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Patch–Street Coupling for Heat-Relief Placement of Small Urban Green Spaces in Temperate Neighbourhoods

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Abstract

Heat adaptation of compact temperate neighborhoods usually relies on green spaces since additional land to accommodate larger parks is scarce. The heat mitigation capacity of such spaces cannot be estimated just in terms of their surface areas. One-hectare intervention may perform like a shade destination, cooling interface with streets, or both depending on patch division, compactness, grouping, width of streets, and direction of streets. Street-Coupled Thermal Allocation (SCTA) methodology is utilized in order to find out which one-hectare layout suits best each of four neighborhood morphologies when pedestrians' heat stress is considered the goal of urban planning. Numerical parameter sets incorporate four types of streets and eight types of one-hectare layouts. Four street types, designated as T1 to T4, vary in street area share, height-to-width ratio, and orientation composition. Eight layouts of one hectare, referred to as S1 to S8, differ in patch area, total patch number, shape index, grouping property, and association with wide and narrow streets. Calculation is performed separately in respect of Local Green Refuge Score and Street Cooling Transfer Score with further aggregation of these two scores with coefficients 0.55 and 0.45, respectively. It turned out that grouped and compact layouts (S7, S8) ensure maximum performance with regard to local refuge, and grouped wide streets provide maximum cooling transfer capacity (S1, S3). Combining the two scores yields maximum values in favor of S1 layout within T1, T2, and T4, equaling to 0.719, 0.689, and 0.740, respectively. Layout S8 wins in terms of SCTA score for T3 with score equaling to 0.721 and also proves to be very effective for T4 neighborhood morphotype with SCTA value of 0.730. Layout S3 maintains its good performance throughout and reaches 0.728 in case of T4 type of morphology. The results suggest that one-hectare green space layout optimization is a morphology-related task, whereby grouping and wide streets are more appropriate for the street cooling transfer goal, while compact cross-street placement is better for diagonal morphology.

Keywords: small urban green space; street morphology; outdoor thermal comfort; Physiologically Equivalent Temperature; urban heat mitigation; green infrastructure placement

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1. Introduction

Heat is increasingly recognised as a planning problem in the context of cities whose design has been based on temperate climate expectations. Urban heat islands emerge due to impervious surfaces, reduced evapotranspiration, long-wave radiation between buildings, human-generated heat, and limited natural airflow. These processes tend to be exacerbated during extreme summer heat periods, as pedestrians are exposed in streets in close proximity to the factors described above. The specific challenge facing the design process arises from the limited flexibility offered by developed neighbourhoods, where an additional large park is rarely feasible. Potential solutions for heat mitigation therefore involve pocket parks, planted courtyard, miniature lawns, greening of schools' perimeters, widened street tree plantings, or any other modification of existing open spaces.

In other words, a small green space has to be analysed specifically for its potential thermal function, rather than being considered simply as an unutilised open space. Thermal potential will depend on the patch shape and relationship to the surrounding street network. A compact one-hectare patch would provide deep shaded refuge within it, whereas four one-quarter hectare patches could allow for a higher frequency of interactions with vegetation within streets. A linear one-hectare patch would be associated with connectivity with corridors, but with a smaller shaded core area. A one-hectare patch crossed by a wide street would create a combination of local refuge and public realm integration.

These differences cannot be identified based only on the overall amount of greenspace area. However, the contribution of vegetation to heat mitigation has been repeatedly verified, involving the thermal effects of shade, evapotranspiration, surface temperature, and radiation interaction [4, 13, 23, 28, 31]. While urban green space contributes to heat mitigation, its cooling performance depends heavily on the geometry of the green patch, vegetation density, trees, surfaces, boundary shape, and surrounding urban configuration [2, 6, 11, 27]. At the street scale, thermal performance also depends on height-to-width ratio, sky visibility factor, orientation, and pattern of shading of the pedestrian realm [1, 7, 9, 16]. On one hand, a green space that provides relief inside itself may not necessarily cool the surrounding streets, while conversely, an aggregation of small patches may provide relief in the form of corridors without a large cool island effect.

It becomes clear that the placement choice is defined by a precise geometric relationship of an urban green space and the existing street network. One-hectare space should either provide a refuge or transfer the benefits of its cooling effect into the streets, or both. Such a choice will depend specifically on the local needs for shade provision inside a neighbourhood and/or the requirement for streets to be cooled. This selection task is different from a broad goal to introduce more greenery to the city because it considers a fixed amount of available space and its interaction with the receiving street system.

This paper applies SCTA to evaluate one-hectare green space as a potential cooling tool with a fixed geometric layout. The four typologies, eight layouts, and corresponding scores will be treated consistently: Local Green Refuge Score, Street Cooling Transfer Score, Combined Planning Score, and weight stability are all calculated from the same descriptor set.

2. Urban green-space cooling and street-scale heat exposure

Studies of heat island mitigation via green space cooling have been conducted at multiple scales. At the city scale, increased vegetation helps reduce surface temperatures and mitigate the heat island effect, but the effectiveness depends on climate, canopy cover, urban density, and extent of impervious surfaces [25, 28, 36]. At the park scale, green spaces can create a park-cool-island effect by creating a microclimate with cooler conditions inside or around vegetated areas than in surrounding built environments [6, 11, 27]. At the pedestrian scale, vegetation cooling often works not through a reduction in air temperature, but primarily through a reduction in radiative heat exposure by shading pedestrians and reducing surface temperatures [3, 17, 29]. The present analysis focuses on the intermediate scale, since one-hectare green spaces are large enough to provide a refuge, but also small enough to rely on adjacent streets for their cooling effect.

Indicators for outdoor thermal comfort help understand why geometry plays an important role. The Physiologically Equivalent Temperature (PET) converts meteorological conditions and radiation intensity into equivalent thermal stress that can be understood from a human comfort perspective [15, 19, 20]. Under street-level summer conditions, PET is highly dependent on mean radiant temperature since solar radiation, reflections, and long-wave radiation emitted from warm surfaces can constitute a primary component of pedestrian heat exposure. Shading and surface temperature management via vegetation can reduce PET, but the effectiveness of such strategies depend on the proximity of shade to pedestrian routes, resting points, intersections, and building edges. In other words, even a large green space may not be able to relieve heat stress if its shade is not strategically positioned for pedestrian interaction points.

Street geometry is another key control factor for thermal performance. Aspect ratio controls solar radiation exposure, sky exposure, airflow, and ability to trap long-wave radiation. Broad streets can more effectively receive and disperse cooler air, but become hot under direct sunlight in the absence of shade from trees. Narrow canyons can provide shade from adjacent buildings during the day, but become hot if wind flow does not penetrate deeply into the street, and vice versa. Orientation is crucial in determining solar access duration and timing, while diversified orientation makes the pattern of shading and radiance more complex [1, 7, 9]. Accordingly, the same green-space layout could perform differently in broad and narrow orthogonal streets, in narrow diagonal streets, and in diverse mixed-radial grid districts.

The planning literature about heat mitigation has evolved from a focus on quantity to greater attention to spatial positioning of green infrastructure [12, 14]. The guidance on designing cooler cities calls for selection and spatial positioning of green infrastructure depending on the climate, geometry, vegetation, and implementation capabilities [14]. Similarly, the research on microclimatic impact of trees and plantings confirms that the shade pattern, canopy layout, and surrounding geometry influence pedestrian comfort in a relevant scale [8, 21, 24]. The challenge of designing small green spaces lies in finding out the most effective arrangement of the fixed green space in order to meet the required criteria of comfort and heat mitigation.

In other words, a distinction between interior refuge and outward cooling transfer should be made. Local refuge relates to the safe interior of a green space, whereas cooling transfer involves its impact on adjacent streets. Both factors are important for achieving the desired performance, but differ in the underlying characteristics: compactness, depth, and continuous shading affect local refuge, while grouping, repeating street connections, and adjacent broad streets favour cooling transfer. The cross-streets compactness may produce a mixed situation whereby the patch is still deep and retains a shaded interior while also connecting with a major street.

In summary, SCTA identifies and compares configurations of one-hectare green space that provide the maximum benefit according to prioritized thermal functions. While thermal simulation software can perform microclimate modelling for particular geometries, SCTA helps determine which ones should be prioritized. The cool-island effect demonstrated by large parks cannot always be replicated by smaller patches, since their proximity to streets, shade coverage, and surface temperature matter much more for their performance. A similar situation exists with tree-lined streets, as vegetation provides better pedestrian thermal comfort, depending on height, street width, and orientation [7]. In broad streets, solar shading is critical to comfort improvement, while in narrow streets, ventilation is critical.

This means that adjacency to wide or narrow streets is treated separately from the street crossing property in SCTA.

3. Materials and calculation procedure

Calculation relies on the four neighbourhood typologies and eight one-hectare green-space layouts. The set of descriptors in each case matches those of Tables 1 and 2, which are informed by heat-related studies of urban neighbourhoods and vegetation cooling literature [32, 33]. Typology descriptors include street area share, street aspect ratio classification, and diversity of orientation. Layout descriptors represent patch size, number, shape index, grouping condition, and adjacency to broad or narrow streets. Thirty-two combinations emerge as a result of crossing typologies and layouts.

3.1. Neighbourhood morphology and one-hectare layouts

The visual analogues of typology configurations presented as aerial maps in Figure 1 correspond to T1-T4, respectively. T1 describes a broad orthogonal street layout with the highest share of streets. T2 represents the same orthogonality of the street network, but with narrow canyon streets as the dominant element. T3 has the same narrow-street property, yet features a diagonal street orientation pattern. T4 introduces the mixed-radial street layout.

The four panels are intended to be read with the numerical descriptors in Table 1. T1 has 35% street area and a strong broad-to-medium street component, which makes it the most open orthogonal setting. T2 and T3 both have 29% street area and 71% H/W 2.5 streets, but T2 is cardinal while T3 is diagonal. T4 has 31% street area and the most balanced orientation mixture. These contrasts establish the receiving environments into which the same one-hectare greening provision is placed.

Table 1. Neighbourhood descriptors.

Typology	Street area	H/W 0.83	H/W 1.25	H/W 2.5	N–S	E–W	NE–SW	NW–SE
T1	35	35	47	18	47	53	0	0
T2	29	0	29	71	42	58	0	0
T3	29	0	29	71	0	0	42	58
T4	31	34	25	41	35	35	15	15

The values in Table 1 indicate that the four typologies should not be treated as minor variants of the same street fabric. T1 is transfer-prone because it contains the largest street-area share and a high contribution from H/W 0.83 and H/W 1.25 classes. T2 is shelter-prone because the narrow-canyon class dominates. T3 is not simply a rotated T2; its diagonal orientation changes the way shade and street direction interact with compact cross-street layouts. T4 is the most mixed case because it combines a moderate narrow-canyon share with high orientation diversity. These differences are central to the interpretation of the score results.

The eight layout panels in Figure 2 show how the same one-hectare provision changes form. S1 and S2 use four compact 0.25 ha patches. S3 and S4 use two 0.50 ha patches. S5 and S6 use a linear one-hectare form. S7 and S8 use compact one-hectare forms. The visual contrast between grouped, scattered, linear, upwind, and cross-street arrangements clarifies why identical total area does not produce identical thermal function.

Table 2 separates three controls. The first is subdivision: four 0.25 ha patches, two 0.50 ha patches, or one 1.00 ha patch. The second is compactness: shape index 1.13 for compact forms, 1.20 for moderately compact two-patch forms, and 1.41 for linear forms. The third is street relation: wide-street adjacency, narrow-street adjacency, upwind

Figure 1. Neighbourhood morphologies.

Table 2. Layout descriptors.

Layout	Patch size (ha)	Patches	Shape index	Spatial condition
S1	0.25	4	1.13	Grouped next to wide streets
S2	0.25	4	1.13	Scattered next to narrow streets
S3	0.50	2	1.20	Grouped next to wide streets
S4	0.50	2	1.20	Scattered next to narrow streets
S5	1.00	1	1.41	Linear patch next to wide streets
S6	1.00	1	1.41	Linear patch next to narrow streets
S7	1.00	1	1.13	Compact patch in the upwind area
S8	1.00	1	1.13	Compact patch across wide streets

Figure 2. One-hectare layout forms.

location, or cross-street placement. The SCTA calculation uses these controls to distinguish interior refuge from street transfer.

3.2. Thermal response quantities

The local thermal condition is represented by the mean PET inside the green-space boundary:

$$PET_{in} = \mathrm{mean} PET_A, \tag{1}$$

where A denotes the green-space area. This expression captures the internal thermal refuge provided by the vegetation and shaded ground.

The street influence is represented by the PET difference between a greening condition and the corresponding ungreened street condition:

$$\Delta PET_{out} = \mathrm{mean} PET_{B_1} - \mathrm{mean} PET_{B_0}, \tag{2}$$

where B_1 is the street area influenced by greening and B_0 is the same street area without greening. Stronger negative values would indicate stronger cooling; the score uses the transfer concept rather than calculating absolute PET fields.

The two panels in Figure 3 show the reason for separating these terms. The refuge domain is spatially concentrated within the green boundary, while the transfer domain follows adjacent streets and crossings. A compact patch can be strong in the first domain but limited in the second. A grouped wide-street arrangement can be weaker as an interior destination but stronger as a cooling interface to movement corridors.

3.3. Street and patch descriptors

For each typology t, the effective broad-street share is

$$W_t^* = p_{0.83,t} \;\; 0.5 p_{1.25,t}. \tag{3}$$

Figure 3. Thermal response domains.

The full contribution of the 0.83 class and half contribution of the 1.25 class reflect the stronger transfer potential of broader streets and the intermediate role of medium-width streets. The narrow-canyon share is

$$N_t = p_{2.5,t}, \quad (4)$$

and the diagonal orientation share is

$$D_t = p_{NE-SW,t} \;\; p_{NW-SE,t}. \quad (5)$$

Street-area exposure is normalised as

$$E_t = \frac{SA_t}{35}, \quad (6)$$

where 35 is the largest street-area share in the typology set. Orientation diversity is calculated as

$$H_t = -\frac{{}_i\, p_{i,t} \ln p_{i,t}}{\ln 4}, \quad (7)$$

where i denotes the four orientation classes. The radial-mixing term is

$$R_t = 2 \min p_{NS,t} \;\; p_{EW,t}, D_t. \quad (8)$$

This term is high only when cardinal and diagonal components coexist.

The Building-Shelter Coefficient is

$$B_t = 0.45N_t \;\; 0.35D_t \;\; 0.201 - W_t^* \;\; 0.15R_t, \quad (9)$$

and the Street-Transfer Coefficient is

$$F_t = 0.45W_t^* \;\; 0.35E_t \;\; 0.20H_t. \quad (10)$$

The two coefficients translate the same street descriptors into two different thermal meanings. B_t values increase where canyon shelter and diagonal geometry are strong; F_t values increase where broad-street share, street-area exposure, and orientation diversity support movement of cooling into the public realm.

For each layout s, single-patch area is transformed as

$$A_s^* = \sqrt{A_s}, \tag{11}$$

and shape compactness is

$$C_s = \frac{1.13}{SI_s}. \tag{12}$$

The square-root term prevents single-patch area from dominating linearly, while the compactness term penalises elongated forms relative to the compact reference shape index of 1.13.

Table 3. Layout coefficients.

Layout	G_s	X_s	ξ_s	ν_s	κ_s
S1	1.00	1.00	1.00	0.00	0.55
S2	0.08	0.40	0.00	1.00	0.10
S3	0.85	0.86	1.00	0.00	0.60
S4	0.10	0.48	0.00	1.00	0.15
S5	0.40	0.74	1.00	0.00	0.45
S6	0.25	0.58	0.00	1.00	0.35
S7	0.35	0.64	0.45	0.35	0.70
S8	0.45	0.90	1.00	0.00	1.00

The coefficients in Table 3 describe how patch form interacts with streets. The grouping coefficient G_s is highest for S1 and high for S3 because those layouts place multiple patches together rather than dispersing them. The edge-exchange coefficient X_s is also highest for S1 and S8 because the layouts create strong street contact. The term ξ_s marks broad-street adjacency, ν_s marks narrow-street adjacency, and κ_s expresses cross-corridor engagement. S8 receives the maximum κ_s value because its compact form crosses a wide street structure. S2 and S4 receive low grouping and cross-corridor values because scattering reduces coherent transfer.

3.4. SCTA score construction

Street-adjacency suitability for local refuge is

$$Q_{ts} = 0.50\xi_s W_t^* \;\; 0.35\nu_s N_t \;\; 0.15\kappa_s H_t. \tag{13}$$

The local shelter bonus is

$$Z_{ts} = 0.50\nu_s N_t \;\; 0.30\kappa_s D_t \;\; 0.20\kappa_s R_t. \tag{14}$$

The transfer suitability term is

$$Y_{ts} = 0.55\xi_s W_t^* \;\; 0.25\kappa_s H_t \;\; 0.20E_t. \tag{15}$$

These expressions allow a layout to change value with morphology. Narrow-street layouts gain from high N_t in refuge terms, wide-street layouts gain from high W_t^* in transfer terms, and cross-corridor layouts gain where orientation diversity or diagonal share is high.

The Local Green Refuge Score is

$$LGRS_{ts} = 0.38A_s^* \ 0.25C_s \ 0.16B_t \ 0.13Q_{ts} \ 0.08Z_{ts}. \tag{16}$$

The Street Cooling Transfer Score is

$$SCTS_{ts} = 0.42G_s \ 0.30X_s \ 0.16F_t \ 0.12Y_{ts}. \tag{17}$$

The Combined Planning Score is

$$CPS_{ts} = 0.55LGRS_{ts} \ 0.45SCTS_{ts}. \tag{18}$$

The 0.55 refuge weight gives slight priority to direct pedestrian heat relief within accessible green space, while the 0.45 transfer weight keeps street-network benefit central to the evaluation. The weight-stability check varies the refuge component from 0.25 to 0.75. This check tests whether the leading layouts remain competitive when the planning priority shifts from street cooling toward internal refuge.

4. Results

4.1. Morphology-dependent street receptivity

The morphology coefficients distinguish four thermal settings. T1 has $W_t^* = 0.585$, $E_t = 1.000$, $B_t = 0.164$, and $F_t = 0.713$. This combination means that T1 is the most transfer-oriented typology because it offers open streets and a large receiving area, but it offers comparatively little shelter from canyon form. T2 has $W_t^* = 0.145$, $N_t = 0.710$, $B_t = 0.491$, and $F_t = 0.453$. It is therefore more favourable for sheltered local refuge than for broad transfer. T3 retains the narrow-canyon composition of T2 but has $D_t = 1.000$, raising B_t to 0.840. T4 combines $W_t^* = 0.465$, $N_t = 0.410$, $D_t = 0.300$, and $H_t = 0.941$, producing $B_t = 0.486$ and $F_t = 0.707$. This makes T4 the most balanced receiving morphology.

Table 4. Morphology coefficients.

Typology	W_t^*	N_t	D_t	H_t	B_t	F_t
T1	0.585	0.180	0.000	0.499	0.164	0.713
T2	0.145	0.710	0.000	0.491	0.491	0.453
T3	0.145	0.710	1.000	0.491	0.840	0.453
T4	0.465	0.410	0.300	0.941	0.486	0.707

The reason for such a conclusion is provided in Table 4. The transfer-oriented layout should be supported by T1 and T4 since they have high coefficients F_t. The refuge-oriented compact layout will be supported by T3 where B_t is maximal. T2 does not seem to combine high morphological performance in terms of shelter and transfer since the shelter advantage of T2 is not complemented by a strong transfer. All these numerical relationships are the reasons for the re-ranking described below.

It is also worth noticing how different B_t and F_t coefficients may affect the interpretation of morphological features. The transfer coefficient for T1 is more than four times higher than its shelter coefficient. Thus, any layout lacking connection to the broad streets would not make use of the thermal potential offered by the typology. T3 demonstrates the opposite tendency with the shelter coefficient being almost twice greater than the transfer coefficient. It means that compact and cross-corridor layouts become more relevant here. T4 is the only morphology with both B_t and F_t being high. That is why T4 provides the maximum score even though it does not maximize either shelter or broad-street share. In other words, mixed morphology makes available several kinds of receptivity.

These numerical disparities also prove that very minor differences in numbers are significant since the layouts differ in their strong sides. For instance, the difference between S1 and S8 in T3 is only one hundredth point while S1 is strong in transfer and S8 in refuge. That means that there is no universal best layout. The best layout under certain morphological conditions is the layout least deficient in these conditions. This approach is preferable to the mere ranking of layouts because it identifies the circumstances under which the rankings would differ.

Figure 4 illustrates this numerical relationship through images that represent the morphological characteristics in spatial forms. T1 is an example of open receiving network, T2 – of canyon-like environment, T3 – of diagonal shelter condition, and T4 – of mixed structure. The images serve an interpretive purpose only because the numerical analysis is based on coefficients only.

Figure 4. Thermal receptivity portraits.

4.2. Local green refuge ranking

The refuge ranking is controlled primarily by patch depth and compactness, with morphology modifying the order among the leading compact forms. S7 is the first-ranked local refuge layout in T1, T2, and T4. Its one-hectare compact form maximises A_s^* and C_s, while its upwind position provides a strong local condition without depending on a broad street interface. S8 is ranked first in T3 because compact cross-street placement interacts with the diagonal narrow-street morphology. S6 enters the top three in T2, T3, and T4 because narrow-street adjacency can compensate partly for its linear penalty when canyon shelter is strong.

Table 5. Top refuge layouts.

Typology	Rank 1	Rank 2	Rank 3
T1	S7	S8	S5
T2	S7	S8	S6
T3	S8	S7	S6
T4	S7	S6	S8

As seen in Table 5, the pattern of rankings here shows that local refuge does not depend on preferences for largeness since the overall area is equal in all layouts. Instead, the significant variable for the analysis is the shape and size of each patch. The compact arrangement of one hectare creates much larger internal areas than four small patches. Furthermore, the shape index of 1.13 prevents any loss of value from the edge-exchange effect associated with the linear form of patches. It is essential to mention that the shift from S7 to S8 in T3 indicates that the compact cross-street arrangement is more locally effective when combined with narrow-canyon orientation.

Thirdly, the selected results give an insight into how secondary effects of morphology contribute to the final ranking. Thus, S5 gets the third position in T1 due to its wide-street relation that corresponds well with open orthogonal settings despite low compactness caused by a linear arrangement. In addition, S6 is included into the selection of T2, T3, and T4 due to the fact that narrow-street relation becomes more effective in cases of high canyon share. Although S6 does not represent a generally strong solution, it proves that there is always a place for a less-effective layout within the urban environment depending on context.

It should be stated that the local refuge ranking is especially significant for pedestrians who do not stay in any indoor spaces but prefer to stay outside. In other words, shaded compact layouts offer an excellent opportunity to wait, rest, interact with each other, and recover thermally from heat conditions. In case the main goal of a heat-adaptation plan involves creating places where people could stop and feel better, one should not break up the hectare into small pieces unless transfer is needed.

4.3. Street cooling transfer ranking

The ranking of the street cooling transfer layouts has proved to be more stable than the ranking of the refuge layouts. S1 is ranked first in all typologies; the second and third ranks are taken by S3 and S8. The reason behind it is the fact that S1 combines high values for grouping, edge-exchange, and wide-street adjacency. While S3 offers slightly fewer patches and less edge-exchange than S1, it is also highly grouped and wide-street adjacent.

Table 6 also shows the significance of the scattered configuration for heat reduction through transfer. S2 and S4 divide up the hectare provision as well, but scatter the patches and place them adjacent to narrow streets, failing thereby to establish the type of linear contact along wide streets that would enable the heat transfer process. S5 and S6 have hectare-sized patches, but the linear shape lacks the grouped repetitions of S1 and S3. Thus, street-based

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Table 6. Top transfer layouts.

Typology	Rank 1	Rank 2	Rank 3
T1	S1	S3	S8
T2	S1	S3	S8
T3	S1	S3	S8
T4	S1	S3	S8

transfer is most strongly supported by grouped configurations of patches alongside wide streets, rather than by total area and patch numbers alone.

This interpretation also helps to explain why S1 contrasts so strongly with S2 and S3 contrasts so strongly with S4, despite having the identical patch sizes and numbers. Both contrasts are determined by differences in grouping and receptivity, in which case the former cannot be due to the patch numbers themselves. Grouped patches can be mutually reinforcing from the spatial perspective, while wide streets allow more exchange space to develop between them. Patch groups may provide point shading from scattered patches by narrow streets, but no public-realm cooling system.

The position of S8 in the transfer ranking also provides valuable insights into the design process. S8 is not a grouped configuration, but it maximizes edge exchange with high cross-corridor engagement. Hence, it achieves superior performance compared to the other single-patch designs in terms of transfer. The reason why this finding is significant is because it introduces a third design family, in which the combination of geometry and street context leads to effective transfer even if the patch remains compact.

The performance-spaces diagram shown in Figure 5 combines these two findings into a comprehensive illustration. The compact forms of S7 and S8 occupy the top positions because they perform best for local shading. The grouped forms of S1 and S3 take places on the side because of high street-contact transfer potential. The forms S5 and S6 retain their intermediate positions, while S2 and S4 continue to score poorly due to scattering.

4.4. Combined placement priority

The combined score reveals the layouts that perform well across both thermal functions. S1 leads in T1, T2, and T4 with values of 0.719, 0.689, and 0.740. S8 leads in T3 with 0.721 and remains second in T4 with 0.730. S3 is consistently close to the leading group, with 0.707 in T1, 0.677 in T2, 0.708 in T3, and 0.728 in T4. The five strongest individual results are S1 in T4 at 0.740, S8 in T4 at 0.730, S3 in T4 at 0.728, S8 in T3 at 0.721, and S1 in T3 at 0.720.

As seen from the combined scores in Table 7, the most preferred layout depends on the receiving morphology. For instance, T4 provides the best scores for S1, S3, S5, S6, S7, and S8 since this typology combines high orientation diversity, strong transfer capacity, and moderate shelter effect. T3 provides S8 slightly higher scores than S1 because of the effect of diagonal sheltering and, thus, relatively compact cross-street placement. However, T2 demonstrates relatively low combined scores due to the absence of a balance between canyon sheltering and strong transfer capacity. As in the previous case, the worst scores include S2 and S4 because of scattering effects.

It is necessary to note that differences in scores in the top three rows are highly significant for urban planners. Thus, in T1, S1 has 0.021 advantage over S8 and 0.012 advantage over S3. In T2, S1 scores have 0.011 advantages over S8 and 0.012 advantages over S3, meaning that although T2 has generally low combined transfer capacity, the layouts in this typology perform quite similarly. However, in T3, S8 has only 0.001 advantage over S1, and thus

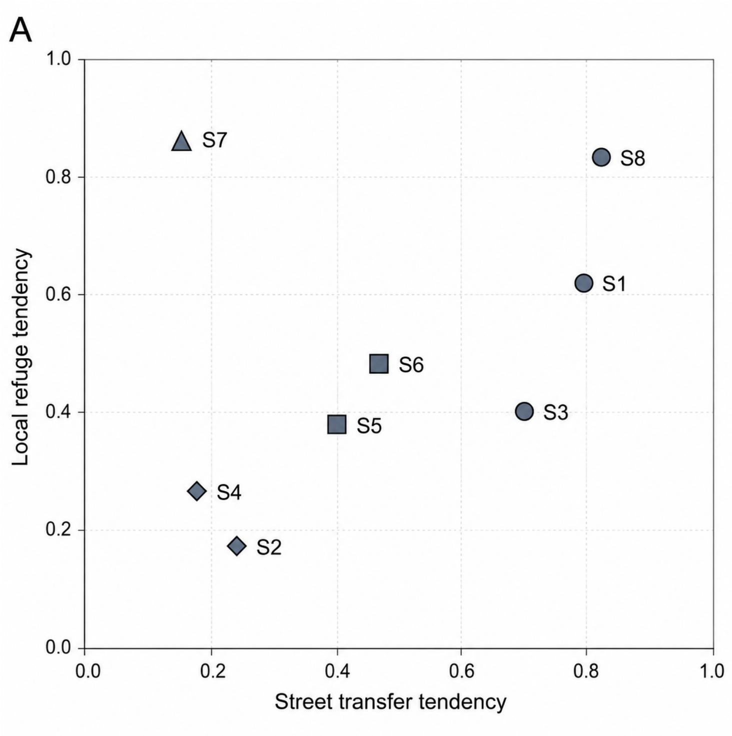

Figure 5. Refuge-transfer performance space.

Table 7. Combined Planning Score.

Layout	T1	T2	T3	T4
S1	0.719	0.689	0.720	0.740
S2	0.400	0.447	0.487	0.514
S3	0.707	0.677	0.708	0.728
S4	0.450	0.497	0.537	0.564
S5	0.648	0.618	0.649	0.668
S6	0.534	0.581	0.621	0.647
S7	0.647	0.630	0.661	0.689
S8	0.698	0.678	0.721	0.730

these two scores may be considered practically identical. Finally, in T4, S1 is 0.010 and 0.012 higher than S8 and S3 respectively, and all three have high combined scores (over 0.728).

In the lower rows, S2 and S4 do not reach even 0.565 in any typology, whereas S2 scores stay below 0.515 in all typologies. Thus, the fact that scattering cannot be compensated by the presence of several small patches is clearly visible. On the other hand, although wide-street adjacency positively affects transfer for S5, thus increasing its score in T1 compared to S6, narrow-street sheltering helps S6 to get close to S5 in T2 and T3. Moreover, even if S7 shows relatively high refuge effect, it does not surpass S1, S3, and S8 because of poor transfer scores.

The score terrain in Figure 6 provides a more complete overview of 32 score combinations. As can be observed, the strongest score ridge is built by S1, S3, and S8 layouts instead of all compact or all subdivided options.

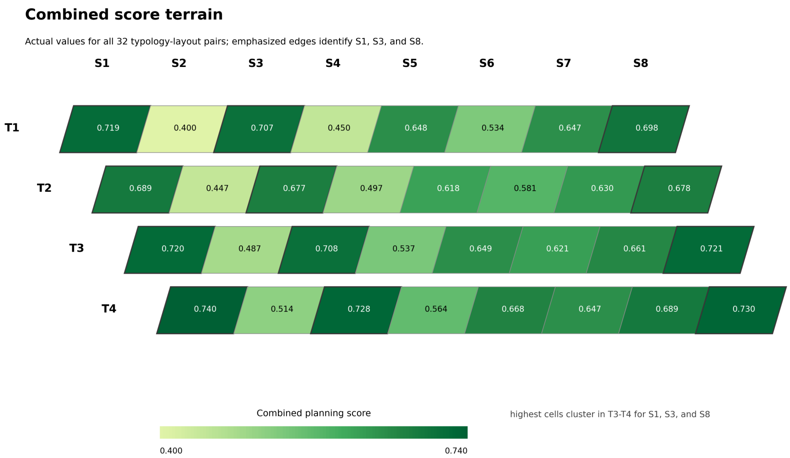

Figure 6. Combined score terrain.

4.5. Typology-specific placement and weight stability

The morphology-specific recommendation graphic in Figure 7 translates the numerical ranking into applied placement choices. T1 favours grouped patches beside wide orthogonal streets because the morphology has the highest transfer coefficient. T2 still selects S1 under the combined score, but the local-refuge pull toward compact layouts remains evident because the morphology is canyon-dominant. T3 selects S8 because diagonal shelter and cross-street compactness reinforce each other. T4 supports S1, S8, and S3 closely because it has both high transfer capacity and moderate shelter.

Figure 7. Morphology-specific priorities.

The weight-stability corridor in Figure 8 shows that the leading design families are not artefacts of a single weighting choice. S1 is strongest when street transfer receives more relative emphasis. S8 strengthens as the refuge weight increases because compact cross-street geometry retains strong interior value. S3 remains a stable middle option because it combines grouped placement with larger patch size than S1. The weaker layouts do not become leading candidates across the tested interval.

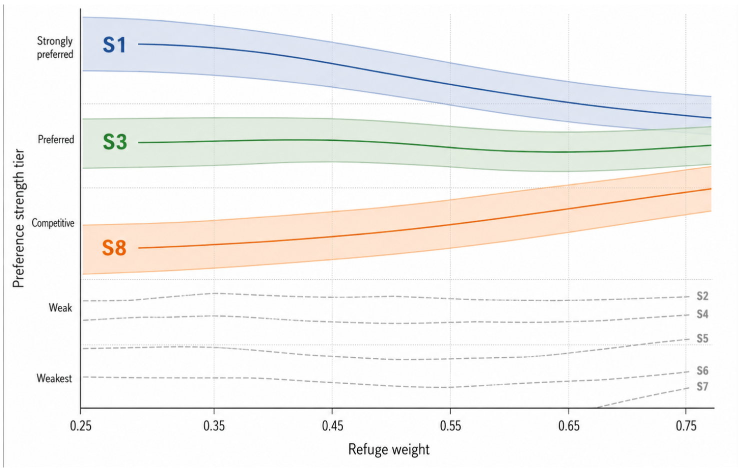

Figure 8. Weight-stability corridor.

The synthesis area in Figure 9 presents the final design interpretation. S1 stands for the distributed contact approach, S7 stands for the compact refuge approach, S8 stands for the compact cross-street approach, and S3 stands for the grouped compromise approach. This figure is most relevant as an illustration of the result structure; it is clear that the optimal location does not necessarily coincide with any of the morphologies since different streets fabrics provide different ways of distribution and sheltering from cooling.

The result regarding stability of the layout families cannot be considered to mean that these layouts are optimal in any city. It rather implies that in the studied combination of 32 urban morphologies and layout typologies these designs are the ones to rely on if the objective function weight changes. Such a finding is crucially important since early discussions on the design are likely to include changes in priorities of the objective functions. Thus, the stable family of designs remains a defendable position despite such changes.

This synthesis helps clarify the role of S7 as well. In fact, it is crucial as a refuge-based design approach although it cannot be referred to as the most stable combined solution due to the lack of street-transfer effectiveness characteristic of S1 and cross-street connectivity characteristic of S8. However, this does not devalue it in terms of a destination coolness objective.

4.6. Role of a one-hectare patch in thermal planning

The main finding is that equivalent green area can fulfill different thermal roles. A one-hectare provision lacks a single value until it is shaped into a specific geometric configuration. The compact patches S7 and S8 achieve a high rating in local refuge because of their deep patch depth and compact shape. Grouped patches S1 and S3 achieve a high rating in street transfer because of their multiple contacts with wide streets. This distinction accounts for S1's ability to dominate the combined score despite S7 being the better local refuge patch. The combined score seeks a layout with strong performance in both occupied green space and pedestrian pathways.

This result reinforces a deeper understanding of compactness. While compactness is an excellent choice for some objectives, it is not necessarily the preferred option for others. In this case, the compact option is most desirable for

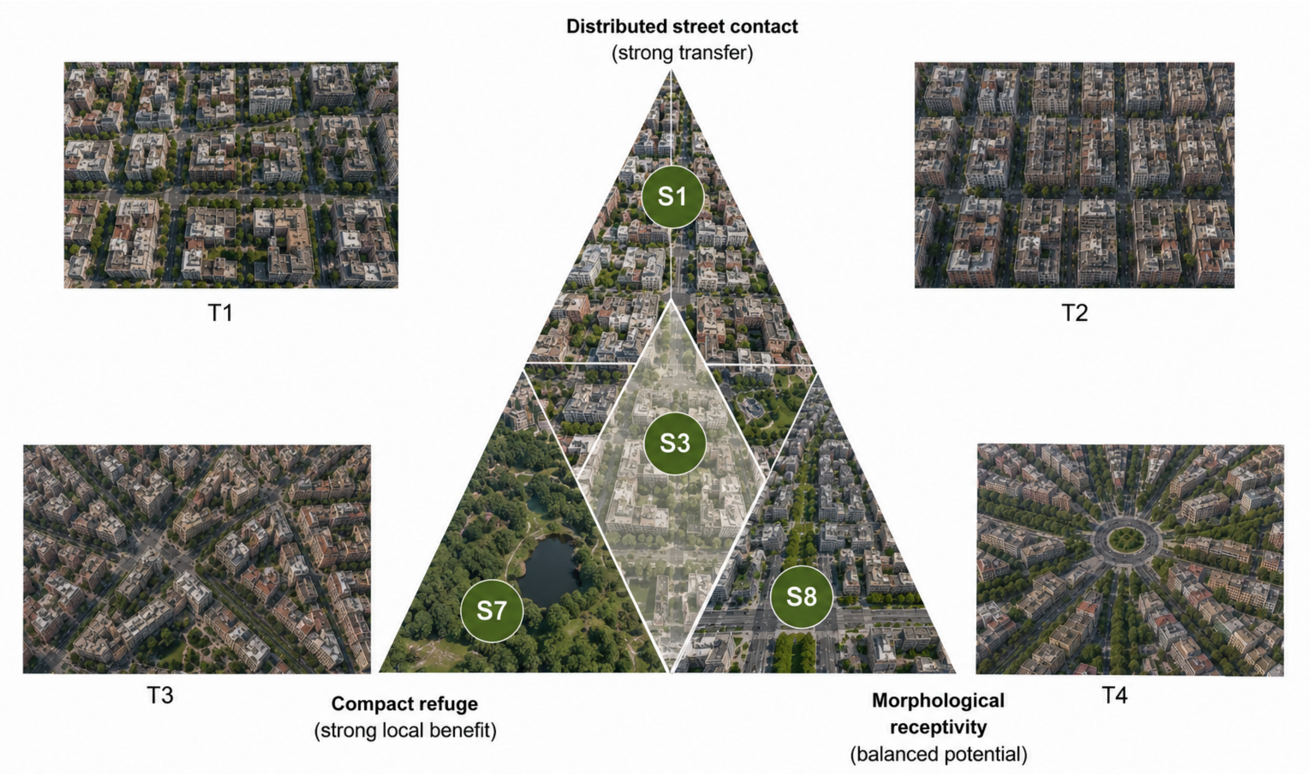

Figure 9. Patch–street synthesis.

neighborhoods with the need for a thermally safe refuge within the green-space boundary. Such needs exist near schools, transit stations, senior residences, health centers, and densely populated residential districts where residents seek shaded destinations. When the goal is a thermally cooled street network, compactness matters less because edge contact and grouping play a greater role in creating thermal benefit that extends beyond the green space.

Another implication is related to land acquisition and parcel assembly. A municipal planner may think that the easiest way to increase green infrastructure is to allocate several smaller parcels at any available locations. However, the SCTA results indicate that scattered green patches and lack of contact with wide streets can reduce thermal performance. An opposite scenario exists: a municipality that can collect several smaller parcels around the same wide street can create a greater cooling effect than allocating those patches to unrelated narrow streets. In other words, thermal efficiency of green spaces depends not only on how much land can be provided, but also how those patches relate to the street network.

One additional implication is that shade cannot be considered separately from pedestrian movement. A large portion of heat exposures is created during walking, waiting, queuing, and crossing the street rather than while occupying parks. Hence, green layouts that promote greater street transfer are better for reducing daily exposure despite the inferior internal refuge created. This is the exact reason why S1 dominates the combined score: while S1 provides a relatively shallow refuge in terms of depth, it places vegetation where the cooling field intersects with the pedestrian movement network.

4.7. Wide streets and grouping for effective street transfer

The dominance of S1 and S3 layouts for street transfer is based on physics. A grouped patch creates several vegetated street edges and increases the likelihood of multiple entry points for thermal influence. Furthermore, wide streets have larger receiving volume for street transfer than narrow streets. As a result, the four 0.25-ha patches in S1 create the largest number of entry points for street transfer. S3 also has two 0.5-ha patches with the greatest grouping and exchange values among the wide streets. Hence, even if S3 generates a slightly weaker street transfer score, it achieves higher combined score due to its patch size.

These results align with the wider body of research on green infrastructure for microclimate improvement. The process of shade creation is not enough; shade must also be received by the built environment and pedestrians. Multiple vegetated edges along walking corridors provide greater pedestrian relief compared to isolated patches. Moreover, S1 and S3 are more effective for daily exposure relief rather than resting in parks. In summary, this result highlights the difference between the need for a cool destination versus a cooler path. S1 serves the second type while S7 serves the first.

4.8. Compact cross-street placement for diagonal narrow streets

T3 represents an important result, showing that the S8 layout is slightly stronger than S1 for the combined score. Both T2 and T3 share the same street-area ratio and the same height-to-width ratio, but differ in orientation, hence the BSC is increased while the STC remains unchanged. S8 takes advantage of diagonal narrow streets because it provides a compact cross-street configuration that can combine depth with a cool destination point.

In summary, diagonal or mixed orientation is a crucial factor in thermal design. A planner who assumes that a diagonal or mixed layout is simply a design preference ignores the effects of sun exposure, wind direction, and shading pattern. In T3, the combination of compact cross-street configuration provides a greater advantage than grouping due to the morphology of streets. Moreover, the result indicates why S7 fails to take the top position: while it shares the same compactness as S8, it is unable to combine it with the street relationship.

4.9. Weak performance of scattered patches and narrow streets

The poor performance of S2 and S4 layouts constitutes an important learning point. Those two layouts share the same one-hectare green provision, and even the same number of patches, yet they do not yield strong thermal performance. The weak thermal performance is caused by the fact that the patches are scattered across several different streets. Hence, while a greater number of patches is beneficial, grouping and appropriate street contact is necessary to create a coherent influence.

While scattered narrow street configurations may have some use for urban planners in achieving other goals, the current results show that they are unsuitable from the thermal planning perspective. Hence, if a municipality decides to select S2 or S4 layout for non-thermal reasons, it is advised to improve thermal performance by selecting a different species or designing a greater canopy coverage.

4.10. Use of the SCTA results

The SCTA analysis provides an initial evaluation for the layout selection based on morphology. The result is useful for determining which layouts deserve further analysis or field testing based on PET. The SCTA result cannot substitute PET, because absolute PET reduction is sensitive to many factors, including wind direction, tree species, canopy height, leaf area, soil moisture, irrigation, and building materials. The main advantage of the current study is that the SCTA score is created using only six variables that become accessible very early in neighborhood planning.

For practical application of this model, a planner must determine his/her goal first. If the objective is creating a shaded destination point for a district, compact layout (e.g., S7 or S8) is most preferable. However, if the need of the district is to cool streets, then the planner should focus on grouping patches on wide streets (S1, S3, or S8). Finally, if the district needs both functions, then S8 or S3 should be selected, with the final choice dependent on the street orientation.

It is essential to distinguish the selection of layout based on ranking with the design choices that a planner makes independently. For instance, in T2 (narrow street orthogonal), the SCTA score ranks S1 first despite the fact that it belongs to a narrow canyon category. Nevertheless, S7 and S8 are also good design options for the same morphology since their street transfer is not significantly weaker. Thus, the SCTA score is a rational approach to making design decisions rather than an absolute prediction.

To make this approach more accurate, it is necessary to calibrate the SCTA scores against actual PET values. Field tests or microclimatic simulation may be helpful in comparing shaded interiors and street networks with respect to different patch and street configurations. The next step for calibration involves changing the SCTA weights for other climates beyond the temperate region. Hot-arid, humid-subtropical, and high-density tropical regions may prioritize evapotranspiration and air movement over shade. As a result, the current rankings become morphology-sensitive planning guidelines rather than universal rules.

5. Conclusion

The purpose of this paper was to identify which green-space patch geometry is preferred for a given street morphology to relieve pedestrians of excess heat. Every tested street morphology has one preferred green-space configuration: compact patches are most suitable for local refuge in T1, T2, and T4; grouped patches for street transfer in all four street morphologies; S1 for broad orthogonals; and S8 for diagonal narrow streets. Hence, the best configuration of a one-hectare patch depends on the morphology.

The SCTA result implies that a one-hectare green budget should not be provided exclusively by area. This statement is valid since every tested layout had the same area of green space. However, street morphology and planned function can play a crucial role in choosing the preferred one-hectare configuration. Therefore, the green space allocation should be performed based on street morphology and intended functions of the neighborhood rather than just area.

Based on SCTA results, it is recommended that S7 should be selected for broad orthogonal and radial grid morphologies, while S8 should be selected for narrow orthogonal and diagonal narrow streets. The S3 configuration is the most stable option because it provides the combination of grouped wide street patches and increased patch size. The poor thermal performance of S2 and S4 confirms that scattering patches on narrow streets is a suboptimal solution under SCTA criteria.

In conclusion, the best green space configuration can be determined according to a conditional rule. When the main goal of a district is to create cooler walking corridors, the grouped patch is preferable over the others. If the goal is to create a shaded destination, compact configuration is preferred. When the morphology is diagonal or mixed, and both functions matter, a planner may select compact patches or two-grouped patches.

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