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Clustering Comfort: A Cluster Analysis on Housing Conditions and Nature-Based Solutions in Polish Cities

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Abstract

As cities struggle to balance affordable housing, sufficient public green space, climate change, and rising temperatures, the urgency for planners to integrate nature-based solutions into urban strategies is magnified. In Poland, social inequalities and neighborhoods with limited access to green areas often characterize cities. Urban strategies are needed to increase environmental justice and mitigate climate change impacts. In a survey conducted in Poland (n = 963), a cluster analysis identified four groups based on their living situations, rating of green spaces, and climate change. The results illustrate differences in perceived impacts of heat waves with one group demonstrating a high tolerance towards heat waves, although they live in unfavorable housing conditions. Green space use varies depending on accessibility and distribution in their neighborhoods. Context-sensitive planning is required to ensure more equitable urban planning in Polish cities, which allocates for both the environmental and social needs of the city.

Keywords: nature-based solutions; Poland; climate change; cluster analysis; housing conditions

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Academic Editor: Petra Schneider

Received: 8 August 2025
Revised: 5 September 2025
Accepted: 11 September 2025
Published: 15 September 2025

Citation: Walter, A.; Wanner, A.; Pröbstl-Haider, U. Clustering Comfort: A Cluster Analysis on Housing Conditions and Nature-Based Solutions in Polish Cities. *Land* **2025**, *14*, 1884. https://doi.org/10.3390/land14091884

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1. Introduction

Many recent publications have emphasized the importance of urban green elements for reducing environmental hazards, air pollution, heat waves, and flooding. These elements, also called nature-based solutions (NbSs), provide further benefits for noise and stress reduction, health, and wellbeing benefits as well as carbon offsetting [1–6]. Furthermore, NbSs and biophilic designs [7–9] are often integrated to improve public spaces, while also providing measures to tackle climate change, urban heat islands, and biodiversity loss in cities [10–12]. The paper at hand focuses on functions of NbSs, which contribute to improving urban environments for residents. This includes improved air quality, temperature reduction, and increasing the number of green spaces in public places, to name only some benefits, but touches less on design principles.

The benefits of NbSs are known, but there is still uncertainty about the effectiveness [13] and an increasing demand for more stakeholder involvement to ensure greater social justice in their distribution across cities [14,15]. When implementing NbSs, trade-offs must be made to determine where they can fit without impeding other necessary infrastructure. Especially when it comes to new housing construction, green areas are faced with fierce competition [14]. NbSs can come in a variety of shapes and sizes with differing functions ranging from communal gardens to smaller rain gardens, large scale green corridors, or simple street trees. The design of these will greatly impact their functionality in a neighborhood.

Equal neighborhood conditions are not always equally experienced. Living conditions are shaped by both the objective, built environment as well as individual, subjective perceptions and experiences. The built environment is described by factors such as the location of the neighborhood, the density and type of buildings, the year of construction, and surrounding gray and green infrastructure [16]. The quality of the neighborhood is linked to both built environment but also functionality, accessibility, and quality of stay and use which are often subjective perceptions [17].

Subjective perceptions include preferences for green areas or types of NbSs or personal experiences with stressors such as noise, heat, or poor air quality [18,19]. Urban green areas are perceived differently and as Bai et al. and Grütter [17,20] state in their separate studies, the time spent here is individual and subjectively valued, adding to residents identification with their neighborhoods and feelings of belonging. NbSs are thus elements of neighborhoods that contribute to sense of place.

As climate change impacts in cities increase, impacts are unequally felt. Those living in densely built areas with little to no green areas and no access to private outdoor spaces such as balconies and terraces are more strongly impacted by rising temperatures [11,21]. Socio-demographics and especially age also play into how heat impacts health and wellbeing [22]. That being said, socio-economic factors such as education and income influence individuals' abilities to cope with and adapt to climate change impacts. NbSs, and, most predominantly, street greening and parks are considered some of the most important measures to tackle this climate change impacts in European cities [19,23,24] but these must also be justly implemented to benefit vulnerable and disadvantaged households and residents [25,26].

Aside from attractive and healthy living conditions, cities should also provide affordable housing, suitable infrastructure, and services for their residents. These requirements are often in conflict with the development of NbSs mostly due to increasing costs for real estate and space. Despite green spaces increasing quality of life and adding to social and ecological quality of urban spaces [17,23,27] the trade-offs made by decision-makers are often against greening and in favor of dense housing structures; even when planning entirely new developments. Therefore, we need to understand if and which consequences it has, if these green spaces and NbSs are not justly distributed and residents are lacking access to these spaces for their health and wellbeing [25].

The rapidly growing Eastern European cities are a good example for exploring this aspect. This study investigates the situation in Poland looking into cities with more than 20,000 residents. Poland has 36.6 million inhabitants of which nearly 60% live in cities [28,29]. Living conditions in urban areas are predominantly characterized by modern, often gated, communities growing in the outer districts, while block high-rises left over from the socialist era of the 20th century continue to remain prominent [30]. The older building stocks are less efficient concerning heating and cooling than newer constructions.

After the political shifts of 1989, housing became a consumable good, leading to rising prices. Currently, affordable housing is difficult to come by for many urban residents, which is leading to an intensification of social segregation across neighborhoods. Government programs designed to support younger people to rent or buy homes had limited success [30]. Social segregation is further strengthened through urban developments, which focus on building new constructions in the urban periphery for more wealthy households, while building stock in the central and urban districts are left to age and decay [30].

Past studies from Poland [31,32] have shown that the provision of green areas across Polish cities vary greatly: while some cities benefit from urban forests in the outskirts, which are easily accessible to residents, many other cities have very limited green areas of notable size for their residents to access. Wysmulek et al. [31] determined that on average, only 20.5% of residents have access to green areas in their neighborhoods and deem the

situation to be insufficient and unevenly distributed. Suligowski et al. [32] highlight that the larger the city is, the worse provision of green areas per resident becomes. This is especially true for Polish cities, where several studies have already identified social and ecological injustice characterized by cramped living conditions with little access to green areas [30]. A comparison of the conditions in different European member states also demonstrates, that living conditions in Poland are more cramped and household sizes are slightly larger than in other European member states [33]. These factors, including the poor access to outdoor green areas, indicate that urban populations in Poland are more vulnerable to climate change impacts, especially heat, and are currently not sufficiently profiting from access to green areas or NbS.

The study area, Poland, provides an interesting study object analyzing the relevance of poor access to green areas for urban residents along with social segregation between neighborhoods characterized by building stock age and density. The paper at hand tries to understand the currently perceived benefits of NbSs by the urban population in the context of their living conditions. To achieve this, we put forward the following hypotheses to be tested by a representative national wide survey:

H1. *Residents of Polish cities experience heat stress independently from their objective living situation.*

H2. *Clusters with different living conditions differ in their desire for improving NbSs in their neighborhood.*

H3. *Differences in the subjective perception of heat can be explained by living conditions and socio-demographic characteristics.*

2. Materials and Methods

2.1. Survey

As part of the European Union funded project UPSURGE [18,34], a pan-European survey was conducted to investigate urban residents acceptance and expectations for NbSs in their neighborhoods. The study at hand focuses on the results obtained from the Polish respondents (n = 1021). The survey was distributed online via a panel in October 2022 among residents of cities with more than 20,000 inhabitants and over the age of 18 [18] and includes respondents from across Poland. Aside from trade-offs on NbS scenarios, the survey also included questions on living situation, building characteristics, surrounding green areas, experiences with climate change, and socio-demographics. After quality control, the final data set used for this analysis included 963 respondents.

For the analysis of the data, SPSS 29.0 was used.

2.2. Cluster Analysis

For a differentiated view of the housing situation a hierarchical cluster analysis was conducted using objective criteria of the built environment as well as subjective criteria concerning rating on green space provision and heat stress. For methodological reasons, all variables were dichotomized with the assignment of values 0 and 1 in order to take account of the different scale levels.

The following objective criteria relating to the living situation were used: area of city (dummy variables: 1 = city center, 0 = no; 1 = suburbs, 0 = no; omitted redundant reference variable = urban districts), type of housing (1 = high-rise, closed block, or cluster, 0 = house, duplex, or row house), building height (1 = 5 or more stories, 0 = less than 5 stories), year built (1= from 1990, 0 = before 1990), open spaces in the residential environment (gardens, public green spaces, traffic areas, paved areas: 1= many/predominantly, 0 = view/none), distance to shops (1 = 0–5 min, 0 = more), distance to green areas (parks, playground, city forest: 1 = 0–5 min to walk, 0 = more than 5 min to walk). Subjective criteria included

the assessment of green space availability (1 = excellent/good, 0 = poor/nonexistent), experience with heat waves (1 = yes, 0 = no) and negative impact of heatwaves/heat stress (1 = yes, 0 = no).

The Ward algorithm was used as a clustering method, based on squared Euclidean distance as a measure of dissimilarities between cluster objects [35]. The dendrogram was applied in order to determine the appropriate number of clusters, suggesting a 3-cluster solution. Since the result was not sufficiently differentiated, further differentiation was carried out based on content considerations [36] resulting in a 4-cluster solution.

Kruskal–Wallis tests were applied to further test if the clusters differ in the desire for improving NbSs. Pairwise comparisons supported the exact differentiation between the clusters. To avoid α-error accumulation, the p-value was corrected in accordance with Bonferroni.

Differences between the clusters with regard to socio-demographic characteristics were determined using chi-square tests, whereby standardized residuals were intended to reveal precise patterns of deviation.

3. Results

3.1. Survey Results

3.1.1. Socio-Demographics

The survey (n = 963) consisted of 50.5% women and 48.7% men (0.1% other; 0.7% preferred not to answer). The age ranged from 18 to 76, with the average being 39.9 years old. Household size varied, with 10.5% living alone and 26% living in a two-person household. Larger households also account for the number of households with children (Table 1). Education levels were high, with over half holding a university degree. Income is varied but generally low, with two-thirds of respondents having a monthly net income of PLN 2000 or below. The socio-demographic overview can be found in Table 1.

Table 1. Socio-demographic overview of the sample (n = 963).

Socio-Demographic		% of Respondents
Gender	Female	50.5
	Male	48.7
	Other	0.1
	Prefer not to say	0.7
Age	<25	10.4
	25–34	24.7
	35–50	31.4
	51–65	16.4
	66+	2.8
	Prefer not to say	14.3
Household size	1 person	10.5
	2	26.0
	3	31.7
	4	21.8
	5+ people	10.1
Children	Yes	49.1
	No	50.9

Table 1. *Cont.*

Socio-Demographic		% of Respondents
Education	Primary	0.9
	Secondary	18.8
	Vocational training	27.4
	University	52.2
	Prefer not to say	0.6
Income (monthly household net)	PLN < 500	10.7
	PLN 500–1000	31.9
	PLN 1001–2000	29.4
	PLN 2001–3000	11.8
	PLN 3001–4000	5.5
	PLN > 4000	3.2
	Prefer not to say	7.5

3.1.2. Housing Conditions

The housing conditions are shaped by city size, area of the city, type of housing, and its height along with the year the buildings were constructed (Table 2). Generally speaking, the respondents resided in city centers and central, urban districts in predominantly closed blocks or clusters, with nearly a quarter living in high-rises and a fifth in houses. Therefore, unsurprisingly, most buildings tended to be three stories or more, and the majority were built after 1970.

Table 2. General living conditions.

Living Conditions		% of Respondents
City size	20,000–50,000	11.6
	50,001–100,000	16.3
	100,001–250,000	19.8
	250,001–500,000	18.5
	500,001–1.5 million	20.4
	>1.5 million	13.4
Area	City center	48.8
	Urban districts	46.2
	Suburbs	5.0
Type of housing	House	18.3
	Duplex or row house	7.1
	High-rise	23.5
	Closed block or cluster	51.2
Building height (stories)	1	6.7
	2	15.7
	3–4	48.6
	5–9	17.3
	10+	11.6
Year built	<1914	1.9
	1914–1939	4.3
	1940–1969	14.7
	1970–1989	37.6
	1990–2009	25.2
	>2010	16.3

Respondents were additionally asked about public space in their neighborhoods. Paved courts (51.8% many or dominating) and traffic spaces (74.5% many or dominating) dominated most surroundings, but there was also a significant proportion of private balconies (79.8%) and public parks (63.4%). Private gardens (35.5%) and private green spaces (30.9%) were less common.

Distances to green areas were measured in walking distance (minutes): 71.9% indicated that street greening was right at their doorstep (0–5 min walking), and 57.1% indicated playgrounds within the same distance. Parks, communal gardens, and green corridors tended to be further away with walking distances often being up to 10 or even 15 min away. Urban forests were not common (56.3%, either more than 16 min walk or not in their neighborhood at all). The proximity of green areas is also reflected in times spent outdoors: 38.5% of respondents spend two to four hours outside in a week, 22.5% at an hour. Only 15% spend less than 30 min in green areas per week.

The subjective rating of neighborhood green areas supply was good (56.9%) with 15.3% saying their surroundings had excellent provision of green areas, and 27.4% saying the green supply was poor. Only 0.4% indicated their neighborhoods had no green areas.

3.1.3. Climate Change Perceptions and Urban Strategies

Respondents were asked to answer several questions concerning their attitudes towards and possible experiences with climate change. In total, 18.1% states that climate change will occur, but the impacts will be felt later. The majority (69.7%) states that climate change is occurring and is already visible. Meanwhile, 10.1% were uncertain and 1.7% did not believe in climate change at all; 0.5% held other opinions. A total of 49% of respondents state that they already see and feel climate change impacts in their own neighborhood and of these, the vast majority indicated that they experience heat waves because of climate change.

High temperatures impact residents in different ways. Of the respondents who stated that they experience climate change impacts, 5.9% said they appreciate high temperatures, while 19% do not mind heat waves. But 61% indicate that heat waves have negative impacts on their wellbeing, and a further 13.5% state that they have experienced negative impacts on their health.

When asked if climate change was important for their local urban strategies, respondents tended to agree that these were very important (43%) or at least important (48.5%). The most important aspects for urban strategies were deemed to be the improvement in air quality, storm water management, and biodiversity conservation. Tackling heat waves and temperature reduction were given less importance.

3.2. Cluster Analysis Results

3.2.1. Description of Clusters

The cluster analysis used objective criteria (are of the city, type of housing, height, amount of green, year built, distance to shops for daily needs, and distance to green areas) as well as subjective criteria (rating surrounding green areas and heat stress) and resulted in four distinct clusters.

Cluster 1 (n = 288, 29.9%); block or cluster housing, poor supply of green areas, high heat stress: Respondents from this cluster are from the city center (50.7%) or urban districts (46.5%), predominantly living in closed blocks (67.7%) or high-rises (25%). Building age is on par with the overall sample (Table 2). While 62.2% have green areas in their neighborhood, only about a quarter are within proximity. Paved traffic and parking spaces dominate the surroundings (80.9%), and shops for daily needs are easily reached (73.3%). Roughly two-thirds (65.3%) find the number of green areas good, but a disproportionately

large portion (34.7.%) rate the provision of green spaces as poor. All the respondents have experienced at least one heat wave and nearly 90% declare they have negative experiences with heat.

Cluster 2 (n = 176, 18.3%); block or cluster housing, good supply of green areas, less heat stress: Similarly to cluster 1, the people in this group reside in the city center or urban districts. They live in closed blocks (63.1%) and high-rises (29.5%), and nearly half of the respondents state that their building has at least five stories. Most of the buildings were built after 1970. The provision of green areas is considered very good, as 97.7% state green areas in the neighborhood, but there is still a significant number of paved areas for parking and traffic. Parks and playgrounds tend to be easily reached on foot and 12.2% are within walking distance of urban forests. It comes as no surprise that 92.6% rate the quantity of green areas as good. Only 10.8% have experienced a heat wave, and none of the respondents have had negative impacts on their health or wellbeing through high temperatures.

Cluster 3 (n = 248, 25.8%); high-rise with poor supply of green areas, less heat stress: 60.1% live in the city center and 32.3% in high-rises. A high percentage (46.8%) indicates that their housing was built in the 1970s and 80s. There are few private green areas, but infrastructure tends to be average in accessibility. Larger green areas such as parks or urban forests are not accessible on foot. Objectively, this cluster is underprivileged regarding housing and built environment. A total of 40.7%, the highest proportion of any cluster, rates the supply of green areas as poor. But nearly nobody in this group has experiences with heat waves or felt negative impacts from them.

Cluster 4 (n = 251, 26.1%); houses with high supply of green areas, low heat stress: In the final cluster, most live in urban districts (53%) with a comparatively high number of suburban residents (12.7%). The vast majority live in houses, duplex of row houses (79.3%); only few in closed blocks (8.8%) or high-rises (53%). Housing tends to be newer and built after 1990. Unsurprisingly, these neighborhoods are dominated by private gardens (93.6%) and report lower traffic spaces. Access to shops, parks, and playgrounds is low in comparison with the other clusters, but they are the closest to urban forests (16.3%). In total, 78.5% rate the quantity of green areas in their neighborhood positively. Additionally, 77.3% have not had any negative experiences with heat waves or high temperatures.

3.2.2. Comparisons Between Clusters

In further analysis, the clusters based on living conditions were compared in regard to the importance given to improving quality of life in their neighborhood. The survey asked respondents to rate the importance of air quality improvement, temperature reduction, heat wave mitigation, storm water management, biodiversity, and urban climate improvements for urban development strategies. Responses ranged from 1 (unimportant) to 4 (important). Those who responded "don't know" were excluded. Table 3 shows the number, mean, and standard deviation per cluster as well as the results of the Kruskal–Wallis Test.

The results indicate significant differences between the clusters ($p < 0.001$) on the importance of the various environmental goals for urban development. Additional Bonferroni-corrections in pair comparisons showed that cluster 1 was significantly different from the remaining three clusters. As the group which has the most experience with heat waves, all six environmental goals were more important to them than to the other clusters. Especially temperature reduction and heat wave mitigation stood out against the other clusters with medium effect size ranging from 0.24 to 0.30.

Table 3. Number (*n*), mean (M), and standard deviation (SD) on environmental goals to improve quality of life in neighborhood (1 = important, 4 = unimportant), divided by cluster; Kruskal–Wallis test ($p < 0.01$ **)).

		Cl. 1	Cl. 2	Cl. 3	Cl. 4	Total	KW-Test (df = 3)
Air quality improvement	*n*	287	171	240	247	945	KW-H = 25.596
	M	3.84	3.60	3.65	3.60	3.68	$p < 0.001$ **
	SD	0.46	0.72	0.64	0.74	0.64	
Temperature reduction	*n*	277	161	223	235	896	KW-H = 63.018
	M	3.44	2.86	2.87	2.98	3.07	$p < 0.001$ **
	SD	0.76	0.92	1.01	0.96	0.94	
Heat wave mitigation	*n*	282	166	231	239	918	KW-H = 69.212
	M	3.59	3.02	3.04	3.09	3.22	$p < 0.001$ **
	SD	0.64	0.97	0.98	0.91	0.90	
Storm water management	*n*	284	171	233	246	934	KW-H = 38.792
	M	3.77	3.50	3.39	3.49	3.55	$p < 0.001$ **
	SD	0.48	0.71	0.80	0.75	0.70	
Biodiversity	*n*	285	165	230	241	921	KW-H = 40.627
	M	3.72	3.45	3.39	3.35	3.49	$p < 0.001$ **
	SD	0.56	0.74	0.79	0.82	0.74	
Urban climate improvements	*n*	281	167	227	243	918	KW-H = 30.411
	M	3.76	3.43	3.48	3.49	3.56	$p < 0.001$ **
	SD	0.46	0.82	0.72	0.73	0.69	

The clusters were also compared in regard to socio-demographics (gender, age, children, household size; Table 4) and socio-economic factors (education, income; Table 5). Although there were significant differences across clusters on gender, the standardized residuals indicate only general tendencies. Cluster 2 (cluster blocks, many green areas, little heat impact) has less women than the overall sample average. Cluster 1 (closed blocks, poor supply of green areas, high heat impacts) has slightly more women. No significant differences were identified in the other two clusters. There were no significant differences identified concerning age distribution.

There were significant differences in households with children. Cluster 4 had an especially high number of children (62.5%). They live predominantly in green areas with a high portion of individual or row houses.

Household size also showed significant differences across the clusters ($p < 0.001$). Respondents of cluster 1 had an above average percentage of two-person households (32.3% compared with the sample average of 26%). As this group also had fewer children, it is an indication that there are more couples without children in cluster 1. Cluster 3 is characterized by a higher proportion of single households (15.3% compared with the sample average of 10.5%). Single and two-person household were underrepresented in cluster 4, where household size was larger (40.6% had four or more people compared with the sample average of 31.9%).

As can be seen in Table 5, there are no significant differences in income distribution. Education on the other hand did demonstrate statistically significant differences in education levels. Respondents from cluster 4 had significantly lower proportions of secondary education and a greater but not significant degree of university education. Although the standardized residuals do not indicate significant deviations, cluster 1 and 2 also deviated slightly from the overall averages. Cluster 1 had higher proportions of secondary schooling.

Cluster 2 had a lower rate of university education and a higher proportion of secondary school diploma. Cluster 3 was in line with the overall sample.

Table 4. Socio-demographic variables (gender, age, children household size) by cluster; household size: p. = person(s); χ^2-Test ($p < 0.05$ *, $p < 0.01$ **), SR = standardized residuals. (Respondents who selected "diverse" or "prefer not to answer" were not included).

		Cl. 1	Cl. 2	Cl. 3	Cl. 4	Total	χ^2-Test
Gender	female	55.6%	42.6%	52.9%	49.4%	50.9%	$\chi^2 = 7.936$, df = 3 $p = 0.047$ *
	SR (f)	1.1	−1.5	0.4	−0.3		
	male	44.4%	57.4%	47.1%	50.6%	49.1%	
	SR (m)	−1.1	1.6	−0.4	0.3		
Age	<25	12.9%	12.3%	10.6%	12.6%	12.1%	$\chi^2 = 7.510$, df = 12 $p = 0.822$
	25–34	29.3%	27.1%	31.7%	26.7%	28.8%	
	35–50	34.8%	38.7%	33.7%	40.3%	36.6%	
	51–65	18.8%	17.4%	21.6%	18.4%	19.2%	
	>66	4.3%	4.5%	2.4%	1.9%	3.3%	
Children (<18 years)	yes	42.4%	51.1%	41.9%	62.5%	49.1%	$\chi^2 = 28.786$, df = 3 $p < 0.001$ **
	SR (y)	−1.6	0.4	−1.6	3.0		
	no	57.6%	48.9%	58.1%	37.5%	50.9%	
	SR (*n*)	1.6	−0.4	1.6	−3.0		
Household size	1 p.	13.5%	7.4%	15.3%	4.4%	10.5%	$\chi^2 = 50.706$, df = 9 $p < 0.001$ **
	SR (1 p.)	1.6	−1.3	2.4	−3.0		
	2 p.	32.3%	24.4%	29.0%	16.7%	26.0%	
	SR (2 p.)	2.1	−0.4	0.9	−2.9		
	3 p.	26.7%	31.8%	30.6%	38.2%	31.7%	
	SR (3 p.)	−1.5	0.0	−0.3	1.9		
	>3 p.	27.4%	36.4%	25.0%	40.6%	31.9%	
	SR (>3 p.)	−1.3	1.1	−1.9	2.5		

Table 5. Socio-economic variables (education, income) by cluster; χ^2-Test ($p < 0.05$ *), SR = standardized residuals.

		Cl. 1	Cl. 2	Cl. 3	Cl. 4	Total	χ^2-Test
Education	primary	24.5%	30.3%	30.4%	30.1%	28.5%	$\chi^2 = 14.407$, df = 6 $p = 0.025$ *
	SR (p)	−1.3	0.4	0.5	0.5		
	secondary	22.4%	22.9%	19.0%	12.0%	18.9%	
	SR (s)	1.3	1.2	0.0	−2.5		
	university	53.1%	46.9%	50.6%	57.8%	52.6%	
	SR (u)	0.1	−1.0	−0.4	1.1		
Income	PLN < 500	14.3%	10.8%	12.3%	8.2%	11.6%	$\chi^2 = 10.118$ df = 12 $p = 0.606$
	PLN 500–1000	37.0%	33.5%	35.7%	31.0%	34.5%	
	PLN 1001–2000	29.1%	31.7%	31.3%	35.3%	31.8%	
	PLN 2001–3000	11.3%	13.2%	11.5%	15.5%	12.8%	
	PLN > 3000	8.3%	10.8%	9.3%	9.9%	9.4%	

4. Discussion

4.1. Real Living Conditions Versus Perceived Heat Experience

The cluster analysis demonstrated that objective, real living conditions and subjectively perceived conditions of green areas complimented each other, for example, in neighborhoods where residents were living in central areas characterized by closed housing blocks

or high-rises with the quantity of surrounding green areas deemed as poor (cluster 1, 3) or in suburban areas with plenty of private gardens in which the amount was deemed very good (cluster 4).

This was not the case for the experience of negative impacts on health and wellbeing caused by high temperatures. Cluster 1 lives in dense housing areas with limited access to green areas and has experienced heat waves. Cluster 2 has more green areas in their surroundings and is less susceptible to suffering under high temperatures. Seebaß [37] recognized that heat stress is often related to the access to green areas, which is confirmed though cluster 1, 2, and 4's experiences with heat waves and access to green areas. Cluster 3 is an outlier in which densely built areas meet poor green supply, yet the residents can tolerate high temperatures well.

Cluster 3 has a high number of single households, and the building stock is older. They spend the least amount of time outdoors as green areas are further away. The results indicate that cluster 3's tolerance for heat is based on subjective assessments rather than objectively measurable factors. Considering the higher proportion of single households, it may be suggested that the low vulnerability to heat is due to the absence of other family or household members to consider or care for. Furthermore, this cluster could also include those who live in the city for job-related purposes and primarily only use their residence as a place to sleep—to determine this, further research would be required.

In contrast to studies from East Asia or Africa, where air conditioning plays a major role, in Poland this adaptation strategy is still uncommon. Especially for clusters such as cluster 3, who live in an older building stock and do not have greater financial means for technical aids.

H1, that residents of Polish cities experience heat stress independently from their objective living situations, is therefore confirmed. The objective built environment must be put into relation with subjective perception of neighborhood residents to understand the perceived quality of life. Both must be incorporated into NbS planning in order to implement solutions that account for both the environmental and social needs of residents.

4.2. Desires for NbS Achievements

NbSs serve many functions in urban environments, and planners must understand which functions are important not only from a functional perspective alone but also in accordance with residents' priorities and desires. When asked to rate the importance of certain goals for urban development strategies, cluster 1 clearly stood out, as presented in Section 3.2.2. As the only group who has experienced heat waves and felt their negative impact, they are experiencing climate change firsthand and therefore temperature reduction and heat wave mitigation are more pronounced goals for them than for the other clusters.

H2, that clusters with different living conditions differ in their desired goals for NbSs, is confirmed. The results have also shown that the desired effectiveness of NbS is not only linked to the built environment, but the subjective perception of environmental impacts on oneself. As cluster 1 has experienced high temperatures, these goals are important to them. For other segments of the population that do not suffer from heat, air quality improvement and storm water management are prescribed greater meaning in urban development strategies.

With vulnerabilities and an unjust distribution of green spaces in Polish cities [30,32,38], it becomes even more central to planning processes to incorporate locals' needs and incorporate NbSs that address their desires and not only tackle objectively identified issues. To increase environmental justice in Polish cities, planners must consider fair distribution of green areas alongside their functionality. Priority should thus be given to neighborhoods that currently only have limited green spaces reachable by foot. Street greening has been

deemed a desirable NbS among many different urban segments [18] and would also be relatively easy to implement compared with larger-scale or more technically complex NbSs. While there are no blanket solutions, planners must ensure NbSs are accessible and meet neighborhood's individual needs to ensure site-specific desires and requirements.

4.3. Subjective Perceptions, Housing Conditions and Socio-Economic Factors

Climate change impacts affect urban residents differently and addressing these impacts in mitigation and adaptation measures are a matter of environmental justice [39]. Often socio-economically disadvantaged households are more exposed to climate change effects. Seebaß [37] recognized an impact of age on subjective heat stress and also an interaction with their individual health status. People over the age of 70 with health problems are especially vulnerable to heat. Our results did not reflect age as an influencing factor, as clusters susceptible to heat and those who were more tolerant had similar age structures. It is possible that the state of health could explain the difference in heat stress between clusters 1 and 3, both of which live in an environment with a poor supply of greenery. However, this characteristic was not surveyed in the present study and should be considered a limitation. Further studies on the topic of health variables appear necessary.

Considering the population of Poland and the entire EU is aging [40], it should be assumed that vulnerability to climate change in Polish cities will carry a growing health burden with it.

A slight gender influence could be recognized in clusters 1 (more women, less resistant to high temperatures) and cluster 2 (more men, more heat tolerant), which is in line with studies that recognize that women report more negative impacts on their health and wellbeing through heat waves and high temperatures [41].

The built environment along with traffic congestion, poor air quality, and low quality and few green areas intensify heat and cause urban heat islands [42], contributing to a higher number of negative evaluations.

Income was not a significant influence on heat perception. A connection could be made between education and perception in that those with higher levels of education and more knowledge about climate change and its impact on health and wellbeing were slightly more sensitive to heat waves. The connection between higher education levels and a greater perception of climate change impacts has also been highlighted in other publications [10,18], reflecting broader patterns in European contexts.

H3, that differences in heat perception could be explained by living conditions and socio-demographics, is rejected as neither age, income, nor the living conditions could explain heat perception. The most heat sensitive group (cluster 1) does not live in ideal conditions, and the housing conditions may be able to explain their perceptions; however, the more heat-tolerant groups (clusters 2, 3, and 4) live in very diverse housing conditions, and thus, a connection cannot be inferred across the groups. Well-rated green areas in cluster 2 and 4 may explain their tolerance levels, but socio-economic factors do not seem to influence their perceptions on heat.

5. Conclusions

Subjective factors include residents' individual needs and expectations for their neighborhood, rating green areas, heat wave experiences with objective conditions of housing and access to green areas. Cluster 1 lives in compact conditions with poor provision of green areas, while cluster 2 although also compact and central has better access to green areas and does not feel heat stress to the same degree. The heat sensitive cluster 1 also views temperature reduction as a more important aspect of urban strategies than the other clusters. Cluster 3's living conditions would lead to the presumption that they feel a strong

negative impact through heat, but this is not the case. Cluster 4, in privileged peripheral areas with a large amount of private green is not facing negative impacts to the same degree as the other clusters. Although previous studies discussed socio-economic injustices in Polish cities as influencing factors, these were not evident in the clusters of this study. To increase the social benefits of NbSs, planners and practitioners must recognize that it is not merely the size of green areas but moreover the distribution that is important.

Urban green infrastructure are vital components of urban quality of life and climate change adaptation and mitigation strategies put forward by cities and desired by residents, especially considering expected temperature rises and the implication of the European Union's nature restoration law, which calls for rapid transformation and the use of NbSs such as street greening and multi-functional public green spaces. The cluster analysis made clear that access to green areas differs significantly among residents of Polish cities. This depends on both the individual living conditions in one's neighborhood and the distribution of green areas and NbSs throughout the city. Improving the accessibility to NbSs will increase residents' quality of life and help tackle climate change impacts currently affecting health and wellbeing. To achieve this, however, NbSs must be planned to account for local needs and neighborhood characteristics to assist in achieving both social and environmental justice throughout the city.

Author Contributions: Conceptualization, A.W. (Anita Walter); methodology, A.W. (Anita Walter); formal analysis, A.W. (Anita Walter); data curation, A.W. (Alice Wanner); writing—original draft preparation, A.W. (Anita Walter) and A.W. (Alice Wanner); writing—review and editing, A.W. (Alice Wanner) and U.P.-H.; visualization, A.W. (Anita Walter); supervision, A.W. (Alice Wanner) and U.P.-H.; project administration, A.W. (Alice Wanner); funding acquisition, U.P.-H. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by UPSURGE, which received funding from the European Union's Horizon 2020 research and innovation program under grant agreement no. 101003818.

Data Availability Statement: Data available upon request.

Acknowledgments: The cluster analysis of this study was part of first author Anita Walter's master's thesis submitted to BOKU University in June 2025.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

EU	European Union
NbS	Nature-based solution

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