

Supplementary Material

Urban archetypes reveal disparities in green cooling efficacy, residential access, and distributional equity across Singapore

S1 Datasets, variables and preprocessing

Table S1. Environmental variable dictionary. All 124 indicators used to construct the exposome archetypes, pooled across the five domains. Spatial support describes the aggregation applied to the underlying raster or vector surface before assignment to the geocoded residential postcode point. “Distance-weighted” greenery indicators apply an inverse-distance kernel within the stated radius. Park accessibility indicators are pedestrian- or cycling-network travel times from the postcode to the nearest park of the stated tier. All indicators were z-standardised within domain prior to principal component analysis; the transformation column records any transformation applied before standardisation.

Domain	Variable code	Description	Spatial support	Unit	Transf.
Heat	GCCI1_max_e400_2019_M01	Jan max UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI2_mean_e400_2019_M01	Jan mean UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI3_min_e400_2019_M01	Jan min UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI4_max_e400_2019_M02	Feb max UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI5_mean_e400_2019_M02	Feb mean UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI6_min_e400_2019_M02	Feb min UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI7_max_e400_2019_M03	Mar max UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI8_mean_e400_2019_M03	Mar mean UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI9_min_e400_2019_M03	Mar min UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI10_max_e400_2019_M04	Apr max UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI11_mean_e400_2019_M04	Apr mean UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI12_min_e400_2019_M04	Apr min UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI13_max_e400_2019_M05	May max UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI14_mean_e400_2019_M05	May mean UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI15_min_e400_2019_M05	May min UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI16_max_e400_2019_M06	Jun max UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI17_mean_e400_2019_M06	Jun mean UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI18_min_e400_2019_M06	Jun min UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI19_max_e400_2019_M07	Jul max UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI20_mean_e400_2019_M07	Jul mean UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI21_min_e400_2019_M07	Jul min UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI22_max_e400_2019_M08	Aug max UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI23_mean_e400_2019_M08	Aug mean UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI24_min_e400_2019_M08	Aug min UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI25_max_e400_2019_M09	Sep max UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI26_mean_e400_2019_M09	Sep mean UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI27_min_e400_2019_M09	Sep min UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI28_max_e400_2019_M10	Oct max UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI29_mean_e400_2019_M10	Oct mean UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI30_min_e400_2019_M10	Oct min UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI31_max_e400_2019_M11	Nov max UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI32_mean_e400_2019_M11	Nov mean UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI33_min_e400_2019_M11	Nov min UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI34_max_e400_2019_M12	Dec max UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI35_mean_e400_2019_M12	Dec mean UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Heat	GCCI36_min_e400_2019_M12	Dec min UTCI	400 m circular mean around postcode	degrees C UTCI	identity
Pollution	pollution_pm25_annual_mean_ug_m3_2016	Annual PM2.5 (2016)	Postcode point value from annual raster	micrograms per cubic metre	identity
Pollution	pollution_pm25_annual_mean_ug_m3_2017	Annual PM2.5 (2017)	Postcode point value from annual raster	micrograms per cubic metre	identity
Pollution	pollution_pm25_annual_mean_ug_m3_2018	Annual PM2.5 (2018)	Postcode point value from annual raster	micrograms per cubic metre	identity
Pollution	pollution_pm25_annual_mean_ug_m3_2019	Annual PM2.5 (2019)	Postcode point value from annual raster	micrograms per cubic metre	identity
Pollution	pollution_pm25_annual_mean_ug_m3_2020	Annual PM2.5 (2020)	Postcode point value from annual raster	micrograms per cubic metre	identity
Pollution	pollution_pm25_annual_mean_ug_m3_2021	Annual PM2.5 (2021)	Postcode point value from annual raster	micrograms per cubic metre	identity
Pollution	pollution_pm25_annual_mean_ug_m3_2022	Annual PM2.5 (2022)	Postcode point value from annual raster	micrograms per cubic metre	identity

Domain	Variable code	Description	Spatial support	Unit	Transf.
Pollution	pollution_pm25_annual_mean_ug_m3_2023	Annual PM2.5 (2023)	Postcode point value from annual raster	micrograms per cubic metre	identity
Pollution	pollution_pm25_annual_mean_ug_m3_2024	Annual PM2.5 (2024)	Postcode point value from annual raster	micrograms per cubic metre	identity
Greenery	GGPA379_ea400_2016	Green area, 400 m (2016)	400 m buffer	square metres	log(1+x)
Greenery	GGPA380_ea800_2016	Green area, 800 m (2016)	800 m buffer	square metres	log(1+x)
Greenery	GGPA381_ea1000_2016	Green area, 1000 m (2016)	1000 m buffer	square metres	log(1+x)
Greenery	GGPA385_ew400_2016	Green weighted index, 400 m (2016)	— buffer	weighted square-metre index	log(1+x)
Greenery	GGPA386_ew800_2016	Green weighted index, 800 m (2016)	— buffer	weighted square-metre index	log(1+x)
Greenery	GGPA387_ew1000_2016	Green weighted index, 1000 m (2016)	— buffer	weighted square-metre index	log(1+x)
Greenery	GGPA388_ea400_2017	Green area, 400 m (2017)	400 m buffer	square metres	log(1+x)
Greenery	GGPA389_ea800_2017	Green area, 800 m (2017)	800 m buffer	square metres	log(1+x)
Greenery	GGPA390_ea1000_2017	Green area, 1000 m (2017)	1000 m buffer	square metres	log(1+x)
Greenery	GGPA394_ew400_2017	Green weighted index, 400 m (2017)	— buffer	weighted square-metre index	log(1+x)
Greenery	GGPA395_ew800_2017	Green weighted index, 800 m (2017)	— buffer	weighted square-metre index	log(1+x)
Greenery	GGPA396_ew1000_2017	Green weighted index, 1000 m (2017)	— buffer	weighted square-metre index	log(1+x)
Greenery	GGPA397_ea400_2018	Green area, 400 m (2018)	400 m buffer	square metres	log(1+x)
Greenery	GGPA398_ea800_2018	Green area, 800 m (2018)	800 m buffer	square metres	log(1+x)
Greenery	GGPA399_ea1000_2018	Green area, 1000 m (2018)	1000 m buffer	square metres	log(1+x)
Greenery	GGPA403_ew400_2018	Green weighted index, 400 m (2018)	— buffer	weighted square-metre index	log(1+x)
Greenery	GGPA404_ew800_2018	Green weighted index, 800 m (2018)	— buffer	weighted square-metre index	log(1+x)
Greenery	GGPA405_ew1000_2018	Green weighted index, 1000 m (2018)	— buffer	weighted square-metre index	log(1+x)
Greenery	GGPA406_ea400_2019	Green area, 400 m (2019)	400 m buffer	square metres	log(1+x)
Greenery	GGPA407_ea800_2019	Green area, 800 m (2019)	800 m buffer	square metres	log(1+x)
Greenery	GGPA408_ea1000_2019	Green area, 1000 m (2019)	1000 m buffer	square metres	log(1+x)
Greenery	GGPA412_ew400_2019	Green weighted index, 400 m (2019)	— buffer	weighted square-metre index	log(1+x)
Greenery	GGPA413_ew800_2019	Green weighted index, 800 m (2019)	— buffer	weighted square-metre index	log(1+x)
Greenery	GGPA414_ew1000_2019	Green weighted index, 1000 m (2019)	— buffer	weighted square-metre index	log(1+x)
Greenery	GGPA415_ea400_2020	Green area, 400 m (2020)	400 m buffer	square metres	log(1+x)
Greenery	GGPA416_ea800_2020	Green area, 800 m (2020)	800 m buffer	square metres	log(1+x)
Greenery	GGPA417_ea1000_2020	Green area, 1000 m (2020)	1000 m buffer	square metres	log(1+x)
Greenery	GGPA421_ew400_2020	Green weighted index, 400 m (2020)	— buffer	weighted square-metre index	log(1+x)
Greenery	GGPA422_ew800_2020	Green weighted index, 800 m (2020)	— buffer	weighted square-metre index	log(1+x)
Greenery	GGPA423_ew1000_2020	Green weighted index, 1000 m (2020)	— buffer	weighted square-metre index	log(1+x)
Greenery	GGPA424_ea400_2021	Green area, 400 m (2021)	400 m buffer	square metres	log(1+x)
Greenery	GGPA425_ea800_2021	Green area, 800 m (2021)	800 m buffer	square metres	log(1+x)
Greenery	GGPA426_ea1000_2021	Green area, 1000 m (2021)	1000 m buffer	square metres	log(1+x)
Greenery	GGPA430_ew400_2021	Green weighted index, 400 m (2021)	— buffer	weighted square-metre index	log(1+x)
Greenery	GGPA431_ew800_2021	Green weighted index, 800 m (2021)	— buffer	weighted square-metre index	log(1+x)
Greenery	GGPA432_ew1000_2021	Green weighted index, 1000 m (2021)	— buffer	weighted square-metre index	log(1+x)
Greenery	GGPA433_ea400_2022	Green area, 400 m (2022)	400 m buffer	square metres	log(1+x)
Greenery	GGPA434_ea800_2022	Green area, 800 m (2022)	800 m buffer	square metres	log(1+x)
Greenery	GGPA435_ea1000_2022	Green area, 1000 m (2022)	1000 m buffer	square metres	log(1+x)
Greenery	GGPA436_ew400_2022	Green weighted index, 400 m (2022)	— buffer	weighted square-metre index	log(1+x)
Greenery	GGPA437_ew800_2022	Green weighted index, 800 m (2022)	— buffer	weighted square-metre index	log(1+x)
Greenery	GGPA438_ew1000_2022	Green weighted index, 1000 m (2022)	— buffer	weighted square-metre index	log(1+x)
Greenery	GGPA439_ea400_2023	Green area, 400 m (2023)	400 m buffer	square metres	log(1+x)
Greenery	GGPA440_ea800_2023	Green area, 800 m (2023)	800 m buffer	square metres	log(1+x)
Greenery	GGPA441_ea1000_2023	Green area, 1000 m (2023)	1000 m buffer	square metres	log(1+x)
Greenery	GGPA445_ew400_2023	Green weighted index, 400 m (2023)	— buffer	weighted square-metre index	log(1+x)

Domain	Variable code	Description	Spatial support	Unit	Transf.
Greenery	GGPA446_ew800_2023	Green weighted index, 800 m (2023)	— buffer	weighted square-metre index	log(1+x)
Greenery	GGPA447_ew1000_2023	Green weighted index, 1000 m (2023)	— buffer	weighted square-metre index	log(1+x)
Greenery	GGPA448_ea400_2024	Green area, 400 m (2024)	400 m buffer	square metres	log(1+x)
Greenery	GGPA449_ea800_2024	Green area, 800 m (2024)	800 m buffer	square metres	log(1+x)
Greenery	GGPA450_ea1000_2024	Green area, 1000 m (2024)	1000 m buffer	square metres	log(1+x)
Greenery	GGPA454_ew400_2024	Green weighted index, 400 m (2024)	— buffer	weighted square-metre index	log(1+x)
Greenery	GGPA455_ew800_2024	Green weighted index, 800 m (2024)	— buffer	weighted square-metre index	log(1+x)
Greenery	GGPA456_ew1000_2024	Green weighted index, 1000 m (2024)	— buffer	weighted square-metre index	log(1+x)
Greenery	GGPA457_ea400_2025	Green area, 400 m (2025)	400 m buffer	square metres	log(1+x)
Greenery	GGPA458_ea800_2025	Green area, 800 m (2025)	800 m buffer	square metres	log(1+x)
Greenery	GGPA459_ea1000_2025	Green area, 1000 m (2025)	1000 m buffer	square metres	log(1+x)
Greenery	GGPA463_ew400_2025	Green weighted index, 400 m (2025)	— buffer	weighted square-metre index	log(1+x)
Greenery	GGPA464_ew800_2025	Green weighted index, 800 m (2025)	— buffer	weighted square-metre index	log(1+x)
Greenery	GGPA465_ew1000_2025	Green weighted index, 1000 m (2025)	— buffer	weighted square-metre index	log(1+x)
Park accessibility	GGNA05_WI_ap_tt5	Walking park access, 5 min	Walking network catchment, 5 min	accessibility-index units	log(1+x)
Park accessibility	GGNA06_WI_ap_tt10	Walking park access, 10 min	Walking network catchment, 10 min	accessibility-index units	log(1+x)
Park accessibility	GGNA07_WI_ap_tt15	Walking park access, 15 min	Walking network catchment, 15 min	accessibility-index units	log(1+x)
Park accessibility	GGNA08_WI_ap_tt20	Walking park access, 20 min	Walking network catchment, 20 min	accessibility-index units	log(1+x)
Park accessibility	GGNA09_CI_ap_tt5	Cycling park access, 5 min	Cycling network catchment, 5 min	accessibility-index units	log(1+x)
Park accessibility	GGNA10_CI_ap_tt10	Cycling park access, 10 min	Cycling network catchment, 10 min	accessibility-index units	log(1+x)
Park accessibility	GGNA11_CI_ap_tt15	Cycling park access, 15 min	Cycling network catchment, 15 min	accessibility-index units	log(1+x)
Park accessibility	GGNA12_CI_ap_tt20	Cycling park access, 20 min	Cycling network catchment, 20 min	accessibility-index units	log(1+x)
Built environment	built_albedo_30m	Surface albedo, 30 m	30 m grid cell	Dimensionless ratio	identity
Built environment	built_anthropogenic_heat_flux_w_m2_30m	Anthropogenic heat flux, 30 m	30 m grid cell	W m ⁻²	log(1+x)
Built environment	built_bcr_100m	Building coverage, 100 m	100 m grid cell	Proportion	identity
Built environment	built_far_proxy_100m	Floor-area intensity, 100 m	100 m grid cell	Dimensionless ratio	log(1+x)
Built environment	built_height_areal_m_100m	Areal building height, 100 m	100 m grid cell	m	log(1+x)
Built environment	built_height_max_m_100m	Maximum building height, 100 m	100 m grid cell	m	log(1+x)
Built environment	built_height_mean_m_100m	Mean building height, 100 m	100 m grid cell	m	log(1+x)
Built environment	built_height_min_m_100m	Minimum building height, 100 m	100 m grid cell	m	log(1+x)
Built environment	built_height_std_m_100m	Building-height variability, 100 m	100 m grid cell	m	log(1+x)
Built environment	built_ndbi_30m	Built-up index, 30 m	30 m grid cell	Dimensionless index	identity
Built environment	built_svf_ground_30m	Sky-view factor, 30 m	30 m grid cell	Proportion	identity

S2 Principal component analysis, domain balancing and archetype construction

Table S2. Domain-wise principal component analysis, balancing, and interpretation of the twelve retained components.

(a) Domain summary

Domain	Raw variables	Retained PCs	Within-domain variance (%)	Balancing multiplier	Contribution after balancing (%)
Heat	36	2	88.46	0.7071	20
Pollution	9	2	85.02	0.7071	20
Greenery	60	1	90.80	1.0000	20
Park accessibility	8	2	88.53	0.7071	20
Built environment	11	5	85.64	0.4472	20

(b) Component interpretation

Component	Domain	Within-domain variance (%)	Interpretation
Persistent Thermal Burden	Heat	72.62	Higher mean and maximum UTCI across the annual cycle
Thermal Baseline	Heat	15.85	Higher monthly minimum UTCI, especially in cooler-season months
Persistent PM _{2.5} Burden	Pollution	67.58	Higher annual PM _{2.5} across most years
PM _{2.5} Trend	Pollution	17.44	Higher earlier-period PM _{2.5} relative to recent years
Green Provision	Greenery	90.80	Higher vegetation provision across years and spatial scales
Park Accessibility	Park accessibility	72.71	Higher walking and cycling accessibility to parks
Modal Park Contrast	Park accessibility	15.82	Greater cycling relative to walking park accessibility
Vertical Built Intensity	Built environment	38.31	Taller buildings and greater floor-area intensity with lower sky openness
Horizontal Built Intensity	Built environment	19.05	Higher building coverage and built-up surface intensity
Open Heat Form	Built environment	10.92	Higher anthropogenic heat and sky openness with lower minimum height
Elevated Heat Form	Built environment	9.59	Higher minimum building height and anthropogenic heat load
Reflective Open Form	Built environment	7.76	Higher surface albedo with lower building coverage

Table S3. Consensus clustering diagnostics, K = 2 to 20. Resampling stability and spatial transferability are reported separately; K = 4 was selected on the joint criterion.

K	Silhouette	Bootstrap ARI	Weakest Jaccard	Minimum cluster (%)	Blocked ARI	Min.-fold ARI	Weakest recall	Status
2	0.158	0.994	0.998	37.14	0.739	0.585	0.916	Passes strict gates
3	0.158	0.997	0.996	16.91	0.602	0.280	0.768	Spatial gate failed
4	0.174	0.991	0.994	15.97	0.826	0.704	0.903	Selected primary
5	0.180	0.994	0.993	12.84	0.844	0.509	0.782	Passes strict gates
6	0.171	0.921	0.917	6.26	0.736	0.349	0.495	Spatial gate failed
7	0.161	0.810	0.745	3.33	0.738	0.528	0.576	Spatial gate failed
8	0.128	0.866	0.989	2.73	0.748	0.472	0.550	Spatial gate failed
9	0.128	0.853	0.962	2.72	0.745	0.636	0.496	Spatial gate failed

K	Silhouette	Bootstrap ARI	Weakest Jaccard	Minimum cluster (%)	Blocked ARI	Min.-fold ARI	Weakest recall	Status
10	0.115	0.783	0.454	0.47	—	—	—	Internal gate failed
11	0.109	0.774	0.582	0.89	—	—	—	Internal gate failed
12	0.110	0.755	0.532	0.47	—	—	—	Internal gate failed
13	0.107	0.726	0.310	0.47	—	—	—	Internal gate failed
14	0.102	0.803	0.440	0.46	—	—	—	Internal gate failed
15	0.104	0.803	0.626	0.47	—	—	—	Internal gate failed
16	0.099	0.809	0.827	0.47	—	—	—	Internal gate failed
17	0.102	0.770	0.430	0.47	—	—	—	Internal gate failed
18	0.098	0.727	0.352	0.47	—	—	—	Internal gate failed
19	0.095	0.710	0.119	0.47	—	—	—	Internal gate failed
20	0.096	0.688	0.209	0.47	—	—	—	Internal gate failed

Table S4. Archetype size, housing composition and domain-balanced component centroids at K = 4. These are the numerical values underlying main-text Fig. 4.

(a) Size and housing composition

Archetype	Label	Postcodes, n	Frame (%)	HDB postcodes, n	HDB postcodes (%)	Dwelling units, n	HDB dwellings (%)
A1	Low-green–Hot	21,073	22.4	1,882	8.9	252,016	76.7
A2	High-PM2.5–Green	23,672	25.2	2,547	10.8	431,913	68.6
A3	Green–Cool	21,267	22.6	3,391	15.9	461,447	79.0
A4	Low-green–Low-PM2.5	28,064	29.8	2,715	9.7	454,884	63.2

(b) Domain-balanced component centroids

Component	A1	A2	A3	A4
Persistent Thermal Burden	+0.317	-0.246	-0.552	+0.388
Thermal Baseline	-0.527	+0.509	-0.640	+0.452
Persistent PM _{2.5} Burden	-0.001	+0.651	-0.282	-0.334
PM _{2.5} Trend	+0.917	-0.224	+0.343	-0.760
Green Provision	-0.828	+0.753	+0.958	-0.739
Park Accessibility	-0.126	-0.459	+0.328	+0.233
Modal Park Contrast	+0.016	-0.392	+0.120	+0.228
Vertical Built Intensity	-0.021	-0.097	-0.076	+0.155
Horizontal Built Intensity	+0.169	-0.244	-0.025	+0.098
Open Heat Form	-0.117	+0.033	+0.100	-0.016
Elevated Heat Form	-0.031	-0.020	-0.023	+0.057
Reflective Open Form	+0.038	-0.112	-0.034	+0.092

S3 Cooling-efficacy, cooling-footprint, and accessibility models

Table S5. Archetype-specific green-UTCI model and the cooling-efficacy estimand.

(a) Archetype-specific overall linear green-cooling association

Archetype	Label	Cooling (°C per +10 pp)	95% CI	P	Postcodes, n
A1	Low-green-Hot	0.0122	0.0081 to 0.0162	3.87e-09	21,073
A2	High-PM2.5-Green	0.1242	0.1210 to 0.1274	<1e-300	23,672
A3	Green-Cool	0.1188	0.1150 to 0.1226	<1e-300	21,267
A4	Low-green-Low-PM2.5	0.0887	0.0844 to 0.0930	<1e-300	28,064

(b) Primary derivative estimand versus finite-difference sensitivity (°C per +10 pp greenery)

Archetype	Derivative, mean	Derivative, median	Finite diff., mean	Finite diff., median	Postcodes, n
A1	0.0342	0.0418	-0.0126	-0.0051	21,073
A2	0.1061	0.1020	0.1367	0.1325	23,672
A3	0.0889	0.0723	0.1343	0.1177	21,267
A4	0.0872	0.0871	0.0906	0.0905	28,064
All	0.0805	0.0848	0.0890	0.0889	94,076

Table S6. Accessible cooling under alternative pedestrian-network catchment radii.

R (m)	Postcodes, n	n served	Served (%)	Mean ACI, all	Median ACI, served	P90 ACI
200	94,076	27,178	28.89	0.00304	0.00524	0.00983
400	94,076	38,996	41.45	0.00412	0.00432	0.01254
600	94,076	48,169	51.20	0.00402	0.00306	0.01311

Table S7. Green-response and nonlinearity tests for accessible cooling. The binomial stage models whether any cooling is reachable; the Gamma stage models accessible cooling volume among served postcode locations.

Archetype	Planning areas	Nonlinearity P	BH q	Spline knots (green %)
A1	19	0.7049	0.7192	10.0 / 15.0 / 19.6 / 30.3
A2	32	0.7192	0.7192	21.7 / 33.3 / 43.1 / 60.7
A3	25	0.1834	0.3667	22.7 / 33.5 / 44.5 / 63.6
A4	28	9.68e-12	3.87e-11	8.6 / 16.5 / 22.0 / 31.0
A1	11	0.7914	0.7914	12.0 / 17.0 / 21.3 / 30.5
A2	22	0.6878	0.7914	24.8 / 39.0 / 48.2 / 64.8
A3	20	0.0016	0.0033	22.2 / 31.9 / 44.0 / 62.6
A4	19	9.32e-07	3.73e-06	12.2 / 19.3 / 24.1 / 35.8

S4 Cooling inequality, thermal need and housing disparities

Table S8. Concentration, inequality and need–service mismatch in accessible cooling, by housing group and weighting.

Housing	Weighting	Postcodes	Dwellings	Unserved (%)	Gini (95% CI)	Gini among served	Mismatch D (95% CI)
HDB	Dwelling units (primary)	10,535	1,141,285	62.9 (54.1–71.5)	0.879 (0.837–0.913)	0.673	0.752 (0.700–0.801)
Other residential	Dwelling units (primary)	83,541	458,975	55.4 (47.7–62.6)	0.845 (0.805–0.877)	0.653	0.724 (0.678–0.768)
HDB	Residential locations (sensitivity)	10,535	1,141,285	63.1	0.879	0.671	0.749
Other residential	Residential locations (sensitivity)	83,541	458,975	58.0	0.849	0.641	0.732

Table S9. Socioeconomic vulnerability by archetype and housing group.

Scope	Archetype_name	Housing	Complete postcodes	Eligible dwellings	High socioeconomic context (%)
A1	Low-green--Hot	HDB	1,832	188,247	9.7 (0.0–34.4)
A1	Low-green--Hot	Other residential	19,191	58,762	8.5 (0.0–38.5)
A2	High-PM2.5--Green	HDB	2,507	291,628	34.0 (0.3–66.7)
A2	High-PM2.5--Green	Other residential	21,113	134,951	16.7 (2.7–33.7)
A3	Green--Cool	HDB	3,389	364,073	11.0 (0.0–32.6)
A3	Green--Cool	Other residential	17,865	96,464	4.7 (0.0–13.3)
A4	Low-green--Low-PM2.5	HDB	2,715	287,392	31.1 (6.8–74.7)
A4	Low-green--Low-PM2.5	Other residential	25,349	167,492	26.3 (5.5–56.4)

Table S10. Planning-area bootstrap uncertainty for the principal equity estimates.

Quantity	Scope	Estimate	95% CI	Replicates
Gini	HDB	0.879	0.837 to 0.913	499
Gini	Other residential	0.845	0.805 to 0.877	499
Gini difference	HDB – other residential	0.034	-0.010 to 0.074	499
Unserved dwellings (%)	HDB	62.9	54.1 to 71.5	499
Unserved dwellings (%)	Other residential	55.4	47.7 to 62.6	499
Unserved gap (percentage points)	HDB – other residential	7.6	-1.6 to 16.2	499
Need–service mismatch D	HDB	0.752	0.700 to 0.801	499
Need–service mismatch D	Other residential	0.724	0.678 to 0.768	499
Need–service mismatch D difference	HDB – other residential	0.028	-0.020 to 0.078	499

Table S11. Sensitivity of the accepted four archetypes to omission of each exposome domain. The remaining domain PCAs and equal-domain scaling were refitted, and the original 23-partition consensus was repeated at fixed K = 4 for all 94,076 official residential postcodes.

(a) Agreement with the five-domain classification

Omitted domain	PCs retained	ARI	Changed (%)	Smallest class (%)
None (five domains)	12	1.000	0.0	22.4
Heat	10	0.746	10.9	20.5
PM2.5 pollution	10	0.443	37.6	13.9
Greenery	11	0.512	33.2	14.6
Park accessibility	10	0.758	10.6	19.3
Built environment	7	0.941	2.2	22.5

(b) Retention of original A1-A4 postcode assignments (%)

Omitted domain	A1	A2	A3	A4
None (five domains)	100.0	100.0	100.0	100.0
Heat	96.5	75.0	92.8	92.7
PM2.5 pollution	10.1	73.9	77.6	80.3
Greenery	85.7	67.3	17.9	89.3
Park accessibility	93.3	71.4	96.8	96.2
Built environment	99.1	97.9	97.8	96.6