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How does perceived heat stress differ between urban forms and human vulnerability profiles? Case study Berlin

Nimra Iqbal et al.

Correspondence to: Nimra Iqbal (nimra.iqbal@ireus.uni-stuttgart.de)

Contents

General

This document provides a comprehensive overview of dataset components of the household survey and earth observation data used for analysing perceived heat stress in different urban structure types (USTs) and in 39 selected PLRs (Fig. S2) for household survey in Berlin. It is a companion document to the main article that serves as a detailed reference for the data contents archived.

In the following, each dataset component (Table 1, Table 2 and Table 3 in the main paper) is discussed in its own section. Each section includes:

1) Overview of files included in the Zenodo archive.
2) Purpose of the dataset.
3) Data generation steps.
4) Detailed dataset description with meta information for all files provided.

File types in dataset

File types of the datasets provided are described in Table S1.

Table S1. File formats used with descriptions and references. Links last accessed on 18/06/2024.

File ending / format	Description	Reference
*.zip	File compression	https://www.loc.gov/preservation/digital/formats/fdd/fdd000354.shtml
*.shp, *.shx, *.cpg, *.dbf, *.prj	ESRI Shapefile	https://www.loc.gov/preservation/digital/formats/fdd/fdd000280.shtml
*.csv	Comma Separated Values	https://www.loc.gov/preservation/digital/formats/fdd/fdd000323.shtml
*.xlsx	Office Open XML	https://www.loc.gov/preservation/digital/formats/fdd/fdd000398.shtml
*.pdf	Portable Document Format	https://www.loc.gov/preservation/digital/formats/fdd/fdd000030.shtml

S1 Aggregation of urban structure types (USTs) related to residential use in the City of Berlin

S1.1. Dataset files

Table S2. Files in Zenodo archive.

Compressed File	File types	General description	Details
USTs_residential_new_classes.zip	Polygons, ESRI shapefile format (zipped: *.shp, *.shx, *.sbn, *.cpg, *.dbf, *.prj)	USTs in Berlin with 7 aggregated residential new classes	Tables S4, S5

S1.2. Data purpose

13 USTs in Berlin related to residential use are further aggregated into 7 classes (Fig. S1). The new classification (Table 1, main paper) ensures that USTs are sufficiently different, but also encompass a reduced number of classes that can be used within further assessment. The criteria were based on various physical and demographic parameters. Table A1 in the main paper presents detailed criteria used for this aggregation.

S1.3. Data generation

The USTs aggregation used ArcGIS pro[1] version 3.1.1.

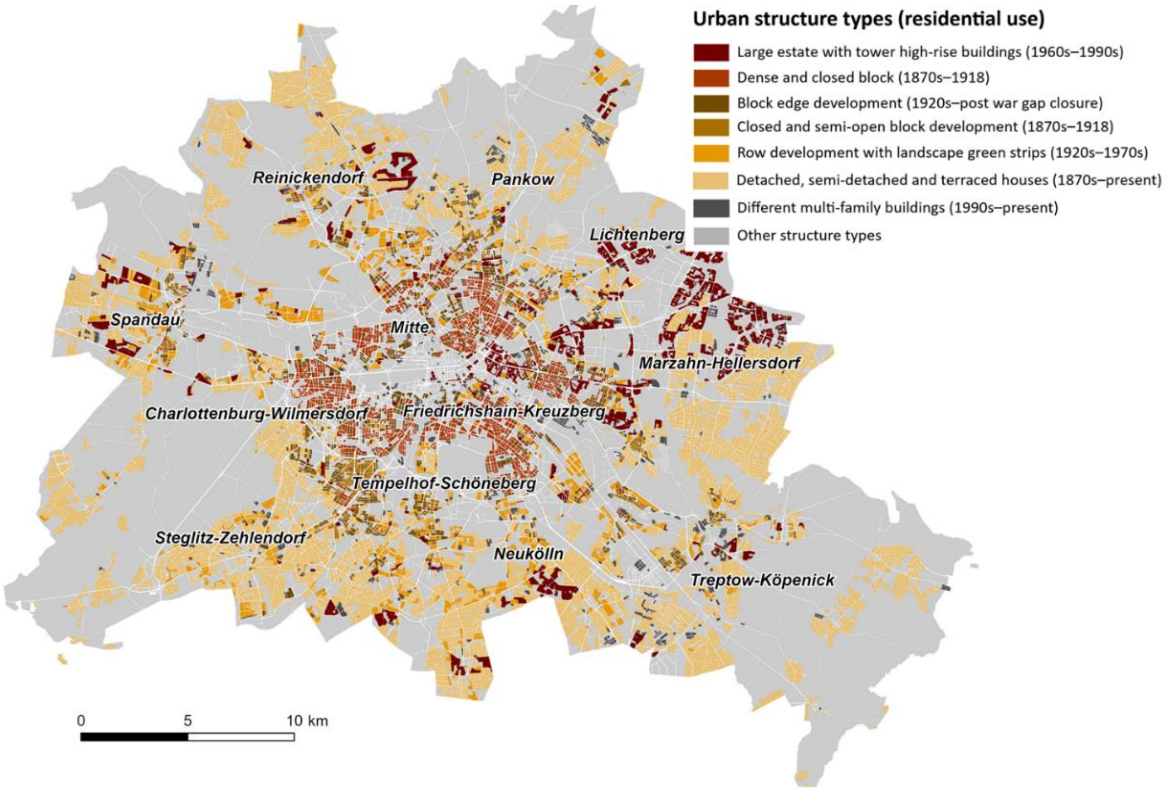

Figure S1. Urban structure types (USTs) residential new aggregated classes in Berlin using the data from Senatsverwaltung für Stadtentwicklung und Wohnen (2020)

Input files

Input data used in the production of this dataset are listed in Table S3.

Table S3. Data source used to aggregate USTs.

	Source	Resolution	Reference year
Urban structure types	Umweltatlas Berlin	Block	2020

[1] https://www.esri.com/en-us/arcgis/products/arcgis-pro/resources, last accessed 20/03/2024

S1.4. Data description

File formats and further meta information are given in Table S4, data attributes in Table S5.

Table S4. Files formats and meta information for the dataset.

Filename(s)	USTs_residential_new_classes.shp and *.shx, *.sbn, *.cpg, *.dbf, *.prj
Coordinate reference system	EPSG 25833; ETRS89 / UTM zone 33N
Format, type	ESRI shapefile; polygons
Resolution	Block
Reference year	2021
Dataset attributes	Table S5

Table S5. Dataset (Table S1.3) attributes.

Attribute name	Unit	Type	Description
Schl5	–	string	Unique ID of each block
Typklar_EN	–	string	UST of the block
SHAPE_Area	m^2	float	Area of the block
Typ_Klar_B	–	string	USTs new aggregated classes (Figure S1)

S2. Household survey data

S2.1. Dataset files

Table S6. Files in Zenodo archive.

File	File type	General description	Details
Berlin_survey_data	*.xls	Selected variables from the household survey in Berlin linked with USTs dataset	Tables S7, S8

S2.2. Data purpose

Primary data on perceived heat and climate adaptation were obtained from a household survey conducted in Berlin in October 2022. To capture diverse groups and behaviors of people, 39 out of 542 PLRs (Fig. S2) were selected for a household survey in Berlin. The selection was based on multiple criteria such as heat exposure, population density, representation of different age groups, unemployment levels, and heat mortality rate. A total of 10,000 addresses were collected from the Population Register of Berlin, using stratified sampling. Survey invitations were posted to selected addresses, along with a QR code to access the online survey conducted using the Evasys online tool (Evasys GmbH, 2021). A total of 565 respondents from 8,000 households received invitation letters. It is important to mention that one PLR (No 39) was excluded from the analysis due to the small number of respondents.

The survey data provided insights into household perceptions and experiences regarding heat stress and their living conditions such as housing typologies, availability and access to green spaces, and adaptation options. The analysis particularly focused on the influence of sociodemographic characteristics (distinguished by age and income) and urban forms on risk perception, experience, and climate change adaptation options to heat stress in the city of Berlin.

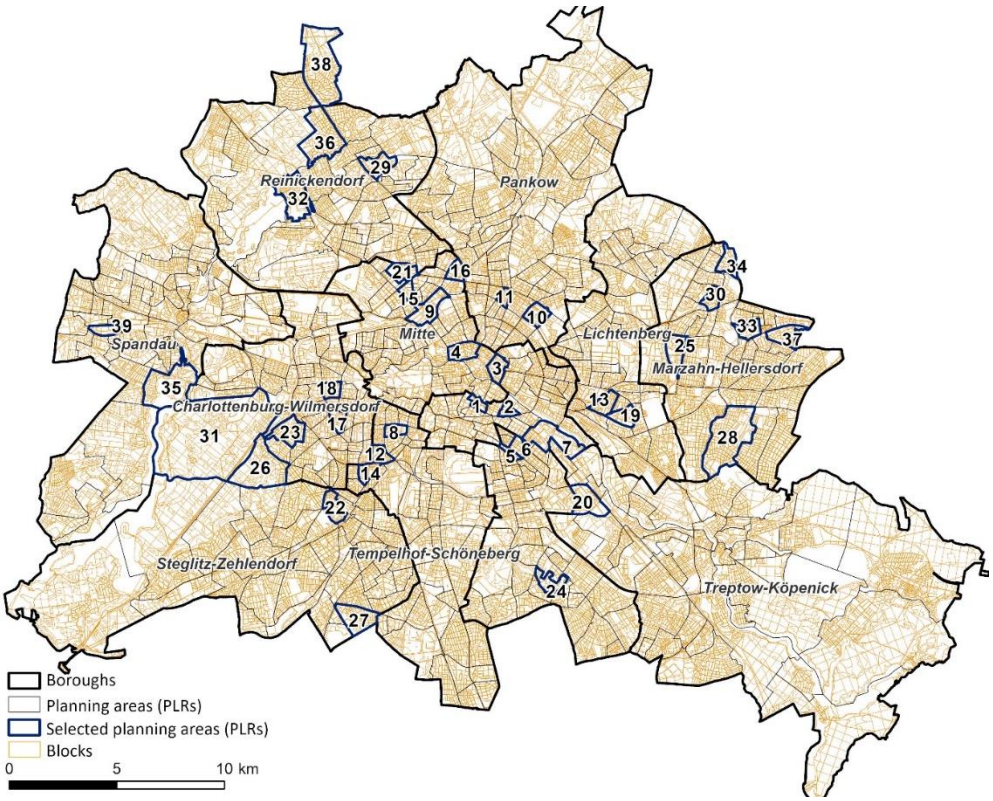

Figure S2. Berlin (a) administrative boundaries showing city (outer line), Boroughs (black), PLRs (grey, planning areas), and those selected for the household survey (blue, numbered 1 to 39) using data from Landesamt für Bürger- und Ordnungsangelegenheiten, 2022

S2.3. Data generation

Household survey data was gathered using the online Evasys GmbH, 2021 tool. All processing done using IBM SPSS-29.0[2]. and R-2.15.0[3].

S2.4. Data description

Table S7. Files formats and meta information for the dataset.

Filename(s)	Berlin_survey_data.xls
Format	Excel
Resolution	PLRs (Landesamt für Bürger- und Ordnungsangelegenheiten, 2022)
Reference year	2022
Dataset attributes	Table S8

Table S8. Aggregated dataset (Table SM2.5) attributes

Attribute name	Type	Description
Urban Structure Types (USTs)	Nominal	Linked to the USTs (Fig. 1) below: Large estate with tower high-rise buildings (1960s–1990s) / Dense and closed block (1870s–1918s) Block edge development (1920s–post war gap closure) / Closed and semi-open block development (1870s–1918) Row development with landscape green strips (1920 – 1970s) / Detached, semi-detached and terraced houses (1870s – present) Different multi-family buildings (1990s – present) / Other structure types
Perceived heat at neighbourhood	Ordinal	Reponses recorded for: How hot or cool do you think your neighbourhood is during a heatwave compared to the average outdoor temperature for the city? Much cooler / Slightly cooler / No difference / Slightly hotter / Very hot
Open spaces	Nominal	How would you describe the area right next to your house/apartment? Lots of green (trees, meadow, lawn) and plenty of space between the buildings / Lots of green (trees, meadow, lawn), but little space between buildings Little green (trees, meadow, lawn) and a lot of space between the buildings / Little green (trees, meadow, lawn), and little space between the buildings None of this applies to my living environment
Age group	Ordinal	How old are you? 18 to 24 years / 25 to 34 years / 35 to 44 years / 45 to 54 years 55 to 64 years / 65 to 74 years / 75 to 84 years / 85 years and older
Health Condition	Nominal	Have you already had problems with heat stress? If yes, which ones: Lethargy/fatigue / Trouble sleeping / Difficulties in concentrating / Dizziness Nausea / Cardiovascular problems / Heat stroke
Household income	Ordinal	What is the monthly net income (Netto) of the household? (Netto = after deduction of taxes, social security contributions, etc.) Less than 900 € / 900 to under 1300 € / 1300 to under 1700 € 1700 to under 2000 € / 2000 to under 2300 € / 2300 to under 2600 € 2600 to under 2900 € / 2900 to under 3200 € / 3200 to under 3600 € 3600 to under 4000 € / 4000 to under 4500 € / 4500 to under 5000 € 5000 to under 6000 € / 6000 to under 7000 € / 7000 € and above Not specified

[2] https://www.ibm.com/spss, last accessed 20/03/2024
[3] https://www.r-studio.com/, last accessed 20/03/2024

Adaptive measures	Nominal	Which of the following measure to protect against heatwaves have you already implemented or are you planning to implement (considering the change of weather in Berlin, as described)? Air conditioner installation		
		Already implemented	In plan/ implementation	Will be an option for future
		Neither today, nor future	Does not apply	

S2.5. Cross-tabulation of variables from household survey

The percentage responses of perceived heat at neighbourhood and open spaces (description of the area next to house/apartment) are aggregated for 7 UST in the Table S9. The results from the cross-tabulation of different variables are reported in the paper in the section 3.2 and 3.3. Tables are provided as below:

Table S9. Urban Structure types, perceived heat and availability of open spaces

Original survey question number	5.3					9.1				
6.2	% responses of perceived heat at neighborhood					% responses of description of the area right next to house/apartment?				
Urban structure types	Very cool	Slightly cooler	No difference	Slightly hotter	Very hot	Lots of green (trees, meadow, lawn) and plenty of space between the buildings	Lots of green (trees, meadow, lawn), but little space between buildings	Little green (trees, meadow, lawn) and a lot of space between the buildings	Little green (trees, meadow, lawn), and little space between the buildings	None of this applies to my living environment
(semi-)detached and terraced houses	6.3%	56.3%	15.0%	17.5%	5.0%	77.2%	19.0%	1.3%	2.5%	0.0%
Row development	1.5%	36.8%	25.0%	25.0%	11.8%	44.1%	25.0%	2.9%	26.5%	1.5%
Closed/ semi-open block development	0.0%	40.0%	20.0%	35.0%	5.0%	21.1%	47.4%	15.8%	10.5%	5.3%
Block edge development	0.0%	21.0%	32.7%	38.3%	8.0%	22.0%	34.0%	5.0%	36.5%	2.5%
Multi-family buildings	0.0%	26.5%	32.7%	34.7%	6.1%	33.3%	28.9%	4.4%	28.9%	4.4%
Dense closed block	0.0%	9.8%	23.2%	43.9%	23.2%	11.1%	39.5%	8.6%	34.6%	6.2%
High-rise buildings	1.1%	22.6%	20.4%	37.6%	18.3%	56.2%	29.2%	6.7%	6.7%	1.1%

The percentage responses of perceived heat and heat-related health issues i.e. cardiovascular problems are cross-tabulated with different age groups in the Table S10. Results are reported in the section 3.3.2 of the paper.

Table S10. Age groups, perceived heat and cardiovascular issues

Original survey question number	17.8					5.15				
14.1	% responses of perceived heat at neighborhood					% responses of cardiovascular problems				
How old are you?	Very cool	Slightly cooler	No difference	Slightly hotter	Very hot	Very often	Often	Sometimes	Rarely	No
18-24 year	0.0%	1.3%	2.2%	2.1%	3.1%	0.0%	3.0%	1.6%	1.2%	2.9%
25–34 year	14.3%	13.0%	22.3%	17.3%	15.6%	16.1%	3.0%	10.5%	21.3%	20.1%
35–44 year	14.3%	13.0%	25.2%	17.8%	18.8%	25.8%	18.2%	15.3%	14.0%	22.5%
45–54 year	0.0%	18.2%	15.1%	12.6%	12.5%	9.7%	9.1%	13.7%	15.9%	14.7%
55–64 year	28.6%	24.7%	20.1%	18.8%	20.3%	12.9%	27.3%	26.6%	24.4%	15.2%
65–74 year	42.9%	20.8%	10.8%	20.9%	14.1%	19.4%	30.3%	16.9%	14.6%	18.1%
75–84 year	0.0%	6.5%	3.6%	8.4%	15.6%	12.9%	3.0%	12.9%	6.7%	5.9%
85 year and above	0.0%	2.6%	0.7%	2.1%	0.0%	3.2%	6.1%	2.4%	1.8%	0.5%

The percentage responses of household monthly net income (€) are aggregated for 7 UST in the Table S11. and household monthly net income (€) is cross-tabulated with adaptation measure i.e., air conditioner installation (Table S12.). The results are reported in the section 3.3.2. of the paper.

Table S11. Urban Structure type and household monthly net income

Original survey question number	17.8							
6.2	% responses of household monthly net income							
Urban structure types	<900	900–1999	2000–2899	2900–3999	4000–4999	5000–5999	6000–6999	≥7000
(semi-)detached and terraced houses	0.0%	4.6%	10.8%	21.5%	24.6%	18.5%	0.0%	20.0%
Row development	6.3%	12.7%	22.2%	23.8%	23.8%	7.9%	1.6%	1.6%
Closed/ semi-open block development	5.6%	0.0%	27.8%	16.7%	27.8%	11.1%	11.1%	0.0%
Block edge development	1.4%	14.4%	24.0%	19.2%	20.5%	14.4%	2.1%	4.1%
Multi-family buildings	4.5%	11.4%	13.6%	29.5%	15.9%	9.1%	4.5%	11.4%
Dense closed block	1.4%	22.9%	7.1%	22.9%	18.6%	10.0%	5.7%	11.4%
High-rise buildings	3.6%	21.4%	23.8%	21.4%	19.0%	9.5%	0.0%	1.2%

Table S12. Household monthly net income and adaptation measures

Original survey question number	**17.8**							
12.4	% responses of household monthly net income vs installation of air conditioner							
Air conditioner installation	<900	900–1999	2000–2899	2900–3999	4000–4999	5000–5999	6000–6999	≥7000
Already implemented	3.3%	10.0%	6.7%	26.7%	16.7%	20.0%	0.0%	16.7%
In plan/ implementation	0.0%	40.0%	20.0%	20.0%	20.0%	0.0%	0.0%	0.0%
Will be an option for future	1.7%	6.8%	16.9%	23.7%	27.1%	3.4%	6.8%	13.6%
Neither today, nor future	3.0%	13.8%	17.2%	20.7%	22.4%	13.4%	2.6%	6.9%
Does not apply	3.4%	18.9%	20.9%	23.0%	16.9%	12.2%	1.4%	3.4%

S3. Earth observation (EO) data processing

S3.1. Dataset files

Table S13. Files in Zenodo archive.

File	Compressed file types	General description	Details
Grass_Trees_fraction_Block.zip	Polygons, ESRI shapefile format (zipped: *.shp, *.shx, *.sbn, *.cpg, *.dbf, *.prj)	Plan area fraction of grass and trees per block (Fig. S2) covering the city of Berlin	Tables S15, S16
Shadow_fraction_Block(Sel_PLR).zip	Polygons, ESRI shapefile format (zipped: *.shp, *.shx, *.sbn, *.cpg, *.dbf, *.prj)	Shadow fraction per block (Fig. S2) within survey PLR	Tables S17, S18

S3.2. Data purpose

Shadow fraction and vegetation fraction are used to assess urban living conditions within Berlin. This data is then coupled with USTs and perceived heat stress.

S3.3. Data generation

Throughout the day, shadows create a distinctive solar loss pattern, with the longest shadows occurring during the early morning and evening hours and the shortest occurring around noon. Shadow length is influenced by the height and spacing of buildings and trees, which impacts surface radiative heating/cooling. In addition, vegetation cover affects the surface airflow and radiational heating/cooling through evapotranspiration (Marando et al., 2022). To facilitate the analysis, the shadow indicator, which represents the fraction of shadows (ranging from 0–1), was developed for the summer of 2022 (June 1–August 31). Simulated hourly shadows for buildings and trees (Lindberg and Grimmond, 2011) during this period, at 1 m spatial resolution, were aggregated over time to estimate the shadow fraction for the entire summer.

The vegetation fraction, estimated at 10 m spatial resolution, used Sentinel-2 images for the summer of 2022 (Mitraka et al., 2017). Information on tree locations and heights at 1 m spatial resolution was obtained from local sources (Lindberg and Grimmond, 2011). Normalized difference vegetation index images were employed to assess low vegetation as well as overall vegetation abundance, resulting in a 10 m spatial resolution vegetation abundance image corresponding to summer months (June, July and August) 2022.

Analysis use different administrative spatial scales, viz (Fig. 2): Boroughs, PLRs (Planungsräume/ Planning areas), and blocks. The block scale USTs (Fig. 2b) data (e.g. grass, trees, and shadow fractions, Table S14) involves aggregating the raster data (Fig. 2). For calculation, pixels centroids within a block boundary but not in a building footprint are used.

Input files

Input data used in the production of this dataset are listed in Table S14.

Table S14. Data source used for calculating grass, trees and shadow fraction (Tables S3.3–S3.6).

	Description	Source	Resolution	Reference year
Grass fraction	1 m land cover data (2021) aggregated to 10 m to compare summer 2022 state using 10 m normalized difference vegetation index (NDVI from Sentinel-2) (Mitraka et al., 2017)	Copernicus Sentinel-2	10 m	Summer 2022
Trees fraction	Same as grass fraction	Geoportal Berlin (2022a, 2022b), Copernicus Sentinel-2	10 m	Summer 2022
Shadow fraction	Hourly shadows from buildings and trees calculated with UMEP (Lindberg et al., 2018)	Geoportal Berlin (2022a, 2022b), Sentinel-2	1 m	Summer 2022

S3.4. Data description

File formats and further meta information for plan area fraction of grass and trees per block are given in Table S15, data attributes in Table S16.

Table S15. Files formats and meta information for the dataset related to grass and trees fraction.

Filename(s)	Grass_Trees_fraction_Block
Coordinate reference system	EPSG 25833; ETRS89 / UTM zone 33N
Format, type	ESRI shapefile; polygons
Resolution	Block, vector
Reference year	Summer (2022)
Dataset attributes	Table S16

Table S16. Dataset (Table S15) attributes.

Attribute name	Unit	Type	Description
*schl5 **	–	string	Unique ID of each block
SHAPE_Length	m	float	Length of the block
SHAPE_Area	m^2	float	Area of the block
typklar_ENG	–	string	UST of the block
Typ_Klar_Broader	–	string	USTs new aggregated classes (Figure S1)
Ring	–	string	City ring to which the block belongs to
fraction_grass	–	float	Fraction of grass per block
fraction_trees	–	float	Fraction of trees per block

File formats and further meta information for shadow fraction are given in Table S17, data attributes in Table S18.

Table S17. Files formats and meta information for the dataset related to grass and trees fraction.

Filename(s)	*Shadow_fraction_Block (Sel_PLR)*
Coordinate reference system	EPSG 25833; ETRS89 / UTM zone 33N
Format, type	ESRI shapefile; polygons
Resolution	Block, vector
Reference year	Summer (2022)
Dataset attributes	Table S18

Table S18. Dataset (Table S17) attributes.

Attribute name	Unit	Type	Description
*schl5 **	–	string	Unique ID of each block
SHAPE_Length	m	float	Length of the block
SHAPE_Area	m^2	float	Area of the block
typklar_ENG	–	string	UST of the block
Typ_Klar_Broader	–	string	USTs new aggregated classes (Figure S1)
Ring	–	string	City ring to which the block belongs to
fraction_shadow	–	float	Fraction of shadow per block

S4. References

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