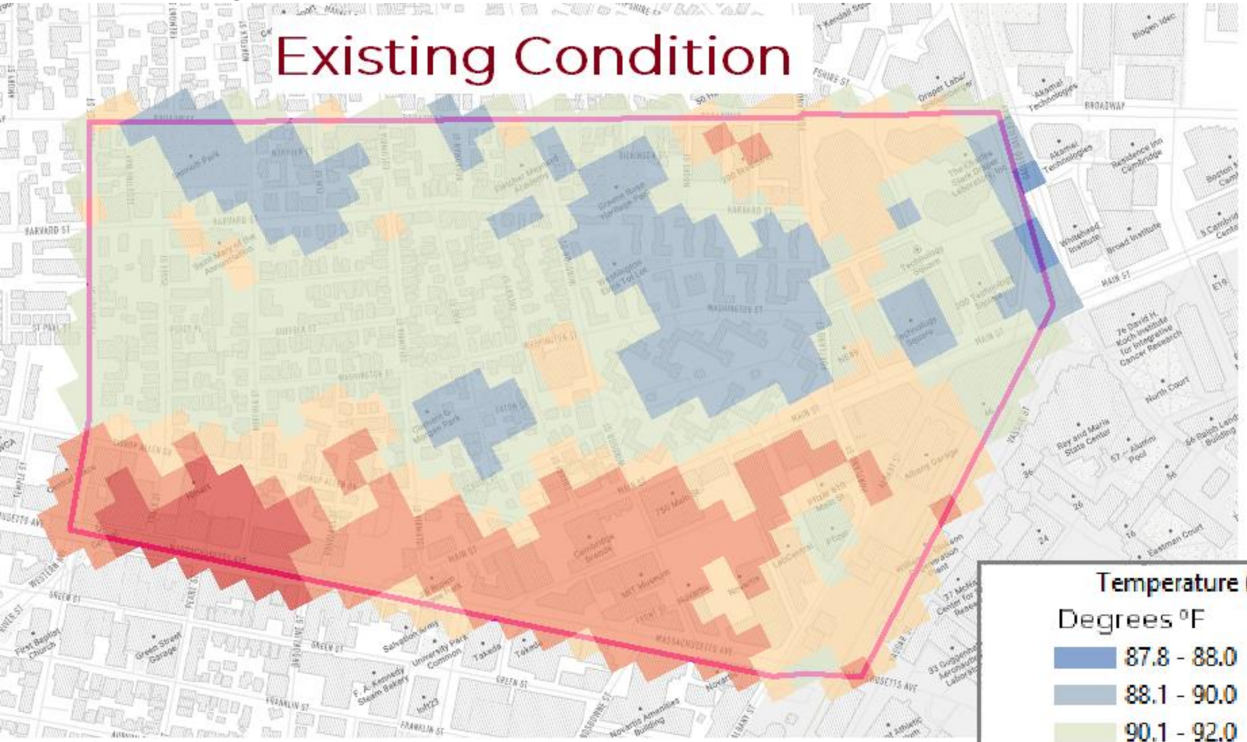
- **Efficient building envelopes** keep inside temperatures in a safe range during power outages.

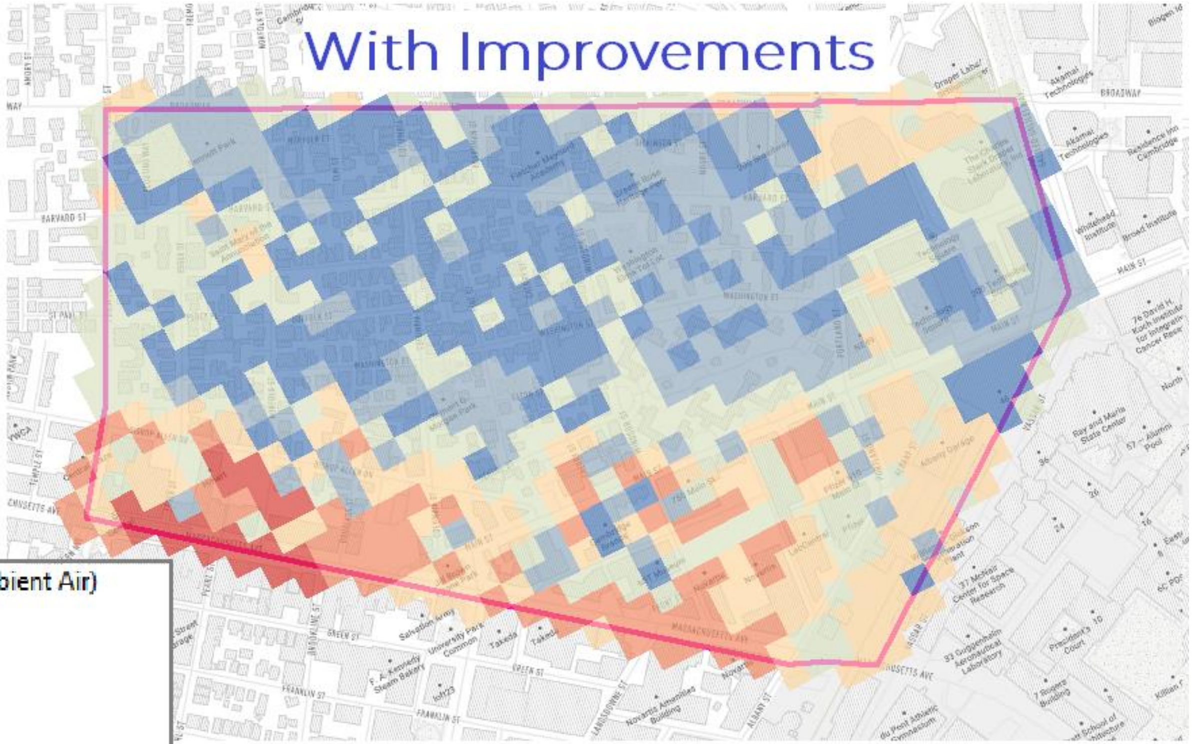
- **A 1% tree canopy increase relates to 0.12 °F of cooling.** For street trees, approximately an average of 1°F cooling is achieved per tree per 100 ft, with a range between 0.15-6.2°F.

What can be done?

More trees

COOLING STRATEGIES: To what extent can localized high temperatures be reduced?





Temperature (2030 Ambient Air)

Degrees °F

- 87.8 - 88.0
- 88.1 - 90.0
- 90.1 - 92.0
- 92.1 - 94.0
- 94.1 - 96.0
- 96.1 - 100.0

Average Temperature = 92°F

Percent of Port area > 92°F : 44%

Average Temperature = 90°F

Percent of Port area > 92°F : 29%

Draft Figure: Based on Ambient Air Temperature on a 90 Degree Day

Cooling from Green Roofs + White Roofs: 1.7 °F

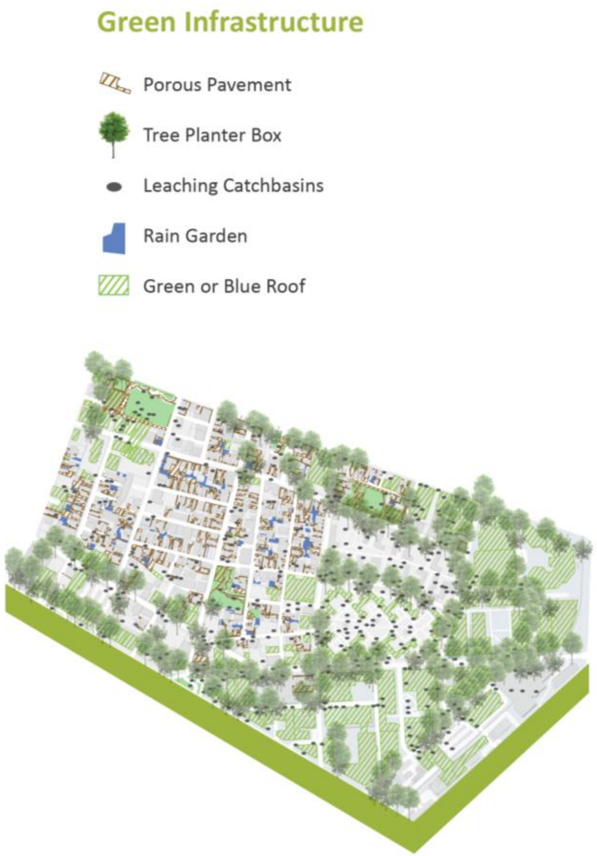
Cooling From New Tree Canopy: 0.3 ° F

What would be gained?

Projected Benefits:

About **9,000** MMBtu in energy savings, equivalent to the annual electricity usage of approximately **375** households

Up to **2°F** reduction in ambient air temperature



Idea for change

#2 Super-Resilient Urban Blocks

To implement maximum resiliency strategies in one defined area.

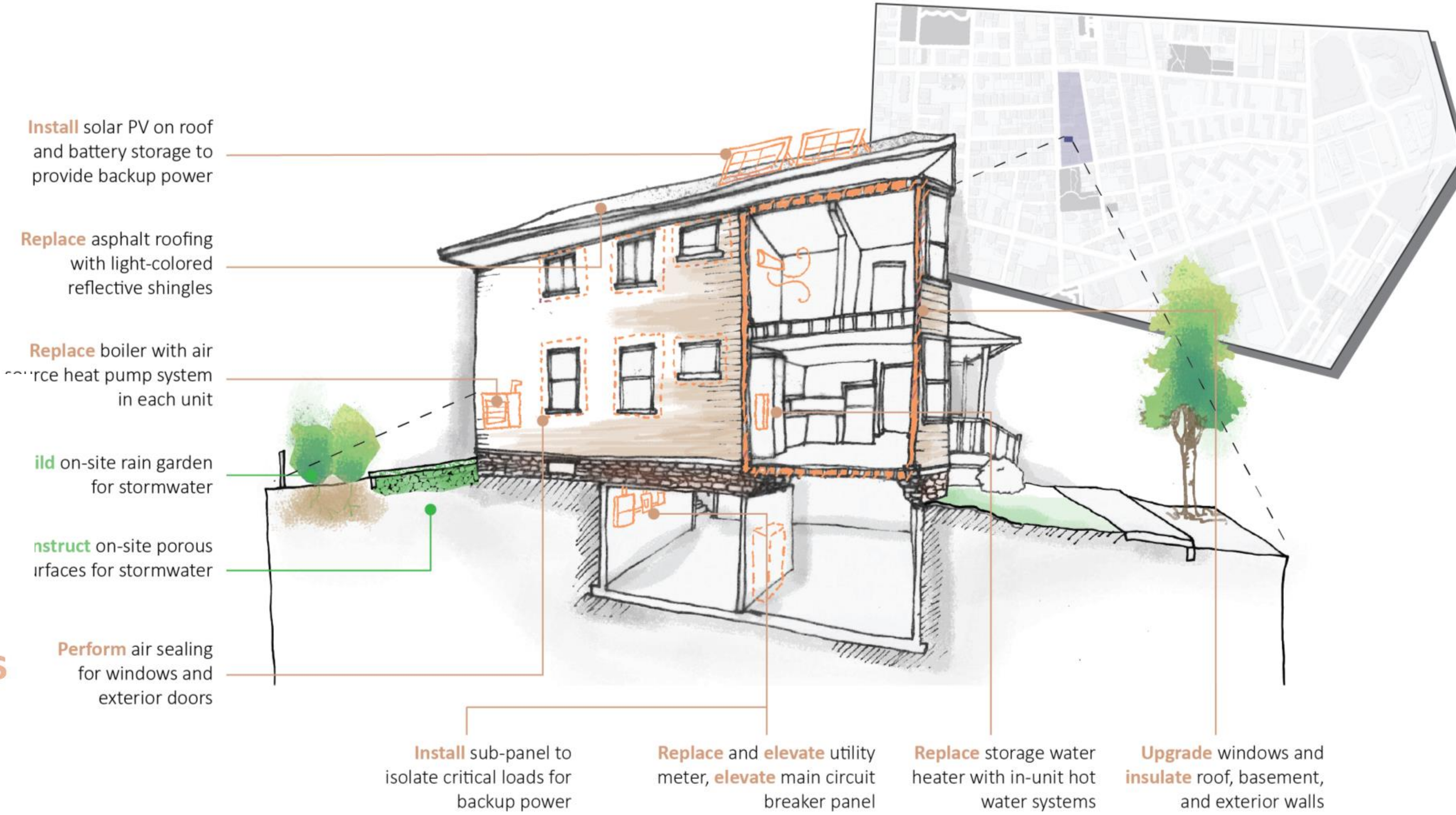
It will help reducing flooding and urban heat island and increase energy resiliency.

What would be gained in the residential block?

Projected Benefits:

Up to **2 °F** reduction in ambient air temperature

3,070-3,780 MMBtu in energy savings if 85% of the buildings in the block are improved (in terms of total area) , equivalent to the electricity usage from approximately **145 households**

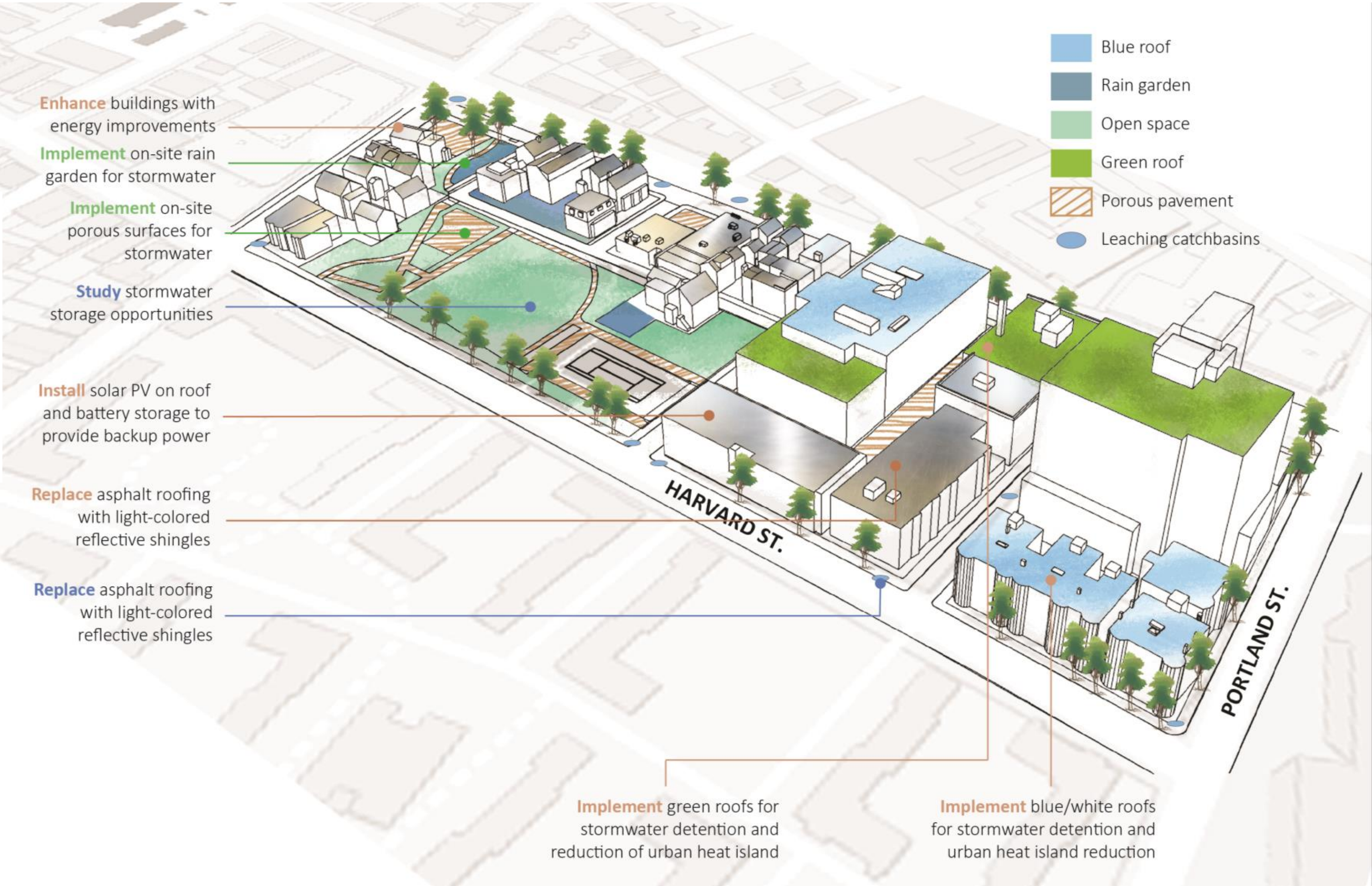


What would be gained in the mixed-use block?

Projected Benefits:

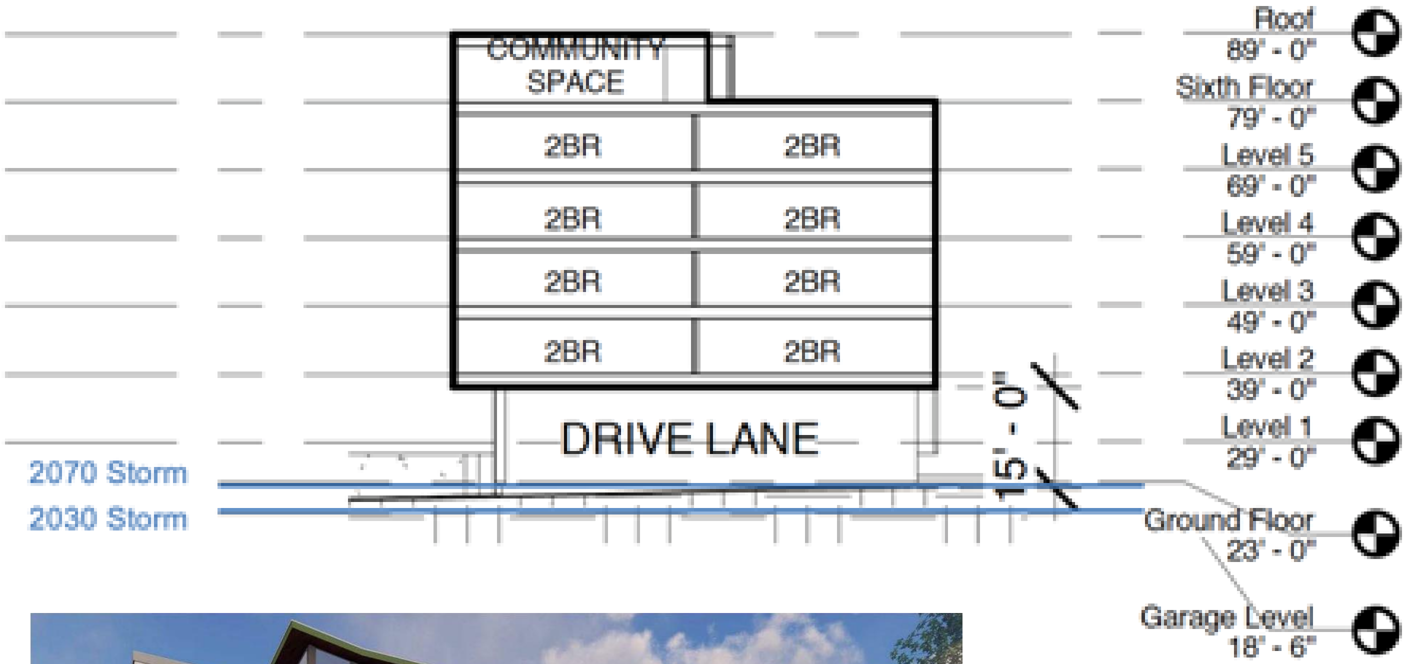
Up to **6 °F** reduction in ambient air temperature

11,320-14,430 MMBtu
in energy savings if 88% of the buildings in the block (in terms of total area), equivalent to the electricity usage from approximately **545 households**



Adapted Buildings: HRI Concord Highlands Affordable Housing

1. High performance building envelope and cool roof (**project will be Passive House certified** under the PHIUS+ 2015 system); **can stay in 55-85˚ F range for 4 days passively**.
2. Heat recovery ventilation system
3. VRF heat pump and efficient central hot water system
4. **83 kW Solar PV on roof Sub-metered utilities and separate sub-panel for life safety loads** (above flood elevation)
5. Sub-metered utilities and **separate sub-panel for life safety loads (above flood elevation)**
6. Building energy management
7. **Top floor community room and residential units elevated above flood elevation**



HRI's Concord Highland property
ICON Architecture
NEI Energy Expertise

Peformance Standards: Examples

- Green Factor: Seattle
- Green Area Ratio: Washington DC
- LEED Resilience Pilot Credit for Passive Thermal Resilience
- Solar Reflectance Index

Prescriptive Standards: Examples

- Minimum landscape requirements
- Maximum impervious cover
- Passive House building envelope
- Community space sheltering requirement
- Back up power/energy storage
- Cool roof requirement

Thank you!