Citizen and Machine Learning-aided High-resolution mapping of urban heat exposure and stress
Supplementary Information

Xuewei Wang[1,2,3], Angel Hsu[1,2,3], TC Chakraborty[4]
[1]Data-Driven EnviroLab, University of North Carolina at Chapel Hill, United States
[2]Department of Public Policy, University of North Carolina at Chapel Hill, United States
[3]Institute for Environment, University of North Carolina at Chapel Hill, United States
[4]Atmospheric Sciences & Global Change Division, Pacific Northwest National Laboratory, United States

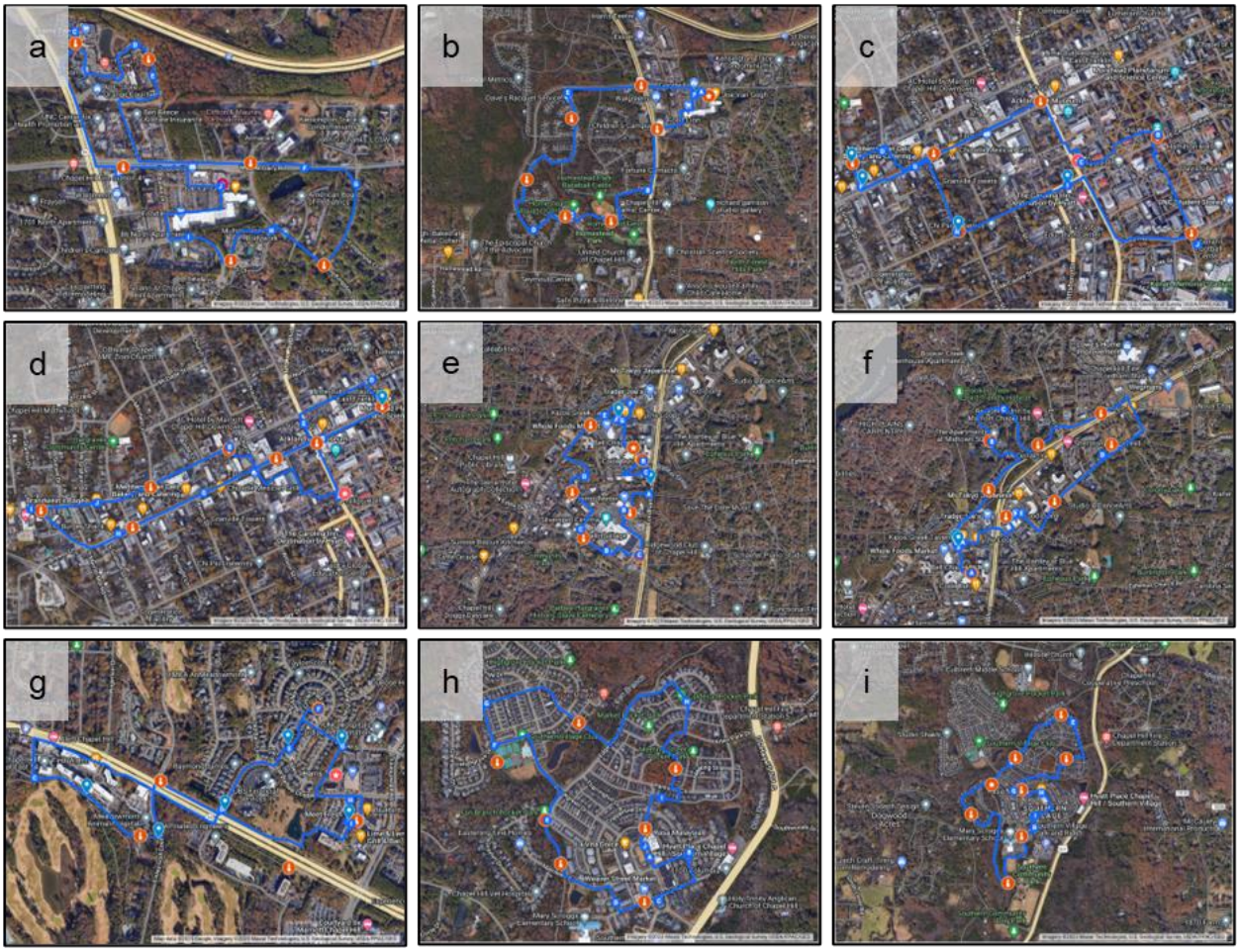

Figure S1. Planned mapping routes for all five neighborhoods (links to higher resolution, interactive maps embedded): a. Chapel Hill North and Timberlyne - route 1; b. Chapel Hill North and Timberlyne - route 2; c.Franklin Street - route 1; d. Franklin Street - route 2; e. University Place Mall - route 1; f. University Place Mall - route 2; g. Glenwood Square and Meadowmont; h. Southern Village - route 1; i. Southern Village - route 2. The orange thermometer symbols designate checkpoints where we requested participants to record in a separate smartphone application a short survey on their thermal comfort; these data, however, were not used for this study.

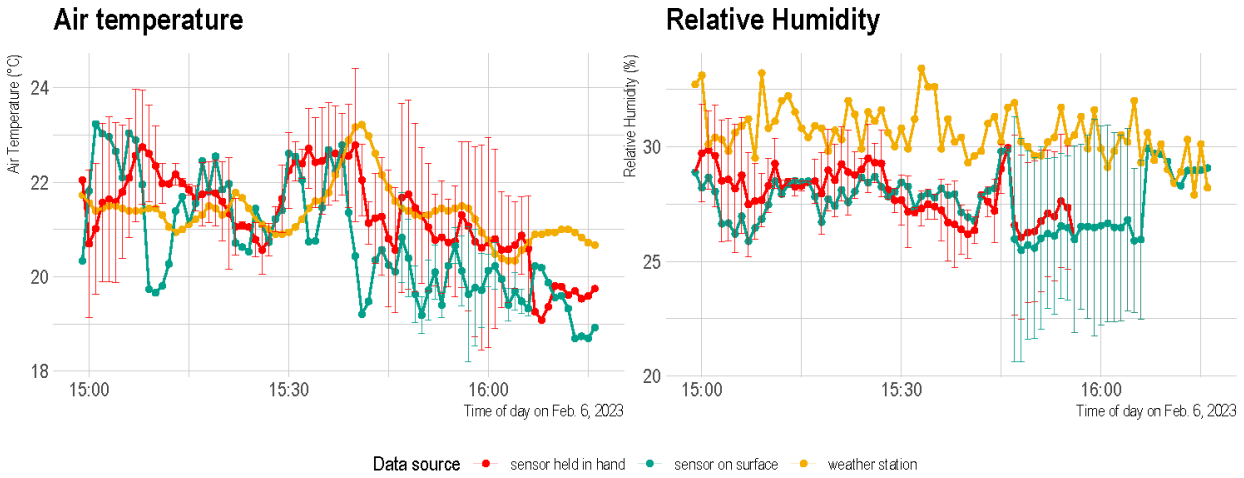

Figure S2. Comparison of PocketLab sensors in human hand (red); on surface (table at ~<1 meter or ground - green), compared to NC State Climate Office's unshaded air temperature (°C) and relative humidity (%) recorded at 2m (yellow). The sensor datapoints plotted are averaged readings from 3 hand-held sensors (red) and 2 sensors placed on a table surface (green). The time is noted on the x-axis and is local time in Eastern Standard Time (EST). Error bars representing standard deviation from the mean are included where SD > 0.

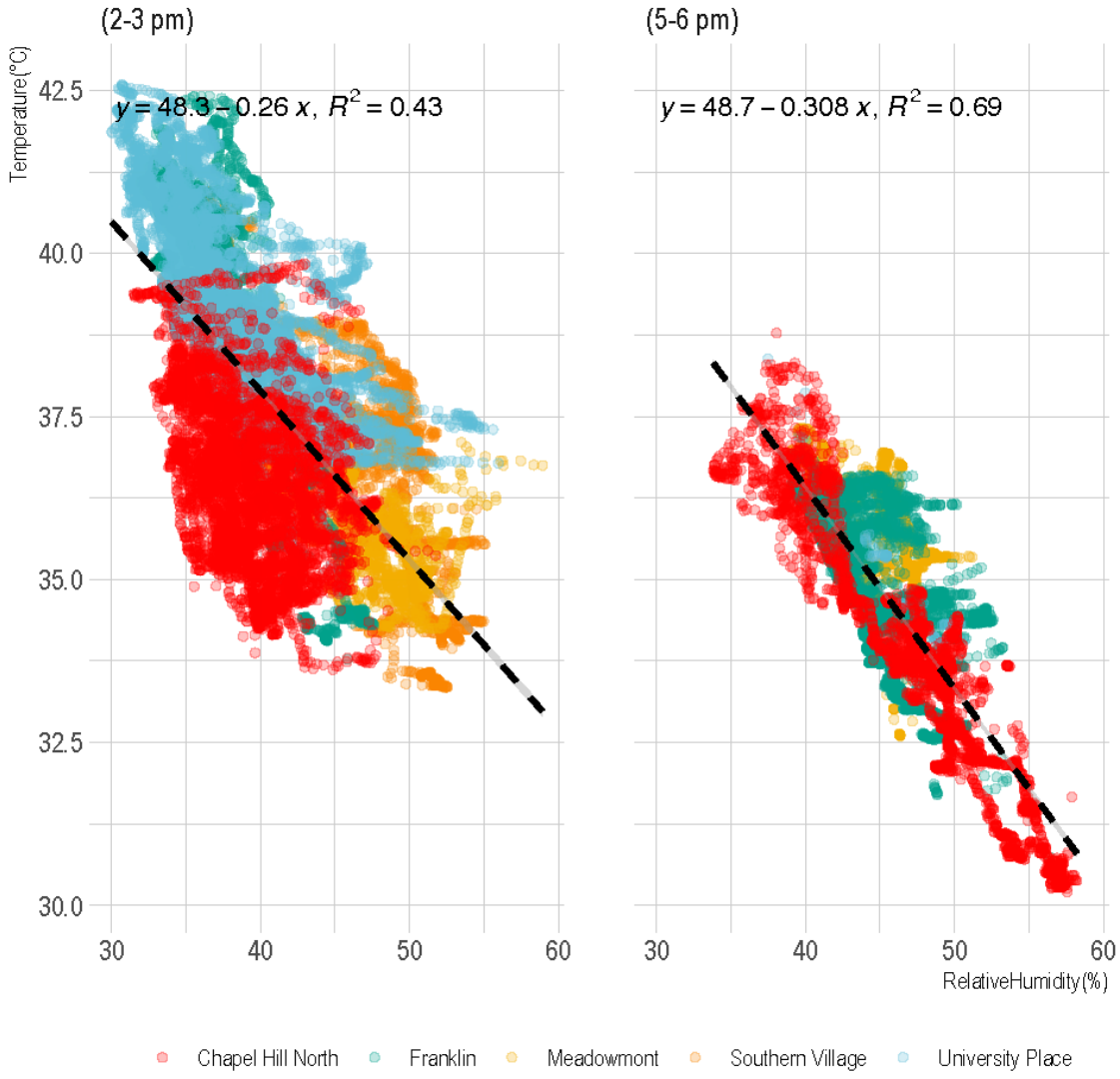

Figure S3. Relative humidity (x-axis) versus Temperature recorded by citizen science volunteers in five neighborhoods in Chapel Hill show a negative correlation.

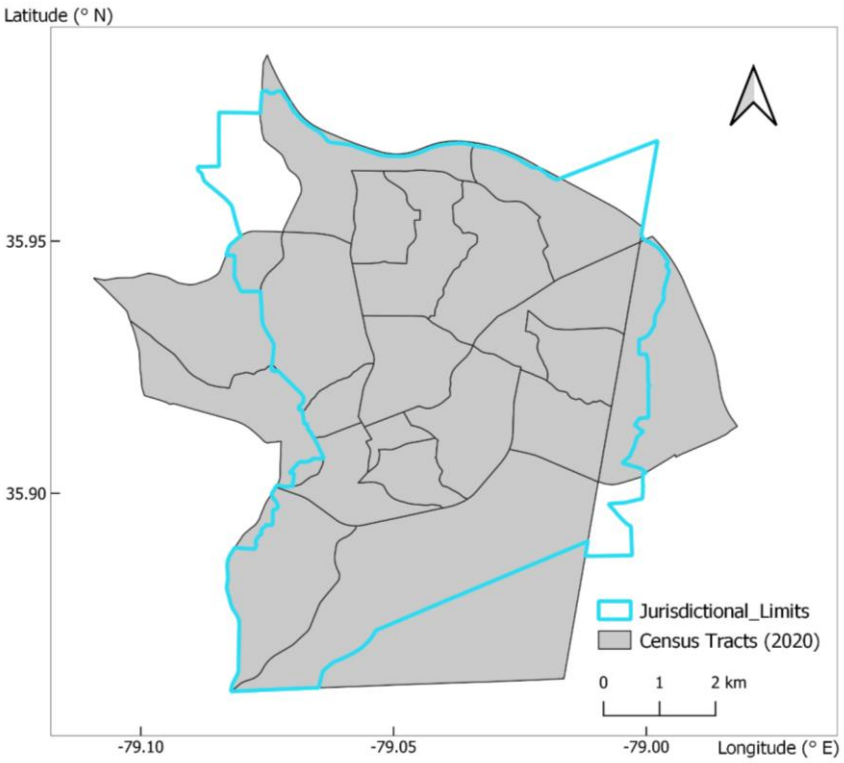

Figure S4. Chapel Hill Jurisdictional Limits (in cyan; Town of Chapel Hill, 2022) and 2020 Census Tracts (in gray; US Census Bureau, 2020) in this study.

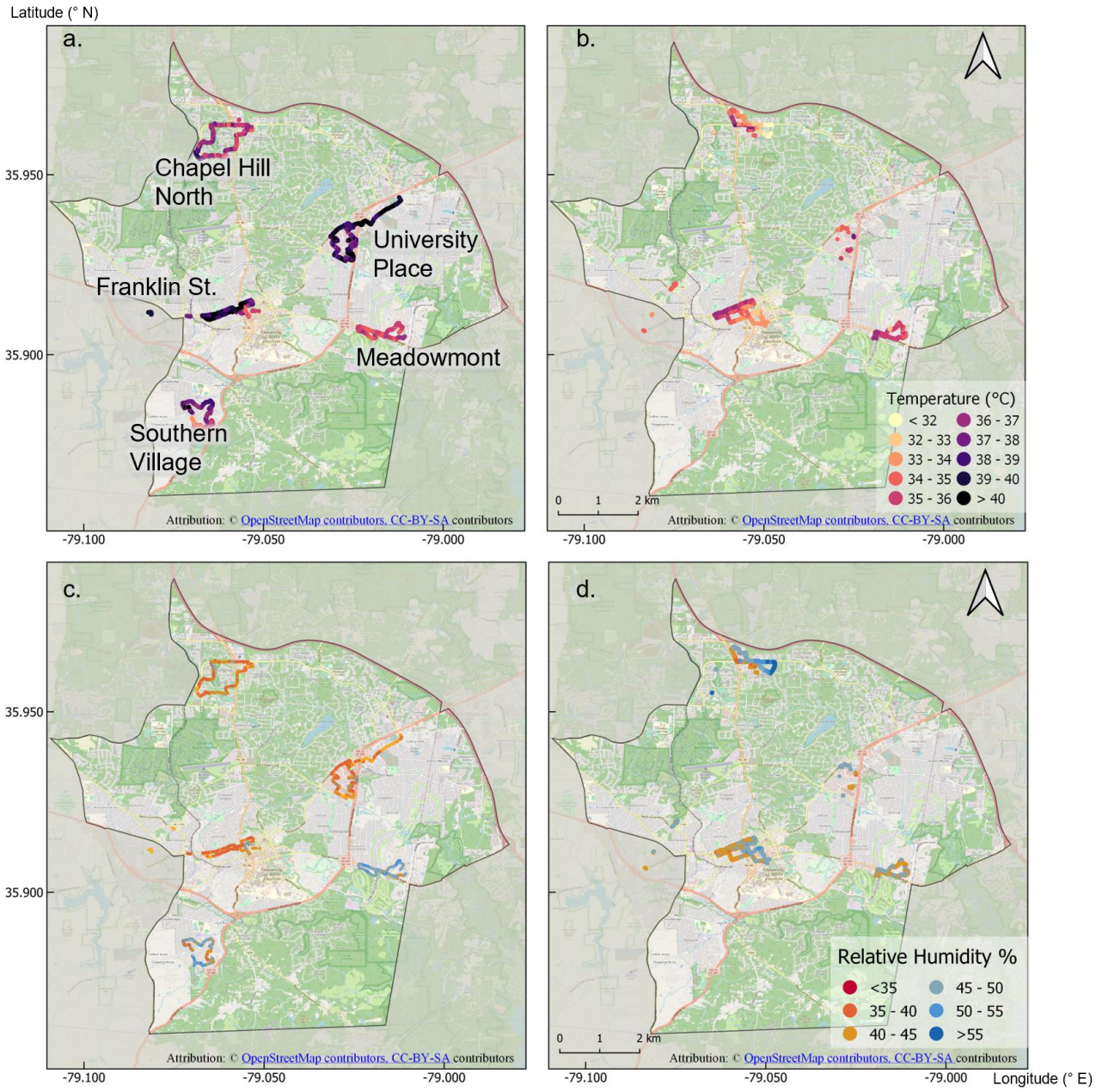

Figure S5. Traverse maps of air temperature and humidity collected by citizens for the a) air temperature - 2-3 pm; b) air temperature - 5-6 pm; c) humidity - 2-3 pm; d) humidity -5-6 pm. Basemap: OpenStreetMap.

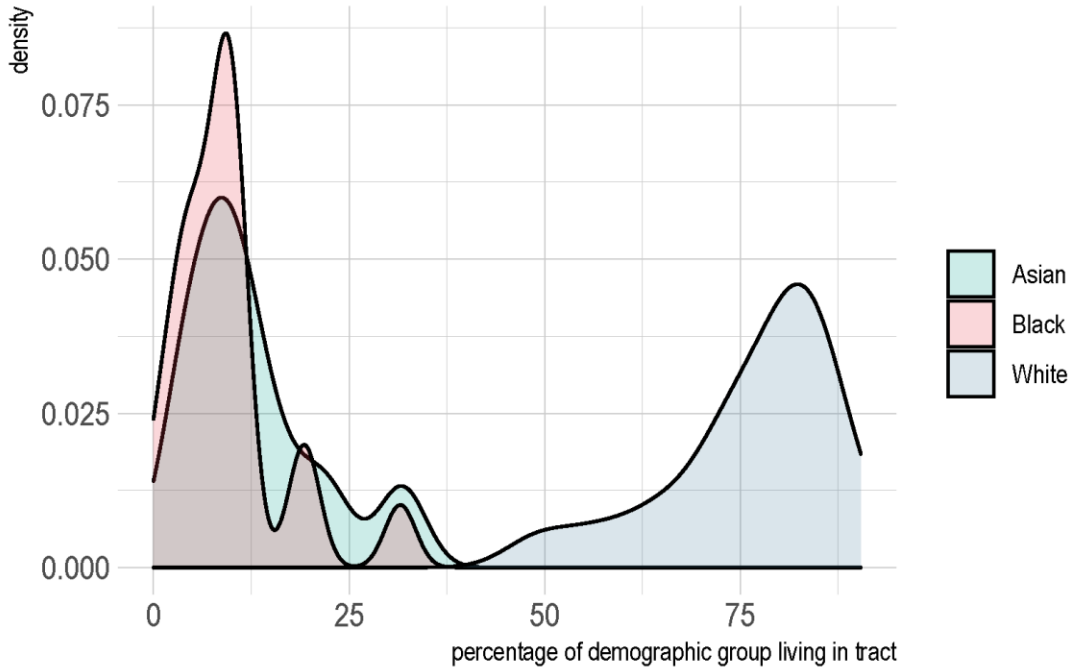

Figure S6. Distribution of percentages of top three racial and ethnic demographic groups in Chapel Hill, NC by census tract. All other U.S. Census-classified racial and ethnic groups (Pacific Islander, Native American, and Other) comprised less than 2 percent of the population living within each census tract.

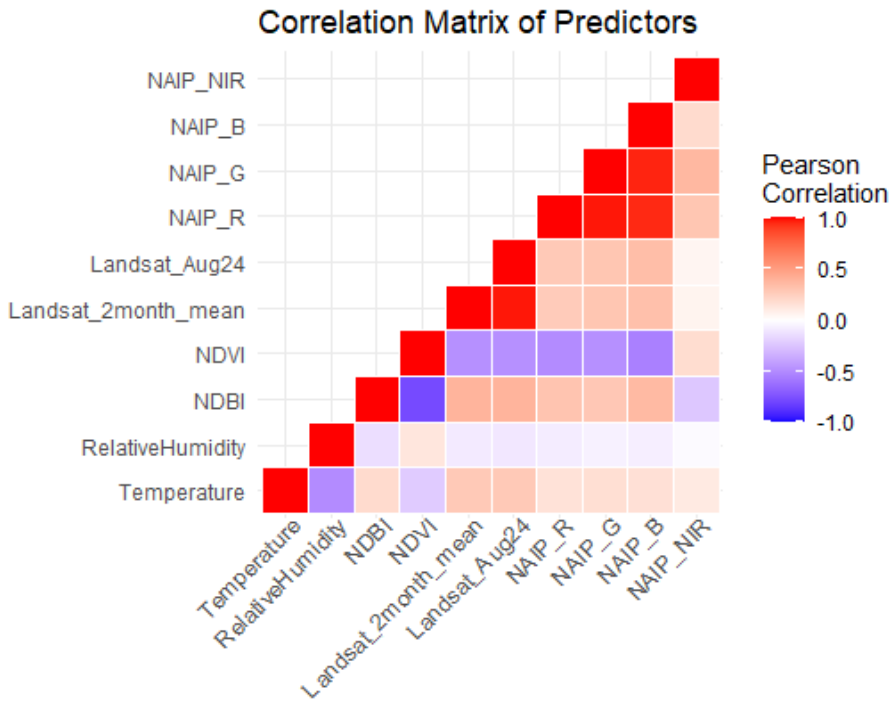

Figure S7. Correlation matrix of predictors (Landsat_2month_mean: the two-month average Landsat 8 LST of August and September, 2021; Landsat_Aug24: a single scene of Landsat 8 LST on August 24th, 2021)

Table S1. Land cover types, pixel count and area percentage of the total mapped area by session

	Session 1 (2-3 pm)		**Session 2 (5-6 pm)**	
Land Cover	**Pixel count**	**Area (%)**	**Pixel count**	**Area (%)**
Built-up	11118	54.1	7266	55.91
Trees	7073	34.42	4682	36.03
Grassland	1622	7.89	606	4.66
Barren/sparse vegetation	733	3.57	431	3.32
Cropland	5	0.02	11	0.08

Table S2. Pearson Correlation Coefficients in air temperature and relative humidity measurements between PocketLab sensors and the NC State Climate Office's Chapel Hill weather station.

Temperature

	handheld	not_handheld	weather_station
handheld	1	0.58	0.48

not_handheld	0.58	1	0.19
weather_station	0.48	0.19	1

Humidity

	handheld	not_handheld	weather_station
handheld	1	0.78	0.05
not_handheld	0.78	1	-0.01
weather_station	0.05	-0.01	1

Table S3. Comparison of PocketLab sensors and NC State Climate Office's Chapel Hill weather station air temperature and relative humidity measurements

	Dependent variable:	
	Air Temperature(°C)	Humidity (%)
Not Handheld	-0.543***	-0.350***
	(0.052)	(0.069)
Weather Station	-0.006	2.870***
	(0.045)	(0.060)
Note:	*p<0.1; **p<0.05; ***p<0.01;	

standard errors are noted in parentheses. The reference case by which the "Not Handheld" and "Weather Station" are compared is the "Handheld" group (see Figure S2), which is not displayed in the table.

Table S4. Total number of participants before and after data cleaning by neighborhood and session

	Total	Chapel Hill North and Timberlyne	Franklin Street	University Place Mall	Glenwood Square and Meadowmont	Southern Village
2-3 pm (participated)	13	3	4	3	1	2
2-3 pm (After data cleaning - AT)	12	3	3	3	1	2
2-3 pm (After data cleaning - RH)	12	3	3	3	1	2
5-6 pm (participated)	14	4	4	1	4	1
5-6 pm (After data cleaning - AT)	12	4	4	1	3	0
5-6 pm (After data cleaning - RH)	12	4	4	1	3	0

Table S5. Air temperature Model Comparison Results – Without NAIP (°C)

	MLR	**Random Forest**	**XGBoost**	**SVR**
Session 1 Train	RMSE = 1.84 R^2 = 0.16	RMSE = 0.54 R^2= 0.92	RMSE = 0.56 R^2=0.92	RMSE = 0.60 R^2= 0.91
Session 1 Test	RMSE = 1.86 R^2= 0.14	RMSE = 0.76 R^2= 0.86	RMSE = 0.74 R^2=0.86	RMSE = 0.92 R^2= 0.79
Session 2 Train	RMSE = 1.35 R^2 = 0.28	RMSE = 0.35 R^2= 0.95	RMSE = 0.38 R^2= 0.94	RMSE = 0.38 R^2= 0.94
Session 2 Test	RMSE = 1.34 R^2= 0.27	RMSE = 0.48 R^2= 0.91	RMSE = 0.48 R^2= 0.91	RMSE = 0.56 R^2= 0.87
Training time	Less than 1 min	6.7mins+ 2.2 mins	52mins + 38 mins	8min +2mins

Table S6. Air temperature Model evaluation results on the dataset with and without NAIP using Random Forest (°C)

	With NAIP	**Without NAIP**
Session 1 Test	RMSE = 0.88, R^2 = 0.81	RMSE = 0.76, R^2 = 0.85
Session 2 Test	RMSE = 0.58, R^2 = 0.86	RMSE = 0.48, R^2 = 0.91

Table S7. Relative Humidity Model Comparison Results - Without NAIP (%)

	MLR	**Random Forest**	**XGBoost**	**SVR**
Session 1 Train	RMSE = 4.81 R^2 = 0.1	RMSE = 1.5 R^2= 0.91	RMSE = 1.46 R^2=0.92	RMSE = 1.66 R^2= 0.89
Session 1 Test	RMSE = 4.77 R^2= 0.07	RMSE = 2.01 R^2= 0.83	RMSE = 1.96 R^2=0.84	RMSE = 2.46 R^2= 0.75
Session 2 Train	RMSE = 3.57 R^2 = 0.18	RMSE = 1.02 R^2= 0.93	RMSE = 1.02 R^2= 0.93	RMSE = 1.14 R^2= 0.92
Session 2 Test	RMSE = 3.59 R^2= 0.17	RMSE = 1.32 R^2= 0.89	RMSE = 1.29 R^2= 0.89	RMSE = 1.56 R^2= 0.84
Training time	Less than 1 min	5.6mins+ 2.2 mins	90mins + 47 mins	17min +4mins

Table S8. Measured relative humidity vs. land cover 2-3 pm

Landcover	count	min (%)	mean (%)	median (%)	max (%)	std (%)	Difference between Trees class (%)
Built-up	18718	30.33	39.66	38.57	58.93	4.78	-4.51
Trees	12061	30.54	41.53	40.58	55.81	5.35	0.00
Grassland	2703	32.00	41.12	40.86	55.78	4.71	-1.00
Barren/sparse vegetation	1158	30.02	38.10	37.43	51.59	3.52	-8.25

**Difference between Trees class: the percent difference between the mean relative humidity of each land cover class to Trees class*

Table S9. Calculated absolute humidity vs. land cover 2-3 pm

Landcover	count	min (%)	mean (%)	median (%)	max (%)	std (%)	Difference between Trees class (%)
Built-up	18718	14.25	18.41	18.36	25.56	1.58	-0.69
Trees	12061	14.00	18.54	18.40	24.81	1.93	0.00
Grassland	2703	14.59	17.74	17.53	24.37	1.57	-4.28
Barren/sparse vegetation	1158	14.69	18.29	18.34	21.17	1.31	-1.33

Absolute humidity is calculated with measured air temperature and relative humidity.

Table S10. TDew temperature vs. land cover 2-3pm

Landcover	count	min (°C)	mean (°C)	median (°C)	max (°C)	std (°C)	Difference between Trees class (%)
Built-up	18718	17.72	21.94	21.95	27.41	1.44	-0.22
Trees	12061	17.42	21.99	21.96	26.93	1.71	0.00
Grassland	2703	18.07	21.26	21.11	26.63	1.44	-3.31
Barren/sparse vegetation	1158	18.14	21.88	21.99	24.43	1.25	-0.49

Table S11. Population-weighted heat exposure metrics by group

Metric	White	Black	Native American	Asian	Other	All People of Color
LST (°C)	32.4	33.2	32.7	32.4	32.4	32.7
Air temperature (°C)	36.1	36.2	36.1	36.1	36.1	36.2
Relative Humidity (%)	39.8	39.5	39.8	39.7	39.8	39.6
Humidex	43.9	44.0	43.9	44.0	43.9	44.0

Table S12. Demographic percentages in Chapel Hill according to 2020 ACS Census

Native American	Asian	Black	Other	Pacific Islander	White
0.3	12.6	10.0	1.2	0	75.9