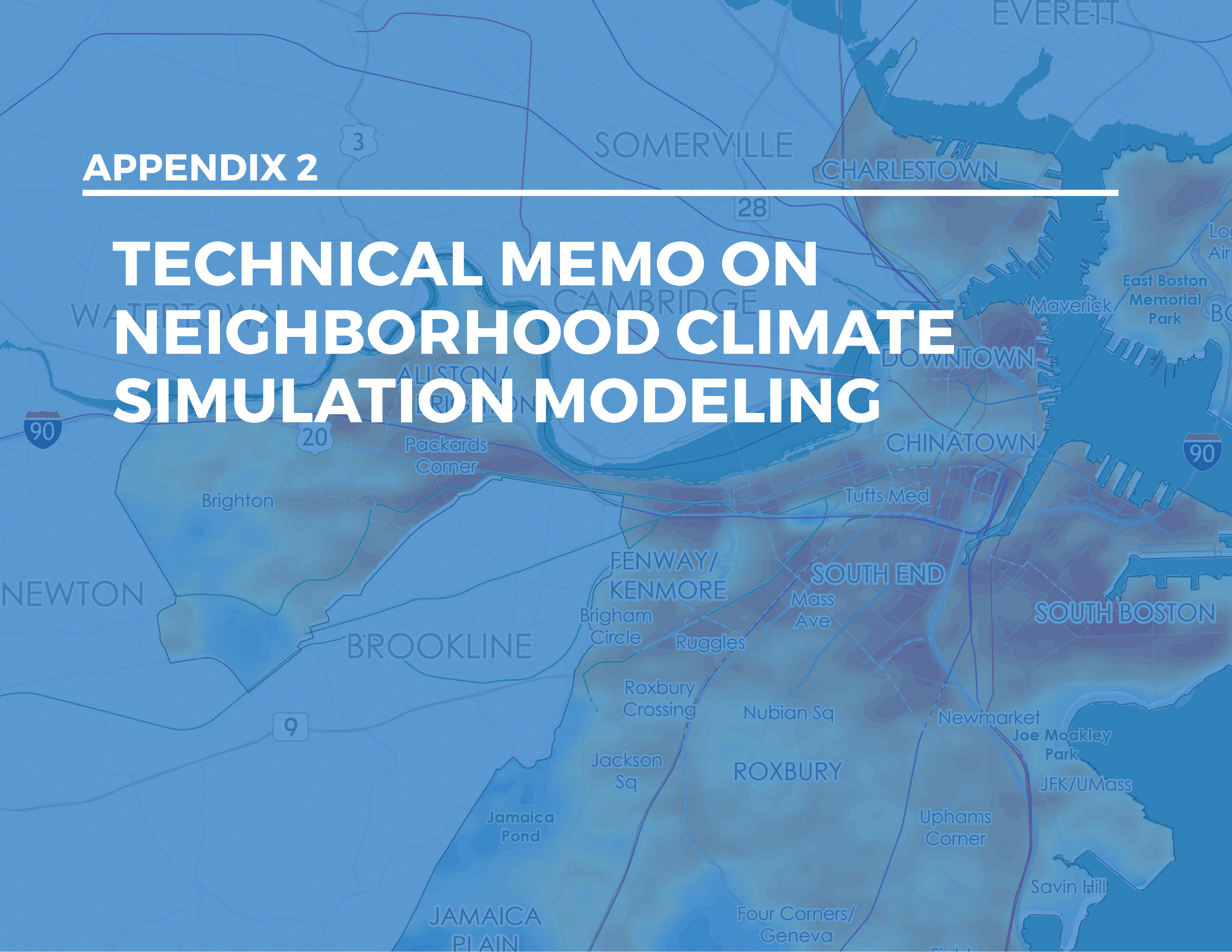
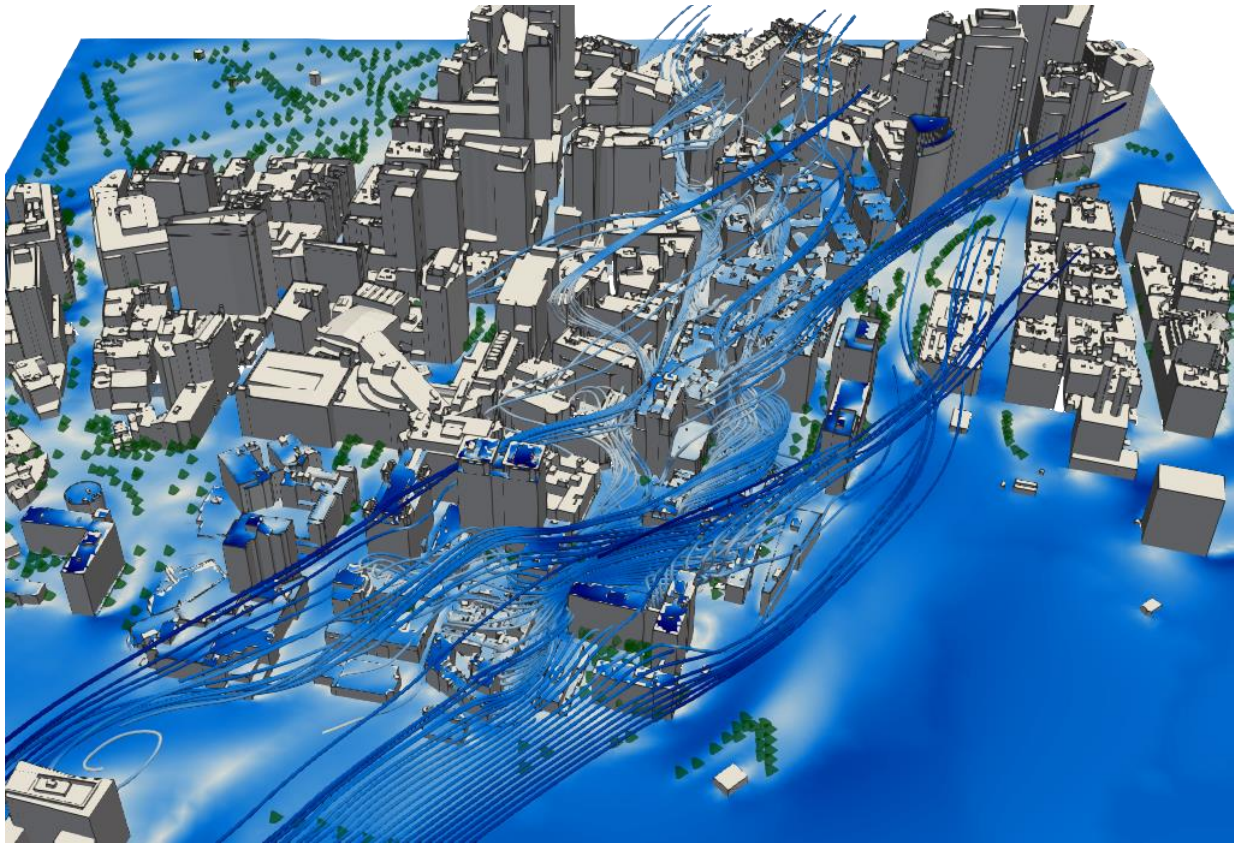
APPENDIX 2

TECHNICAL MEMO ON NEIGHBORHOOD CLIMATE SIMULATION MODELING



Boston Heat Resilience Study

Neighbourhood Urban Climate Simulation



Meiring Beyers
Klimaat

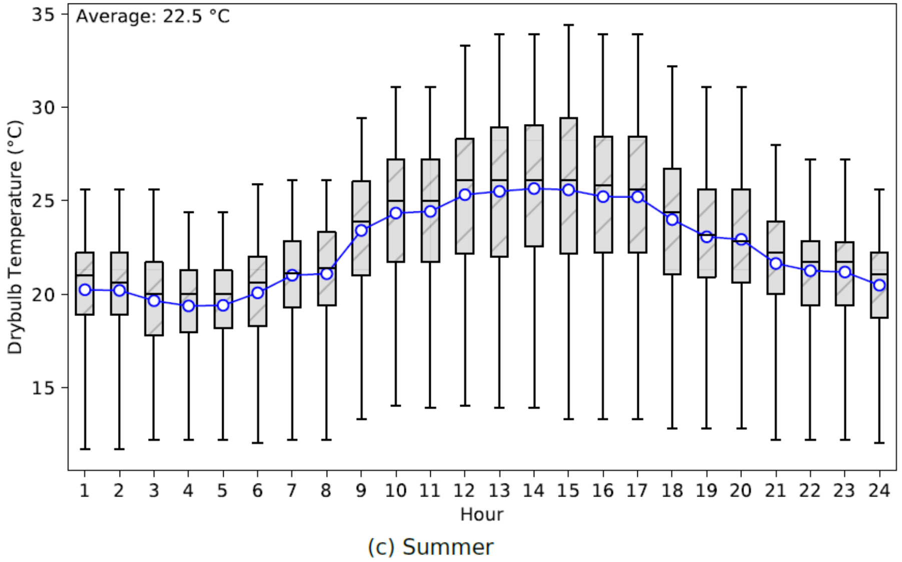
2021-09-24

Typical Climate Characteristics

Climate Characteristics

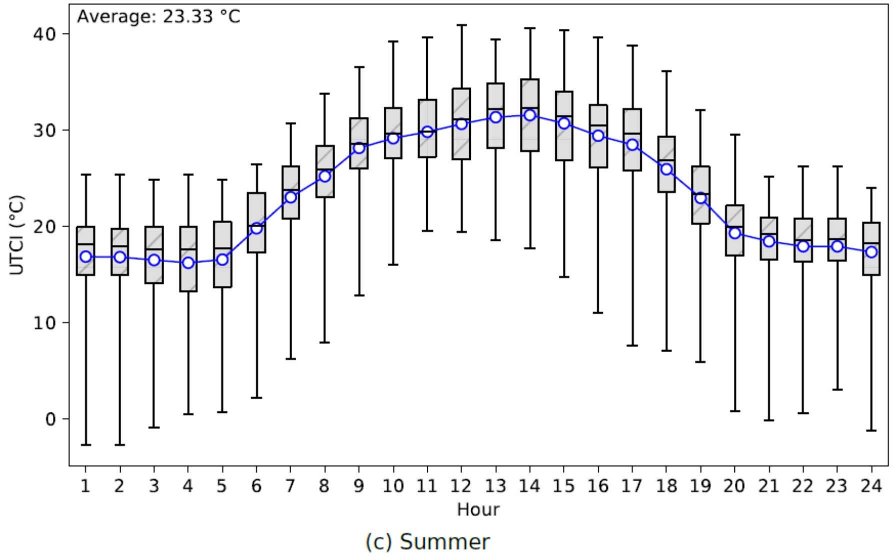
Temperature
Based on typical annual hourly meteorology data for Boston from its Boston Logan International Airport, the average Summer dry-bulb temperature is 22.5°C.

A more detailed meteorology data report of the data used for the urban climate analysis is available as:



Average diurnal range of dry-bulb temperatures for Summer (blue line) with grey boxes indicating 25% and 75% percentile values, and whiskers indicating the maximum and minimum range..

Perceived Thermal Comfort
The combination of humidity, temperature, solar and wind exposure can provide an estimated perceived temperature, or thermal comfort. The current analysis uses the Universal Thermal Climate Index (utci.org) to create an effective or perceived thermal climate. The mean daily perceived temperature for solar and wind exposed terrain for Summer is approximately 23°C (73°F). However, Summer daytimes will generally be considered warm to hot with moderate to high heat stress conditions during the afternoon (>30°C, >86°F).

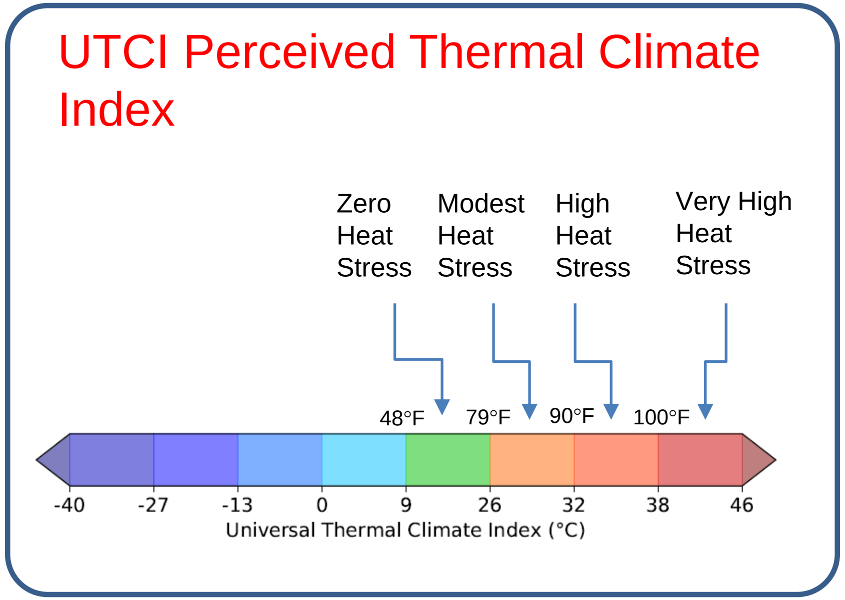


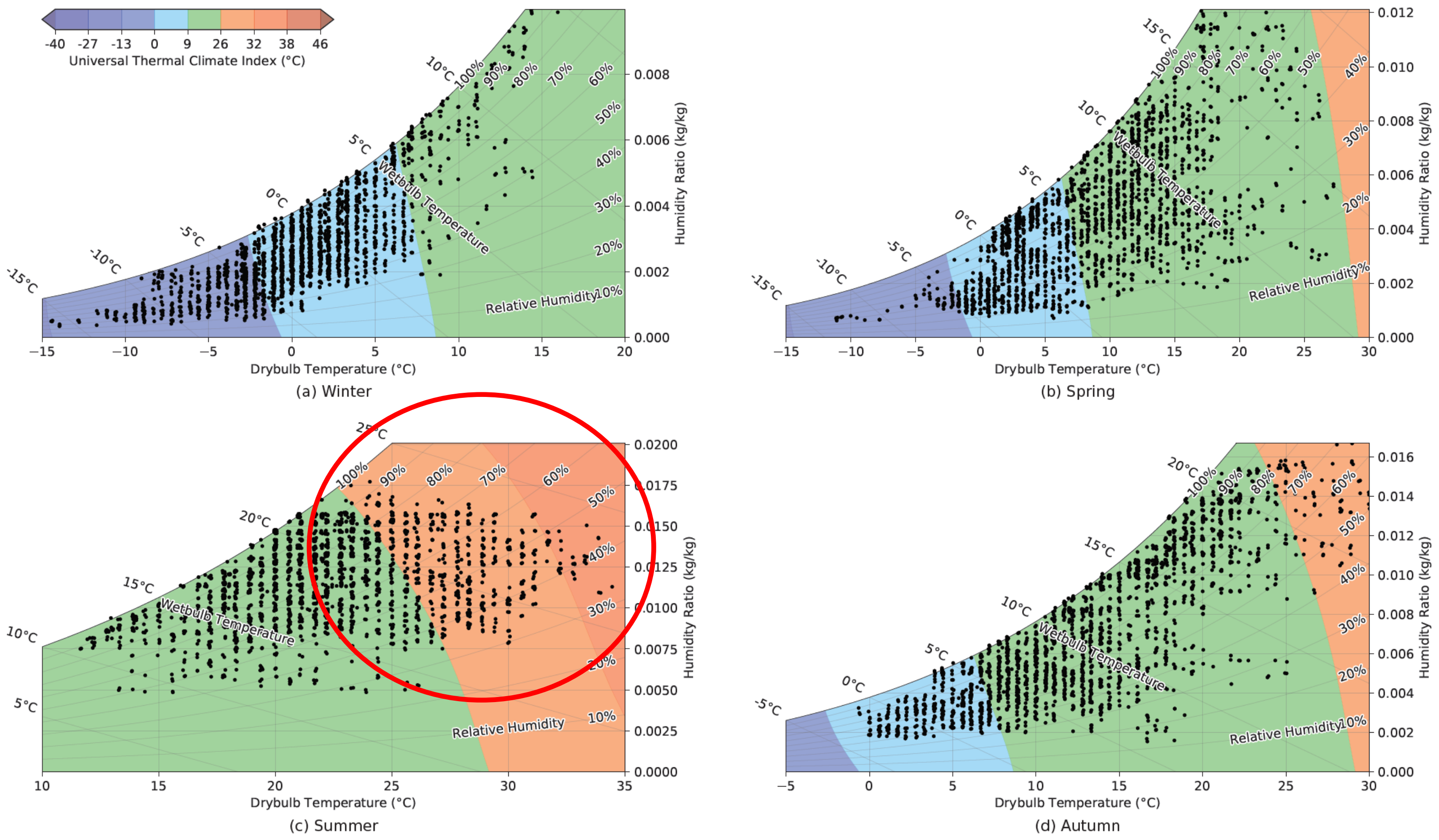
Seasonal average diurnal range perceived temperature (blue line).

Climate Characteristics

Thermal Comfort – Universal Thermal Climate Index

Annual hourly combinations of dry-bulb temperature and relative humidity is shown here on a psychrometric chart, overlaid with the UTCI thermal comfort scale. This shows hours (black dots) during different season that are comfortable (green overlay) or with mild or severe heat stress (orange to red) or mild to high cold stress (light blue to dark blue). For the UTCI, comfortable perceived temperatures are associated with 9ºC < T_{utci}< 26ºC, while warm conditions with moderate heat stress are 26ºC < T_{utci}< 32ºC. High heat stress conditions are associated with $T_{utci>}$32ºC. On average, Summer conditions are mostly associated with comfortable to moderately warm conditions (at the airport). Urban conditions with limited wind ventilation, high solar exposure and higher urban heat island intensities will feel warmer more often.



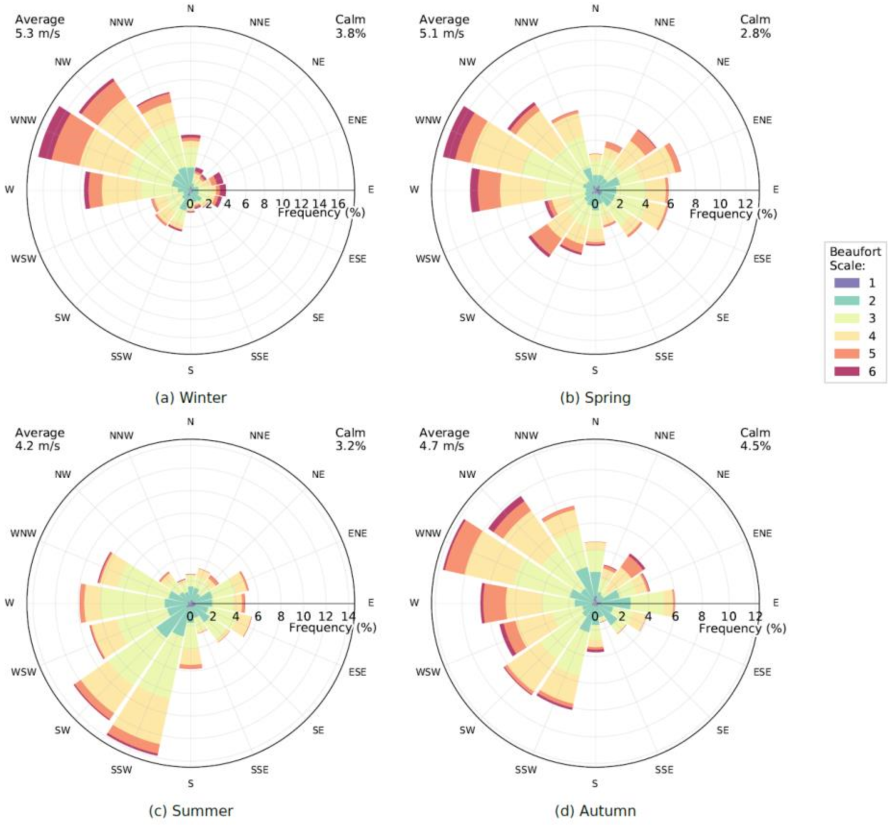


Seasonal psychrometric conditions showing the combination of dry-bulb temperature and relative humidity overlaid on the perceived thermal comfort scale (UTCI)

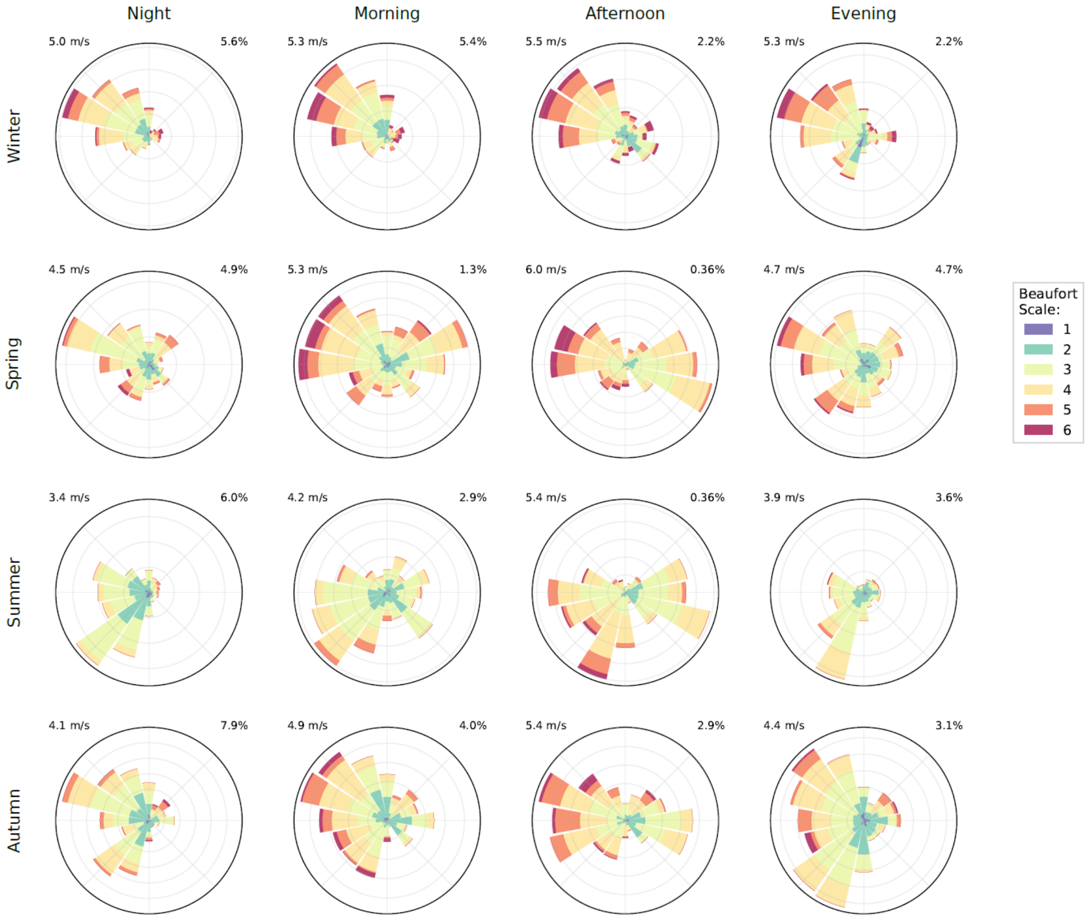
Climate Characteristics

Wind Distribution
Based on typical hourly meteorological data it is expected that Boston will, on average, exhibit wind speeds averaging 5.3m/s to 4.2m/s during Winter or Summer, respectively.

Prevailing winds are frequently from the Southwest in Summer. Wind speeds generally increase during the afternoon.



Seasonal directional wind distribution

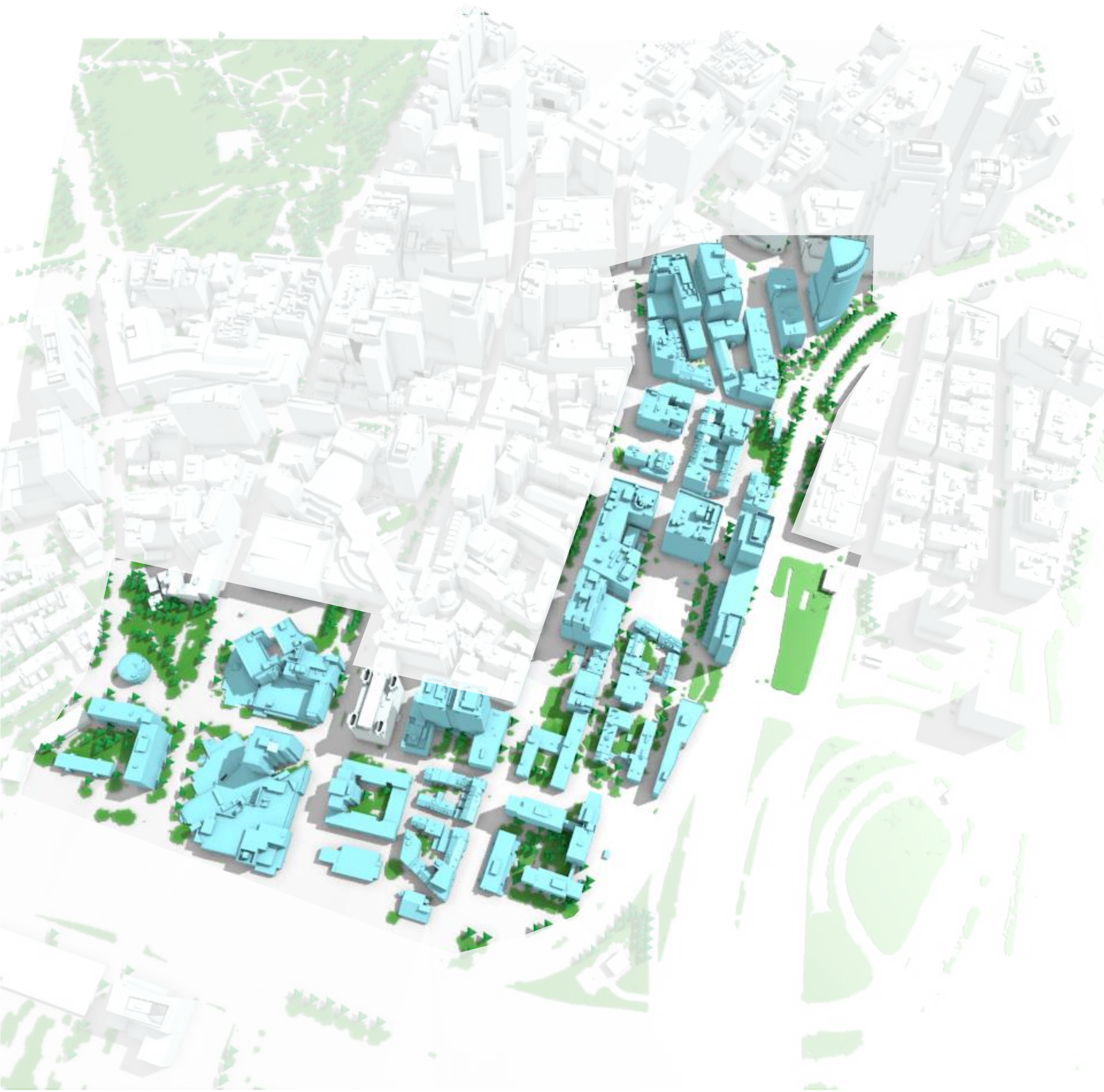


Seasonal and daily directional wind distribution

How the Neighborhood Climate Simulation Model Works

BASELINE Urban climate simulation

An urban climate simulation was performed that couples computational wind simulations and hourly solar exposure modelling, with annual hourly meteorology data reflective of the local climate, to deliver climate performance maps for different seasons during the year. The computational model uses the neighbourhood massing geometry with different surface specifications for site buildings, surrounding buildings, terrain and site ground planes, as well as landscape condition. An initial baseline urban climate simulation was performed to mimic the existing conditions of the site.



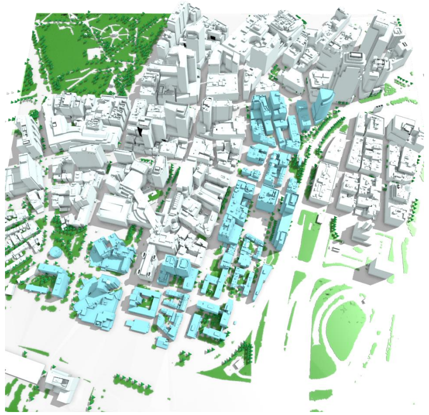
Baseline Neighbourhood: Urban climate simulation geometrical model with site and surrounding buildings and terrain/landscape features.

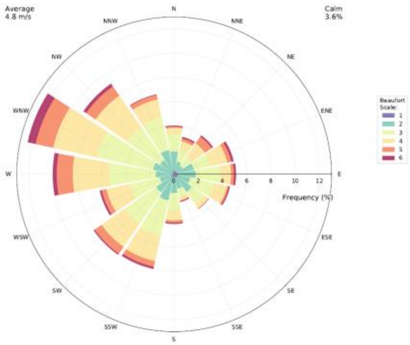
CONCEPT Urban climate simulation

A second urban climate simulation was performed for a modified neighbourhood with different passive urban cooling strategies. The modified urban surface layers, shading strategies and increased urban tree canopy is shown to the right to highlighting additional or modified geometrical layers. Layer surface specifications are provided in Appendix A.

Baseline Neighbourhood: Urban climate simulation geometrical model with site and surrounding buildings and terrain/landscape features.

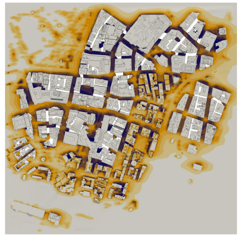
Urban Climate Simulation - Process





Geometrical model for urban massing with different layers for land surface characteristics and urban landscape elements are combined with annual hourly meteorological data in a computational solver.

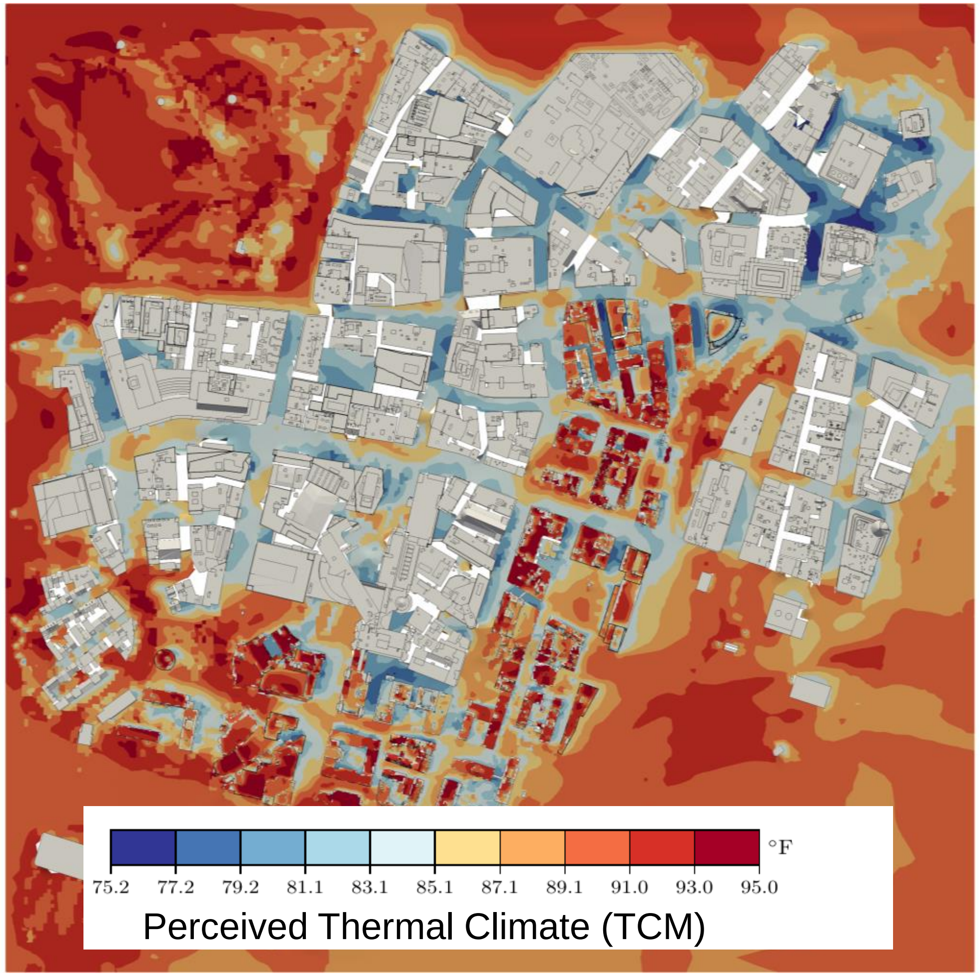
Sky View Factor



Solar Radiation

The solver combines solutions of hourly wind exposure throughout the domain with modelled hourly solar exposure, sky view factors and land surface temperatures to derive local climate performance characteristics

Finally, maps of seasonal average climate performance indicators are produced through statistical averaging of the hourly simulation results. For example, the perceived temperature distribution shown here is a result of the combination of the modelled wind exposure, ambient temperature and humidity condition, solar exposure and evapotranspiration, among other factors.



Climate Performance Indicators (KPI) Legend Definitions

<u>Solar Shading Factor (SHF)</u>

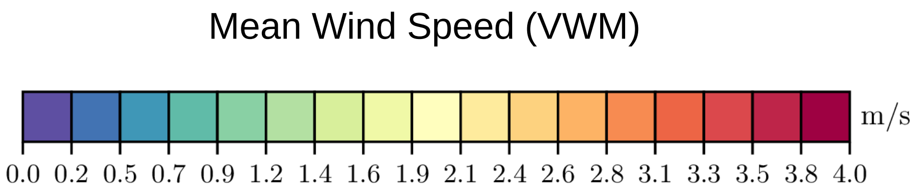
Solar shading factor is the fraction of time that the area is fully shaded

Example: A SHF value of 0.6 for Summer Afternoon means that the area is completely shaded for 60% of the time during Summer Afternoon hours.

<u>Mean Wind Speed (VWM)</u>

Mean wind speed at pedestrian level (1.8m above grade) for the period

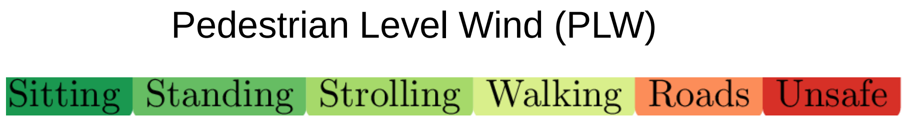
Example: A VWM value of 2.6m/s for Summer Afternoon means the average wind speed at 1.8m above the terrain is 2.6m/s, averaged for all Summer Afternoon hours between 1pm and 6pm



<u>Pedestrian Level Wind (PLW)</u>

Pedestrian level wind comfort activity suitability index, based on the Lawson pedestrian level wind criteria

Example: Standing means local wind conditions will be suitable for standing or lingering activities for most of the time during the season



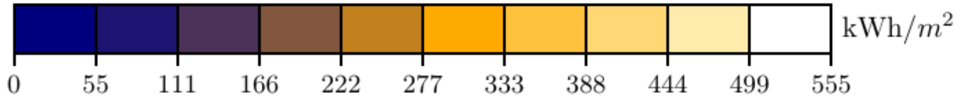
Climate Performance Indicators (KPI) Legend Definitions

Total Solar Insolation (TCF)

Average incident solar insolation on surfaces (kWh/m2)

Example: A TCF value of 200 for Summer All Day means that the seasonal average incident solar insolation per day (direct and diffuse) is 200 kWh/m2.

Solar Insolation (TCF)

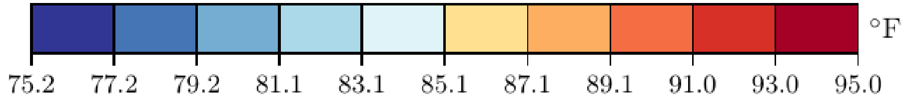


Thermal Climate Mean (TCM)

The mean thermal climate represented as the perceived temperature (thermal comfort) as a combination of the modelled exposure to wind, temperature, humidity, solar radiation, averaged for the period

Example: A TCM value of 95ºF for Summer Afternoon means that the average perceived temperature felt at pedestrian level is 95F due to sun, wind, humidity and temperature exposure

Thermal Climate Mean (TCM)

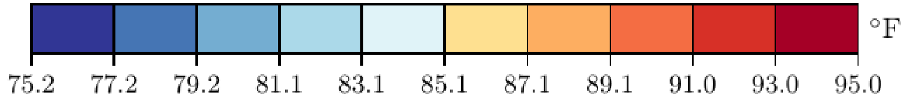


Surface Temperature (TGR)

The average surface temperature for the period

Example: A TGR value of 131ºF for Summer Afternoon means that the surface temperature for the entire Summer season during afternoons is 131ºF.

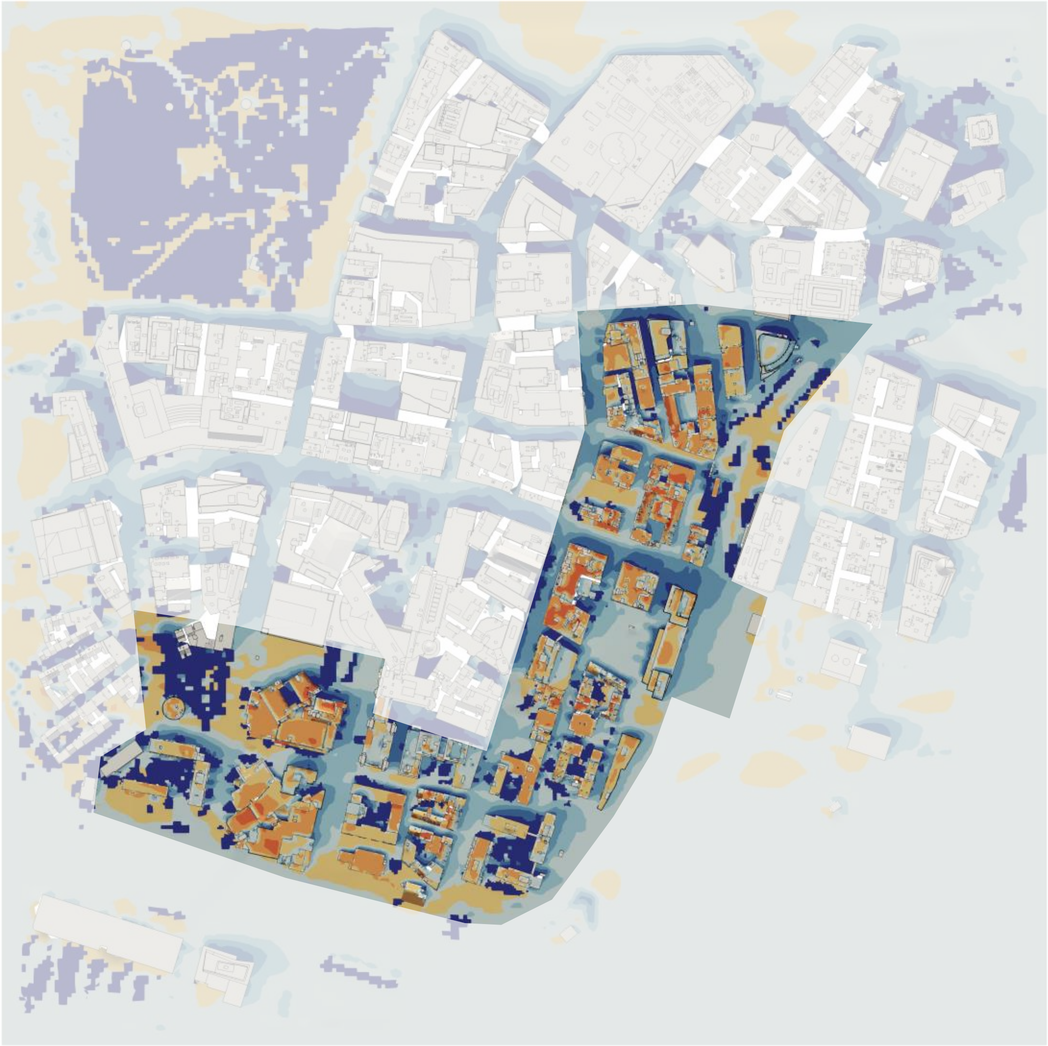
Surface Temperature (TGR)



Baseline and Concept Neighbourhood Comparison

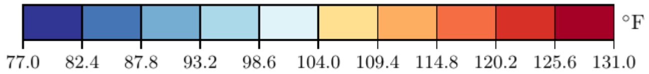
Summer Afternoon - Surface Temperature

In Summer, surface temperatures are significantly reduced through the introduction of combinations of high albedo surfaces for roads and roofs, green roofs and the application of shade and solar canopies. Surface temperature also vary due to differences in different solar and wind exposures within the neighbourhood.



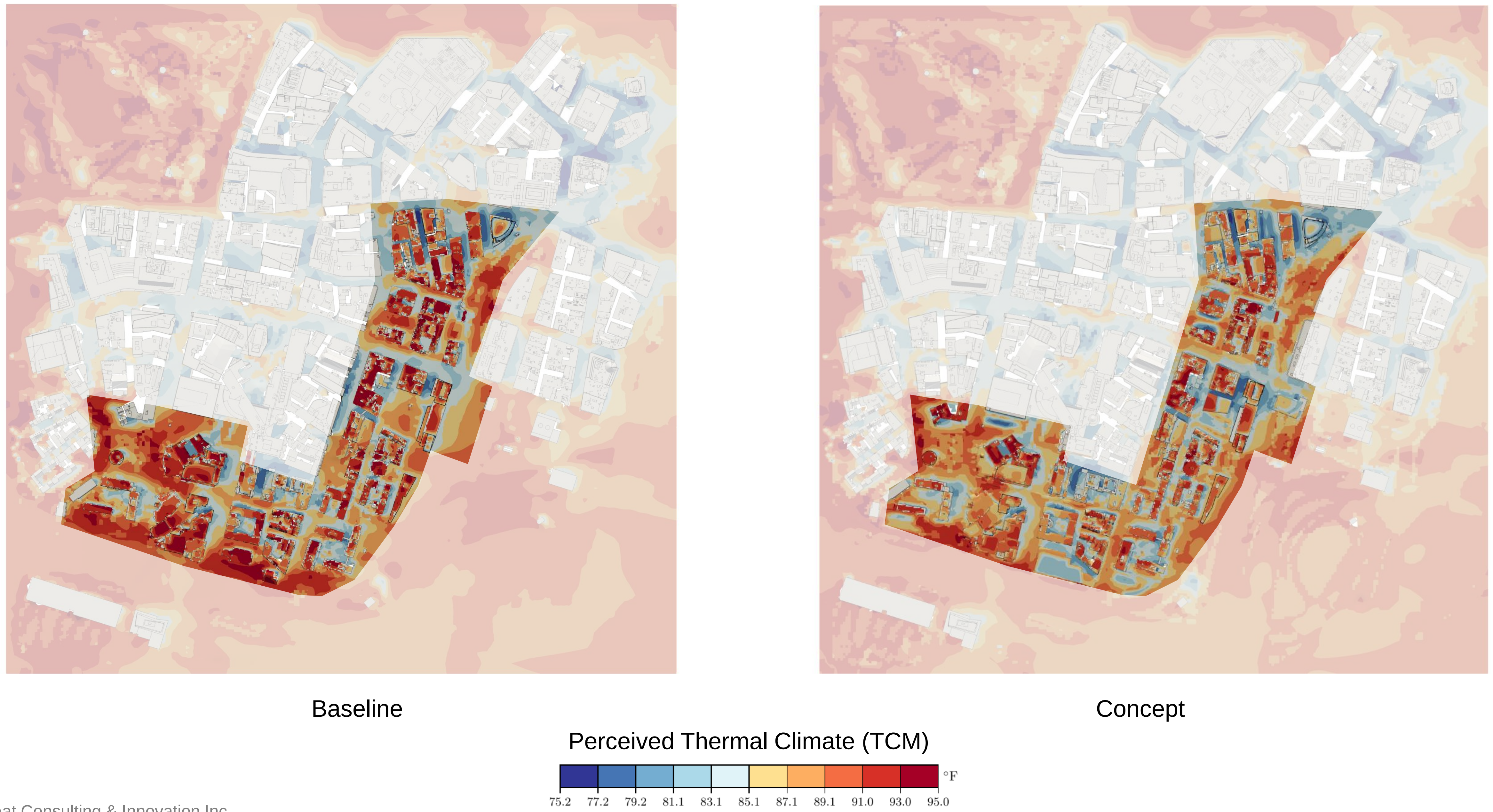
Baseline

Concept



Summer Afternoon - Perceived Temperature

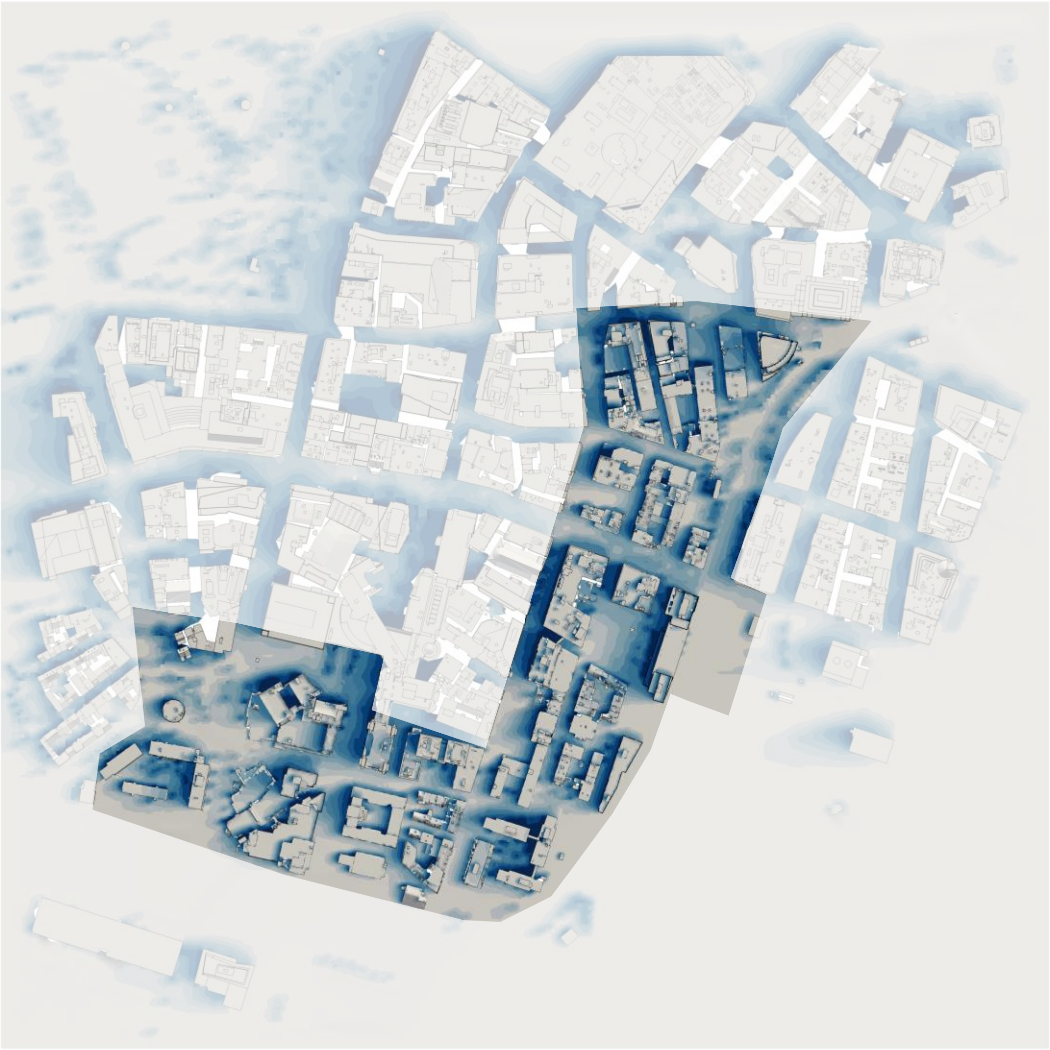
In Summer, perceived temperature reductions are achieved through the introduction of combinations of high albedo surfaces for roads and roofs, green roofs and the application of trees and or shade and solar canopies. Again, perceived temperatures may also vary due to different wind and solar exposures within the neighbourhood.



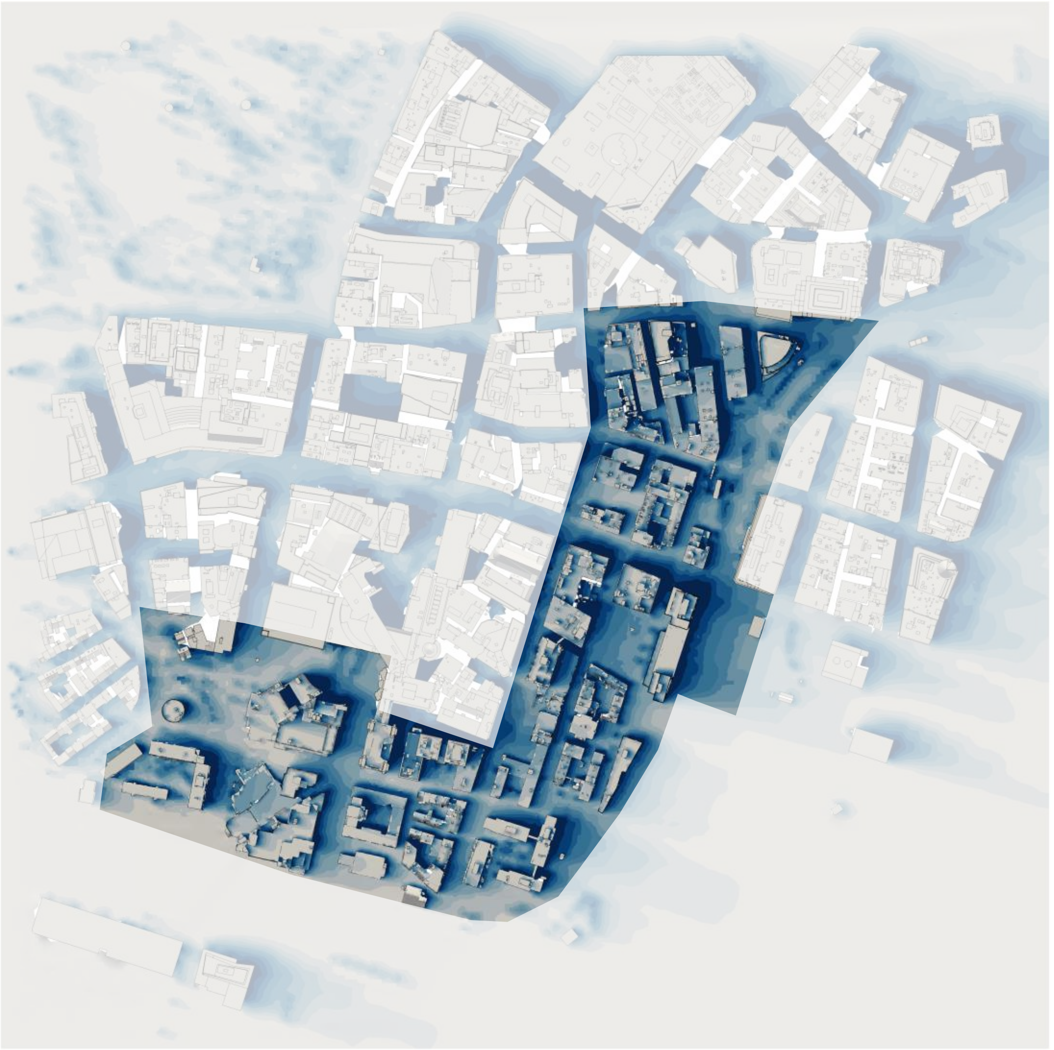
Baseline Neighbourhood

Summer – Solar Shading Fraction

Summer sun exposure creates mostly deeper shade either on the west or east side of buildings during morning and afternoons, respectively.

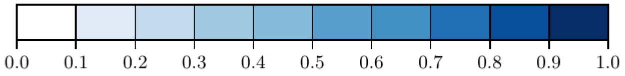


Morning



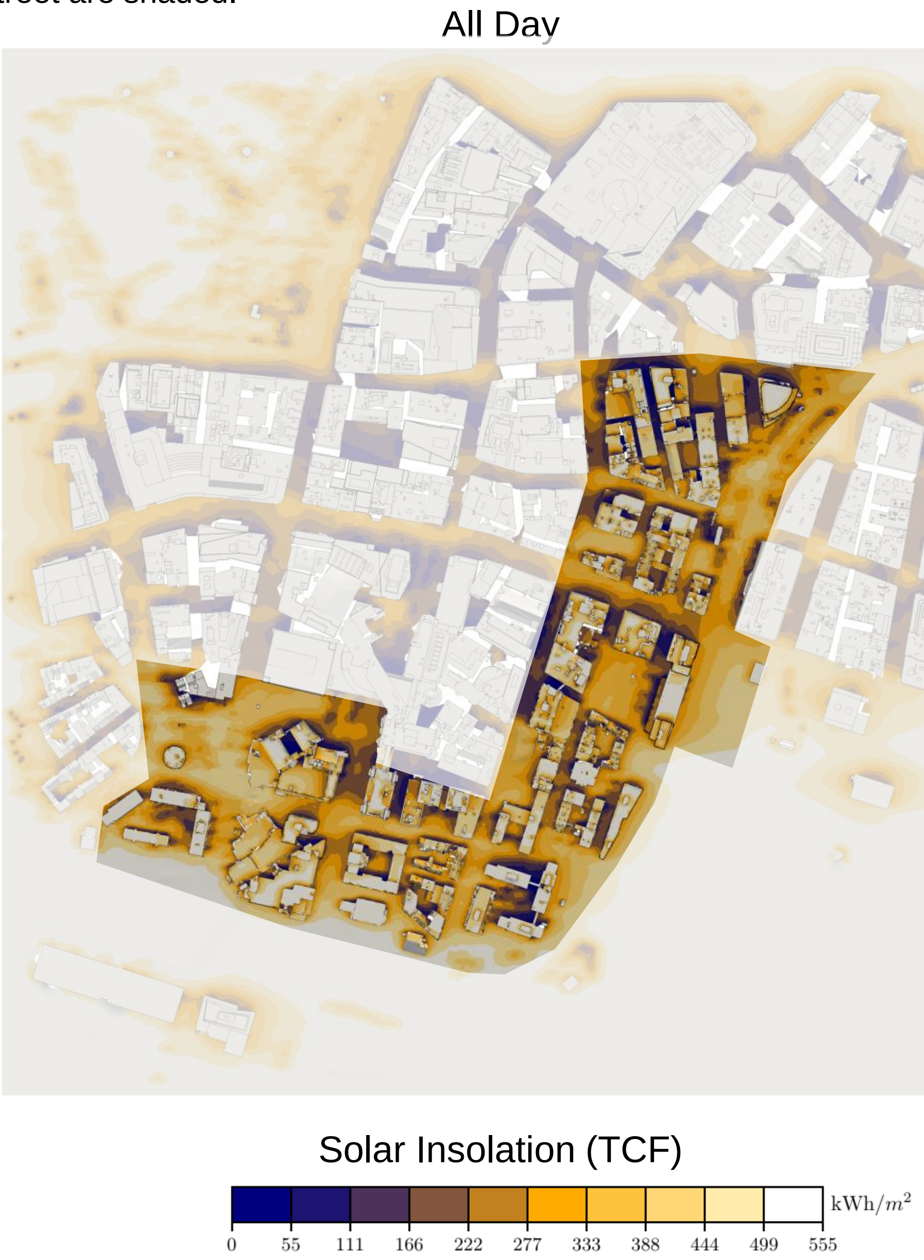
Afternoon

Solar Shading Factor (SHF)



Summer – Total Solar Insolation

During Summer, solar insolation is relatively low along narrow N-S streets, and higher along E-W streets or wide open areas. The north side of E-W streets tends to have the highest solar exposure while the south side of these street are shaded.



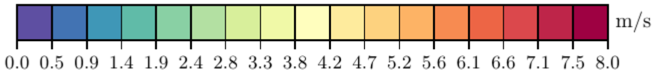
Summer - Mean wind speed distribution

Summer mean wind exposure at pedestrian level and above rooftops. Local wind ventilation is important to help ventilate the urban setting, reduce heat build-up and improve thermal comfort.

Morning

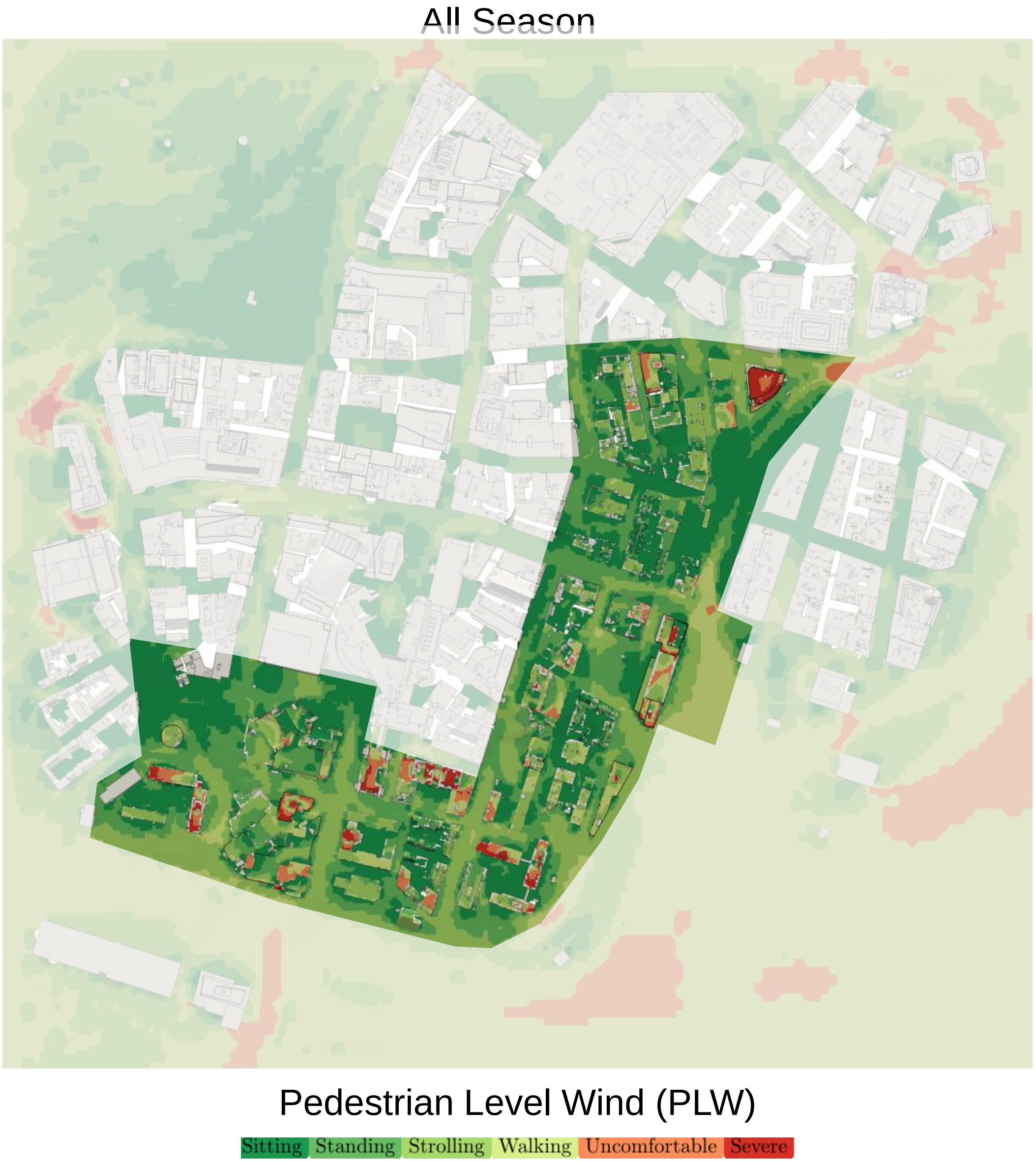
Afternoon

Mean Wind Speed (VWM)



Summer – Pedestrian level wind comfort (PLW)

Mostly comfortable conditions during Summer across the site with localised areas of elevated wind speeds and conditions more suitable for standing or walking on some areas of where flow is channels between taller buildings and at roof level.

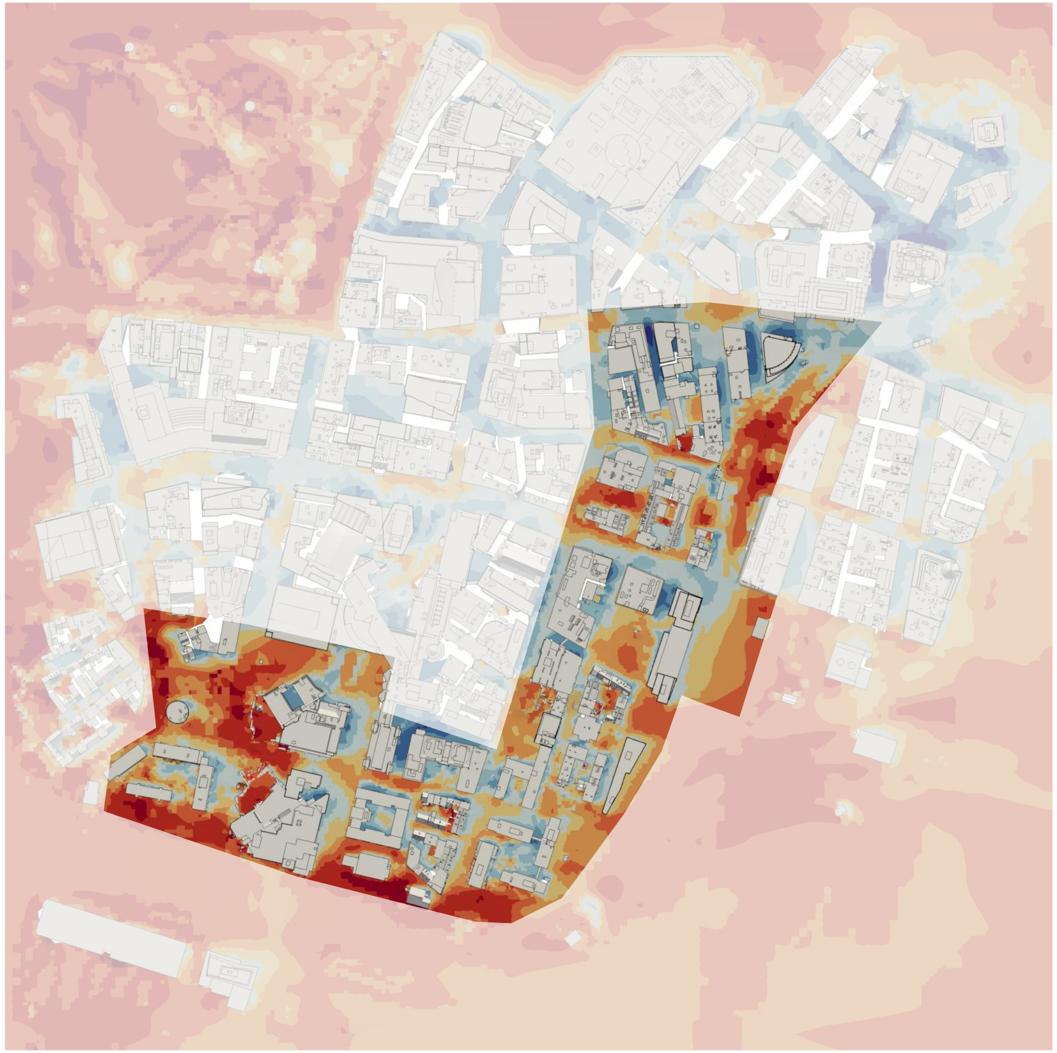


Baseline Neighbourhood - Grade

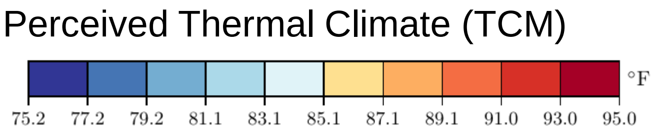
Summer – Thermal comfort

During Summer afternoons, average perceived temperatures will be between 80 and 85ºF in shaded and or wind exposed areas. This will be associated with modest heat stress conditions. More solar exposed areas will be associated with high heat stress conditions.

Morning



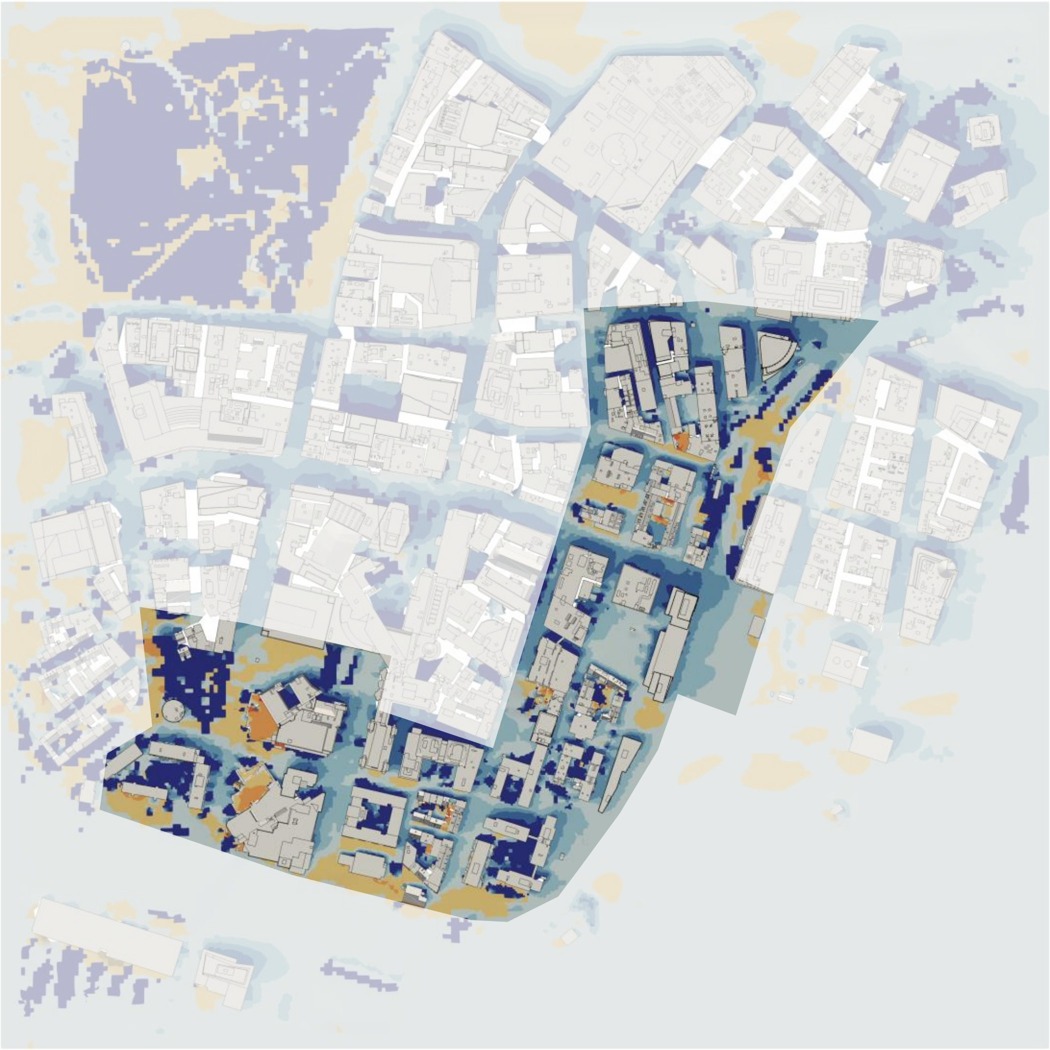
Afternoon



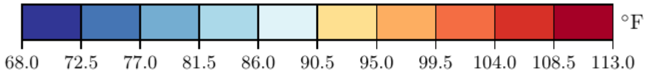
Summer – Surface Temperature

During Summer afternoons, grade level surface temperatures will range between 82ºF and 109ºF depending on the surface material and condition and the local solar and or wind exposure.

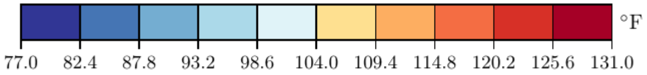
Morning



Afternoon



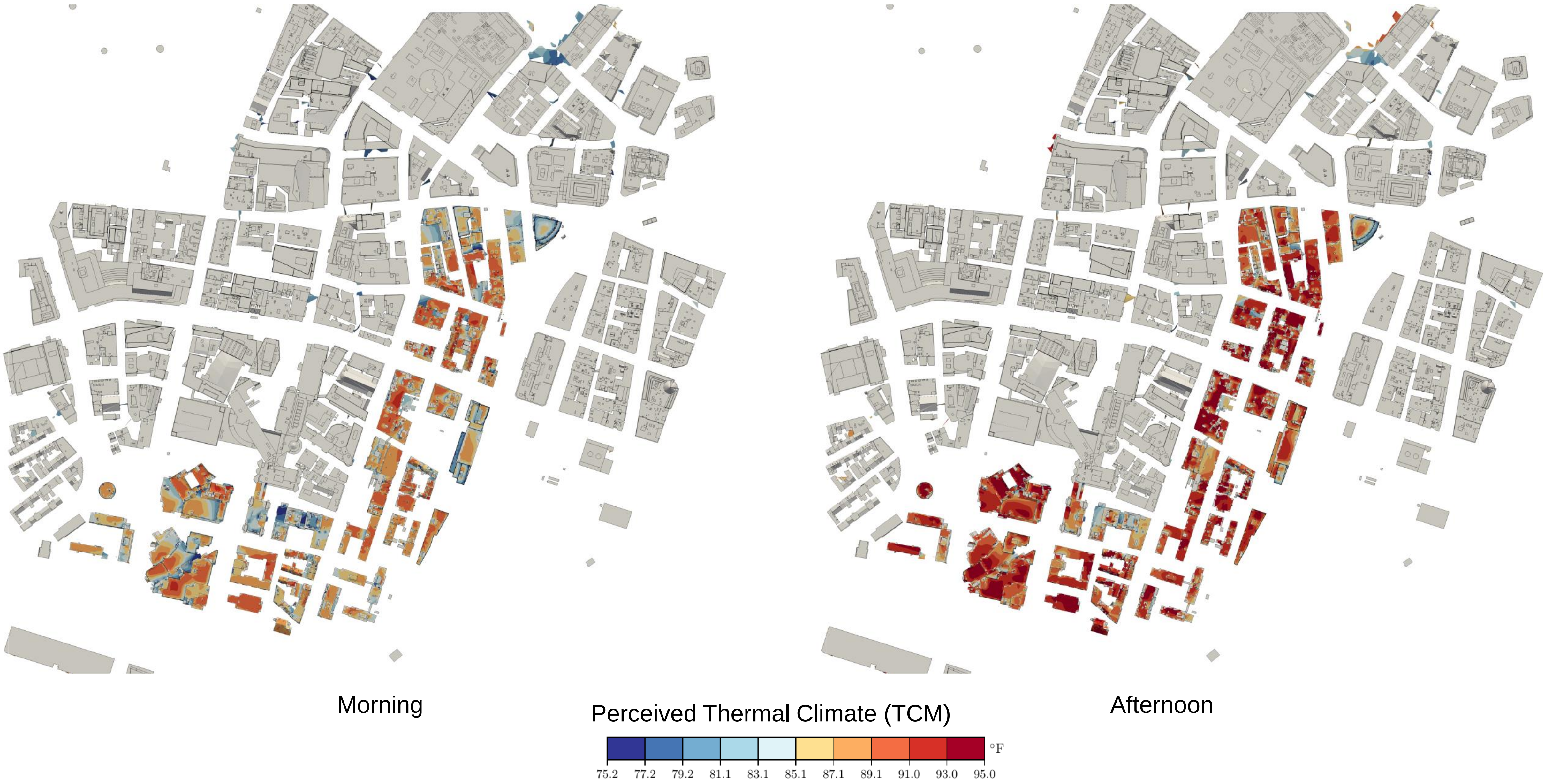
Surface Temperature (TGR)



Baseline Neighbourhood - Roof

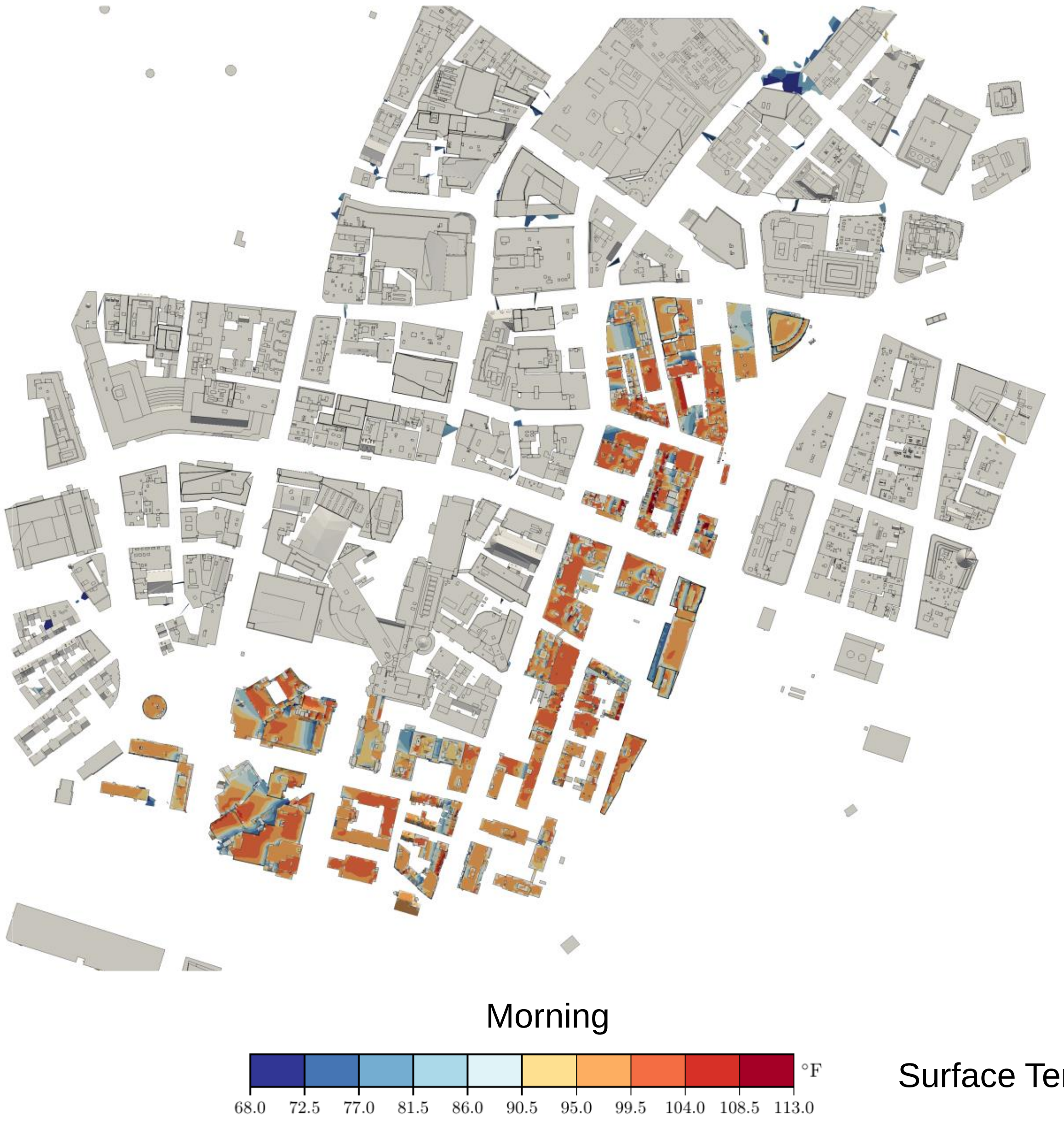
Summer – Thermal comfort

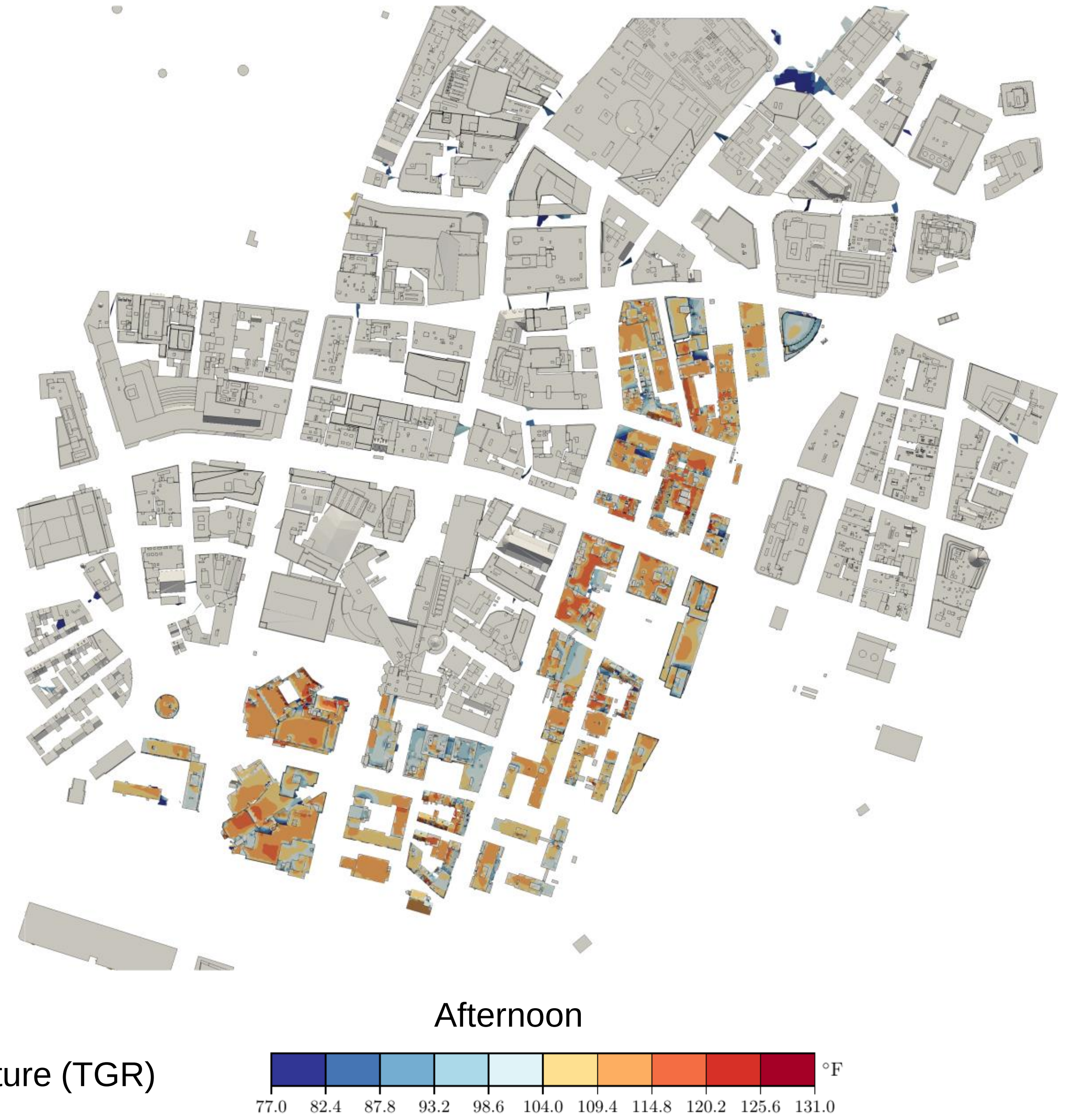
During Summer afternoons, average perceived temperatures will be between 87ºF and 95ºF in shaded and or wind exposed areas. This will be associated with moderate to high heat stress conditions.



Summer – Surface Temperature

During Summer afternoons, roof level surface temperatures will range between 98ºF and 125ºF depending on the surface material and condition and the local solar and or wind exposure.



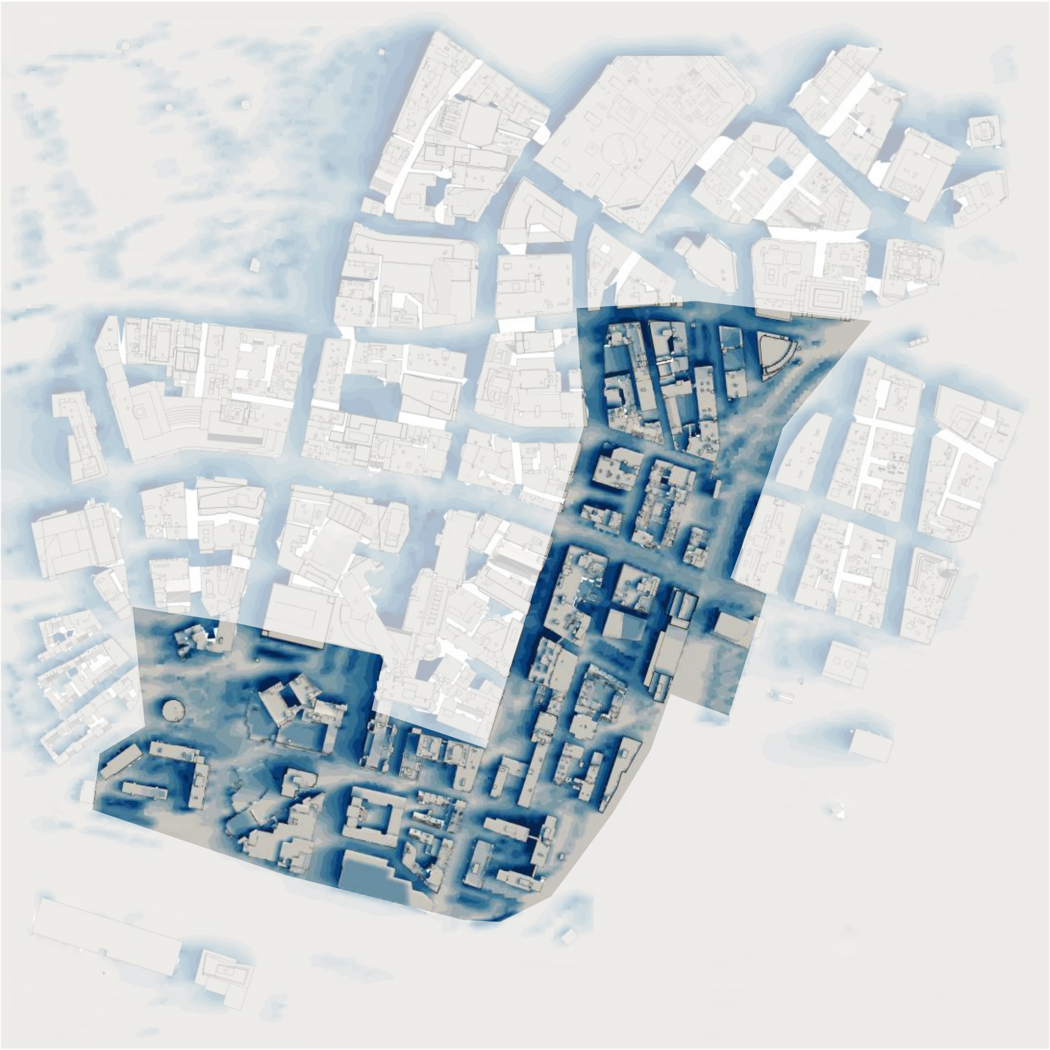


Surface Temperature (TGR)

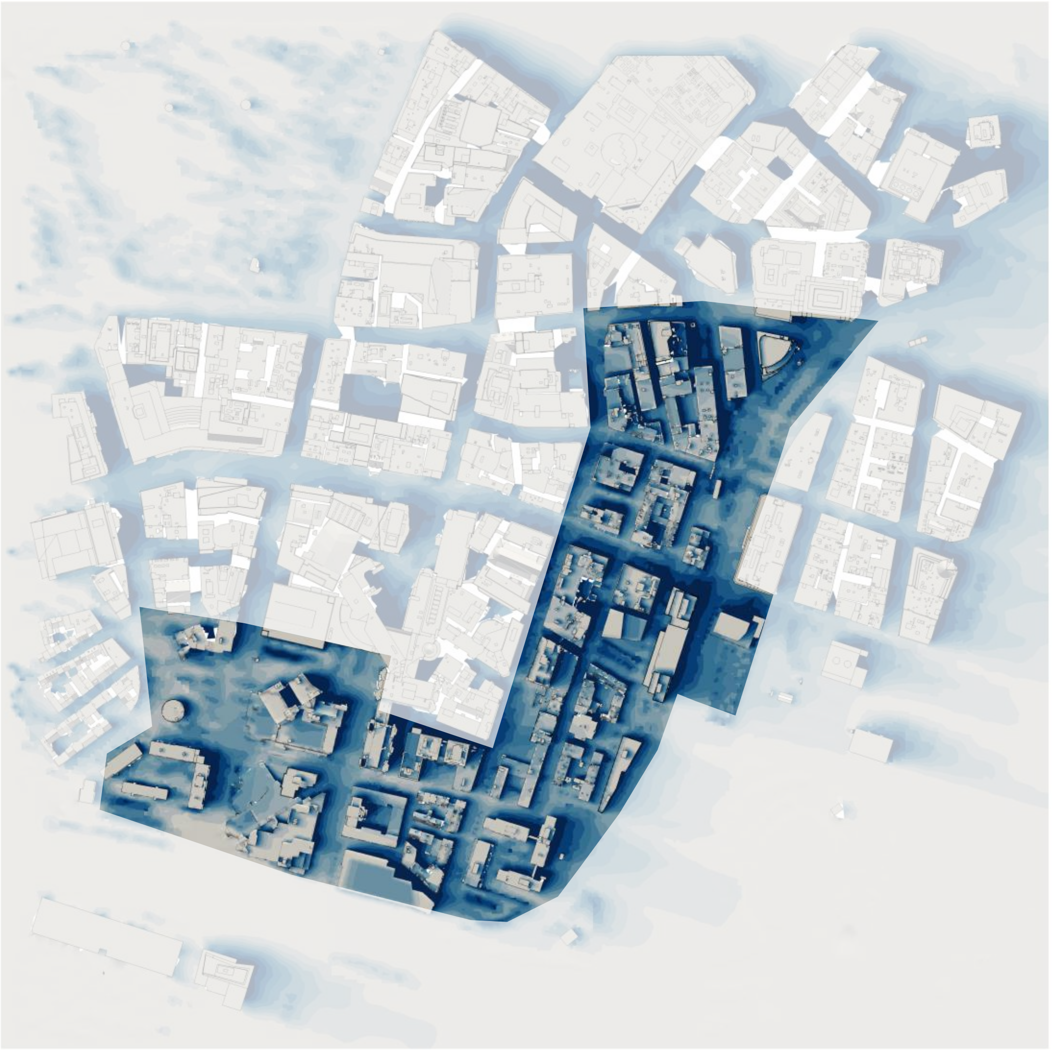
Concept Neighbourhood

Summer – Solar Shading Fraction

Summer sun exposure creates mostly deeper shade either on the west or east side of buildings during morning and afternoons, respectively. Additional shade is provided by the introduction of variations of shading canopies and tree cover.

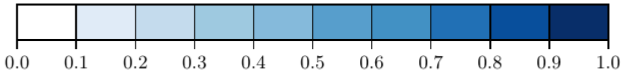


Morning



Afternoon

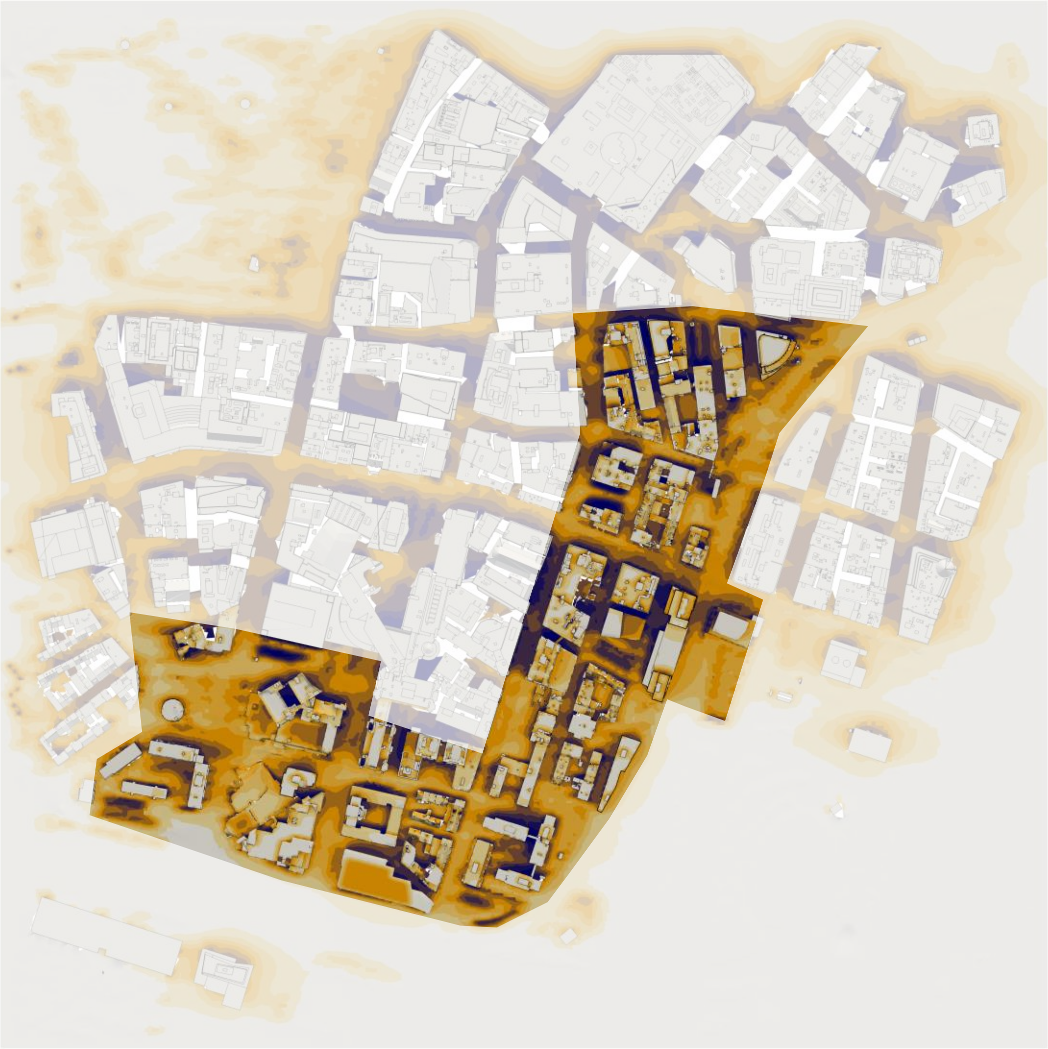
Solar Shading Factor (SHF)



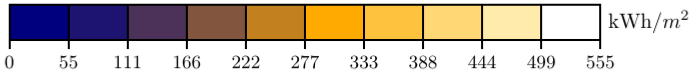
Summer – Total Solar Insolation

During Summer, solar insolation is relatively low along narrow N-S streets, and higher along E-W streets or wide open areas. The north side of E-W streets tends to have the highest solar exposure while the south side of these street are shaded.

All Day



Solar Insolation (TCF)



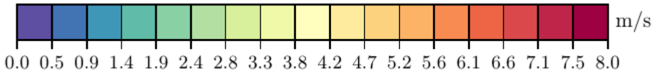
Summer - Mean wind speed distribution

Summer mean wind exposure at pedestrian level and above rooftops. Local wind ventilation is important to help ventilate the urban setting, reduce heat build-up and improve thermal comfort.

Morning

Afternoon

Mean Wind Speed (VWM)



Summer – Pedestrian level wind comfort (PLW)

Mostly comfortable conditions during Summer across the site with localised areas of elevated wind speeds and conditions more suitable for standing or walking on some areas of where flow is channels between taller buildings and at roof level.

All Season

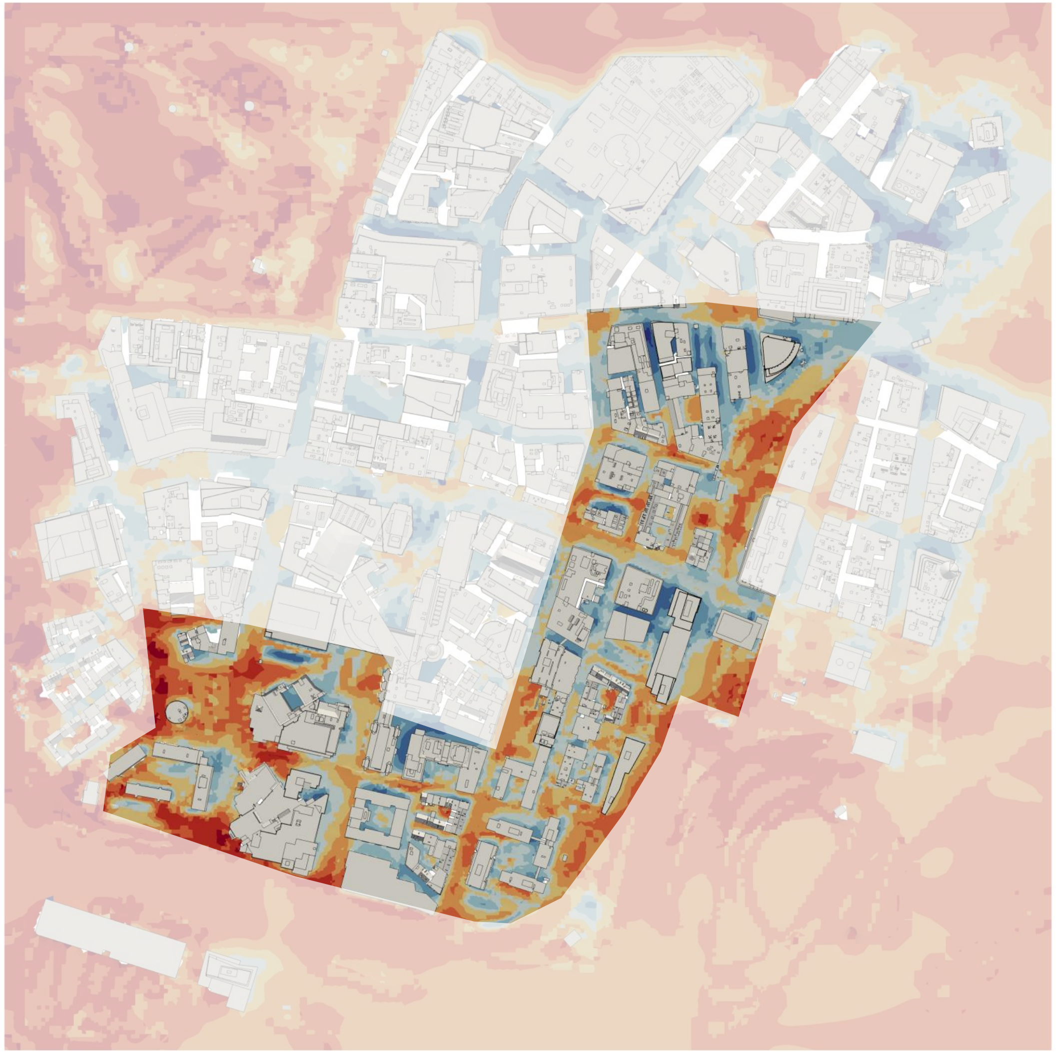
Pedestrian Level Wind (PLW)

Concept Neighbourhood - Grade

Summer – Thermal comfort

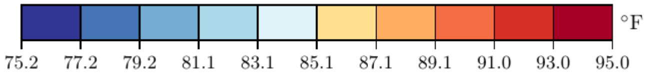
During Summer afternoons, average perceived temperatures will be between 80 and 85ºF in shaded and or wind exposed areas. This will be associated with modest heat stress conditions. More solar exposed areas will be associated with high heat stress conditions.

Morning



Afternoon

Perceived Thermal Climate (TCM)

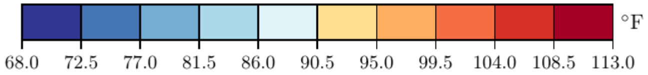


Summer – Surface Temperature

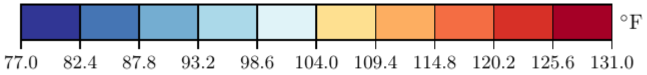
During Summer afternoons, grade level surface temperatures will range between 82ºF and 109ºF depending on the surface material and condition and the local solar and or wind exposure.

Morning

Afternoon



Surface Temperature (TGR)



Concept Neighbourhood - Roof

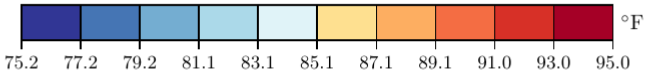
Summer – Thermal comfort

During Summer afternoons, average perceived temperatures will be between 81ºF and 95ºF in shaded and or wind exposed areas. This will be associated with moderate to high heat stress conditions. Reduced perceived temperatures occurs in areas with green or blue roofs, or roofs with shading canopies.

Morning

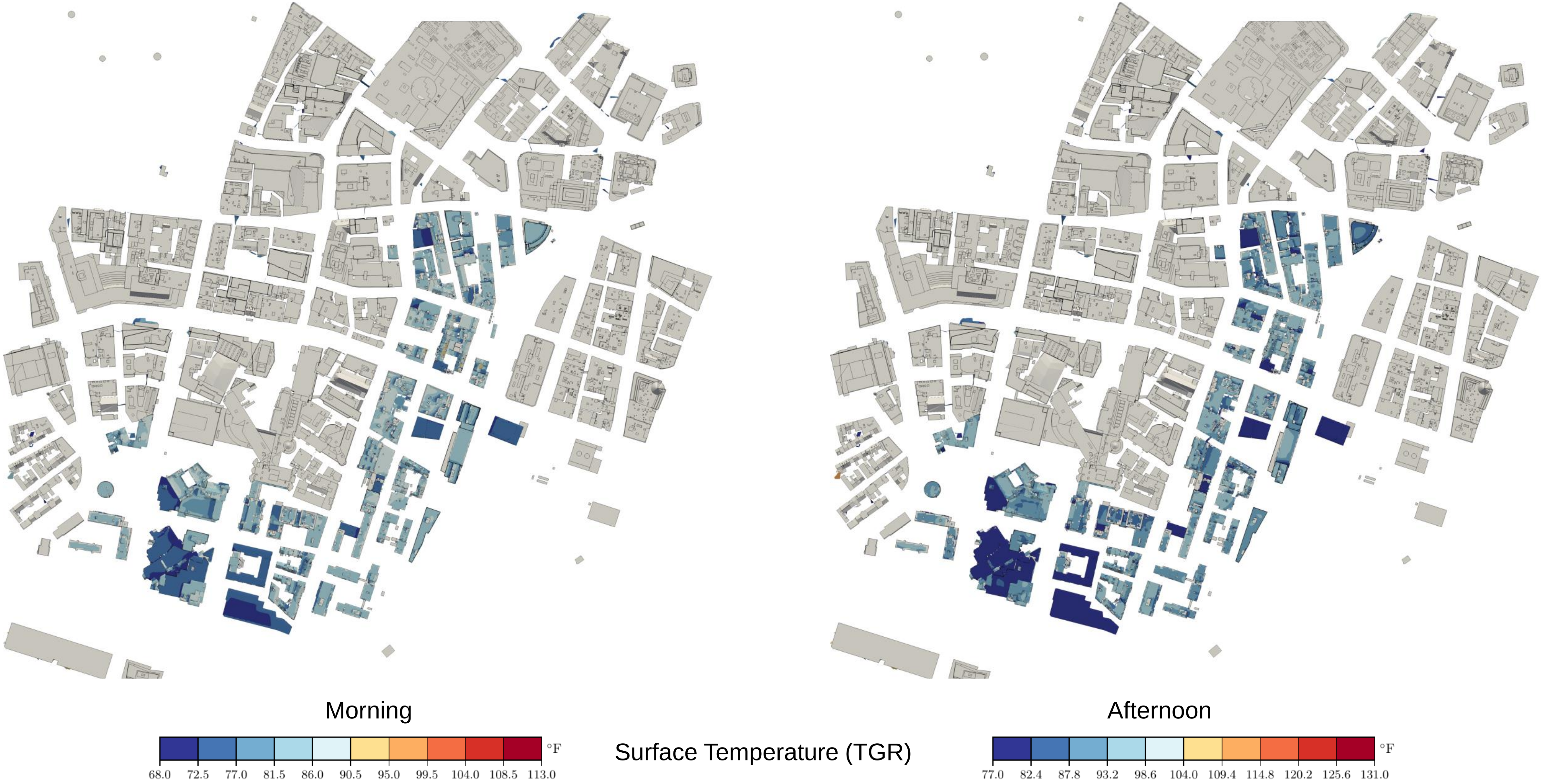
Afternoon

Perceived Thermal Climate (TCM)



Summer – Surface Temperature

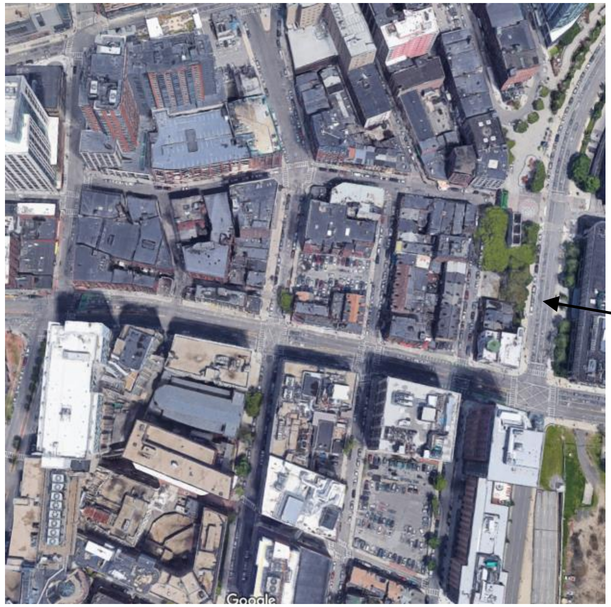
During Summer afternoons, roof level surface temperatures will range between 82ºF and 98ºF depending on the surface material and condition and the local solar and or wind exposure. Roof surface temperatures are significantly reduced with the introduction of cool roof and roof shading strategies.



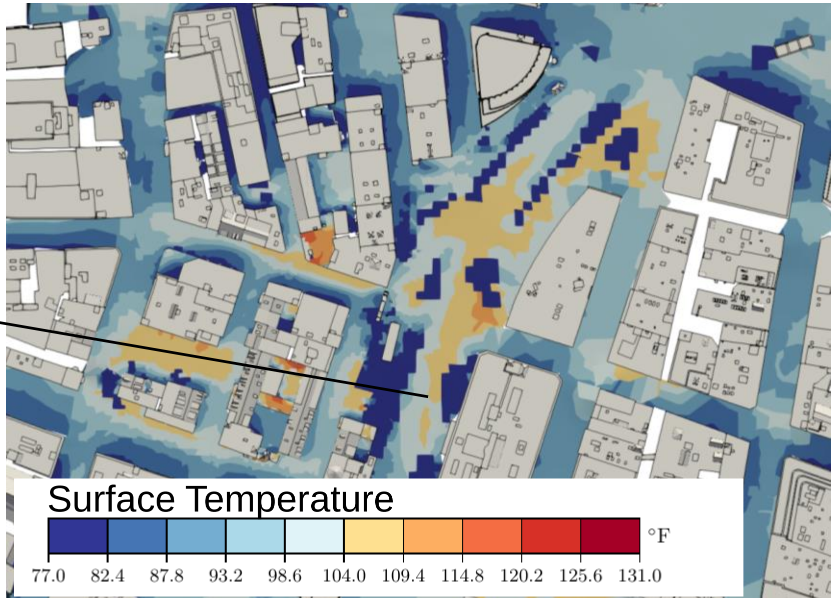
Detailed Observations

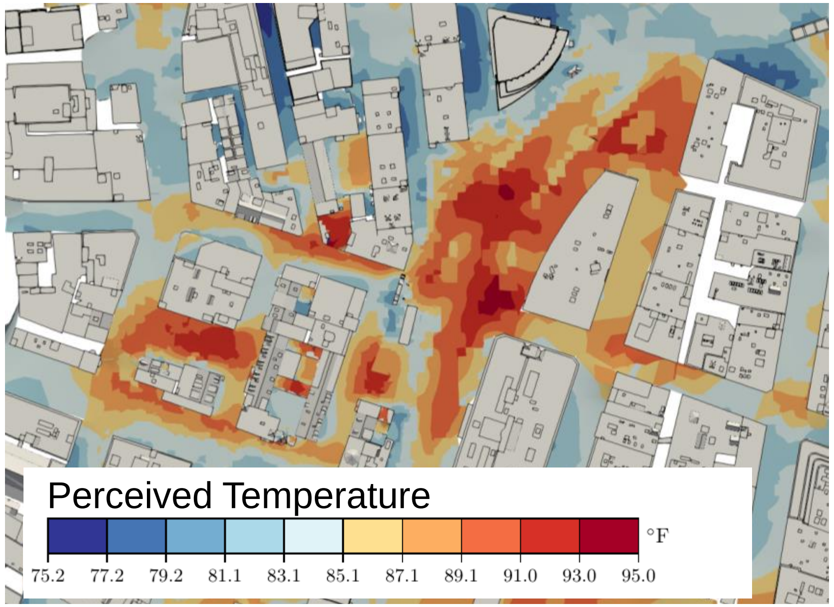
1. High SRI Roads

1) High albedo vs low albedo road reduces afternoon surface temperatures from 104ºF to 93ºF.
2) Effect of lower surface temperatures reduces perceived temperatures from 90ºF to 88.6ºF with high solar exposure still dominating high thermal stress.

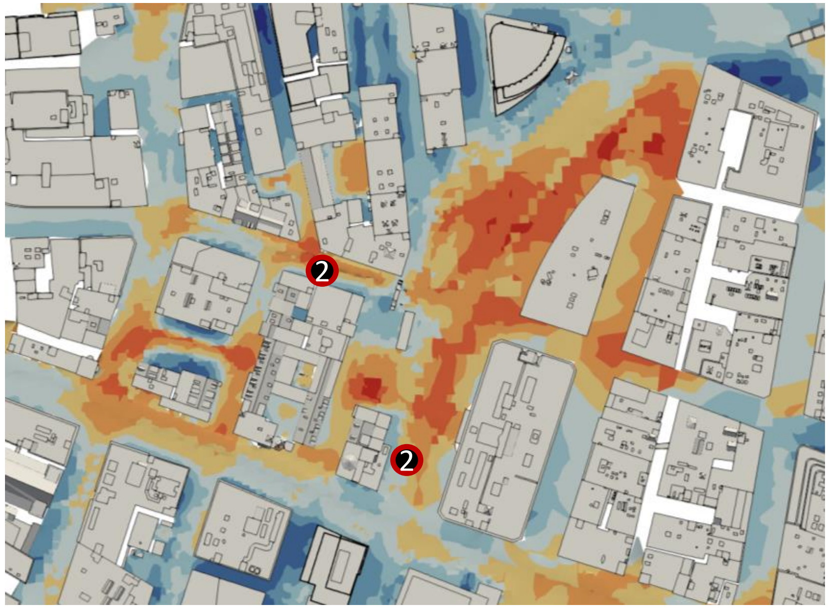


Baseline





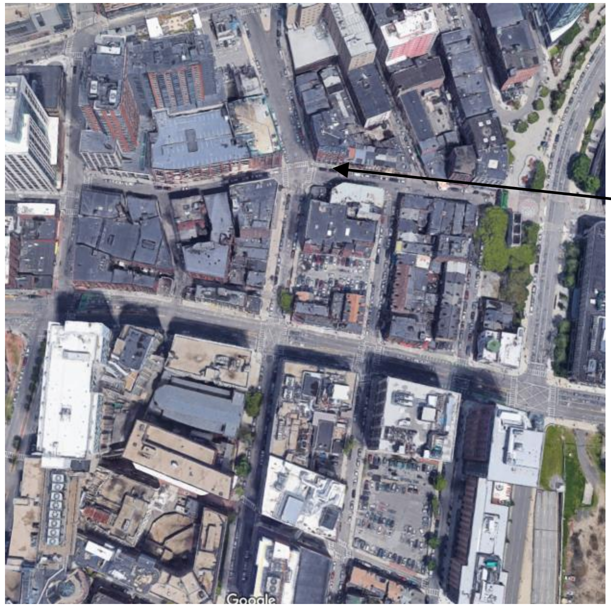
Concept

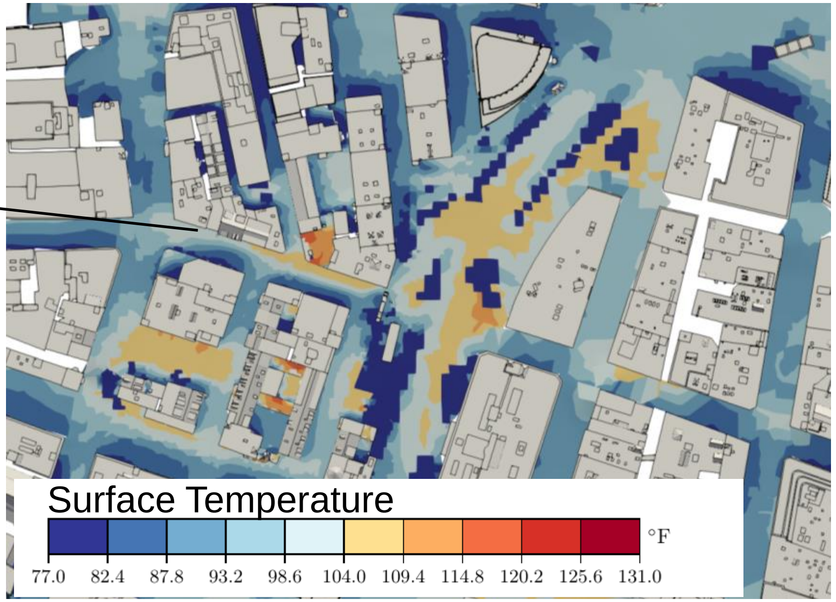


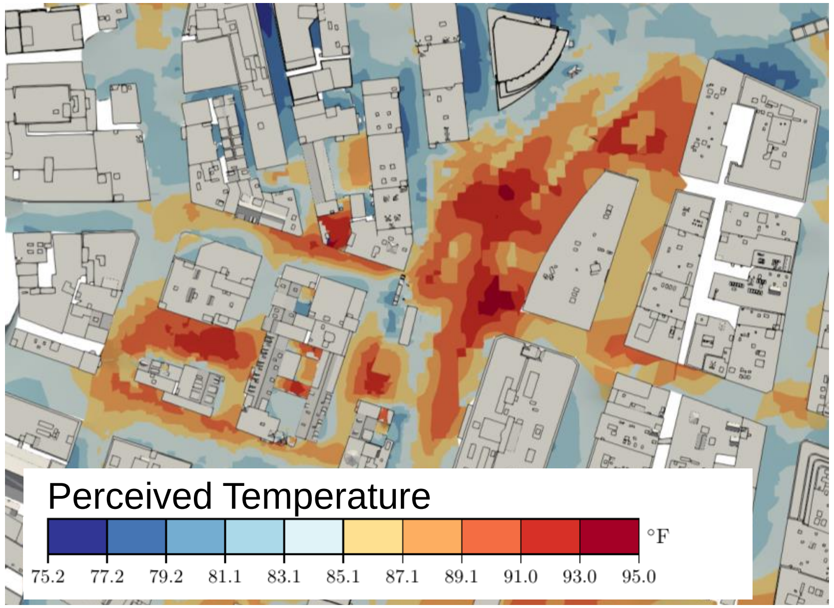
2. Effect of canopy (50%) over E-W street

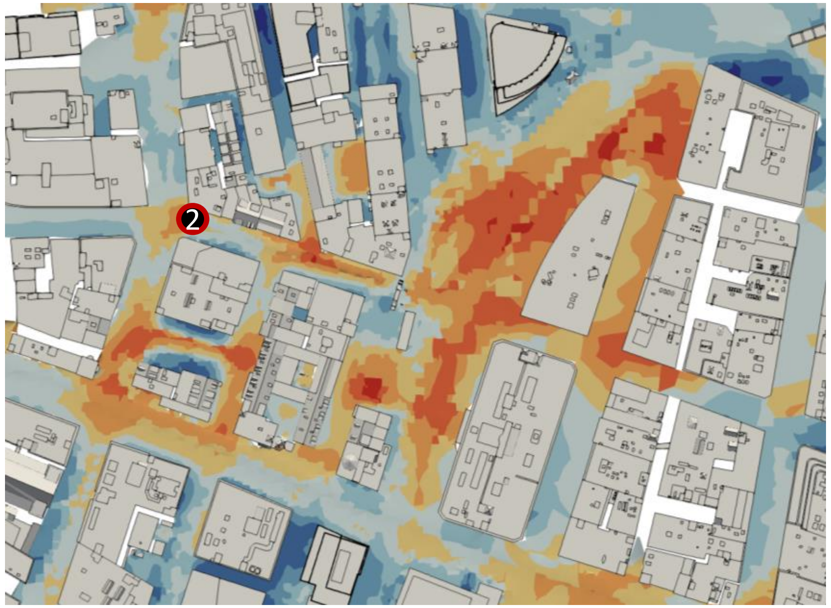
1) Canopy reduces afternoon surface temperatures on north side of street from 103ºF to 87ºF.
2) Canopy reduces perceived temperatures from 87ºF to 84ºF by reducing solar exposure and surface temperatures.

	Baseline	Concept



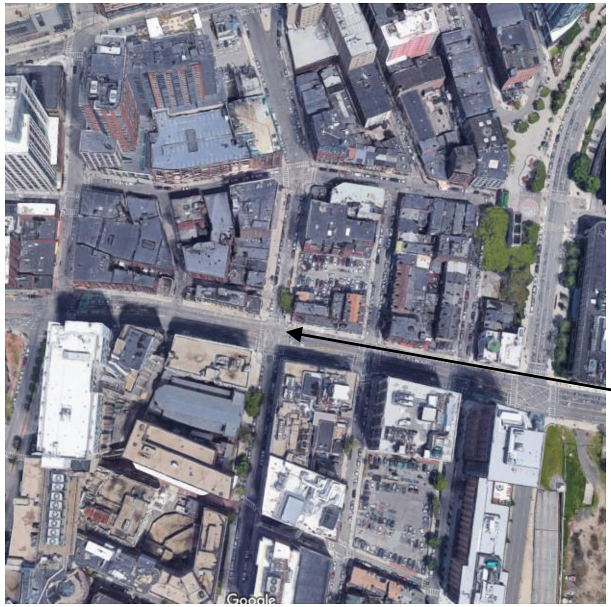




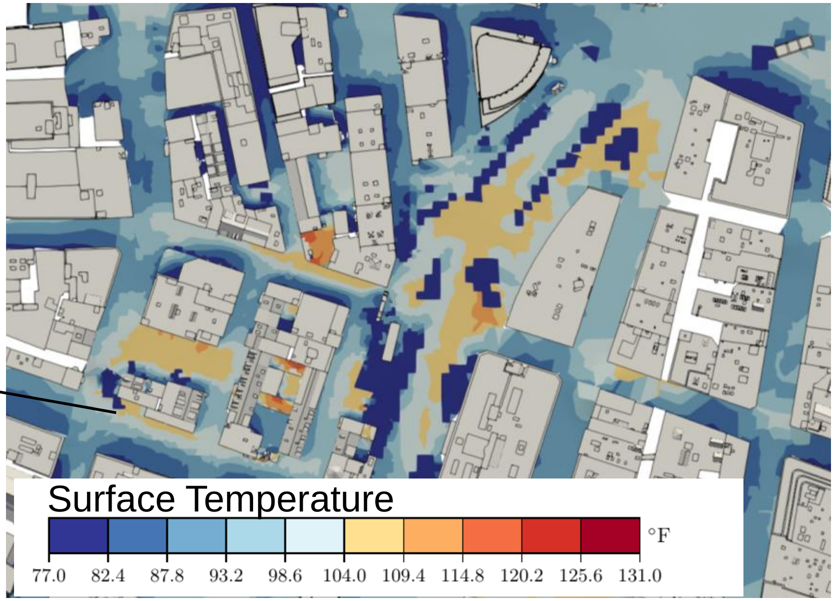


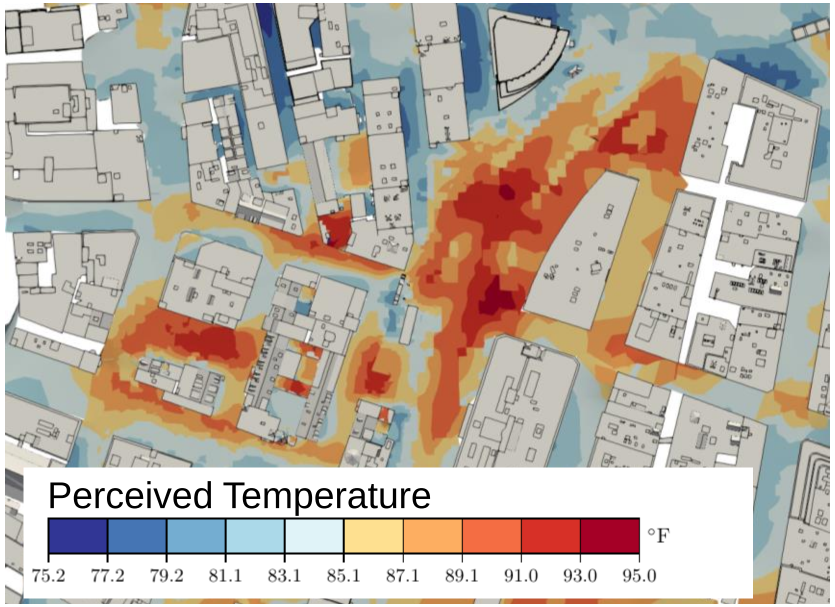
3. Trees North Side of Street

1) High albedo vs low albedo road reduces afternoon surface temperatures from 105ºF to 90ºF.
2) Effect of lower surface temperatures reduces perceived temperatures from 90ºF to 85ºF.

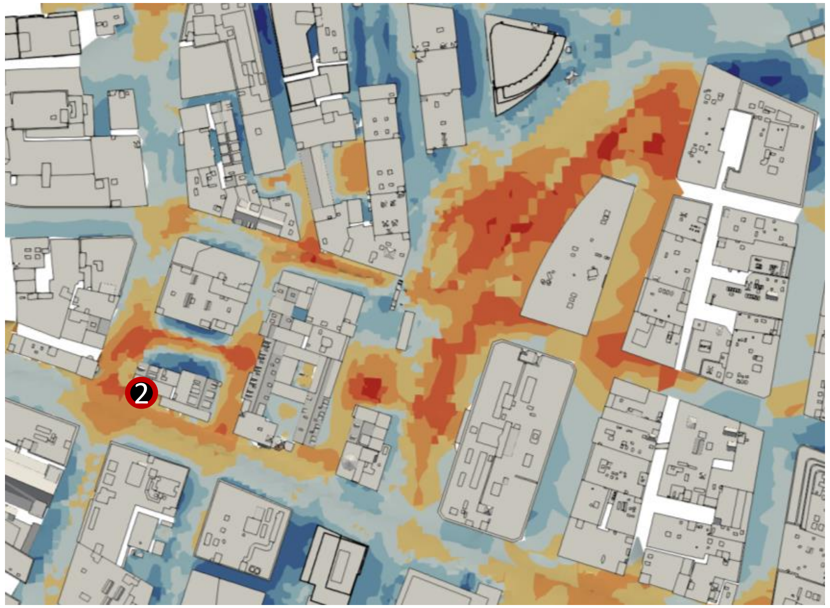


Baseline





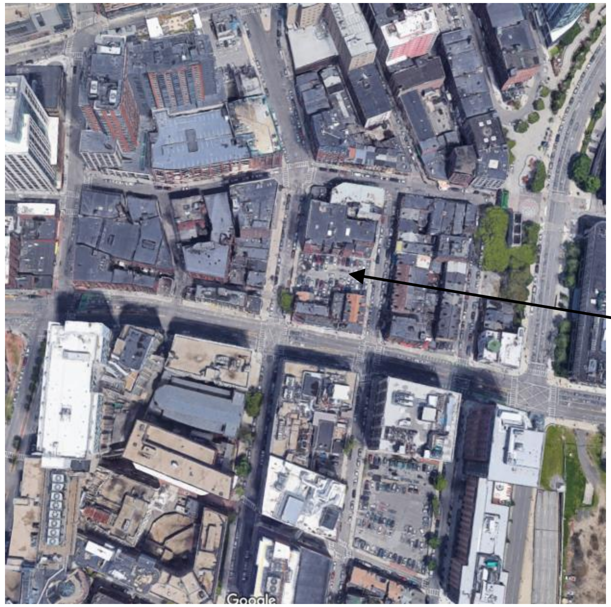
Concept

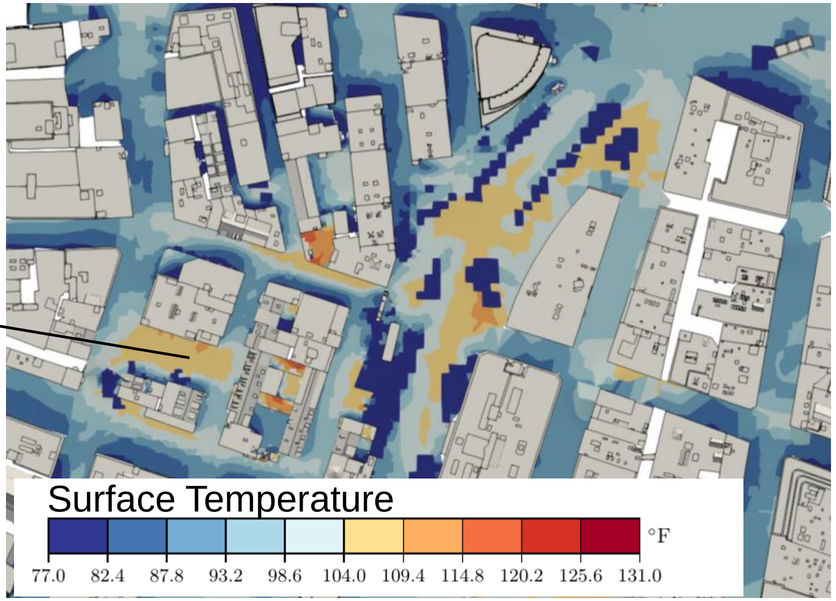


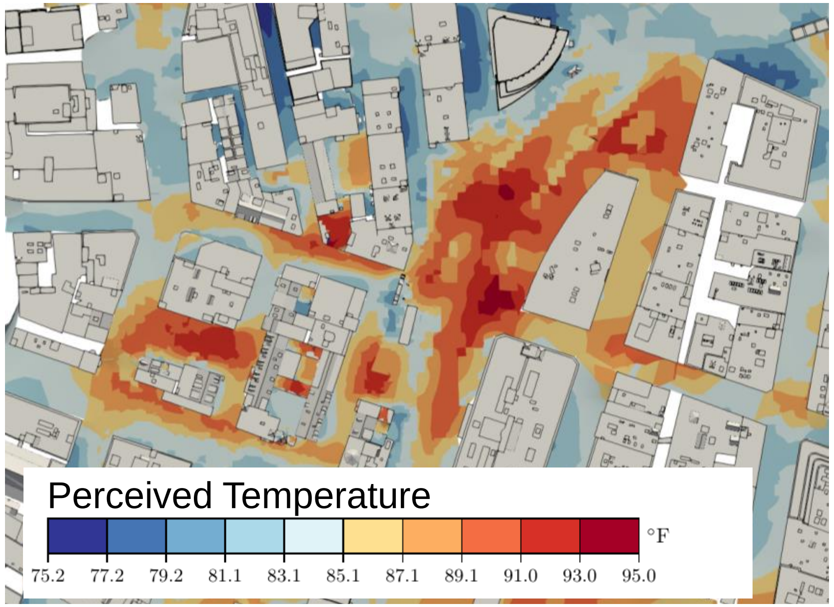
4. Effect of full shade solar canopy (solar)

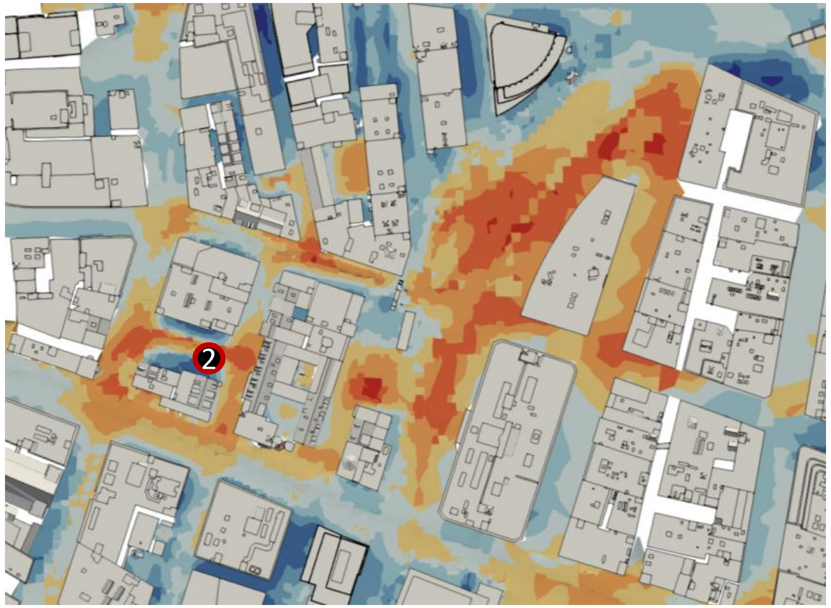
1) Solar canopy reduces afternoon surface temperatures from 109ºF to 76ºF.
2) Full shade solar canopy reduces perceived temperatures from 92ºF to 80ºF by limiting solar exposure and reducing surface temperatures.

Baseline | **Concept**





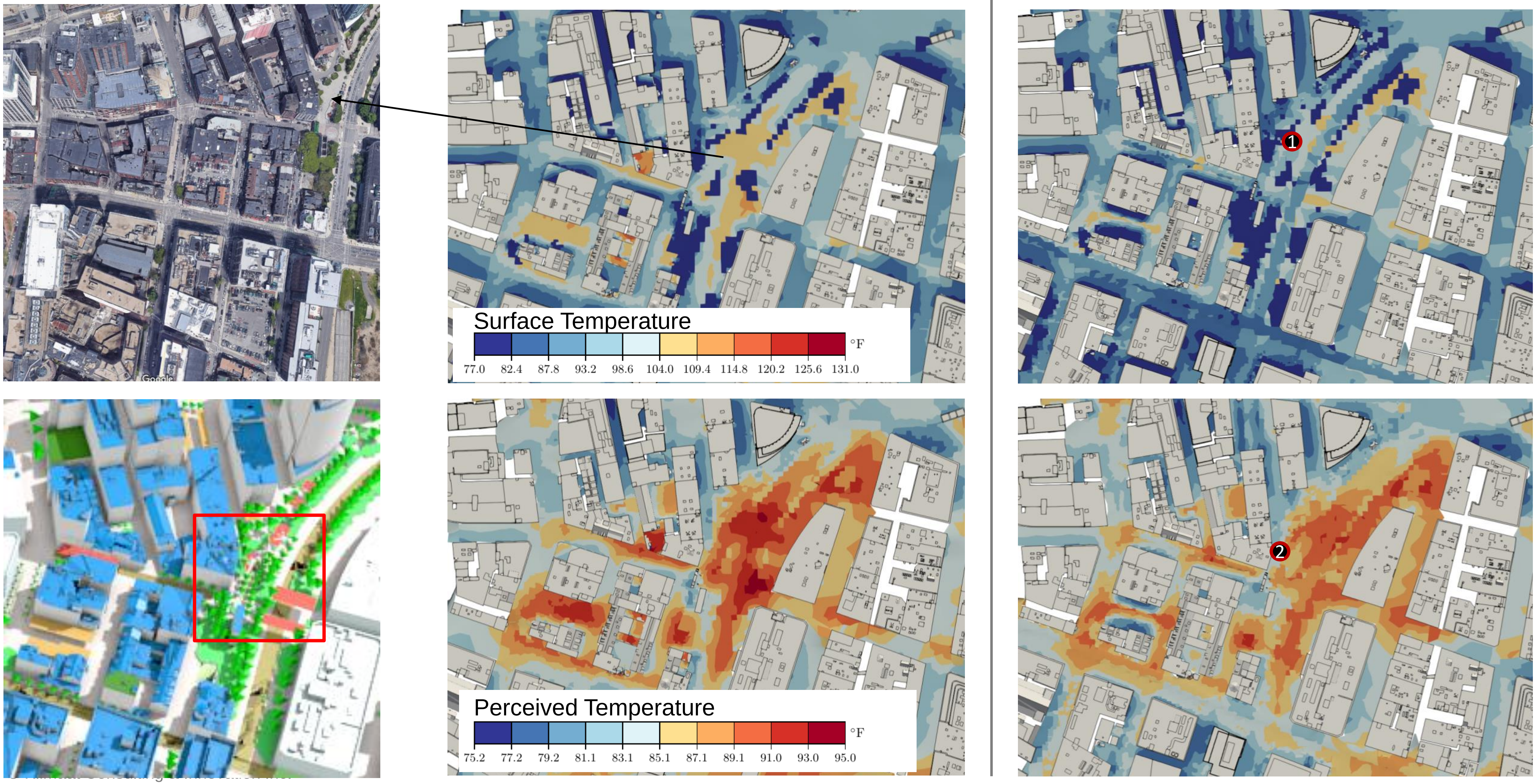




5. Effect of medium tree cluster or shading canopies at sun exposed areas

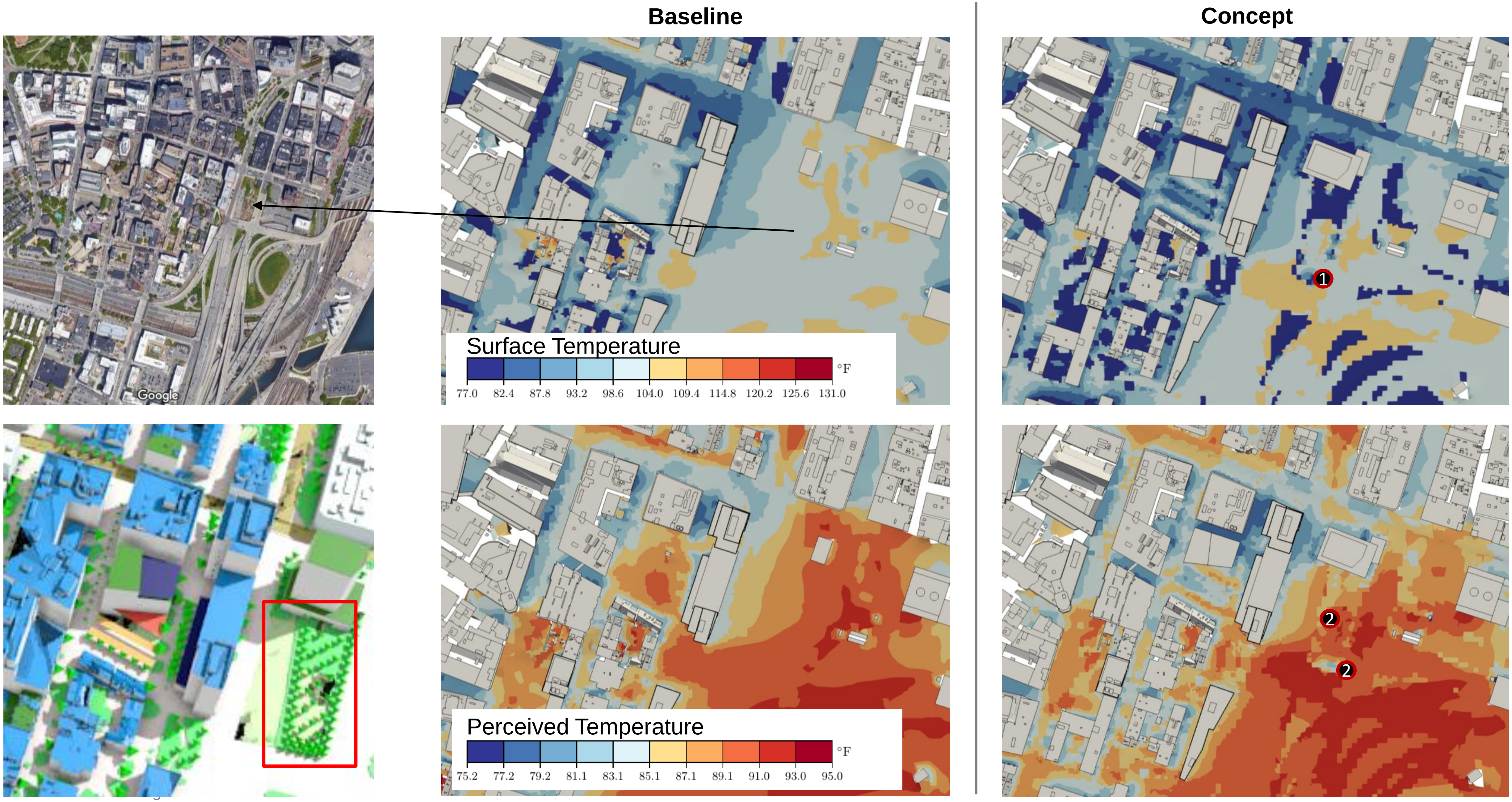
1) Tree canopy reduces afternoon surface temperatures from 100ºF to 90ºF.
2) Tree canopy reduces perceived temperatures from 88ºF to 84ºF by reducing solar exposure and surface temperatures.

Baseline | **Concept**



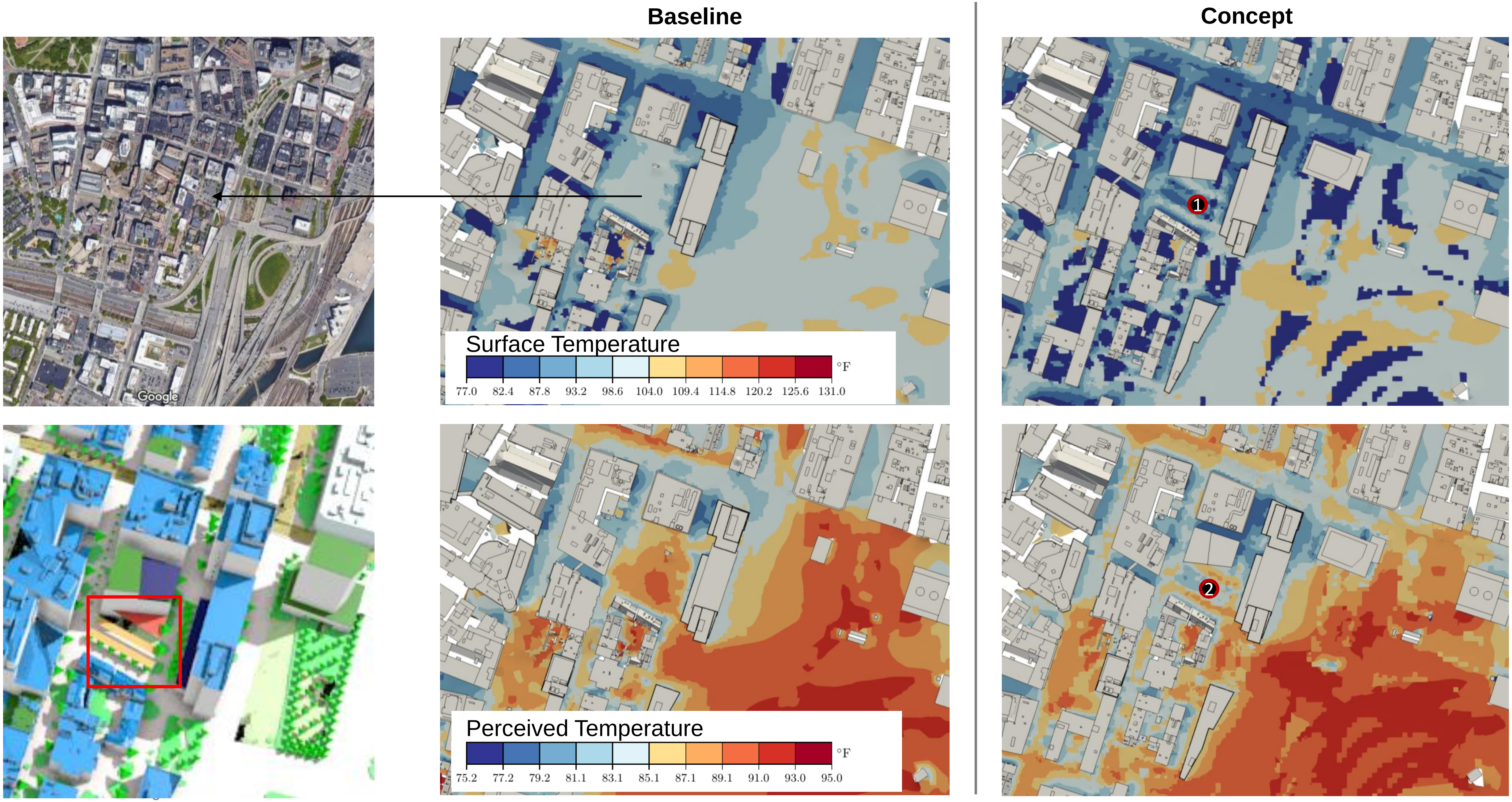
6. Effect of medium tree canopy cluster with grass open space in solar and wind exposed area

1) Medium tree canopy and grass surfaces reduces surface temperatures from 103ºF to 73ºF.
2) Densely arranged medium tree canopy and grass surfaces reduces perceived temperatures from 90ºF to 81ºF. More exposed areas between trees are ~88ºF.



7. Effect of full shade solar canopy

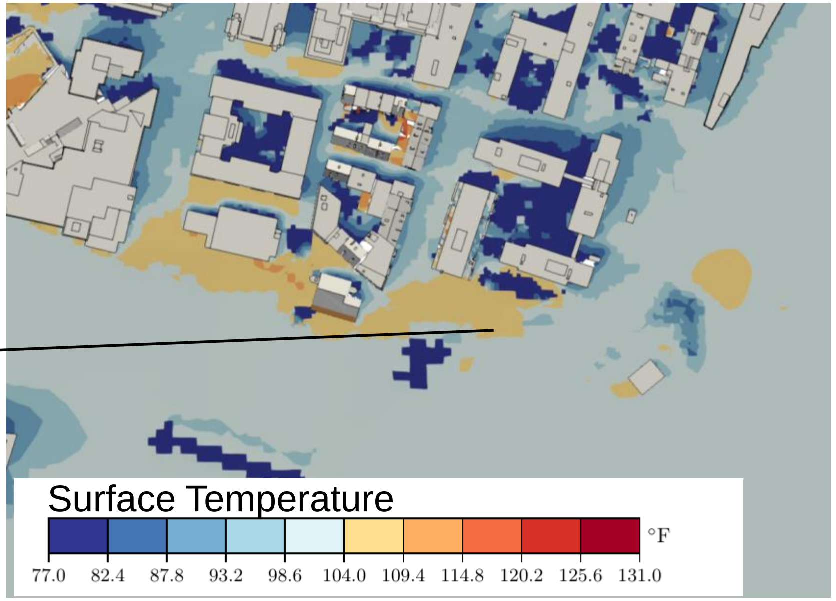
1) Solar canopy reduces afternoon surface temperatures from 103ºF to 85ºF.
2) Full shade solar canopy reduces perceived temperatures from 90F to 82ºF by limiting solar exposure and reducing surface temperatures

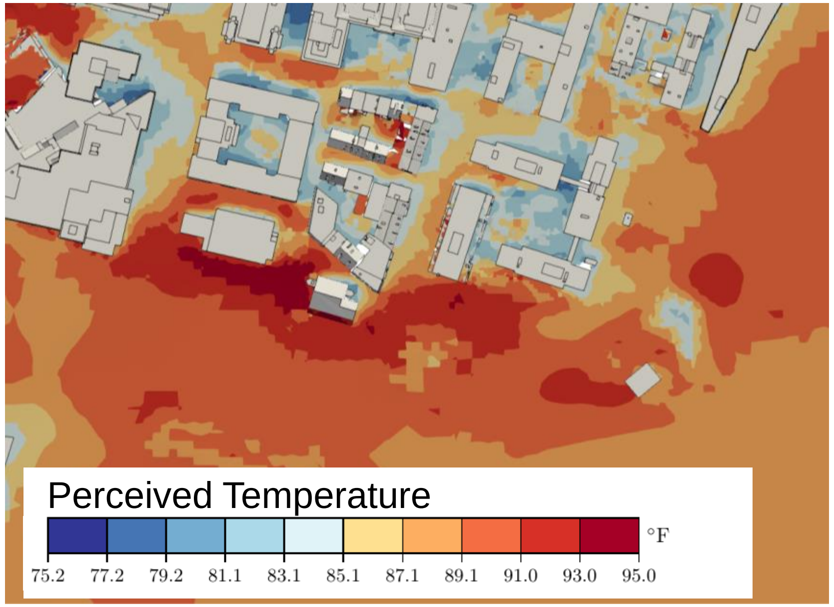


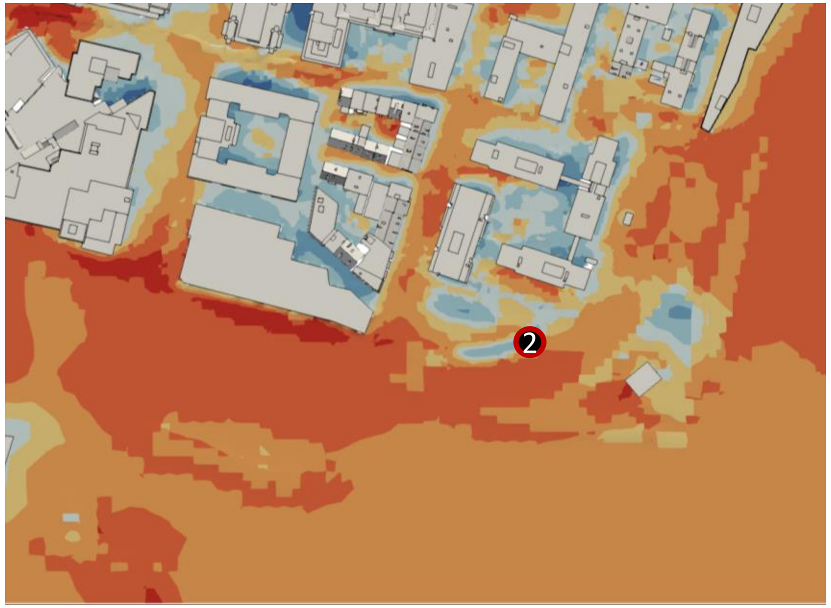
8. Effect of full shade solar canopy in exposed areas

1) Solar canopy reduces afternoon surface temperatures from 106ºF to 82ºF.
2) Full shade solar canopy reduces perceived temperatures from 93ºF to 81ºF by limiting solar exposure and reducing surface temperatures

Baseline | **Concept**



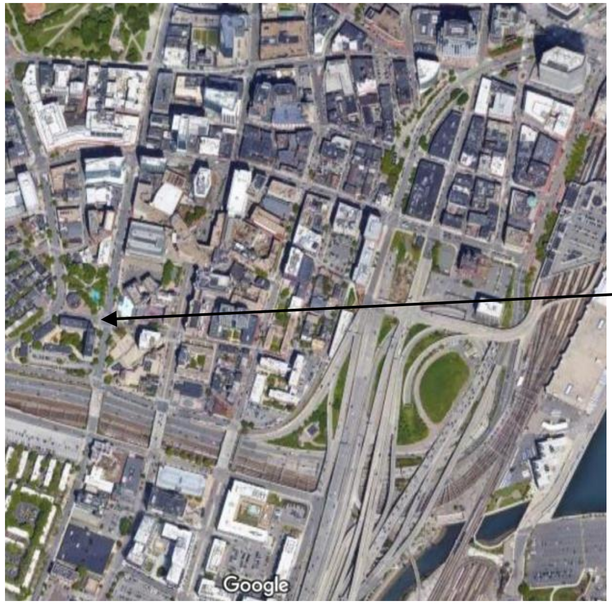


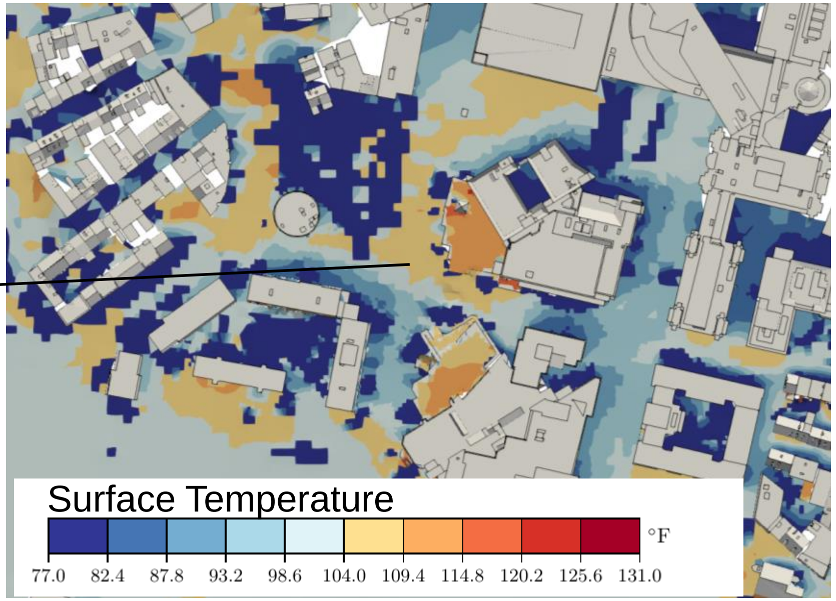


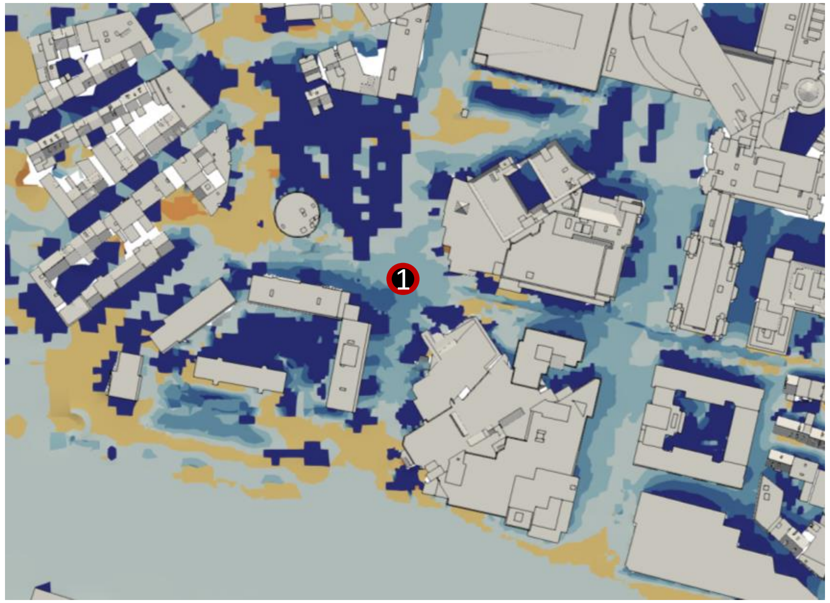
9. Effect of canopy (50%) over street intersection

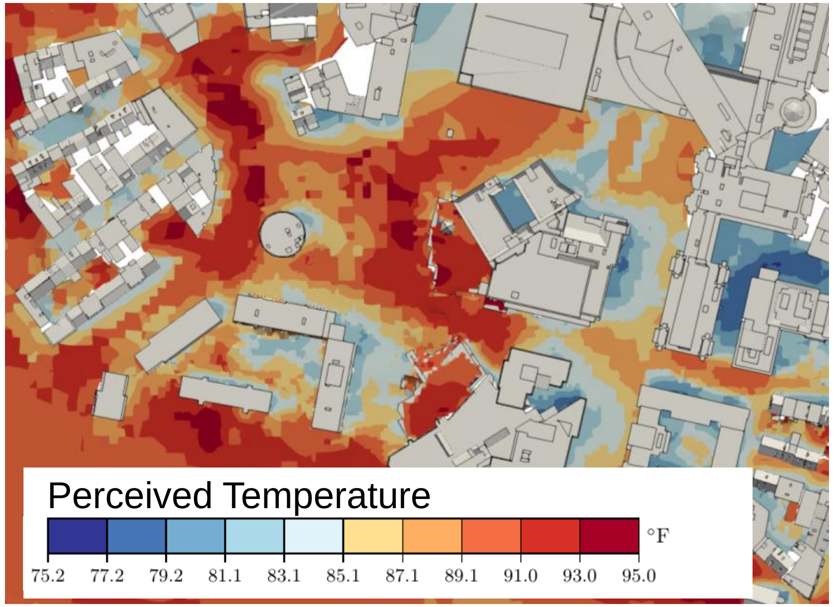
1) Canopy reduces afternoon surface temperatures from 107ºF to 96ºF.
2) Canopy reduces perceived temperatures from 93ºF to 88ºF by reducing solar exposure and surface temperatures.

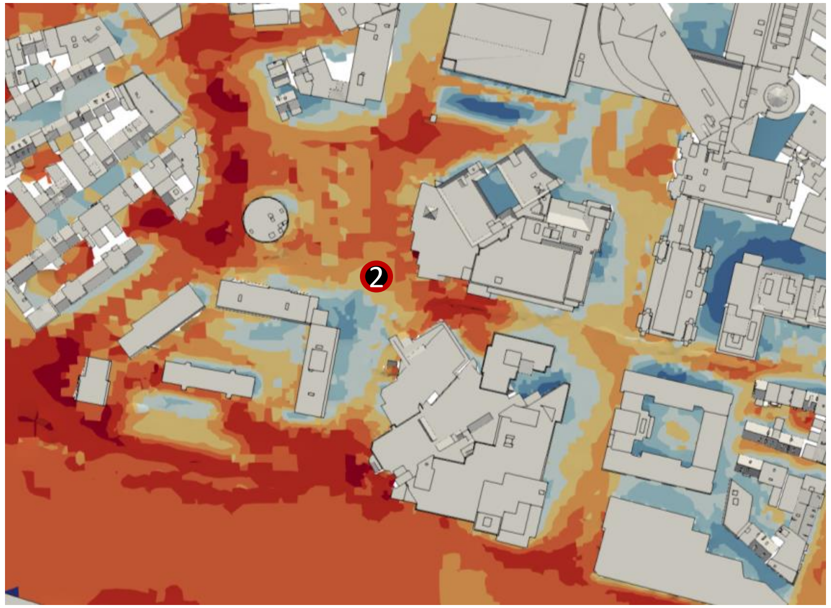
Baseline | **Concept**





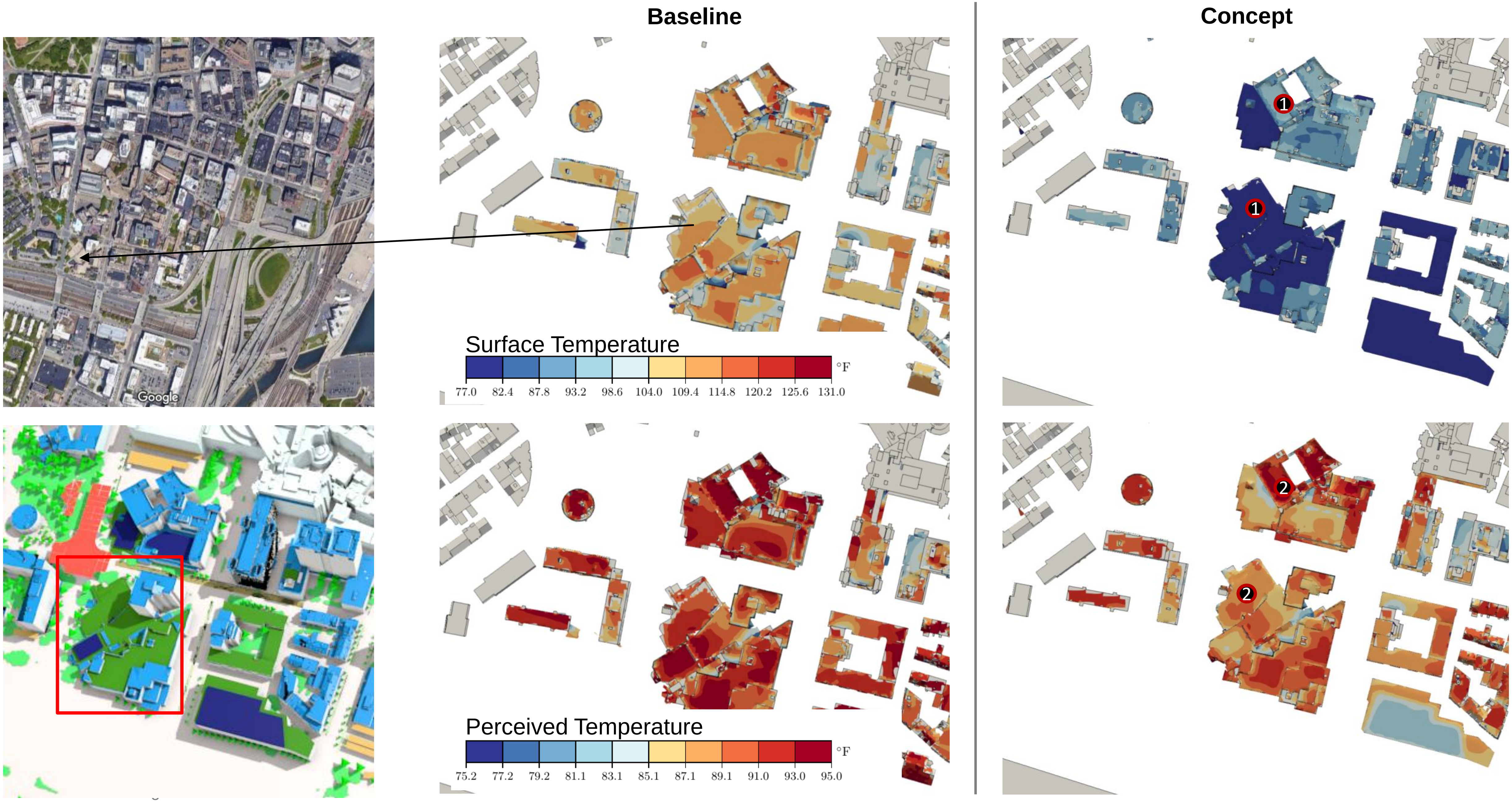






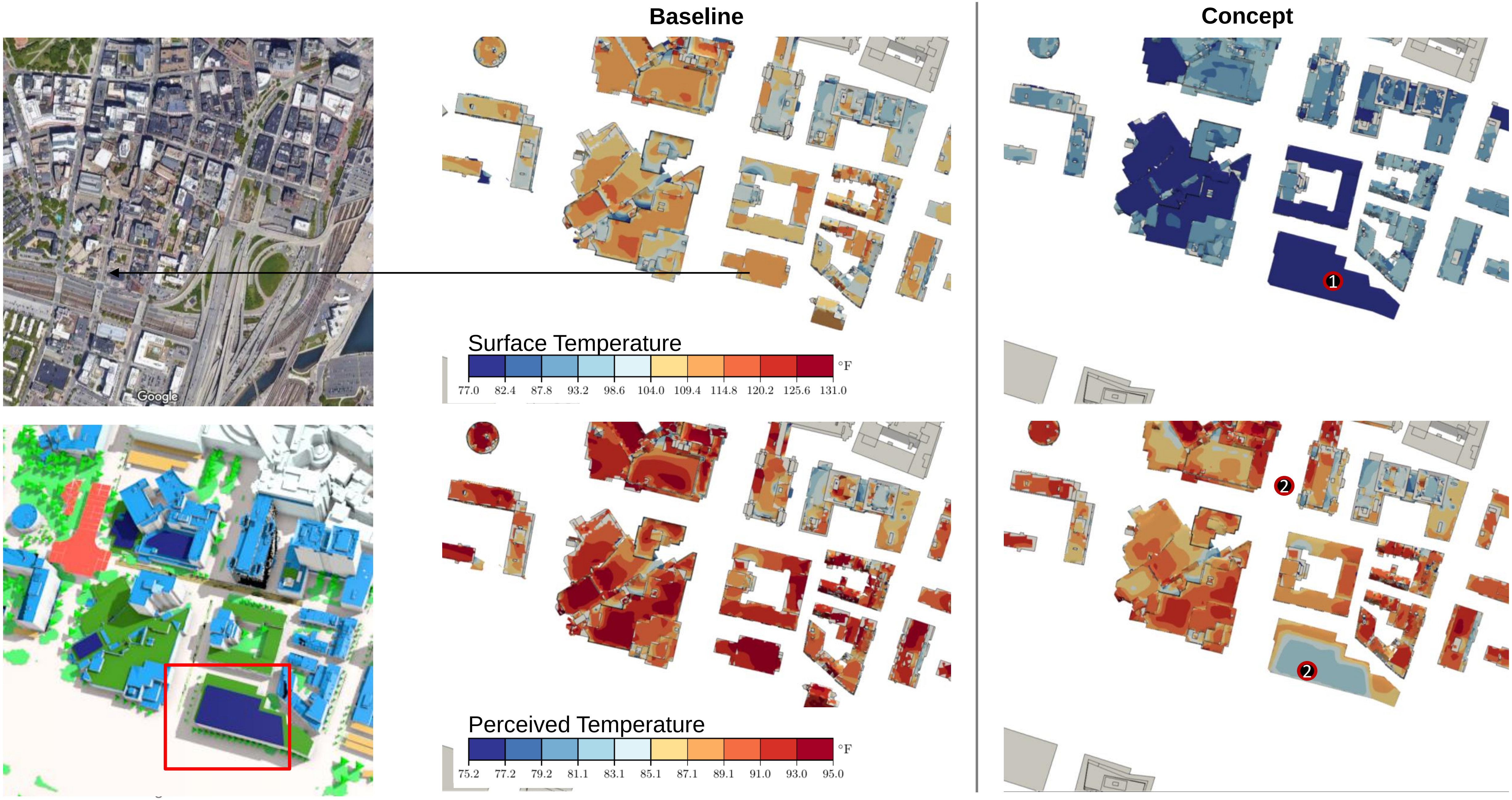
10. Effect of green and cool roofs

1) Green roof reduces afternoon surface temperatures from 110ºF to 81ºF. Cool roof reduces afternoon surface temperatures from 111ºF to 95ºF
2) Green roof reduces afternoon perceived temperatures from 93ºF to 89ºF. Cool roof reduces afternoon perceived temperatures from 94ºF to 93ºF



11. Effect of shade canopy (50%) over green roof

1) Canopy over green roof reduces afternoon surface temperatures from 112ºF to 75ºF
2) Canopy over green roof reduces afternoon perceived temperatures from 93ºF to 82ºF

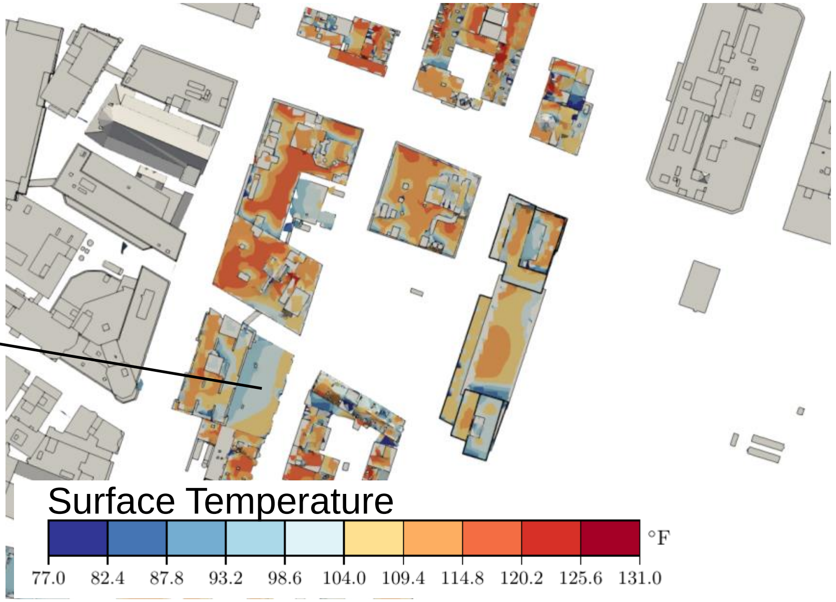


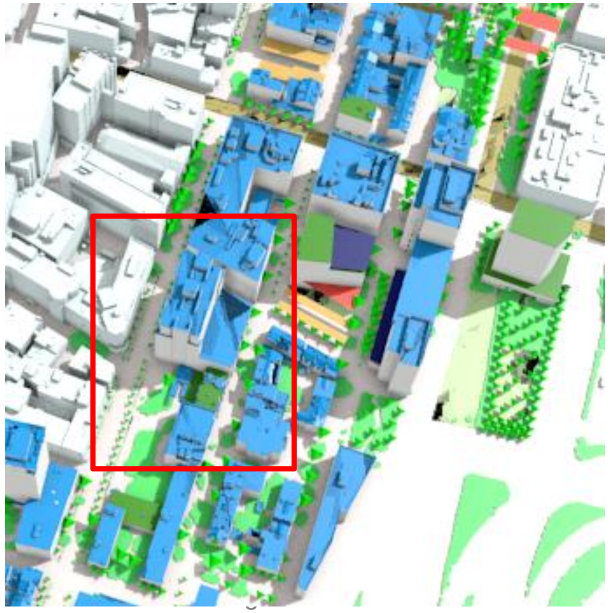
12. Effect of roof step

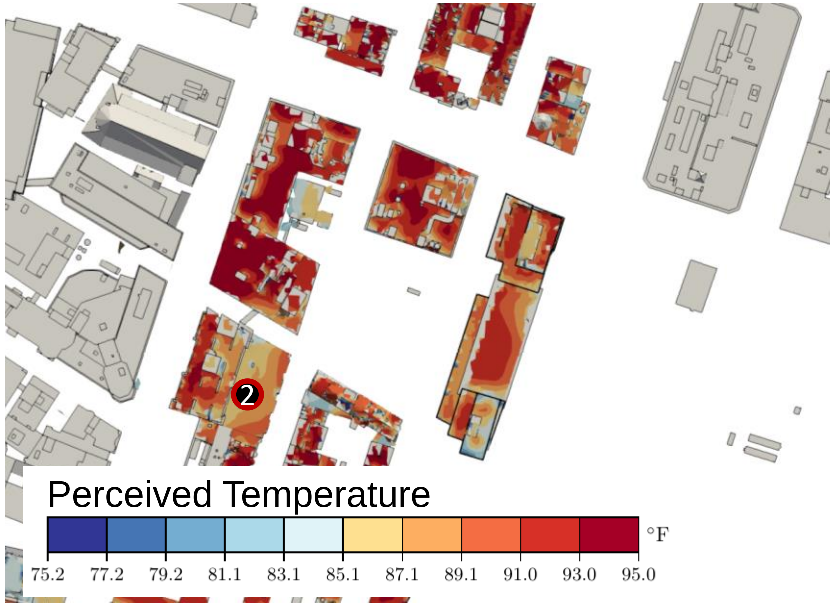
1) Building height steps that create shade reduces the surface temperatures from 114ºF to 81ºF compared to fully solar exposed roof areas.
2) Building height steps reduces afternoon perceived temperatures from 95ºF to 87ºF compared to fully solar exposure roof areas.

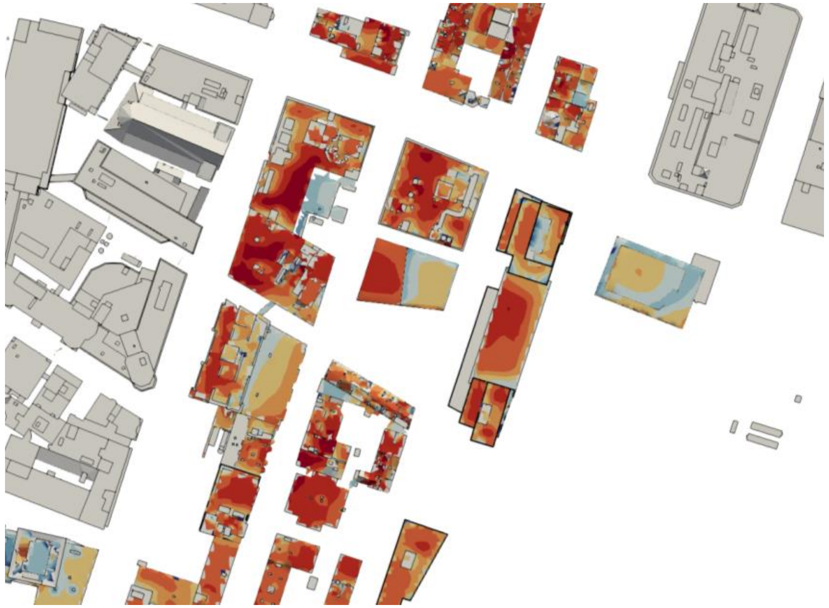
Baseline

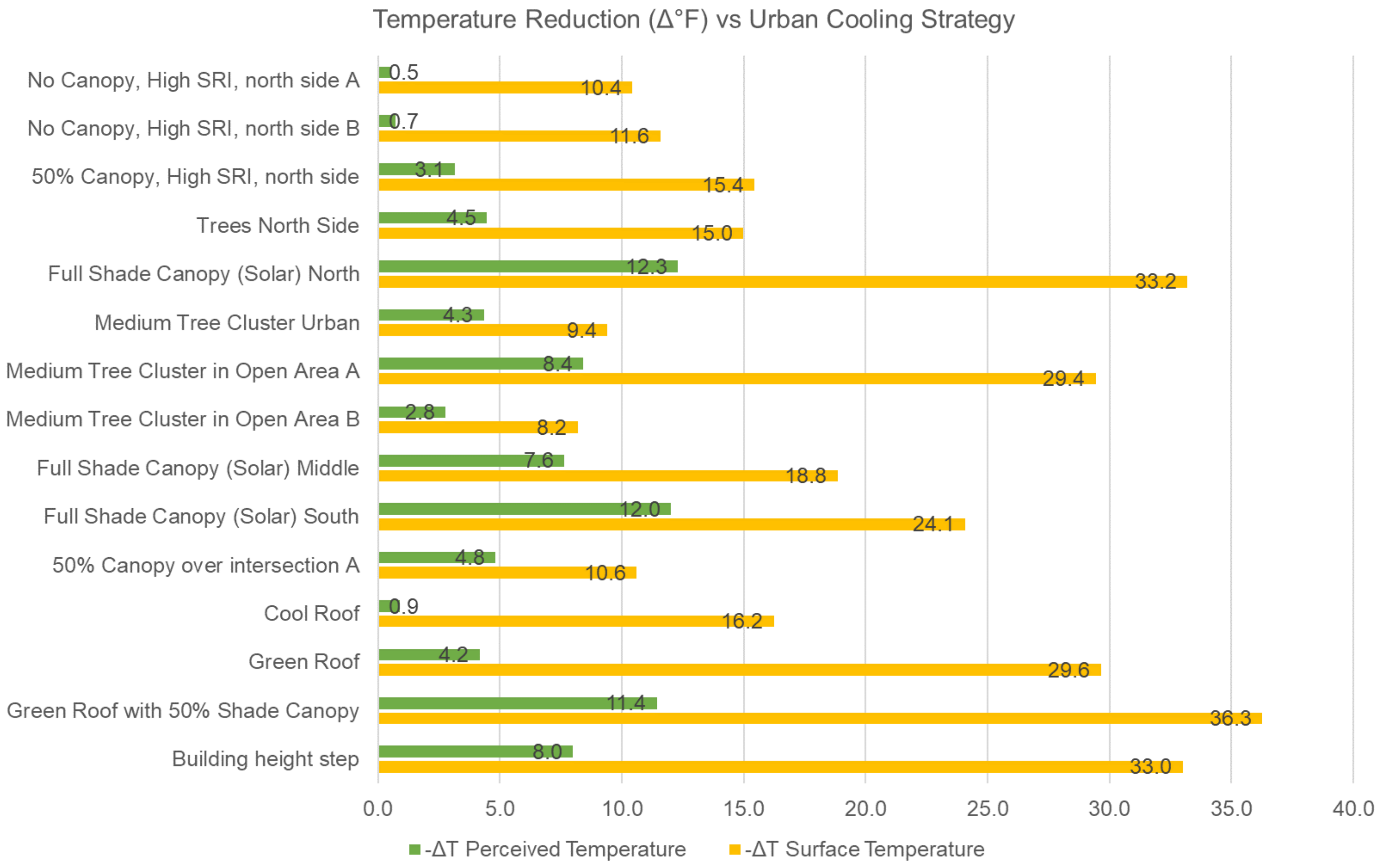
Concept










Temperature Reduction (Δ°F) vs Urban Cooling Strategy
No Canopy, High SRI, north side A
0.5
10.4
No Canopy, High SRI, north side B
0.7
11.6
50% Canopy, High SRI, north side
3.1
15.4
Trees North Side
4.5
15.0
Full Shade Canopy (Solar) North
12.3
33.2
Medium Tree Cluster Urban
4.3
9.4
Medium Tree Cluster in Open Area A
8.4
29.4
Medium Tree Cluster in Open Area B
2.8
8.2
Full Shade Canopy (Solar) Middle
7.6
18.8
Full Shade Canopy (Solar) South
12.0
24.1
50% Canopy over intersection A
4.8
10.6
Cool Roof
0.9
16.2
Green Roof
4.2
29.6
Green Roof with 50% Shade Canopy
11.4
36.3
Building height step
8.0
33.0
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
-ΔT Perceived Temperature
-ΔT Surface Temperature

Appendix A: Layer surface specifications for urban climate simulation

Layer specifications

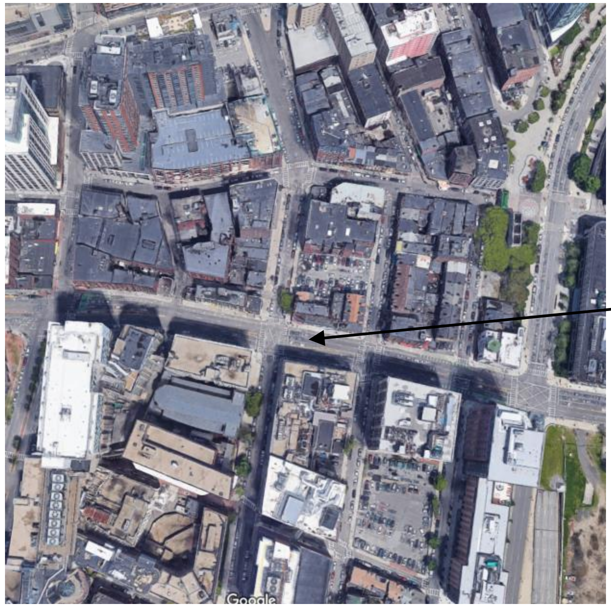
Layer	Material	Thermal Conductivity	Specific Heat Capacity MJ	Albedo	Solar Transmission	LAI
Base layer	Asphalt over concrete	1.2	1.9	0.12	-	0.0
Open Space	Concrete	0.8	1.33	0.25	-	0.0
Light road	High SRI on asphalt/concrete	1.2	1.9	0.45	-	0.0
Grass	Low Vegetation	1.2	1.8	0.25	-	2.88
Green Roof	Low Vegetation	1.2	1.8	0.25	-	2.88
Blue Roof	Light coloured roof	0.6	1.4	0.50	-	-
Dark Roof	Dark coloured roof	0.6	1.4	0.08	-	-
Solar Canopy	PV Modules	-	-	0.1	0.0	0.0
Shade Canopy	Shade cloth	-	-	0.25	0.5	0.0
Water Feature	Water	0.6	4.2	0.08	-	2.88

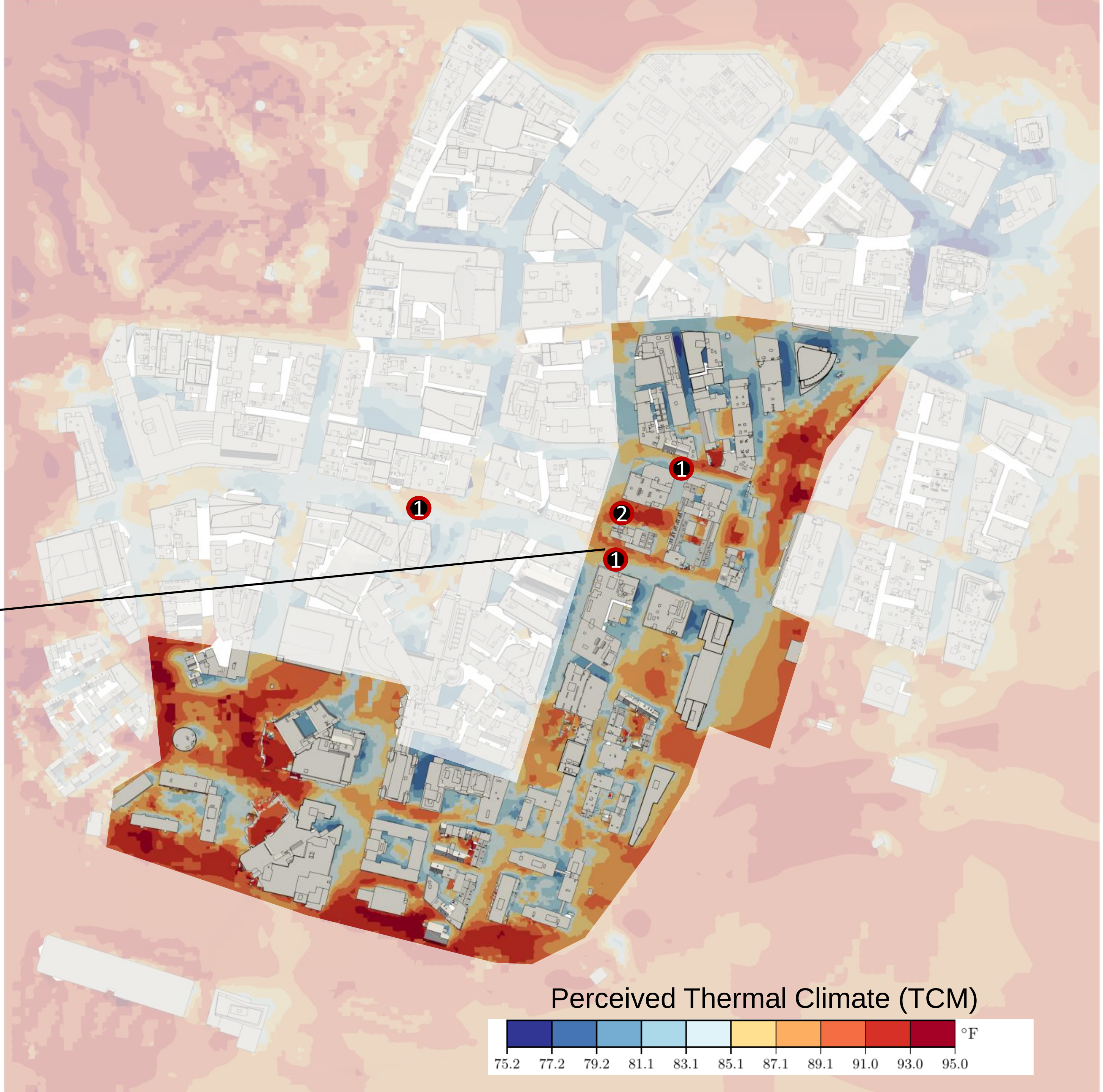
Trees	Diameter (m)	Height	LAI	Solar transmission
Trees - Existing	5		5	0.08
Trees – Medium	5		5	0.08
Trees - Small	3		5	0.08

Appendix B: Initial Observations for Baseline Simulations

Summary observations

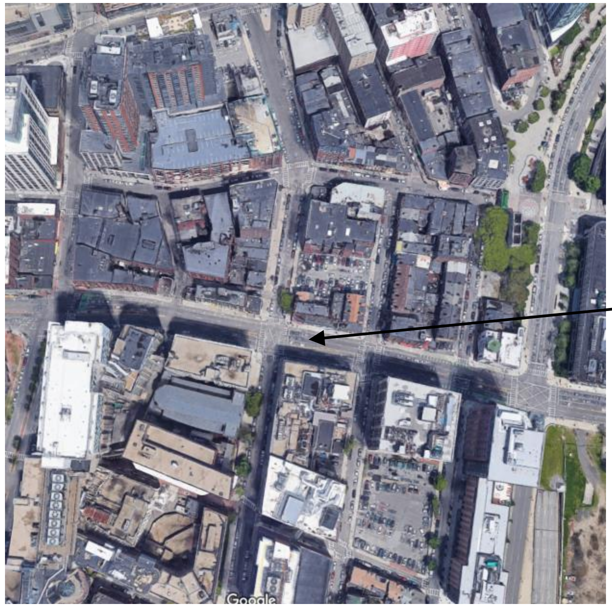
1) Hot conditions on north side of streets due to high solar exposure and low vegetation cover
2) Hot conditions due to high solar exposure, low vegetation and limited wind ventilation

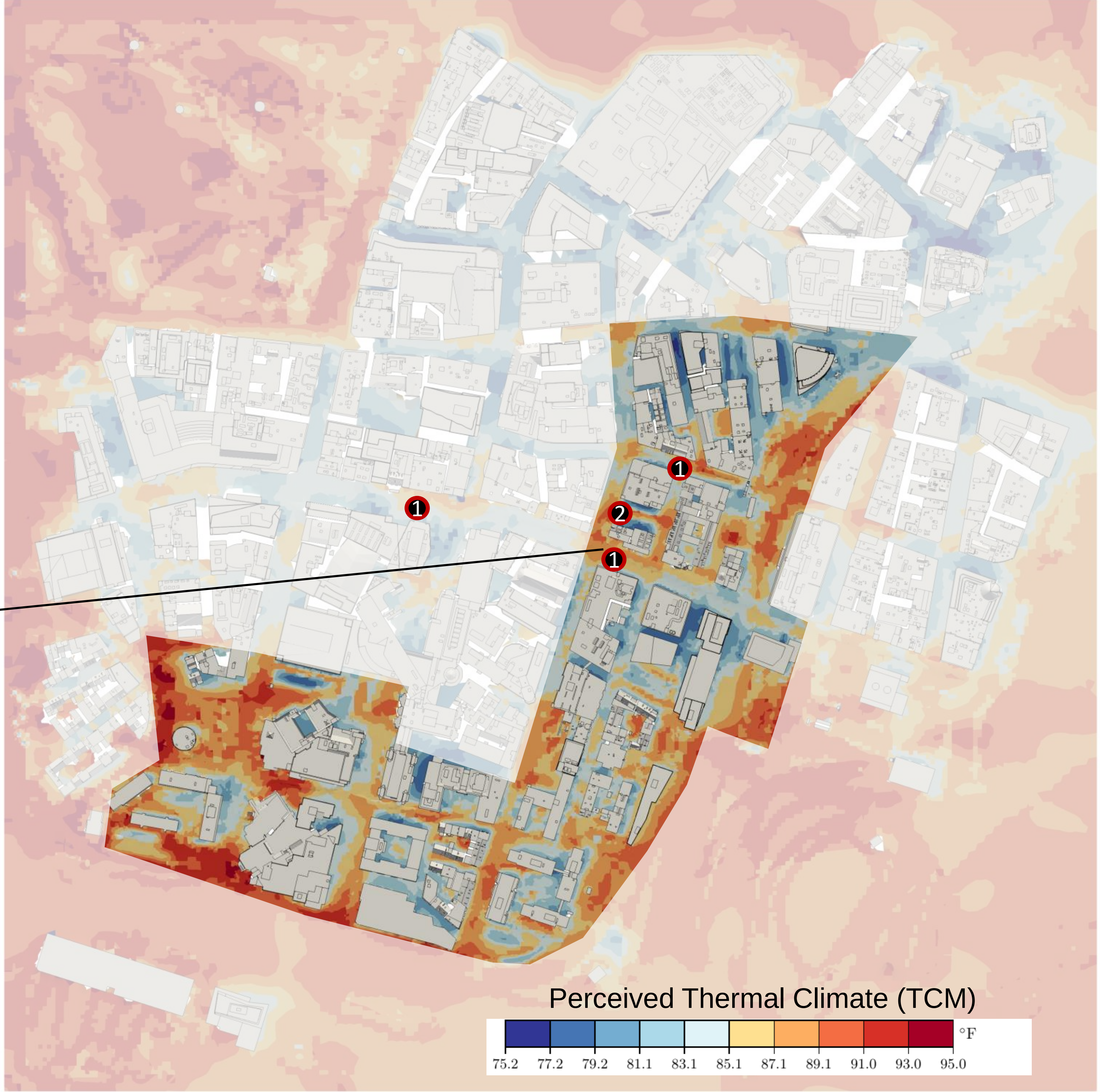




Summary observations

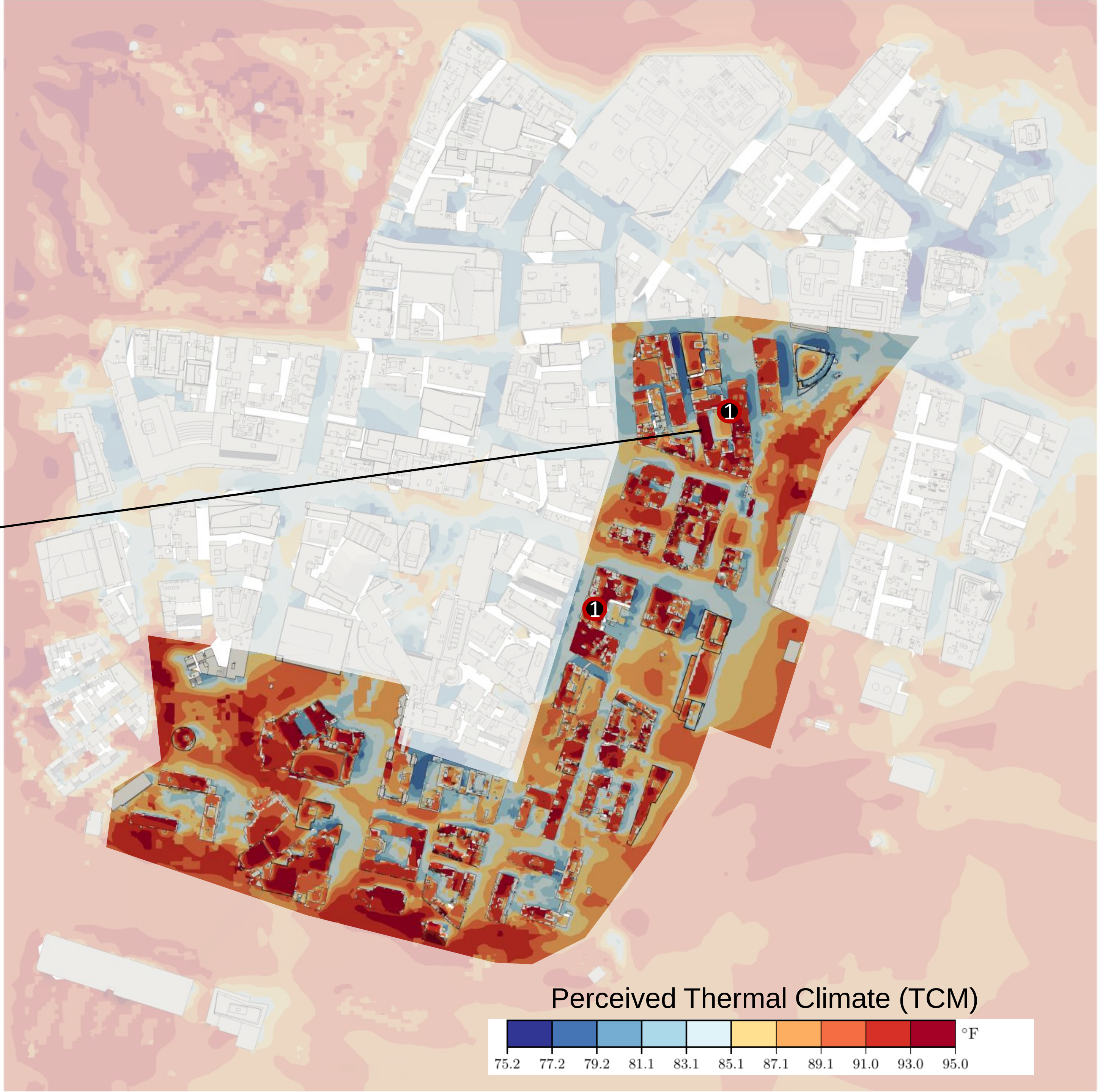
1) Hot conditions on north side of streets due to high solar exposure and low vegetation cover
2) Hot conditions due to high solar exposure, low vegetation and limited wind ventilation





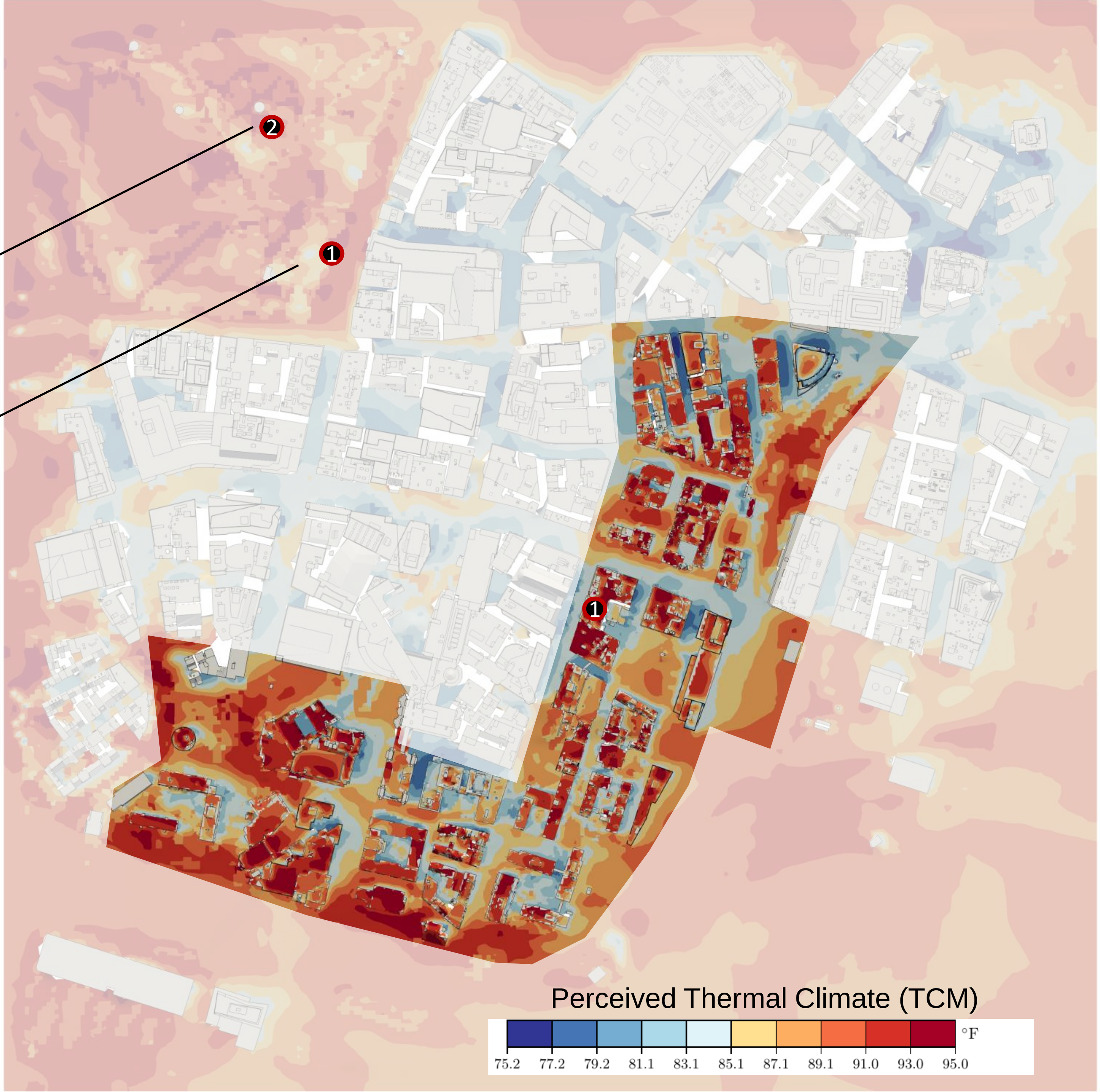
Summary observations

1) Very hot perceived thermal conditions on most roofs due to high surface temperatures and high solar exposure.



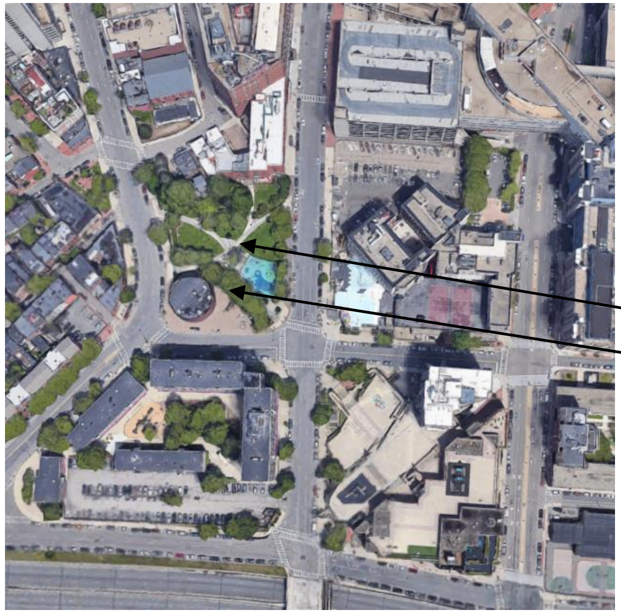
Summary observations

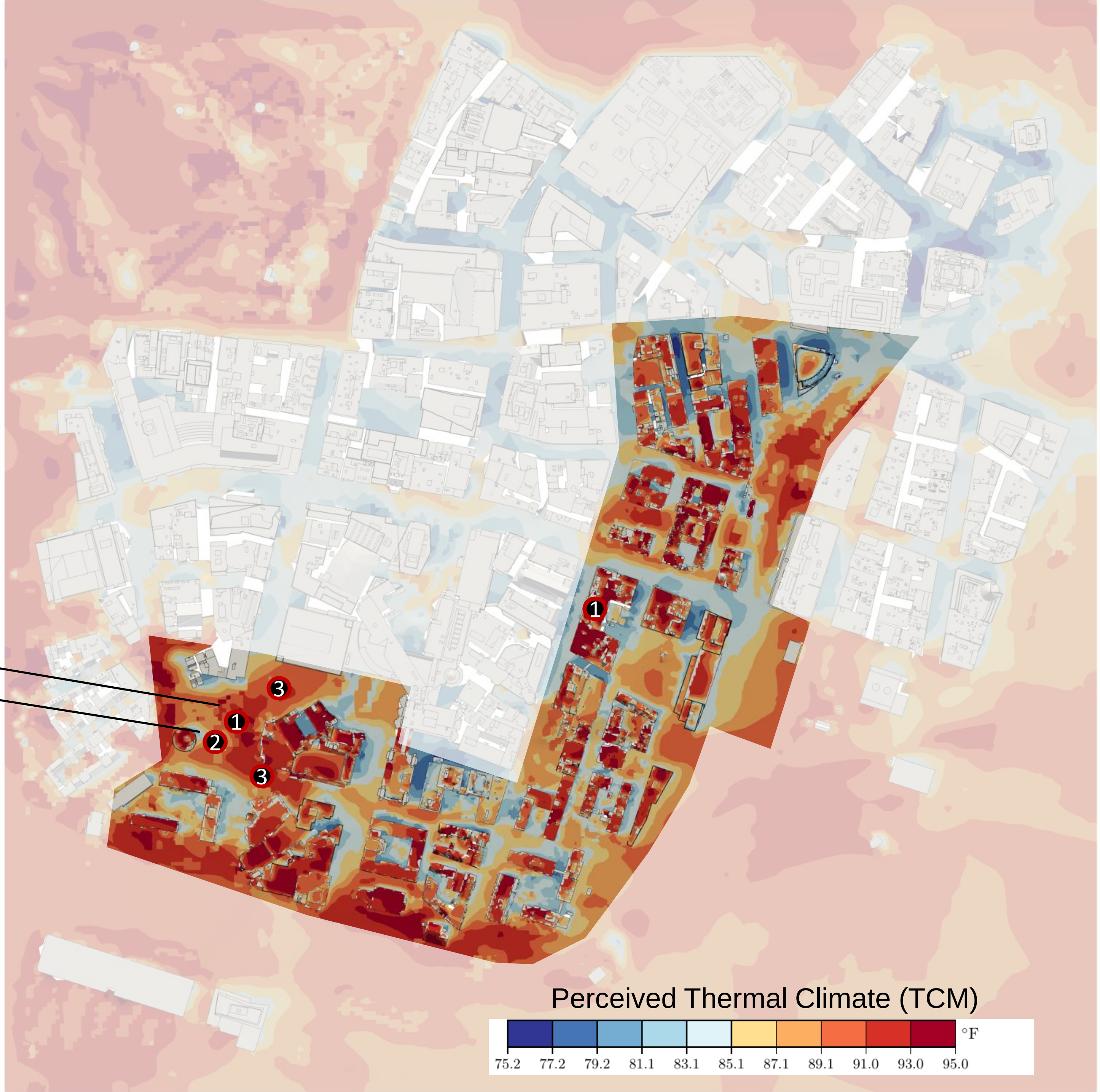
1) Relatively cool conditions (comfortable to moderate heat stress) across areas with higher density tree cover within park.
2) More exposed park areas (grass or hardscape) perceived thermal climate is warm with moderate to high heat stress on average



Summary observations

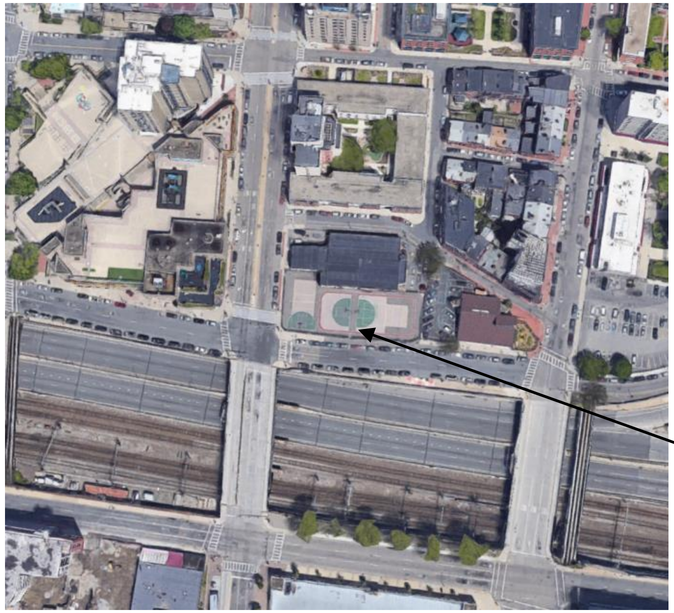
1) Exposed park areas with limited tree cover remains warm to hot on average.
2) Tree cover and or building shade provides more solar shelter and creates conditions that are comfortable to warm with moderate heat stress on average.
3) Very hot conditions due to limited shading from buildings and low vegetation cover.

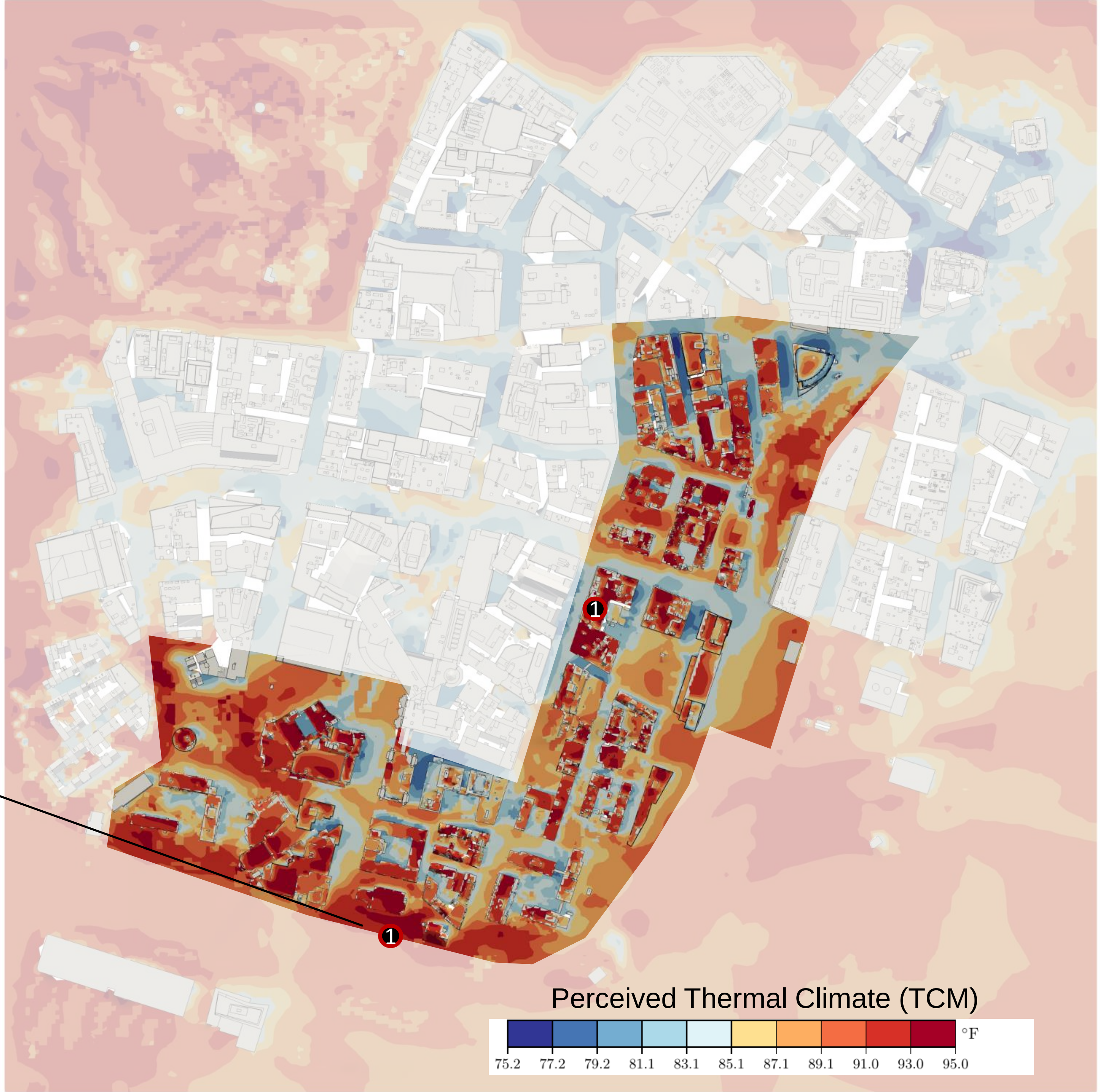




Summary observations

1) Very hot conditions, especially on South side of buildings, due to high solar exposure, limited shade from buildings or landscape, and negligible vegetation





Summary observations

1) Relatively warm conditions (moderate heat stress) due to high solar exposure (limited shading from adjacent buildings, and limited wind ventilation
2) Comfortable and relatively cool conditions due to high solar shading, good vegetation cover