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Urban Formative Indicators Affecting Outdoor Thermal Comfort on Campus

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ABSTRACT

Thermal comfort in university outdoor spaces is a fundamental requirement for creating a sustainable environment that supports student activities and events, and it is linked to the physical characteristics of the campus. The research problem emerged from a knowledge gap regarding the impact of urban formation on achieving thermal comfort in these spaces. The research assumes that specific urban formation indicators effectively influence users' perceptions of thermal comfort. It aims to analyze the impact of these indicators on improving thermal comfort within the university environment, with a focus on identifying the most effective in achieving thermal balance. A comparative analytical methodology was adopted that included diverse university environments from international studies, selected based on their diverse climates, formation patterns, and geographical distribution. This aimed to evaluate the performance of formation indicators and extract the most important factors influencing thermal comfort. The results showed that sky view factor, building coverage ratios, and vegetation cover are among the most influential formation indicators. Other indicators also emerged, such as the ratio of open spaces, building and wall heights, surface reflectivity, height-to-street width ratio, and ground coverage, which collectively contribute to reducing air and surface temperatures. The study recommended increasing vegetation cover and enhancing urban elements that are effective in reducing temperatures, while also ensuring a dynamic thermal balance between humans and the built environment to support a comfortable and sustainable university environment.

Keywords: Campus, Outdoor thermal comfort, Thermal balance, Urban formation.

1. INTRODUCTION

The term campus is used to define the types of physical components (mass components and outdoor spaces related to higher education), as buildings and spaces are integrated with boundaries and green spaces to please the viewer and give a physical definition and a special sense of place **(Dober, 2000)**, while utopian idealists define the campus as a small city containing an urban environment **(Ar-Rifai, 1983)**. The campus is also described as a small

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city model, and ideas that consider the university as a miniature part of the city are the ideas of (Oscar Neumann) and (Louis Sert) **(Frey and Drew, 1964)**. While it is classified as an example and urban addition to the built environment, it is also seen today as a campus system, urban university buildings, or a group of buildings that have undergone changes in function **(Kurdoğlu et al., 2018).**

Thus, the campus masterplan, in reference to its urban formation elements, includes three main components: buildings, landscape, and movement paths. Place design describes the arrangement of the campus masterplan, the distribution of campus land uses, the location of buildings and open spaces, the movement network (pedestrians and cars), the boundaries of the campus, and its interface with the adjacent urban fabric **(Dober, 1992)**. Place design and spatial marking are also two essential aspects of campus design.

Thermal comfort is defined according to the LEED rating system for green and sustainable buildings as "the mental state experienced by building occupants expressing their satisfaction with the surrounding thermal environment" **(Kamoona, 2016)**. While there are many studies on indoor thermal comfort, such as the works of (**Djongyang, 2010**; **Nicol and Roaf, 2017)**. Measuring outdoor thermal comfort remains a fundamental requirement that researchers are striving to achieve. However, many studies conducted at the beginning of this century started with the use of indoor thermal comfort assessment tools and then adapting them, especially since the factors affecting indoor thermal comfort are the same as those affecting outdoor thermal comfort, but they change more over time and space in addition to the multiple human activities in various urban areas such as streets, squares, playgrounds and gardens **(Givoni et al., 2003).**

Many scientific studies and research have addressed the factors affecting thermal comfort in university outdoor spaces, including urban heat islands, natural landscapes, landscape architecture, urban engineering and others. It also addressed the engineering and environmental solutions that must be provided in external environments in order to achieve the required levels of thermal comfort in those environments, as in the study of **(Wang et al., 2017; Yu et al., 2020; Eslamirad et al., 2022; Zhang et al., 2023; Qi et al., 2025)**, and other studies addressed aspects related to urban morphological and formative indicators, as **(Elzeni et al., 2022)** indicated in his study the method of classifying urban morphological indicators towards the possibility of urban renewal, in order to simplify the generative process of urban formation of cities, as he classified them into street indicators, land plot indicators, building indicators, and open space indicators. The study **(Kheirkhah and Nemati Mehr, 2021)** dealt with the analysis of urban form elements and indicators according to different spatial scales based on a qualitative analytical methodology.

Despite the diversity of previous studies that addressed the relationship between urban form and thermal comfort, the critical analytical nature of these studies remained limited, as most focused on public spaces in a comprehensive manner without delving into the specificities of university environments.

Literature lacks studies that focus on the formative and urban character of university campuses as a microcosm of the city, which this research seeks to address through a comparative and analytical methodology of influential urban indicators within this specific context. Based on this knowledge gap, this research seeks to address this deficiency through a comparative analytical methodology that focuses on testing and evaluating the urban formative indicators that influence thermal comfort in outdoor university spaces. The research is based on the hypothesis that there is a set of urban indicators that effectively influence thermal comfort levels within these spaces.

Accordingly, the research aims to determine the extent to which a set of these formative indicators influences improving outdoor thermal comfort levels within the university environment. The study also seeks to identify the most effective indicators within diverse climatic and morphological contexts to achieve more comfortable and thermally sustainable outdoor university environments.

2. MATERIALS AND METHODS

The research hypothesis is tested using a qualitative descriptive-analytical approach, including a comparative analysis of a selection of international applied studies that addressed the relationship between urban morphology and thermal comfort on campus. These studies were selected based on a set of scientific criteria, including: climate diversity (tropical, seasonal, cold), Multiple urban patterns on campus (compact, diffuse), Balanced geographical distribution, and the availability of analyzable quantitative data on urban morphological indicators and their impact on outdoor thermal comfort. These studies are applied to a standard framework of urban indicators extracted from the literature, to assess the effectiveness of each indicator in achieving thermal comfort. An analytical matrix based on a binary evaluation mechanism (active/inactive indicator) was adopted. Based on empirical evidence, such as a decrease in air temperature or an improvement in thermal comfort indicators, as shown in **Fig. 1.**

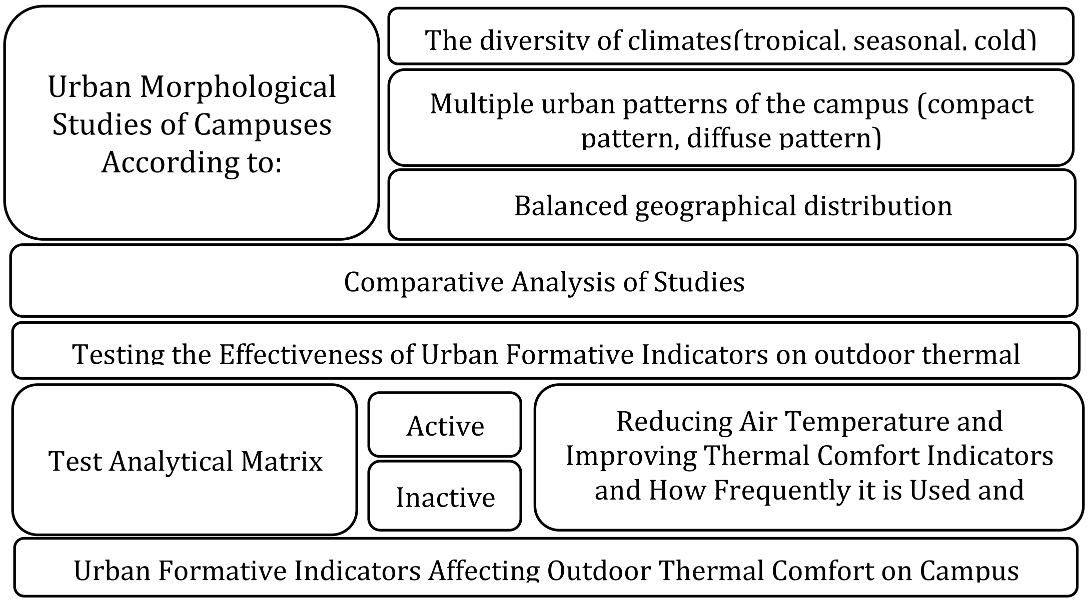

Figure 1. Research methodology diagram.

3. URBAN FORMATIVE INDICATORS

The urban formation is measured in terms of its spatial relationships and characteristics using several equations specific to the indicators. The indicators calculate many morphological relationships (numbers, dimensions, sizes, areas, directions, and percentages) observed between the different elements of the urban formation to describe the characteristics of the built environment, its engineering, and its classification. Most existing studies and research, whether global or local, have become increasingly interested in the environmental approach to researching the various basic building blocks that embody the relationship between urban indicators and different climatic conditions **(Elzeni et al.,**

2022). Below, we will discuss the most important urban formative indicators related to environmental aspects such as thermal performance and thermal comfort in outdoor spaces, which act as a ruler for measuring the efficiency of the indicators specified in the global examples, as in **Table 1**. This presents an analytical summary of formative indicators extracted from several recent international studies reviewed to identify the factors influencing thermal comfort in university outdoor spaces.

Table 1. Standard list of urban formative indicators, measurement methods, units and description.

Indicators	Methods of Measurement	Units	Description	Reference
Green Coverage Ratio (GCR)	$GCR = \frac{\text{GC area}}{\text{URBAN area}}$	%	Describes the percentage of areas covered by trees, shrubs, or grass within urban boundaries.	**(Huang and Xu, 2022)**
Density of Roads and Urban Corridors (Ra)	$Ra = \frac{\Sigma \text{ Ri Wi}}{A}$	%	Describes the area of roads and lanes relative to the total area of the urban area.	**(Ryu et al., 2017)**
Height to Width Ratio (H\W)	$H\backslash W \text{ Ratio} = \frac{H}{W}$	%	Describes the percentage of building height to street width.	**(Sharmin et al., 2019)**
Sky View Factor (SVF)	$SVF = \frac{1 - (\Sigma \sin Yn)}{n}$	-	It is a dimensionless index, with a value ranging from 0 to 1, and it represents the ratio of the radiation emitted from the sky to the radiation received from the entire hemispherical radiation environment.	**(Abaas and Khalid, 2023)**
Building Coverage Ratio (BCR)	$BCR = \frac{\Sigma F}{A}$	%	Describes the percentage of total building area to the total area of the urban area.	**(Pan et al., 2008)**
Open Space Ratio (OSR)	GIS	%	Describes the percentage of open space to total land area within an urban area.	**(Kesarovski and Hernández-Palacio, 2023)**
Building Wall Area (WALL)	3D Model	m2	Describes the total surface area of a building's exterior walls.	**(Wong et al., 2011)**
Albedo Factor (ALB)	MODIS	-	Describes the portion of incident solar radiation reflected from the Earth's surface over the entire solar spectrum.	**(Abaas and Khalid, 2023)**
Perimeter to Building Area Ratio (P\A)	3D Model	%	Describes the percentage of the building's perimeter to the total building area.	**(Purevtsere et al., 2018)**
Urban Dispersion Index (UDI)	$UDI = \frac{Nuc}{A}$	-	Describes the degree of closeness, distance and spatial arrangement of urban centres or nuclei in relation to the total urban area.	**(Abass, 2024)**
Normalized Variation of	$NDWI = \frac{NIR - SWIR}{NIR + SWIR}$	-	Describes the degree of water sensitivity within the urban area, and its value ranges from -1 to +1.	**(Szabo et al.,2016)**

Watersheds (NDWI).				
Building Orientation (BO)	GIS	-	Describes the geographical orientation of the building.	**(Ahmed and Hamed, 2023)**
Building Height (BH)	3D Model	m	Describes the difference in height between the roof and the exterior floor	**(Wang and Xu, 2021)**
Surface to Volume Ratio of the Building (S\V)	$S\backslash VRatio = \frac{Si}{Vi}$	%	Describes the ratio of the total exterior building surfaces to the building volume.	**(Morganti et al.,2017)**
Floor Area Ratio (FAR)	$FAR = \frac{Fx}{Ax}$	%	Describes the ratio of ground floor area to overall site area. It is used to measure the density of land development.	**(Chen et al., 2023)**

GCR area refers to the area of each urban green space cover. Urban area refers to the area of each urban area. Ra is the urban road and corridor density, Wi is the width of the road or urban corridor. n is the number of rings into which the fisheye image is divided. H is the building height, W is the street width. F is the building area, A is the total area of the urban area. OSR is the percentage of open space. (MODIS) Moderate Resolution Imaging Spectrometer instruments on NASA's Terra and Aqua satellites. (NIR) Near-infrared bands. (SWIR) Short-wave infrared bands. Si is the exterior surface of a building, Vi is the volume of a building. Fx is the total floor area of a building, Ax is the overall site area. Nuc is the number of urban cores, and A is the regional area (km^2).

4. TESTING URBAN FORMATIVE INDICATORS ON EXAMPLES OF GLOBAL CAMPUS REALITY

4.1 Studying Kent Ridge Campus

The Kent Ridge Campus by **(Yu et al., 2020)** of the National University of Singapore (NUS) is an advanced architectural and planning model for the tropical region, located on natural hills in the southwest corner of Singapore. The campus features a clear integration of architectural and natural elements, reflecting an intelligent response to the hot and humid climate.

From a formative perspective, the campus features a high vegetation density covering a large proportion of the outdoor spaces, both in the courtyards and around the buildings. Climbing plants and shade trees were used thoughtfully to provide solar radiation protection and enhance the visual quality. The covered paths connecting the various sections of the campus demonstrate a clear design ability to provide thermal comfort for pedestrians and are an effective urban formative element that combines function and aesthetics. In terms of architectural style, the campus follows a diffuse architectural pattern that harmonizes with the site's topography. The colleges, research centers, and residential facilities are spread across the hills, allowing for natural ventilation and multi-level visual openness. The architectural masses were designed using materials with balanced thermal properties, such as double-glazed glass and light-colored concrete, which reduce heat absorption and increase light reflectivity. The architectural orientation of the buildings and pathways reflects a clear understanding of prevailing wind directions and solar movement, resulting in improved natural shade distribution and airflow. Outdoor spaces were also designed to be thermally comfortable, combining natural and artificial shade and incorporating water and plant elements that contribute to reducing air temperatures, as shown in **Fig. 2**

- Urban Formative Indicators**:** Sky View Factor (SVF), Building Coverage Ratio (BCR), Height to Building Area Ratio (HBDG), Wall Area of Building (WALL), Open Space Ratio (OSR), Green Coverage Ratio (UGSC) and Albedo Ground Factor (ALB
- Study results**:** The results revealed significant temporal variation in the effect of urban morphological indicators on outdoor air temperature within the campus environment, in a tropical climate characterized by high humidity and persistent heat. Some urban indicators play a pivotal role in amplifying or mitigating the impact of the urban heat island phenomenon, especially during daylight hours. The results highlighted that the sky view factor (SVF), the building coverage ratio (BCR), and the building wall area (WALL) were among the most influential indicators in increasing temperatures. High SVF values were associated with increased exposure to direct solar radiation, and consequently, higher air temperature in open areas. A low open space ratio (OSR) and an increase in low reflectivity surfaces (ALB) contribute to higher temperatures, due to poor ventilation and the accumulation of longwave radiation. In contrast, areas with high vegetation cover (UGSC) showed significant improvements in thermal comfort indicators due to shade and evaporative cooling. The study concluded that managing the urban composition of the university campus by adjusting the distribution of blocks, providing shading, and employing materials with appropriate thermal properties can reduce the heat island effect and improve the quality of the external environment for students and staff. **Table 2.** below shows the effect of urban formative indicators on outdoor thermal comfort that appeared in the study.

Table 2. Effect of urban formative indicators on outdoor thermal comfort

Urban Formative Indicators	Effect on Thermal Comfort	Interpretation
SVF	Rising Air Temperatures	Higher Values Increase Exposure to Direct Solar Radiation, Which Raises the Air Temperature During the Day.
BCR	Rising Air Temperatures	The High Percentage Limits Natural Ventilation and Contributes to Heat Retention on Campus.
WALL	Rising Air Temperatures	Large Walls Increase Heat Emission, Especially in Narrow, Enclosed Areas.
OSR	Reduce Air Temperatures	Its Low Temperature Hinders Air Movement and Increases the Feeling of Heat.
ALB	Rising Air Temperatures	It Absorbs More Solar Radiation, Which Leads to A Rise in the Temperature of Surfaces and the Surrounding Air.
UGSC	Reduce Air Temperatures	Trees and Vegetation Provide Shade and Evaporative Cooling, Contributing to Lower Temperatures.

Figure 2. Kent ridge campus map. (Google Earth)

4.2 Studying Technology Kuala Lumpur

The University Campus of Technology Kuala Lumpur (UTM) by **(Zaki et al., 2020)** represents a prominent model for applying sustainable urban design principles in a humid tropical climate, where high temperatures and humidity pose significant challenges to outdoor thermal comfort. The campus's design relies on in-depth strategies to improve thermal environmental quality by integrating urban formation with climatic factors, as shown in **Fig. 3**. The architectural masses within the campus are distributed in a way that allows for the creation of open spaces of varying sizes, allowing for a balanced distribution of sun and shade. The campus's open space ratio (OSR) ranges between 35% and 50%, an ideal ratio for enhancing airflow and creating natural shading. The building height to street width (H/W) ratios range from 1.5 to 2.0, allowing for good ventilation while providing adequate shade in the spaces between buildings. Vegetation covers more than 30% of the campus area, with a focus on trees that provide dense shade, providing effective evaporative cooling and reducing the impact of solar radiation on roofs and open spaces. Plants were strategically distributed to direct wind paths and reduce temperatures in seating and walking areas.

- Urban Formative Indicators**:** Sky View Factor (SVF), Height to Street Width Ratio (H/W), and Average Building Height (BH).
- Study results: The results showed that shade from buildings effectively contributes to reducing outdoor air temperatures on campus in a hot and humid climate. Lower temperatures were observed in areas with continuous shade compared to open areas. Urban formative indicators such as sky view factor (SVF), height-to-width ratio (H/W), and Average Building Height (BH) significantly influence temperature distribution. The study recommends adopting these strategies in urban planning to reduce heat and improve user experience in areas with hot and humid climates. **Table 3** below shows the effect of urban formative indicators on outdoor thermal comfort that appeared in the study.

Table 3. Effect of urban formative indicators on outdoor thermal comfort

Urban Formative Indicators	Effect on Thermal Comfort	Interpretation
SVF	Rising Air Temperatures	Higher Values Allow Greater Exposure to Solar Radiation, Which Increases Air Temperature.
H\W	Double Effect (Value Dependent)	Higher Ratios Provide More Shade, While Lower Ratios May Lead to Increased Sun Exposure.
BH	Reduce Air Temperatures	High Buildings Provide Sufficient Shade to Reduce Direct Solar Radiation and Lower Outdoor Temperatures.

Figure 3. Technology Kuala Lumpur campus map (Google Earth).

4.3 Studying Tongji Campus

Tongji University campus by **(Wei et al., 2023)** is located in the Yangpu District of Shanghai, eastern China, a city with a humid subtropical climate, characterized by hot, humid summers and mild winters. This climate poses challenges to urban design, particularly with regard to outdoor thermal comfort. It is one of the most important university urban models that balances urban density with environmental design. It consists of a regular network of academic buildings, administrative facilities, student housing, and open spaces, creating an interconnected urban fabric. The campus extends over relatively large areas and displays a superimposed pattern of blocks and spaces, reflecting a modern trend toward sustainable design, as shown in **Fig. 4.**

- Urban Formative Indicators: Sky View Factor (SVF), Open Area Ratio (OSR), Floor Area Ratio (FAR), Wall Surface Area (WALL), Length of the Streets (L), Building Coverage Ratio

(BCR), High-Rise Building Density (HBDG), Green Area Ratio (UGSC), and Paving Ratio (PAVE).

- Study results: The results showed a strong relationship between urban morphological factors and the microclimate on campus, with hot summers and cold winters, with varying effects between spring and summer. In spring, indicators such as the built-up area ratio (FAR) and sky view factor (SVF) are significantly related to temperature and solar radiation, while in summer, the influence of environmental factors such as the green Area ratio (UGSC) and paved surface coverage ratio (PAVE) increases. The influence of wind speed also shifts from environmental factors in spring to morphological factors in summer. Multiple regression models showed that SVF, GnPR, and FAR affect temperature, while SVF, street length, and coverage ratio affect solar radiation, while street length, SVF, and hard surface coverage ratio affect wind speed. The results suggest the need to consider seasonal differences in urban planning to improve thermal comfort. **Table 4** below shows the effect of urban formative indicators on outdoor thermal comfort that appeared in the study.

Table 4. Effect of urban formative indicators on outdoor thermal comfort.

Urban Formative Indicators	Effect on Thermal Comfort	Interpretation
SVF	Rising Air Temperatures	Higher Values Increase Exposure to Direct Solar Radiation, Which Raises the Air Temperature During the Day.
BCR	Rising Air Temperatures	The High Ratio Reduces Natural Ventilation and Contributes to Heat Retention within the Campus.
WALL	Rising Air Temperatures	Large Walls Emit More Heat, Especially in Narrow, Enclosed Spaces.
OSR	Reduce Air Temperatures	Open Spaces Allow Natural Air Movement, Reducing the Sensation of Heat and Enhancing Ventilation.
PAVE	Rising Air Temperatures	Paved Surfaces Absorb Solar Radiation Significantly, Which Heats up the Surfaces and the Surrounding Air.
UGSC	Reduce Air Temperatures	Trees and Vegetation Provide Shade and Evaporative Cooling, Contributing to Lower Temperatures.
FAR	Rising Air Temperatures	High FAR Reflects High Urban Density, Which Reduces Ventilation and Increases Heat Accumulation.
HBDG	Rising Air Temperatures	The Concentration of high buildings Limits Wind Movement and enhances the Urban Heat Island Effect.
L	Variable Impact (by Season and Location)	Long Streets may Enhance Ventilation in the Summer, but they may also contribute to Heat Accumulation Depending on Direction and Enclosure.

4.4 Studying Qingdao Campus

The university campus **(Qi et al., 2023)** is located in the coastal city of Qingdao, Shandong Province, which has a temperate climate with humid summers and cool winters. Its proximity to the sea gives it a noticeable maritime influence, with relatively high humidity levels in the summer, enhancing the importance of ventilation and shading in urban design. The campus's pattern is a flexible grid, combining functional axes and green corridors, with buildings oriented to take into account sun and wind movements. A functional hierarchy is evident between academic, residential, and service areas, which supports spatial organization and improves airflow. Most buildings are low to medium height (3 to 6 floors), distributed so as not to block winds or cause dense, overlapping shadows. Green spaces are abundantly distributed throughout the campus, including tree-lined walkways, grassy plazas, and small gardens between buildings.

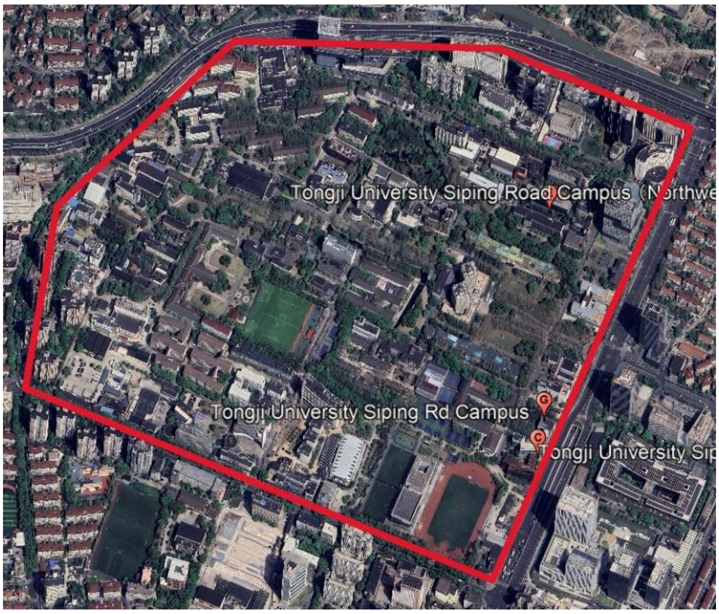

Figure 4. Tongji campus map (Google Earth)

Deciduous trees are also used to provide a seasonal balance between shade and natural lighting. The general orientation of the buildings is based on a south or southeast axis, maximizing the benefit of moderate sea winds in the summer. Long open corridors allow air to flow between the building blocks, as shown in **Fig. 5**.

- Urban Formative Indicators: Sky View Factor (SVF), Building Coverage Ratio (BD), Green Area Ratio (UGSC), and Total Building Scale (BS).
- Study results: The results showed that the spatial configuration of the university campus has a direct impact on the external thermal environment. They revealed a strong correlation between certain morphological indicators, such as the sky view factor (SVF), the percentage of building coverage (BD), and the percentage of vegetation cover (PVC), and the levels of the physiological equivalent temperature (PET). The results also indicated that a lower SVF value (i.e., reduced sky exposure through building formations or trees) leads to lower temperatures in outdoor spaces during the day, as a result of reducing users' exposure to direct solar radiation. They also demonstrated that increasing the percentage of vegetation cover contributes effectively to improving thermal comfort through shading and evaporative cooling. The study proposed a set of design measures that would enhance thermal comfort, such as relocating buildings to create airways, increasing urban shade, and increasing vegetation cover in open spaces. **Table 5.** below shows the effect of urban formative indicators on outdoor thermal comfort that appeared in the study.

Table 5. Effect of urban formative indicators on outdoor thermal comfort.

Jrban Formative Indicators	Effect on Thermal Comfort	Interpretation
SVF	Rising Air Temperatures	Higher Values Allow Greater Exposure to Solar Radiation, Which Increases Air Temperature.
BD	Increased BD Leads to Decreased Thermal Comfort.	High Building Density Reduces Natural Ventilation and Increases Heat Absorption from Surfaces, Raising Local Temperatures.
UGSC	Reduce Air Temperatures	Vegetation Provides Shade and Evaporative Cooling, which Helps Reduce the Perceived Heat in Outdoor Spaces.
BS	Increased BS Leads to Decreased Thermal Comfort.	The Increase in BS Leads to Increased Rates of Reflected Solar Radiation and Higher Air Temperatures.

Figure 5. Qingdao campus map (Google Earth)

5. RESULTS AND DISCUSSION

The study aimed to analyze the extent to which urban formative indicators influence the improvement of outdoor thermal comfort levels within the university environment, with a focus on identifying the most effective indicators in achieving thermal balance in outdoor spaces. The study also seeks to evaluate the performance of these indicators within diverse climatic and morphological contexts, with the aim of extracting the most important formative factors that contribute to enhancing thermal comfort on campus. Four examples of university environments were selected from global studies based on their diverse climates, multiple formative patterns, and geographical distribution. The impact of their formative indicators on thermal comfort in their outdoor spaces was measured. These studies included, **(Yu et al., 2020)** for the Kent Ridge University campus of the National University of Singapore, **(Zaki et al., 2020)** for the University of Technology campus in Kuala

Lumpur, **(Wei et al., 2023)** for the Tongji University campus in Shanghai, and **(Qi et al., 2023)** for the Qingdao University campus in China. **Table 6** below shows the effective indicators that emerged in the selected studies and according to their specific university environments.

- ✓ Active
- • Inactive

Table 6. Verifying urban formative indicators in the studied university environments.

Indicators	Kent Ridge Campus	Technology Kuala Lumpur Campus	Tongji campus	Qingdao Campus
Green Coverage Ratio (UGSC)	✓	•	✓	✓
Density of Roads and Urban Corridors (Ra)	•	•	•	•
Height-to-width ratio (H/W)	•	✓	•	•
Sky View Factor (SVF)	✓	✓	✓	✓
Building Coverage Ratio (BCR)	✓	•	✓	✓
Open Space Ratio (OSR)	✓	•	✓	•
Building Wall Area (WALL)	✓	•	✓	•
Albedo Factor (ALB)	✓	•	•	•
Perimeter-to-Building Area Ratio (P/A)	•	•	•	•
Urban Dispersion Index (UDI)	•	•	•	•
Normalized Variation of Water Areas (NDWI)	•	•	•	•
Building Orientation (BO)	•	•	•	•
Building Height (BH)	•	✓	•	•
Surface to Volume Ratio of the Building (S\V)	•	•	•	•
Floor Area Ratio (FAR)	•	•	✓	•

The results showed that the sky view factor, building coverage ratio, and green coverage ratio have been repeatedly used in global studies and research. This is evidence of the strong and direct impact of these indicators on the levels of thermal comfort in the outdoor spaces of university urban systems. Studies have shown that a high value of (SVF) is associated with higher air temperature during the day by creating an urban cold island effect, given that long-wavelength radiation is directly affected by the value of (SVF). The higher the value of (SVF), the higher the flux of long-wavelength radiation emitted from building surfaces into the sky during the day. Consequently, the lower the value of the sky view factor and the lower the value of the building coverage ratio, the greater the feeling of thermal comfort. This is also linked to the value of the green coverage ratio in university outdoor spaces, as open green spaces, including dense trees (rather than short grasses), have many benefits in mitigating hot climatic phenomena such as urban heat islands. Increasing the percentage of vegetation cover in urban areas leads to lower air and surface temperatures. Trees affect the thermal environment by providing shade, altering wind flow, intercepting direct solar radiation through their canopy, and lowering surface temperatures. This is followed by convectional heat transfer from warmer regions. Additional cooling is provided by converting radiation into latent heat and evaporating through transpiration. Vegetation thus provides transpirational cooling, as absorbed solar energy increases latent heat, thus cooling the surrounding air.

The results showed a significant correlation between the indices (H\W, OSR, WALL, BH, FAR, and ALB) and the levels of thermal comfort achieved in outdoor spaces on campus. The values of these indices influence the reduction of air and surface temperatures in the urban environment by controlling air currents that affect outdoor air temperatures and the heat emitted by direct solar radiation waves and reflected from the exterior surfaces of buildings, roof finishing materials, and urban walkways surrounding outdoor spaces. Increasing the values of (WALL, FAR, and ALB) causes an increase in outdoor temperatures. Conversely, increasing the values of (H\W, OSR, and BH) leads to a decrease in air and surface temperatures. It is necessary to control the values of other urban formative indicators, such as the sky view factor, the percentage of building coverage, and the area of green areas. This indicates the importance of achieving a delicate balance between these indicators within the urban design of the university campus. The results of the studies reflect variations in the performance of the indicators depending on the climatic context, as follows: In hot, humid climates, shade and dense vegetation were the most effective. In cold climates, it was observed that low SVF may lead to blocking the required solar radiation in winter, requiring a careful balance. Therefore, the integrated performance of the indicators depends on the contextual interactions between the urban form and the local climate, highlighting the importance of adopting an adaptive design approach. **Table 7** shows the indicators that appeared in the studies within the four university environments and did not appear within the previously specified formative indicators. The results demonstrated the extent of their effectiveness in achieving thermal comfort through the feeling of lower temperature values in the university's outdoor spaces, whose urban design took into account these factors as auxiliary and effective indicators.

The research presented in **Table 8** below is a proposed preliminary design framework that shows the values of urban formative indicators and the objectives achieved by them for designers and urban planners when embarking on designing university environments to achieve the required levels of outdoor thermal comfort on campus.

Table 7. Formative indicators that appeared in the studies and did not appear in the evaluation of the previously specified formative indicators.

Indicators	Methods of Measurement	Units	Description
Building Scale (BS)	$BS = \frac{Havg}{BD}$	%	Describes the ratio of the average building height to the building's building density.
Height to Building Area Ratio (HBDG)	GIS	%	Represents the thermal mass of the environment within the radius of the influence zone by calculating the ratio of average building heights to total floor areas.
Length of the Streets (L)	GIS	m	It refers to the linear distance of streets or urban paths within the urban fabric, which connect buildings or open spaces.
Paving Ratio (PAVE)	GIS	%	The paving ratio refers to the proportion of the hard surface area within a circle of a given radius.

Table 8. A proposed preliminary design framework.

Indicators	Proposed Values	The Goal
SVF	0.25-0.4	Reducing Direct Solar Radiation
OSR	>35%	Providing Ventilation and Shading
FAR	<2.0	Reducing Building Density
H\W	>1.5	Enhancing Street Shading
BH	>12 m	Enhancing Shading and Wind Direction
UGSC	>30%	Enhancing Shading and Transpiration Cooling

6. CONCLUSIONS

The study was limited to four models selected based on data availability, which limits the possibility of generalizing the results to all university campuses with their various climatic and geographical diversity. The research focused on the concept of thermal comfort, particularly with regard to university environments, and emphasized that achieving the required comfort levels in university outdoor spaces contributes significantly to the sustainability and longevity of these environments, given the levels of activity and various activities. The research highlighted important recommendations that help achieve thermal comfort in university environments by adopting effective formative indicators to achieve the required levels of thermal comfort in university outdoor spaces, for measurement and verification when designing university urban environments. This is due to their specificity and effective contribution to achieving sustainability goals, and the diversity and multiplicity of activities and events for those using these environments. These recommendations include:

• Adopting low values for SVF in hot regions (0.25–0.4).
• Raising the OSR ratio to between 35–50% to achieve adequate ventilation and shade.
• Encouraging dense vegetation coverage (>30%) and focusing on trees instead of short grasses.
• Enhancing H/W and BH ratios to support airflow and provide shade.
• Redistributing built-up density (FAR < 2.0) to reduce heat absorption.
• Using environmental simulation tools to test the proposed framework before field implementation.
• The need to pay attention to expanding and increasing the proportions of green spaces, trees, shrubs, and other elements that reduce temperatures in outdoor spaces and areas of university environments, with a focus on achieving the desired thermal balance between humans and the environment.
• The proposed preliminary design framework can be developed and tested using environmental simulation tools and numerical modeling of thermal comfort in future phases. It is recommended that applied field studies be conducted to support the current findings and expand the scope of the research to include different areas and sizes of university campuses. It is also proposed to develop practical design models or frameworks based on the identified key indicators, to facilitate their application by specialists in the field of urban planning and urban climate improvement.

NOMENCLATURE

Symbol	Description	Symbol	Description
ALB	Albedo Factor.	NDWI	Normalized Variation of Watersheds.
BCR	Building Coverage Ratio, %.	OSR	Open Space Ratio, %.
BH	Building Height, m.	PAVE	Paving Ratio, %.
BO	Building Orientation, N,E,W,S.	P\A	Perimeter to Building Area Ratio, %.
BS	Building Scale.	Ra	Density of Roads and Urban Corridors, %.
FAR	Floor Area Ratio, %.	S\V	Surface to Volume Ratio of the Building, %
GCR	Green Coverage Ratio, %.	SVF	Sky view factor.
HBDG	Height to Building Area Ratio, %.	UDI	Urban Dispersion Index.
H\W	Height to Width Ratio, %.	WALL	Building Wall Area, m^2.
L	Length of the Streets, m.		

Credit Authorship Contribution Statement

Zainalabideen A. Yaseen studied, analysed and wrote the research. Zaynab Radi Abass reviewed and supervised the research.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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المؤشرات التشكيلية الحضرية المؤثرة على الراحة الحرارية الخارجية في الحرم الجامعي

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الخلاصة

تُعد الراحة الحرارية في الفضاءات الخارجية للجامعات متطلبًا أساسيًا لإنشاء بيئة مستدامة تدعم الأنشطة والفعاليات الطلابية، وترتبط بالخصائص الفيزيائية للحرم الجامعي. وتبرز مشكلة البحث في وجود فجوة معرفية حول تأثير التشكيل الحضري على تحقيق الراحة الحرارية في هذه الفضاءات. يفترض البحث أن هناك مؤشرات تشكيلية حضرية محددة تؤثر بفعالية في شعور المستخدمين بالراحة الحرارية. ويهدف إلى تحليل تأثير هذه المؤشرات في تحسين الراحة الحرارية ضمن البيئة الجامعية، مع التركيز على تحديد أكثرها فاعلية في تحقيق التوازن الحراري. تم اعتماد منهجية تحليلية مقارنة شملت بيئات جامعية متنوعة من دراسات عالمية، تم اختيارها بناءً على تنوع مناخاتها وأنماطها التشكيلية وتوزيعها الجغرافي، بهدف تقييم أداء المؤشرات التشكيلية واستخلاص أهم العوامل المؤثرة في الراحة الحرارية. أظهرت النتائج أن عامل رؤية السماء، ونسب تغطية المباني والغطاء النباتي، تُعد من أبرز المؤشرات التشكيلية المؤثرة. كما برزت مؤشرات أخرى مثل نسبة المساحات المفتوحة، وارتفاعات المباني والجدران، ومعامل انعكاسية الأسطح، ونسبة الارتفاع إلى عرض الشارع، والتغطية الأرضية، التي تساهم مجتمعة في خفض درجات حرارة الهواء والأسطح. أوصت الدراسة بزيادة الغطاء النباتي، وتعزيز العناصر الحضرية الفعالة في خفض درجات الحرارة، مع ضرورة تحقيق توازن حراري ديناميكي بين الإنسان والبيئة المبنية لدعم بيئة جامعية مريحة ومستدامة.

الكلمات المفتاحية: التشكيل الحضري، التوازن الحراري، الحرم الجامعي، الراحة الحرارية الخارجية .