

Assessing the Urban Morphology Impact on Land Surface Temperature Around Elementary Schools

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Abstract—Urban morphology significantly influences localized thermal conditions, impacting heat exposure in sensitive environments such as elementary schools. This study examines the relationship between urban form and land surface temperature (LST) around 78 elementary schools in Clermont Auvergne Metropolis, France, using the Local Climate Zone (LCZ) framework. By analysing a 250-meter buffer zone around each school, we compare morphological characteristics with satellite-derived LST data to classify schools according to their thermal risk. The results identify a pronounced urban heat island gradient, with peak temperatures in compact mid-rise and industrial zones and the coolest conditions in vegetated landscapes. Contrary to expectations, open mid-rise zones exhibited slightly higher temperatures than compact mid-rise areas highlighting the complexity of urban heat dynamics. Statistical analyses confirmed significant correlations between thermal traits and observed temperatures, underscoring the influence of urban form on school microclimates. This approach offers a practical framework for assessing heat vulnerability in school environments, supporting climate-resilient urban planning.

Keywords—Urban Morphology, Elementary School, Microclimate, Urban Overheating, Urban Heat Island.

I. INTRODUCTION

URBAN environments exhibit highly heterogeneous thermal behaviour, largely shaped by their morphological characteristics, such as building density, height, land cover, and vegetation presence [1]. These elements influence the way heat is absorbed, stored, and radiated, giving rise to phenomena such as the urban heat island (UHI) effect.

One widely adopted framework for analyzing urban form in climate-sensitive contexts is the Local Climate Zones (LCZ) classification, introduced by Stewart and Oke

[2]. This system offers a standardized way to classify areas based on urban morphology and surface cover, facilitating comparative thermal studies across cities and regions (see Figure 1 for detailed descriptions of each LCZ type). LCZs have proven particularly effective when paired with remote sensing tools like Land Surface Temperature (LST) analysis, enabling a better understanding of how built environments contribute to localized heat stress.

Built types	Definition	Land cover types	Definition
1. Compact high-rise	Dense mix of tall buildings to tens of stories. Few or no trees. Land cover mostly paved. Concrete, steel, stone, and glass construction materials.	A. Dense trees	Heavily wooded landscape of deciduous and/or evergreen trees. Land cover mostly pervious (low plants). Zone function is natural forest, tree cultivation, or urban park.
2. Compact mid-rise	Dense mix of midrise buildings (3–9 stories). Few or no trees. Land cover mostly paved. Stone, brick, tile, and concrete construction materials.	B. Scattered trees	Lightly wooded landscape of deciduous and/or evergreen trees. Land cover mostly pervious (low plants). Zone function is natural forest, tree cultivation, or urban park.
3. Compact low-rise	Dense mix of low-rise buildings (1–3 stories). Few or no trees. Land cover mostly paved. Stone, brick, tile, and concrete construction materials.	C. Bush, scrub	Open arrangement of bushes, shrubs, and short, woody crops. Land cover mostly pervious (bare soil or sand). Zone function is natural scrubland or agriculture.
4. Open high-rise	Open arrangement of tall buildings to tens of stories. Abundance of pervious land cover (low plants, scattered trees). Concrete, steel, stone, and glass construction materials.	D. Low plants	Featureless landscape of grass or herbaceous plants/crops. Few or no trees. Zone function is natural grassland, agriculture, or urban park.
5. Open mid-rise	Open arrangement of midrise buildings (3–9 stories). Abundance of pervious land cover (low plants, scattered trees). Concrete, steel, stone, and glass construction materials.	E. Bare rock or paved	Featureless landscape of rock or paved cover. Few or no trees or plants. Zone function is natural desert (rock) or urban transportation.
6. Open low-rise	Open arrangement of low-rise buildings (1–3 stories). Abundance of pervious land cover (low plants, scattered trees). Wood, brick, stone, tile, and concrete construction materials.	F. Bare soil or sand	Featureless landscape of soil or sand cover. Few or no trees or plants. Zone function is natural desert or agriculture.
7. Lightweight low-rise	Dense mix of single-story buildings. Few or no trees. Land cover mostly hard-packed. Lightweight construction materials (e.g., wood, thatch, corrugated metal).	G. Water	Large, open water bodies such as seas and lakes, or small bodies such as rivers, reservoirs, and lagoons.
8. Large low-rise	Open arrangement of large low-rise buildings (1–3 stories). Few or no trees. Land cover mostly paved. Steel, concrete, metal, and stone construction materials.	VARIABLE LAND COVER PROPERTIES	
9. Scarsely built	Sparse arrangement of small or medium-sized buildings in a natural setting. Abundance of pervious land cover (low plants, scattered trees).	b. bare trees	Leafless deciduous trees (e.g., winter). Increased sky view factor. Reduced albedo.
10. Heavy industry	Low-rise and midrise industrial structures (towers, tanks, stacks). Few or no trees. Land cover mostly paved or hard-packed. Metal, steel, and concrete construction materials.	s. snow cover	Snow cover >10 cm in depth. Low admittance. High albedo.
		d. dry ground	Parched soil. Low admittance. Large Bowen ratio. Increased albedo.
		w. wet ground	Waterlogged soil. High admittance. Small Bowen ratio. Reduced albedo.

Figure 1 Local Climate Zones descriptions [2].

Recent research has extended the LCZ approach beyond city-wide applications to localized contexts, where

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microclimatic variation has immediate implications for public health and daily life. For example, LCZ methods have been used to study residential neighbourhoods [3], [4], and roads configuration [5], offering a more granular understanding of urban overheating risks. Among these local contexts, educational institution [6], [7].

A growing body of research has explored how urban morphology influences thermal comfort in school's environment, recognizing the spatial and material characteristics of the built environment as key factors in shaping microclimates. Studies such as [8] have utilized simulation tools like ENVI-met to model microclimates in and around schoolyards, examining how variables such as vegetation coverage, open space layout, and building orientation affect outdoor thermal comfort. These studies emphasize the role of urban form in either exacerbating or mitigating thermal stress, particularly in spaces occupied by children.

Expanding on this, [9], investigates how landscape features like surface permeability and greening influence schoolyard temperatures. Combining field-based temperature measurements with spatial greening indices, the study provides a methodology for evaluating how microclimatic interventions perform in real-world school settings.

A similar perspective is offered by [10], which employed a comparative framework across multiple school sites. By combining vegetation mapping, solar radiation analysis, and field temperature data, highlighting how localized landscape features influence intra-urban thermal differences in educational settings.

These findings have laid the groundwork for research on adaptation and mitigation strategies in school environments. Studies like [11] emphasize the significance of green infrastructure—such as tree cover, shading elements, and reflective materials—in reducing heat exposure in schoolyards. Their methodologies combine geospatial analysis, on-site audits, and stakeholder engagement to identify practical design interventions that enhance resilience to urban heat.

Building on this, [12] provides a detailed comparison of climate-sensitive redesign strategies. It explores the impact of various landscape modifications—including tree planting, canopy installations, and surface changes—on microclimatic conditions and thermal comfort, offering a framework for scalable schoolyard interventions.

Despite growing interest in the relationship between urban form and thermal exposure, there remains a need for practical, locally adaptable tools that integrate LCZ classifications with LST data to better assess thermal vulnerability—particularly in sensitive environments like schools. In the French context, where initiatives such as the OASIS program [13] which reimagining schoolyards as climate-resilient spaces, the demand for data-informed approaches to guide spatial prioritization during heatwaves is increasingly apparent. Addressing this gap, our study explores the potential of LCZs as a basis for a

rapid and scalable tool for intervention prioritization. However, before such a tool can be implemented, it is essential to first investigate whether LCZ classifications can reliably support this kind of targeted decision-making. Such tools can contribute to protecting vulnerable populations, especially children, and support broader efforts toward sustainable urban and educational planning.

In this context, the present study responds to both national and municipal concerns by focusing on the Clermont Auvergne Metropolitan area in central France. It investigates how urban morphology influences local thermal conditions around elementary schools by integrating the LCZ classification with LST data. The analysis covers 78 school sites, examining the morphological characteristics within each school's surrounding area and comparing them with observed temperature patterns. The aim is to identify spatial and thermal trends that can inform local decision-making, support climate adaptation planning, and help prioritize schools most vulnerable to urban heat.

II. METHODOLOGY

The methodological framework of the study is summarized in the Figure 2, which outlines each key step from the spatial distribution of schools through local climate classification, buffer delineation, temperature data extraction, and statistical analysis. Detailed descriptions of these steps and their rationale are provided in the following subsections.

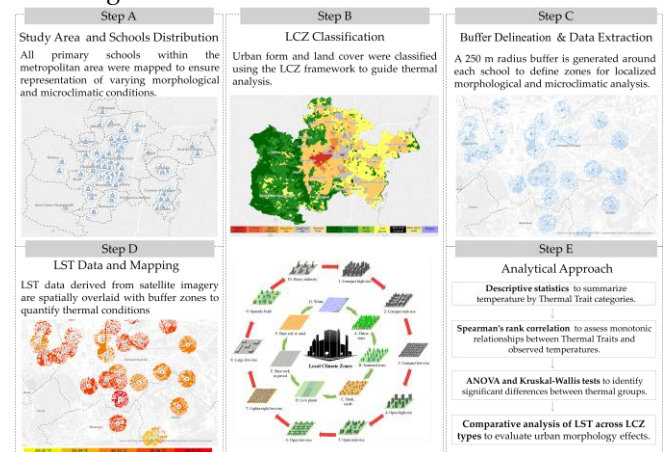


Figure 2 Methodological Framework of the Study

A. Study Area and School Spatial Distribution

The study was conducted in the Clermont Auvergne Metropolitan area, located in central France. This metropolitan area presents a diverse urban morphology, including a mix of compact city centers, open suburban neighborhoods, industrial corridors, and extensive vegetated zones. A total of 78 elementary schools were included in the study (Figure 3), encompassing all known school sites within the metropolitan area at the time of analysis. No sampling, filtering, or selection criteria were applied—the inclusion was exhaustive, based solely on geographic location and school type. This inclusive

approach ensures that the study captures a broad range of urban conditions, including variations in land cover, building form, and microclimatic exposure. While Figure 3 illustrates the spatial distribution of the observation sites across the metropolitan area, a summary of their morphological contexts is provided in Table 1 (see Subsection C) to highlight the diversity of urban settings represented in the dataset.

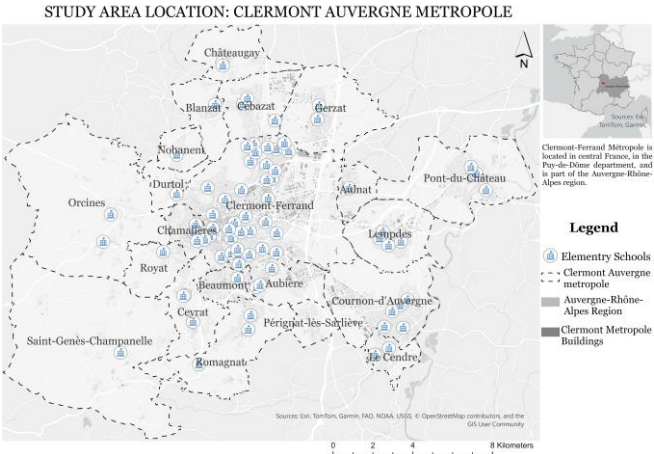


Figure 3 Location of the study area and the spatial distribution of observation sites (elementary schools) in Clermont Metropole.

B. Local Climate Zone (LCZ) Classification

AN LCZ map (Figure 4) representing the morphological characteristics across the entire Clermont Auvergne Metropolitan area was developed following the standardized classification system by Stewart and Oke [2]. In the subsequent analytical steps, the LCZ classification map will serve as the foundational reference for identifying the dominant land cover types. Preliminary observations suggest that schools are primarily located within urban LCZ classes, especially compact and open built forms.

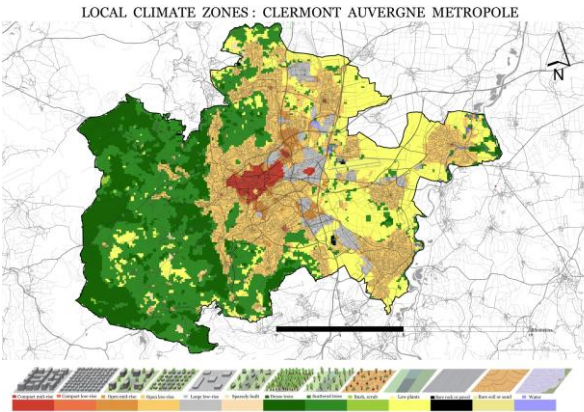


Figure 4 Local Climat Zone in Clermont Auvergne Métropole.

C. Buffer Delineation and Data Extraction

A 250-meter radius buffer was defined around each school to capture the microclimatic influence of surrounding urban morphology, including effects of shading and ventilation. This distance is consistent with previous studies demonstrating that the cooling and shading effects of urban vegetation and built form can extend up to 200–250 meters into the urban environment.

For instance, research on urban forests has shown that their cooling influence on air temperature and relative humidity can similarly reach distances of approximately 200 to 250 meters, depending on forest typology and structure [14]. This scale encompasses the range at which morphological elements—such as building configurations, street canyons, and vegetation patterns—exert significant control over the local microclimate through mechanisms. Within each buffer, morphological and thermal indicators were spatially extracted to support statistical analysis. The dominant LCZ type within each 250-meter zone was identified to characterize the local urban morphology for each school site.

Table 1 presents the distribution of school sites based on their dominant LCZ type. Only LCZ types identified as dominant within school proximity zones are included; types not observed as dominant (e.g., Dense trees, Compact low-rise, Bare soil, Water) were excluded from the table.

TABLE 1
DOMINANT LCZ TYPES WITHIN SCHOOL PROXIMITY AREAS

LCZ Type	No. of Schools	% Of Total
Open low-rise	58	74.4%
Open mid-rise	7	9.0%
Compact mid-rise	8	10.3%
Scattered trees	2	2.6%
Large low-rise	1	1.3%
Low plants	1	1.3%
Total	78	100%

D. Land Surface Temperature (LST) Data

Land Surface Temperature (LST) data were collected from satellite imagery and spatially overlaid with each school buffer zone (figure 5). LST within this area was calculated to represent the local surface heat conditions. Each school’s dominant LCZ type was associated with a qualitative thermal expectation referred to as a “Thermal Trait” based on the typical thermal performance of that LCZ type. These traits were translated into an ordinal scale for analysis: Cool (0), Moderately warm (1), Warm (2), and very hot (3). A fifth category, Warm (rural heat), appeared only once and was excluded from statistical tests due to its singularity and ambiguous classification.

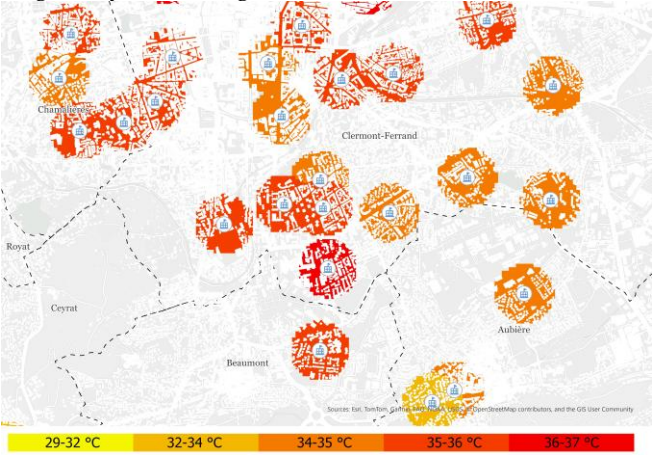


Figure 5 LST Mapping Across Elementary School Buffer Zones

E. Analytical Approach

To evaluate the alignment between observed LST and the expected thermal behavior of each zone, several analytical steps were undertaken. Descriptive statistics were computed to summarize the temperature distribution across Thermal Trait categories. A Spearman's rank correlation was used to assess the monotonic relationship between ordinal thermal classifications and observed temperatures. To test statistically significant differences between groups, both parametric (ANOVA) and non-parametric (Kruskal-Wallis) methods were employed. Finally, LST values were compared across LCZ types to examine how morphological typologies correspond to thermal performance.

III. RESULTS AND DISCUSSION

The LCZ classification shows that Clermont Auvergne Metropolitan area is largely composed of natural and semi-urban zones. Vegetated surfaces dominate the landscape, with LCZ 12 (Bush, scrub) accounting for 27.21%, primarily located in the peripheral hills and undeveloped outskirts of the metropolitan area. LCZ 11 (Scattered trees), covering 17.64%, is distributed throughout rural fringes and interstitial green spaces within suburban areas. LCZ 6 (Open low-rise buildings) makes up 25.54%, forming the fabric of suburban neighborhoods surrounding the urban core, particularly in communes such as Chamalières, Aubière, and Beaumont. LCZ 14 (Bare rock or paved surfaces) accounts for 20.47%, mainly concentrated in industrial zones, major transportation corridors, and central paved plazas. Dense urban zones like LCZ 2 (Compact mid-rise) remain limited to 1.76% and are concentrated in Clermont-Ferrand's city center. Water-related zone—LCZ 17 (Water) is nearly absent, mostly found in isolated pockets near the Allier River and a few small wetland remnants in the southern area of the metropolitan territory (see Table 2).

TABLE 2
LCZ CLASSIFICATION RESULTS

LCZ Code	LCZ Type	Area (m ²)	% of Area
LCZ 2	Compact mid-rise	5320000	1.76%
LCZ 3	Compact low-rise	300000	0.10%
LCZ 5	Open mid-rise	5670000	1.87%
LCZ 6	Open low-rise	77380000	25.54%
LCZ 8	Large low-rise	12980000	4.28%
LCZ 9	Sparsely built	1380000	0.46%
LCZ 11A	Dense trees	53460000	17.64%
LCZ 12B	Scattered trees	82440000	27.21%
LCZ 13C	Bush, scrub	850000	0.28%
LCZ 14D	Low plants	62030000	20.47%
LCZ 15E	Bare rock or paved	260000	0.09%
LCZ 16F	Bare soil or sand	20000	0.01%
LCZ 17G	Water	890000	0.29%
Total		302980000	100.00%

To validate the relevance of the LCZ classification in capturing thermal patterns across the metropolitan scale, a horizontal UHI profile was generated along a transect crossing the Clermont skyline. As illustrated in Figure 6, This profile revealed a clear thermal gradient that

corresponded closely with urban morphology, with surface temperatures increasing steadily from rural LCZs toward the urban core and decreasing again toward the outskirts. Peak LST values were observed in compact mid-rise and industrial zones (LCZ 2, LCZ 8), while the coolest temperatures appeared in forested and vegetated LCZs (LCZ A and LCZ B). This pattern highlights the strong correlation between built form and surface temperature, confirming that built-up areas contribute significantly to localized heating.

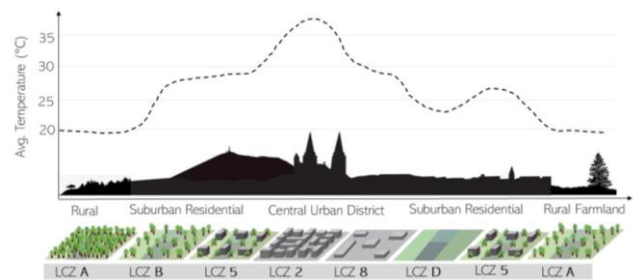


Figure 6 Horizontal UHI profile based on LCZ and LST data along the Clermont Auvergne Metropolis skyline (Created using assets from[2][15])

Overall, Clermont Auvergne Metropolitan area demonstrates a spatial organization where urban development is interspersed with vast natural or semi-natural zones. Vegetated areas occupy a significant portion of the territory, while open and compact building forms are concentrated around the urban core and suburban neighborhoods.

A. Thermal Traits and Observed Temperatures Around Elementary Schools

The results revealed a clear and coherent relationship between the thermal classification of school zones and their observed LST values. Average surface temperatures increased progressively from Cool to Very hot zones, with Cool zones averaging 29.79 °C and Warm and Very hot zones exceeding 35 °C. The Moderately warm category, which encompassed most school sites (n=57), exhibited an average LST of 34.78 °C.

Statistical testing confirmed the robustness of this pattern. A Spearman's correlation coefficient of $\rho = 0.4741$ ($p < 0.001$) indicated a moderate and statistically significant positive association between thermal traits and LST values. Furthermore, both the one-way ANOVA ($F = 15.04$, $p < 0.000001$) and Kruskal-Wallis test ($H = 20.27$, $p < 0.001$) detected significant differences in temperature across thermal categories, reinforcing the conclusion that morphological traits significantly shape local thermal exposure.

To further explore this relationship, we analyzed temperature variance across 57 schools to determine whether significant differences exist in localized thermal conditions. The results revealed substantial variability, with a standard deviation of 1.29°C and a temperature range of 7.03°C. Notably, the temperature distribution was non-normal, exhibiting left skewness—suggesting that a minority of school's experience markedly lower

temperatures. Several schools were identified as statistical outliers, particularly those with temperatures clustered around 30–32°C, indicating localized anomalies in heat exposure. These findings underscore the importance of site-specific characteristics in shaping thermal environments and highlight the heterogeneity in thermal exposure even within a relatively narrow geographic area.

B. Influence of Urban Morphology on Thermal Conditions Around Elementary Schools

A parallel analysis comparing average LST across the LCZ categories revealed that urban form plays a role in determining microclimatic conditions. As expected, vegetated LCZ types such as Scattered trees and Low plants recorded the lowest average temperatures (29.79 °C and 31.23 °C, respectively), while built forms—especially Open mid-rise and Compact mid-rise zones—exhibited markedly higher temperatures, averaging 36.01 °C and 35.69 °C, respectively.

Contrary to conventional expectations, Open mid-rise zones exhibited slightly higher average LST than Compact mid-rise areas. While denser, more compact forms are typically associated with greater heat retention due to reduced ventilation and higher impervious surface coverage, several contextual factors may explain this deviation. Microclimatic variability, including street orientation, surface materials, and shading, can modulate thermal behaviour even within the same morphological class. Additionally, the limited sample size in both categories ($n=9$) raises the possibility that a few outlier sites influenced the results.

The observed relationship between urban morphology and localized thermal conditions aligns with broader findings in urban climate research. The general trend of lower LST in vegetated areas compared to built-up zones reflects well-established knowledge that green infrastructure mitigates heat accumulation through shading and evapotranspiration [2], [16]. Recent empirical and modelling studies emphasize the nuanced role of urban form in shaping thermal exposure, highlighting how building density, height, and spatial arrangement affect airflow, solar radiation, and surface heat retention [17]. These complexities can lead to counterintuitive patterns, such as the higher temperatures observed in open mid-rise zones. Such outcomes suggest that surface materials and local spatial configurations—like the presence or absence of shading and impervious features such as paved plazas—can outweigh simplistic density-based expectations [18], [19].

Moreover, studies focusing on school environments reinforce the importance of small-scale vegetative elements and design interventions in mitigating heat stress. The variability in thermal conditions within similar urban morphological categories points to the critical role of micro-scale features such as tree placement, orientation of open spaces, and the presence of green courtyards—elements that can substantially alter local microclimates

even within the same LCZ classification [20]. These insights support the approach of integrating LCZ-based morphological classification with thermal remote sensing as a vast framework for identifying heat risk patterns in urban school zones [21]. Importantly, they emphasize the need for incorporating fine-grained spatial details—such as shading, surface composition, and localized vegetation—in future assessments and planning efforts aimed at enhancing thermal comfort and resilience in school settings.

IV. CONCLUSION

This study investigated how urban morphology influences local thermal conditions around elementary schools by integrating the Local Climate Zone (LCZ) classification with satellite-derived Land Surface Temperature (LST) data in the Clermont Auvergne Metropolis. By analyzing the thermal characteristics of 78 school environments within a 250-meter buffer, the research aimed to identify spatial patterns of heat exposure and assess the feasibility of LCZ-based tools for guiding climate-resilient planning in educational settings.

The observed surface temperature patterns closely align with expected Thermal Traits, affirming the utility of morphological classification as a reliable proxy for estimating heat exposure in urban environments. Statistical analyses, including both correlation and variance testing—consistently demonstrate that urban form exerts a significant influence on localized temperature levels.

Compact and mid-rise urban zones consistently exhibit higher land surface temperatures, while areas with more vegetation—such as open, low-rise configurations—are markedly cooler. Notably, the finding that Open Mid-rise areas recorded slightly higher average temperatures than their Compact Mid-rise counterparts underscore the nuanced nature of urban heat dynamics. This suggests that built form alone is not a deterministic factor in heat exposure; rather, it must be evaluated alongside surface materials, vegetation coverage, and urban design patterns.

These findings reinforce the value of using Thermal Traits as a practical and scalable indicator for thermal exposure risk, particularly in the context of urban schools. For predictive modelling efforts, integrating both Major Local Climate Zones (LCZs) and Thermal Traits can enhance the accuracy of temperature estimations. From a planning perspective, promoting open and vegetated urban forms—such as “Scattered trees” or “Open low-rise”—offers a promising strategy to mitigate localized heat impacts.

Future research should build on these insights using larger sample sizes, high-resolution remote sensing data, and in-situ thermal measurements to further refine our understanding of urban thermal variability and inform more climate-resilient urban design strategies.

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