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Analysis of the Area of the College of Engineering of Najran University in Saudi Arabia in Terms of its Microclimate and the Campus Walkability

By Abdulrahman Almajadiah[*]

This study assesses pedestrian behavior, thermal comfort, and spatial usability within the College of Engineering at Najran University, Saudi Arabia—an institution situated in a hot-arid climate and currently lacking comprehensive climate-responsive design strategies. The research investigates how environmental conditions and spatial configurations affect user movement patterns, exposure to thermal stress, and opportunities for social engagement in campus outdoor spaces. Using a qualitative case study approach, the study employed systematic behavioural observation and spatial assessment across six non-consecutive days, encompassing over 20 observation sessions and totalling approximately 12 hours of fieldwork. Data were collected across morning, midday, and evening periods to capture temporal variations in user behavior. Observations were coded using a structured protocol, achieving a 70% inter-rater reliability score to ensure consistency and validity in the analysis. Findings reveal that high ambient temperatures, limited shading, poorly integrated pedestrian pathways, and the absence of rest or comfort infrastructure significantly reduce walkability and discourage prolonged outdoor activity. Users were observed adjusting their routes, walking speeds, and spatial choices to minimize heat exposure—demonstrating behavioral adaptations to an environment that fails to support basic thermal comfort. The study concludes that integrating passive cooling strategies—such as shaded walkways, water features, green infrastructure, and designated pedestrian-first zones—can substantially enhance thermal comfort, mobility, and user well-being. These recommendations have broader implications for sustainable campus design, especially in regions facing intensifying heat due to climate change. By highlighting the spatial and behavioural consequences of neglecting climatic adaptation, this study contributes to the growing discourse on resilient and human-centered design in educational environments.

Keywords: *Climate-responsive design, walkability, thermal comfort, campus planning, Najran University, arid regions, pedestrian behaviour*

Introduction

In the context of arid and extreme climate regions, the intersection between environmental design and human comfort becomes critically important. As climate change intensifies, urban and institutional planners are increasingly challenged to design spaces that are not only functional but also adaptive to harsh climatic conditions. Climate-responsive design—an approach that tailors

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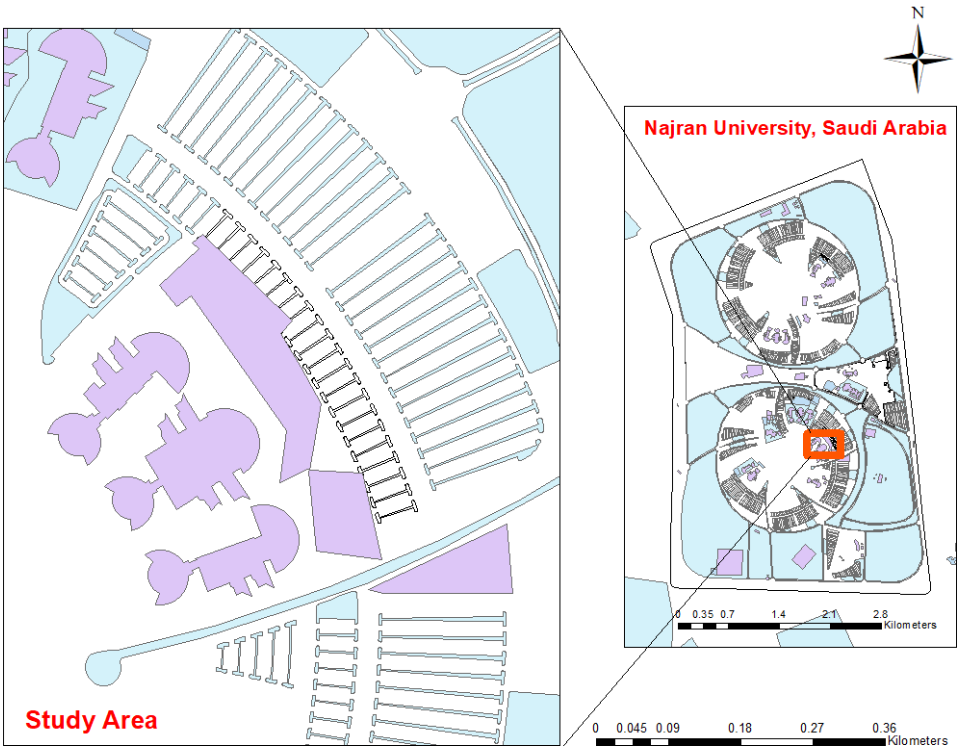
architectural and urban elements to the local climate—has emerged as a key strategy in promoting environmental sustainability, livability, and public health (Emmanuel & Krüger, 2012; Olgyay, 2015).

University campuses, as microcosms of urban life, serve as important testing grounds for such strategies. Walkability—the ease and safety with which people can move on foot across a space—is especially vital in educational environments where daily movement between classrooms, housing, and services is essential. A campus that is walkable and thermally comfortable fosters social interaction, physical activity, and academic engagement. Conversely, when design neglects the local climate, as is often the case in hot and arid regions, the outdoor environment becomes underutilized, impacting both accessibility and wellbeing (Gehl, 2010; Mehta, 2013).

Figure 1. *Map and Location of Najran University*



Najran University, located in the southern part of Saudi Arabia, presents a unique case for examining these dynamics. The region's high temperatures, low humidity, and intense solar radiation pose significant challenges to outdoor mobility. In such a context, climate-responsive design is not merely an aesthetic choice but a functional necessity. By focusing on Najran University as a case study, this research explores how climatic adaptation in design influences campus walkability, offering insights relevant not only to similar geographic contexts but also to broader discussions of sustainable urbanism in a warming world (Johansson et al., 2018; Ng & Cheng, 2012).

Research Question & Hypothesis

This study seeks to explore - How do climatic factors influence the design and functional use of the built environment at Najran University, and what climate-responsive strategies can enhance campus walkability, social interaction, and overall quality of life?

Sub-Questions

To address the central research question, the study will consider the following guiding sub-questions:

1. In what ways do extreme temperatures and arid environmental conditions influence the movement patterns and outdoor behaviors of Najran University's campus users?
2. Which aspects of the existing built environment facilitate—or obstruct—physical activity, pedestrian flow, and opportunities for social engagement?
3. How accessible are essential campus amenities for pedestrians, and what implications does this have for the overall walkability of the university environment?
4. What role do shaded areas and green spaces play in shaping the use and comfort of outdoor campus zones?
5. What specific design interventions can be proposed to promote environmental sustainability and improve thermal comfort and well-being for users of the campus?

Literature Review

Climate-Responsive Design in Arid Regions

Climate-responsive design refers to the adaptation of architectural and urban form to local climatic conditions to improve environmental performance and human comfort (Olgyay, 2015). In arid regions—marked by extreme temperatures, intense solar radiation, and low humidity—design strategies such as solar orientation, natural ventilation, shading, and reflective materials are essential for mitigating thermal stress and reducing energy loads (Emmanuel & Krüger, 2012; Alwetaishi, 2020).

More recent studies have emphasized the value of site-scale thermal mapping to inform such interventions. For instance, Nasrollahi et al. (2021) conducted comparative research on urban microclimates in arid cities, demonstrating that adaptive landscape design significantly enhances walkability. Similarly, Liu et al. (2022) highlight how integrating microclimatic data into campus design can inform passive cooling interventions such as evapotranspiration zones, shaded rest areas, and building envelope optimization.

In line with these findings, Rezaei et al. (2023) argue for climate-responsive design as a critical tool in shaping thermally comfortable urban campuses, particularly under increasing heat stress from climate change.

Walkability and Campus Design

Walkability refers to the degree to which the built environment supports pedestrian movement, comfort, and accessibility (Southworth, 2005). In university settings, high walkability fosters active transport, spontaneous social interaction, and improved physical and mental health outcomes (Gehl, 2010; Mehta, 2013). Key variables influencing walkability include the quality and continuity of pathways, shade provision, proximity to amenities, and safety infrastructure.

Recent studies reinforce the importance of designing campuses as integrated, pedestrian-prioritized spaces. Wang et al. (2020) suggest that thermally adaptive walkways and spatial connectivity significantly influence students' willingness to walk. Shahidan et al. (2021) also found that vegetation density, tree canopy coverage, and shaded rest nodes improve both thermal perception and walkability scores on Middle Eastern campuses.

Furthermore, design elements that respond dynamically to heat—such as responsive canopy systems, smart materials, and thermochromic surfaces—are increasingly being explored as tools to enhance pedestrian comfort (Kim & Schaefer, 2022). These innovations support walkability in extreme climates by adapting to real-time environmental conditions.

Thermal Comfort and Social Behavior

Thermal comfort is defined by ASHRAE (2017) as "that condition of mind which expresses satisfaction with the thermal environment." It is influenced by air temperature, humidity, solar radiation, wind speed, and personal factors such as activity level and clothing. In arid climates, thermal discomfort has a direct impact on outdoor activity levels, route choices, and spatial usage.

Lin et al. (2011) and Johansson et al. (2018) demonstrate that people in hot climates seek shaded zones or walk along building edges to reduce heat exposure. In university settings, this behavioral adaptation leads to unequal usage of space, with large unshaded courtyards or sidewalks often underutilized. Moreover, Sharifi et al. (2021) emphasize that thermal stress can disproportionately affect vulnerable users—such as women, older adults, and individuals with disabilities—thereby making inclusive design a priority in educational institutions.

Design Interventions for Sustainable Campuses

Sustainable campus planning in arid regions necessitates holistic strategies that merge environmental responsiveness with human-centered design. This includes passive cooling strategies (e.g., pergolas, arcades, green roofs), spatial configuration, and shading technologies tailored to the local climate (Edwards, 2010; Attia, 2018).

Recent advancements in smart shading systems—such as kinetic canopies, thermally adaptive facades, and solar-powered misting stations—offer promising solutions for improving outdoor comfort (Kim & Schaefer, 2022; Rezaei et al., 2023). For example, universities in the UAE and Qatar have begun incorporating mobile shading structures and real-time heat monitoring to create responsive learning environments (Alwetaishi, 2020; Nasrollahi et al., 2021).

These innovations suggest that climate adaptation in campus design must be both technically grounded and behaviorally informed, with continuous engagement from users, designers, and policymakers.

Case Study

Najran University, located in the southern region of Saudi Arabia, represents a typical educational campus operating in an arid, high-temperature environment. This case study focuses on the College of Engineering (Building 14), where observational and spatial data were collected to analyze walkability and thermal comfort under real-world climatic conditions.

Figure 2. *Showing Site Plan with Distances from the Parking to the Main Entrance of the College*

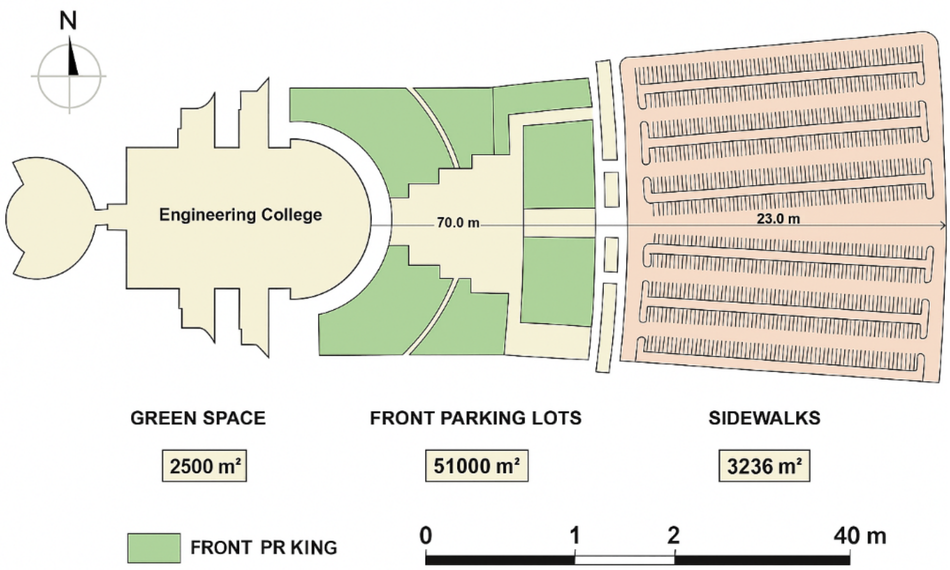


Figure 2 illustrates the site plan of the Engineering College, highlighting the distances from the primary parking zones to the main building entrance. The spatial separation between pedestrian drop-off points and academic buildings emphasizes the need for well-shaded, clearly designated, and accessible walking routes to facilitate comfort and safety—particularly for students and staff during midday heat. The plan also reveals a lack of intermediate shaded areas or seating options, making the journey on foot a physically demanding experience.

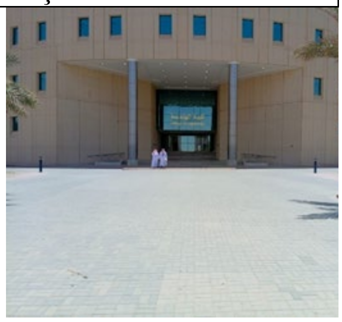
Figure 3. *Towards the Entrance by the Western Façade*	**Figure 4.** *Towards the Parking Area*	**Figure 5.** *Towards the Entrance by the Eastern Façade*
		

Figure 3 shows the approach to the building from the western façade, where minimal shading infrastructure was observed. While a few palm trees line the edge of the walkway, their distribution is sparse, offering limited microclimatic relief. Users approaching from this direction are largely exposed to direct sunlight, influencing walking behavior and speed. Figure 4 provides a view toward the main parking area, which serves as a common drop-off and access point for off-campus commuters. The surface is largely paved and exposed, and no dedicated pedestrian walkways or protective canopies are present. As a result, individuals frequently cross unmarked vehicular paths to shorten walking distances, increasing the risk of pedestrian-vehicle conflict. Figure 5 captures the eastern façade entrance, which sees significant foot traffic, particularly during class transitions. Although the spatial flow is intuitive, the design lacks essential pedestrian-oriented features such as shade structures, seating, or cooling interventions. This absence reduces the functional walkability of the area and discourages lingering or outdoor engagement.

Together, these spatial characteristics reflect the broader challenges of climate-responsive campus planning in desert regions. The findings from the case study underline the necessity of integrating passive design strategies—such as natural shading, surface treatment, and safety infrastructure—to support sustainable and inclusive mobility across the campus.

Methodology

Methodological Overview

This study employed a qualitative case study approach to explore the relationship between climate-responsive design and campus walkability at Najran University, situated in a hot-arid region of southern Saudi Arabia. The methodology integrated two core components: direct behavioral observation and systematic spatial assessment. Behavioral observations were conducted to capture real-time user activity, movement patterns, and adaptive responses to heat and sun exposure across varying time intervals. Simultaneously, a structured spatial protocol was used to assess the physical environment—including the availability of shade, street furniture, circulation zones, and accessibility infrastructure—that could either facilitate or hinder pedestrian mobility. Data collection focused on user demographics, activity types, environmental conditions, and spatial usage patterns. These were analyzed using a combination of thematic qualitative analysis, descriptive statistics, and inter-rater reliability testing to evaluate consistency in observation and generate insights into how climate-sensitive planning could improve outdoor usability and well-being on campus.

Observation Protocol and Tools

Observations were conducted over six non-consecutive days in April 2025, covering morning, midday, and evening periods. Najran University hosts approximately 25,614 students and 1,389 faculty and staff. While this study recorded over 300 pedestrian instances within the College of Engineering precinct, the sample is illustrative rather than statistically representative of the broader campus population. However, the data provides valid insight into typical behavioral responses to thermal stress and spatial constraints in arid campus environments. Each session lasted approximately 30 to 90 minutes, totaling around 12 hours of observation. Two independent coders—trained in behavioral mapping techniques—used a standardized checklist covering thermal adaptation behaviors, movement patterns, and pedestrian safety. Spatial assessment was supported using GIS-based mapping, Adobe Illustrator, and photographic documentation to evaluate shade coverage, sidewalk connectivity, and infrastructure availability.

Statistical Analysis

To ensure the validity and reliability of the collected data, a structured statistical analysis was conducted following the field observations and spatial assessments. The analysis aimed to identify behavioral patterns, evaluate spatial conditions, and quantify agreement between independent observers. Both qualitative and quantitative techniques were employed, including descriptive statistics for frequency analysis and reliability testing through inter-rater agreement. This approach enabled a nuanced interpretation of how environmental conditions influenced user behavior and walkability outcomes.

Calculating Percent Agreement

The formula for calculating percent agreement is simple and straightforward, and it is by far the easiest reliability technique available to researchers. Percent agreement (PA) is equal to the number of agreed upon ratings (NA) divided by the sum of the cases with agreements and the cases with disagreements (ND), multiplied by 100 to arrive at a percent, (Roaché, 2017).

$$PA= (NA+NDNA) \times 100$$

The following example of coded data between two independent judges is used to motivate the formula for calculating percent agreement. Two independent judges coded for the presence ("1") or absence ("0") of a given behavior:

Coder A	1	1	0	1	0	0	1	0	0	1
Coder B	0	1	1	1	0	0	1	0	1	0

In this present example, there are six cases where Coder A and Coder B are in agreement and four cases of disagreement. Thus, the percent agreement for Coder A and Coder B is 94.28%.

PA = (NA / (NA + ND)) × 100,

where **NA** is the number of agreements and **ND** is the number of disagreements.

For example, if there are 66 agreements and 4 disagreements, **PA = (66 / (66 + 4)) × 100 = 94.28%**.

This value represents the extent to which two independent observers consistently recorded similar behaviours, offering a straightforward measure of inter-rater reliability.

Using the formula and the current example, it is evident that calculating percent agreement among two or more independent judges is a straightforward and simple endeavour. Despite its ease, researchers should be also being aware of its other strengths and shortcomings (Roaché, 2017).

Strengths and Weaknesses of Percent Agreement

Percent agreement is a valuable and convenient tool for assessing how well two independent judges consistently identify a variable or set of variables. It satisfies the criterion of an adequate measure of reliability by using two independent judges. In other words, percent agreement values are not biased by the judges used in the coding of variables. However, beyond satisfying the requirement of two independent judges, its use is rather limited (Roaché, 2017).

Inter-Rater Reliability: Percent Agreement

As part of the reliability protocol, two independent observers coded a shared set of behaviours across different time periods and scenarios.

Table 1. *Summary of Inter-Rater Reliability by Behaviour Category*

Behaviour Category	Number of Observations	Agreement Rate (%)
Transport Mode	3	67%
Social Behaviour	15	93%
Thermal Comfort	12	83%

Data Analysis and Results

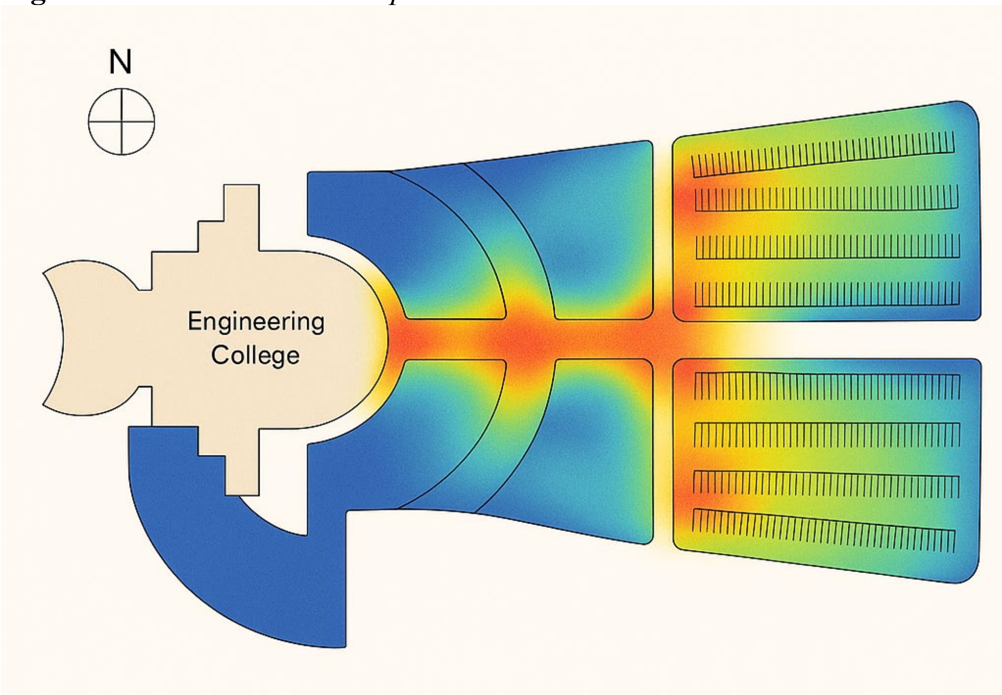
Behavioural Observation Findings

The direct behavioural observations conducted across different times and days at Najran College of Engineering revealed significant patterns in outdoor space usage, movement behaviours, and climatic adaptation strategies among campus users.

Temporal Variations in Outdoor Activities

A clear temporal trend emerged showing that pedestrian activity levels fluctuated in response to changes in temperature and solar exposure. During mid-morning and early afternoon periods when temperatures peaked above 39°C, outdoor movement declined markedly. Observers noted that individuals displayed signs of thermal stress, including walking along shaded building edges, taking frequent rest stops, and seeking informal shelter (Observation notes, July 1, 10:00 AM–12:00 PM). Conversely, while temperatures tend to moderate during early mornings and late evenings, only a modest increase in pedestrian activity was observed. This variation appears to depend primarily on the scheduling of evening master classes rather than general outdoor engagement (Observation notes, July 1, 5:30–7:30 PM). These temporal variations are further illustrated in Figure 5, which shows a pedestrian heat map identifying changes in foot traffic intensity throughout the day

Figure 6. *Pedestrian Heat Map*



Behavioural Adaptations to Thermal Stress

Campus users employed a variety of adaptive behaviors to mitigate the effects of high heat. Many individuals walked beside walls to exploit limited shading, while some covered their heads with clothing or personal belongings to shield themselves from the sun. Instances of older individuals stopping frequently to rest, and in some cases requiring assistance such as wheelchairs, were common during peak heat hours. In situations where no formal seating or shaded resting areas were available, users often resorted to leaning against walls or sitting on stairs (Observation notes, July 2, 1:00–3:00 PM; July 7, 1:00–4:00 PM).

Demographic Patterns of Space Usage

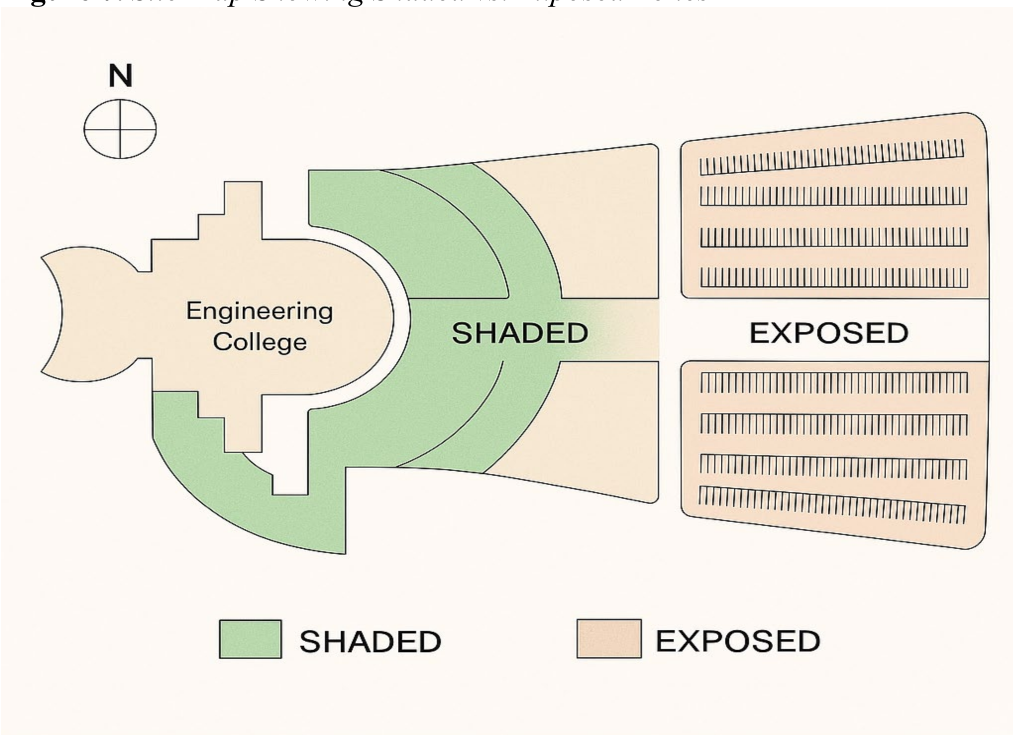
Analysis of observed demographics indicated that different user groups experienced outdoor spaces differently. During high-temperature periods, the majority of outdoor users were younger adults, particularly male students and staff. Older adults and women appeared less frequently outdoors during peak heat times, suggesting greater vulnerability to climatic discomfort. Some students are often engaging in social or leisure activities such as photographing (Observation notes, July 2, 6:00–8:00 AM).

Movement Patterns and Spatial Constraints

The spatial layout and lack of adequate shading significantly influenced movement patterns. In areas where sidewalks are huge usually about 3699m^2 starting from the parking lot but poorly connected, users frequently moved into roadways, raising safety concerns (Observation notes, July 3, 4:00–7:00 PM).

Furthermore, the absence of sufficient resting infrastructure, such as benches or shaded seating, limited the ability of users—particularly older adults—to comfortably navigate longer distances across campus. As shown in Figure 8, the shaded zones are mainly located along the building perimeters, leaving wide open areas exposed to direct sunlight, thus influencing pedestrian navigation strategies.

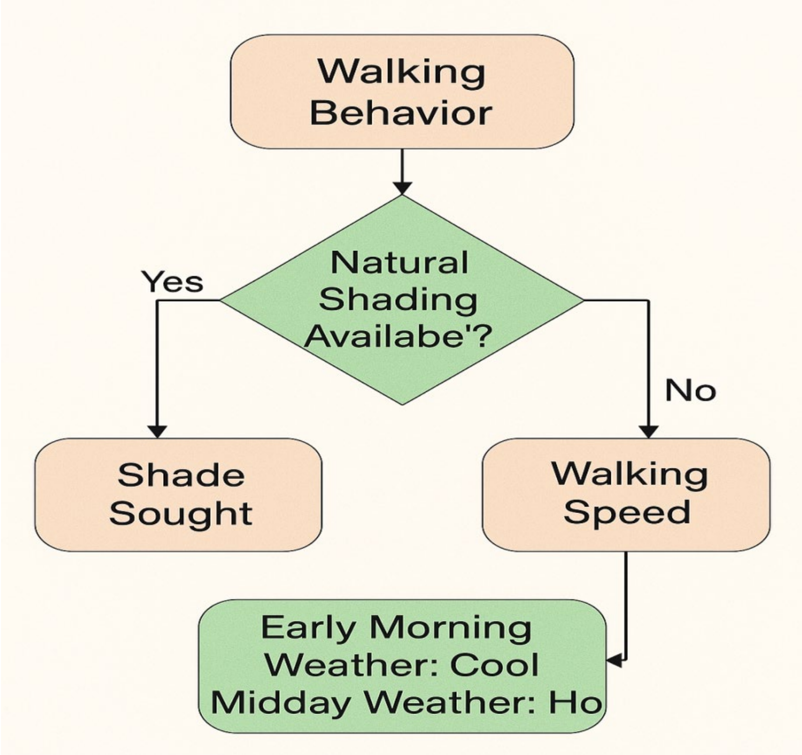
Figure 7. *Site Map Showing Shaded vs. Exposed Zones*



Influence of Class Times on Pedestrian Flows

Observation revealed that class times had a substantial impact on movement intensity. Approximately 30 to 45 minutes early morning, pedestrian flows toward mosques increased sharply, often leading to crowding along main pathways. After classes, dispersal patterns varied, with some users taking time to socialize briefly outdoors if conditions were tolerable, and others moving quickly to shaded or indoor spaces (Observation notes, multiple days). Class schedules, such as the 8:00 am to 12:00 pm block, followed by a one-hour break, and then the 1:00 pm to 3:00 pm class period, also influenced pedestrian behavior. Movement patterns on campus were affected by the overlap between prayer times and class transitions, with some students adjusting their routes or taking extended breaks after prayers. These intersecting temporal and spatial factors are synthesized in Figure 7, which illustrates common user-behavior flow patterns in response to environmental conditions and institutional schedules."

Figure 8. *Common User-Behaviour Flow Pattern*



Systematic Spatial Assessment Findings

College precinct (Building 14) at Najran University. The analysis focuses on user behavior, sidewalk infrastructure, thermal comfort, and the availability of climate-responsive elements in relation to walkability.

<u>Walking Behavior</u>

Walking is the predominant mode of access to the Engineering College. On-campus students arrive by university bus and walk approximately 3.5 kilometers from drop-off points, while off-campus students and faculty typically use private vehicles. The majority of pedestrian activity occurred in the early morning and post-class hours, while mid-day usage declined significantly due to heat.

"Time of walking seemed to be less at noon times and more at end of classes time" (Observation note, April 22).

Figure 9. *Scaled Pedestrian Activity*

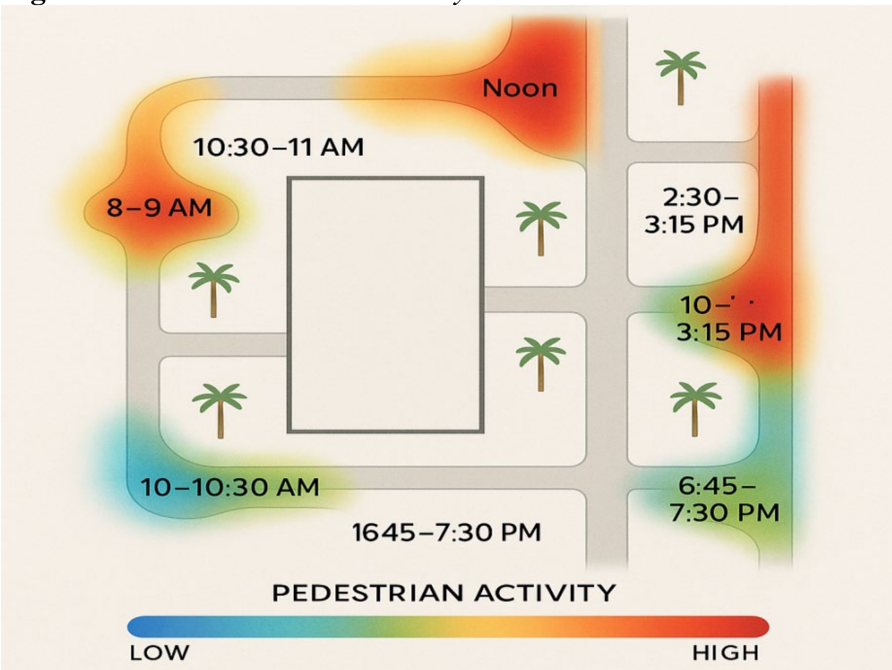


Table 1. *The Pedestrian Volume Data Captured Across Six Days Further Confirms These Temporal Fluctuations*

Day	Date	Time Slot	Weather	No. of People Observed
Tuesday	April 22	10:00–10:30 AM	Sunny, 31°C	22 students (incoming)
		12:00–12:30 PM	Sunny, 33°C	40 students, 5 faculty
		2:42–3:15 PM	Sunny, 34°C	7 in, 23 out (students)
Wednesday	April 23	2:39–3:00 PM	Sunny, 35°C	15 in; 35 students, 6 faculty, 18 cleaners out
Thursday	April 24	12:00–12:40 PM	Sunny, 35°C	30 students, 1 faculty in; 35 students, 5 faculty out
		2:45–3:15 PM	Sunny, 37°C	11 in; 23 students, 12 faculty, 20 cleaners out
Friday	April 25	12:45–1:15 PM	Sunny, 36°C	None
Monday	April 28	10:30–11:00 AM	Sunny, 34°C	59 male, 3 female students, 6 faculty in; 15 students, 1 faculty out

		6:45–7:30 PM	Sunny, 32°C	10 students in; 1 student out

This dataset demonstrates a significant drop in outdoor activity during peak afternoon hours, supporting the conclusion that walkability is directly limited by climatic stressors.

Sidewalk Design & Walking Behavior

Sidewalks around Building 14 are uniformly 5 meters wide and technically continuous, but their usability is affected by environmental and design limitations. Observers noted that individuals avoid walking in the center of sidewalks, instead favouring the shaded margins along palm trees or building edges. Several behavioral adaptations emerged in response to sidewalk conditions:

- Students used sidewalks early in the day when the sun's intensity was moderate.
- During high heat, students used vehicles to minimize walking distances, often illegally parking near building entrances.
- Conversations and standing activities took place in shaded spaces, such as tree bases or stairways.

"*The sidewalk design might have forced some behavior to occur, especially where the shade is provided*" (Observation note, April 24).

Thus, while technically accessible, the sidewalks function sub-optimally due to poor thermal design.

Street Furniture and Green Infrastructure

Infrastructure for comfort and rest was found to be critically lacking. Observations and field surveys revealed the following.

Table 2. *Street Furniture and Climate Infrastructure Inventory*

Feature	**Quantity / Condition**
Fixed seating	0
Palm trees (natural shade)	~6, scattered unevenly
Built shade structures	None
Trash bins / Hygiene units	2 (near entrances)
Water fountains	None
Ramps	4 (2 poorly constructed)

This limited provision of infrastructure not only affects user comfort but also deters longer-duration outdoor activity, particularly among more vulnerable groups.

Thermal Comfort

Thermal comfort was observed to be a major determinant of pedestrian behavior, mobility choices, and space usage around the Engineering College. The absence of climate-responsive infrastructure forced users to adopt behavioral and temporal strategies to cope with high temperatures, intense sun exposure, and lack of rest areas.

Thermal Stress

Exposure to direct sunlight and hot daytime temperatures made it very tiring and difficult for people to walk. Physical exhaustion was clearly visible as users struggled with sun intensity, especially between 12:00 PM and 3:00 PM. Without protective infrastructure such as shaded corridors or artificial canopies, most students had to improvise. To cope, some pedestrians preferred shifting their walking times—even when temperatures remained high—if that allowed them to align with personal schedules or avoid sun exposure during prayer transitions. This coping strategy was evident in multiple observations.

Without shade facilities, "*people looked tired because of the heat with an area that has no shade and walked along the palm trees to get some shades"* Palm trees, although few and sparsely distributed, became informal rest areas. In the absence of protection from the sun, "*most of the students covered their heads from the sun by wearing shumag and sunglasses*"

People trying to survive in this kind of weather were observed "*wearing light clothes, and some still sweating from walking*." These efforts underscore that essential environmental requirements are crucial in such climatic conditions. There was a consistent link between temperature changes and pedestrian behavior. For example, a warm wind at 13 mph made people walk slowly and enjoy their walk, while the absence of the sun made people more comfortable, increasing their outdoor engagement. In contrast, direct sun exposure and heat fatigue often forced students to shift their mode of transport, such as jumping onto sidewalks illegally to get closer to college doors and minimize sun exposure. Apparently, students prefer not to be exposed to the sun or feel the heat.

Shade played a critical role in shaping movement: "*With the shades and a bit of warm wind, a decrease in the temperature was noted, and more people walked*." Additionally, some students were seen *using shumag and bottles of water while walking* to reduce the effects of heat and solar radiation. However, not all users appeared adequately prepared for the conditions, as "*some found places to get rest and protection from the sun under the palm trees, and people felt more comfortable there—even though these spaces were very limited*."

This evidence collectively supports Hypotheses H1, H2, and H5, which posit that thermal stress directly reduces walkability in unshaded zones and influences user comfort through microclimatic adaptation.

Pedestrian Speed

Pedestrian speed was directly impacted by both environmental factors and temporal routines. Speed increased noticeably during early morning class times (around 8:00 AM), as users hurried to reach their destinations and participate in prayers without delay. As noted, "*pedestrian speed usually increases during class times… when the classes finish, movement slows down as people exit the college with a kind of peaceful pace"*

In contrast, during high-heat periods, walking pace visibly declined. *"People walked slower, appearing physically exhausted, particularly under sun exposure."* When cooler winds were present, walking became more leisurely and enjoyable: *"With a bit of cool wind (NW 12 mph), people walked slowly and enjoyed their walking more."* On the other hand, "**heat lowered speed because people felt exhausted."

This variation in speed affirms that thermal comfort is not only a matter of tolerance but also a determinant of pace and stamina in outdoor environments.

Pedestrian Safety

The spatial assessment also revealed systemic weaknesses in pedestrian safety infrastructure. There was a lack of clear separation between traffic lanes and sidewalks, which encouraged vehicular encroachment into pedestrian zones. Observers consistently noted that *"cars interfered with pedestrian movement, particularly where sidewalks were unprotected."*

Poor signage at pickup and drop-off points contributed to disorganized and unsafe conditions for alighting passengers, especially during high-traffic transition periods. Furthermore, *"pedestrians have no right of way at most intersections, leading to random crossings, most of which lack designated crosswalks."*

While traffic officers were sometimes present to manage peak-hour flow, this proved insufficient. "*Certain times of the day had more cars interfacing with pedestrians, and even with traffic control, congestion remained high*." The combination of poor infrastructure and increased pedestrian load resulted in hazardous conditions that discourage walking and increase reliance on vehicular shortcuts.

Discussion

The study confirms that thermal discomfort due to extreme temperatures significantly constrains pedestrian activity and walkability at Najran University. In alignment with the findings of Lin et al. (2011), users were observed altering their movement patterns, speed, and even choice of transport to avoid sun exposure. The correlation between thermal stress and decreased outdoor engagement is further supported by Johansson et al. (2018), who argue that poor thermal environments in hot-arid cities suppress public life and limit healthy, outdoor interaction. Students and staff demonstrated behavioral adaptations consistent with urban microclimate theories. These include shifting walking paths toward shaded walls, wearing local protective clothing like the *shumag*, and avoiding the outdoors during midday peaks. This aligns with Nasrollahi et al. (2021), who observed similar behavioral responses to thermal conditions in Middle Eastern educational campuses.

A key finding from this study—the discrepancy between available infrastructure and actual usability—mirrors the work of Taleghani et al. (2015), who highlight that green spaces and wide sidewalks in hot climates often remain underutilized unless paired with appropriate shading, cooling features, and seating. Despite Najran University's spatial capacity and provision of palm trees, their poor distribution renders them ineffective as consistent shade providers. Furthermore, the absence of artificial canopies or built shading structures exacerbates the thermal challenge. The lack of pedestrian prioritization through design also plays a central role in discouraging walkability. This observation aligns with the works of Southworth (2005) and Ewing & Handy (2009), who emphasize that safe, continuous, and shaded pedestrian infrastructure—including crosswalks and signage—are essential for encouraging walking behavior. Najran's current layout, where sidewalks intersect with vehicular paths without formal crossings or traffic calming measures, compromises pedestrian safety and agency, a risk also outlined in recent WHO urban health assessments (WHO, 2016).

The temporal dimension of mobility at Najran further highlights design limitations. Walking speeds and crowd flows were observed to rise significantly during class transitions and prayer periods, exposing users to peak thermal discomfort and congested unsafe crossings. These dynamics emphasize the need for adaptive design solutions that integrate both climatic data and daily social rhythms—a principle emphasized by Emmanuel & Krüger (2012) and more recently echoed in the adaptive urbanism movement (Sharifi & Yamagata, 2016). Moreover, this research highlights a gap in inclusive design, as vulnerable populations such as older adults and women were less present during high-heat hours, indicating that the current design disproportionately affects these groups. This reflects the findings of Norton et al. (2015), who stress that thermal comfort interventions must be equitable and consider differentiated impacts on various user groups.

The findings also underscore the significance of temporal and cultural rhythms in shaping pedestrian behavior. The overlap of midday class transitions and congregational prayer times created peak pedestrian volumes during the hottest hours, exacerbating thermal discomfort. Furthermore, gender-specific outdoor usage patterns were evident; female users were significantly underrepresented during high-heat periods, likely reflecting both climatic sensitivity and cultural norms regarding sun exposure. These insights highlight the need for gender-inclusive, culturally aware spatial planning in arid academic environments. Collectively, these findings reinforce the notion that climate-responsive campus design is not optional in arid regions—it is foundational to promoting health, equity, mobility, and academic engagement. Integrating bioclimatic features such as pergolas, wind towers, high-albedo pavements, and water features, as seen in projects across the UAE and Qatar (Alwetaishi, 2020; Attia, 2018), could transform Najran University's pedestrian spaces into liveable, walkable microclimates. In addition, smart shading technologies, responsive urban surfaces, and thermal comfort monitoring could provide real-time adaptive responses to fluctuating weather, thus enhancing usability and wellbeing.

Conclusion

This study explored how climate-responsive design—or the absence thereof—influences campus walkability, thermal comfort, and pedestrian behavior at Najran University, Saudi Arabia. The findings reveal that extreme heat, limited shading, inadequate pedestrian infrastructure, and insufficient signage significantly hinder walkability and reduce outdoor engagement. Observations showed that students and staff frequently adjusted their walking behavior—altering routes, walking speeds, or choosing vehicular alternatives—in response to thermal stress. These behavioral adaptations highlight systemic design deficiencies, particularly problematic in arid regions where environmental stressors are both intense and consistent.

The study addressed RQ1 by revealing that solar exposure and midday heat drastically reduced pedestrian volumes and modified movement behaviors, as users sought shaded routes or avoided walking altogether. In response to RQ2, it was found that the lack of climate-responsive features—such as shading, seating, and visual cues—directly inhibited walkability and spontaneous social interaction, while palm trees offered only limited informal relief. Finally, for RQ3, several passive and infrastructural strategies were identified—including pergolas, shaded corridors, water fountains, and pedestrian-priority walkways—which could substantially improve thermal comfort and safety (see Table 4).

Table 4. *Research Questions and Corresponding Key Findings*

Research Question	Key Findings
RQ1: How do extreme heat and solar exposure influence movement patterns and outdoor behaviours?	Peak heat significantly reduced pedestrian activity. Users altered walking speeds, sought shade, and avoided central walkways.
RQ2: Which design features facilitate or hinder walkability and social interaction?	Absence of shading, poor signage, and exposed sidewalks discouraged walking. Palm trees provided limited informal shade.
RQ3: What passive-cooling and infrastructural strategies can enhance thermal comfort and safety?	Suggested strategies include pergolas, shaded corridors, water fountains, and dedicated pedestrian pathways separated from vehicular traffic.

In line with previous studies (e.g., Emmanuel & Krüger, 2012; Lin et al., 2011), the absence of passive cooling interventions on campus not only limits comfort but suppresses social and academic life. The findings strongly support the need for climate-sensitive, inclusive, and safety-oriented design approaches that prioritize the well-being, equity, and mobility of all campus users—especially in hot-arid settings increasingly impacted by climate change.

Recommendations

To enhance walkability and mitigate thermal discomfort at Najran University and similar arid campuses, the following recommendations are proposed:

i. Integrate Passive Shading and Cooling Strategies - Architectural shading elements such as pergolas, arcades, tensile canopies, and colonnades should be installed along primary pedestrian routes. These should be complemented by increased planting of native, shade-providing vegetation like palm trees and drought-tolerant canopy species, as well as the use of high-albedo and permeable sidewalk materials to reduce heat absorption.
ii. Provide Climate-Responsive Street Furniture and Amenities - Install benches, water fountains, and misting systems at key rest points, especially near entrances and along major pedestrian paths. These should be shaded and placed at accessible intervals to serve users with limited mobility.
iii. Redesign Pedestrian and Vehicular Interfaces - Ensure clear separation of pedestrian walkways from vehicular traffic using textured paving, bollards, or elevation changes. Raised crosswalks with zebra markings and traffic-calming elements like speed bumps should be used to enhance pedestrian safety.
iv. Utilize Smart and Climate-Adaptive Technologies - Introduce solar-powered lighting and cooling stations that respond to temperature conditions, and explore adaptable shading solutions such as mobile canopies or dynamic systems used in other arid-region campuses.
v. Re-evaluate Campus Planning through Climatic Mapping - Conduct seasonal thermal comfort mapping to guide infrastructure upgrades. All new construction and renovations should apply bioclimatic design principles focusing on orientation, ventilation, and shading.
vi. Promote Behavioral Awareness and Inclusive Access - Implement awareness campaigns on heat risks and shaded routes. Provide shaded waiting and resting areas for vulnerable groups, particularly the elderly, people with disabilities, and women, whose mobility is often restricted in extreme heat.
vii. Policy Integration and Institutional Commitment - Institutionalize climate-responsive design in campus planning and maintenance policies. Collaborate with urban designers and municipal authorities to develop a long-term climate adaptation strategy for the university.

Implementing these recommendations would not only mitigate thermal stress but also support academic engagement, social interaction, and health outcomes. As climate change continues to intensify regional temperatures, such adaptive planning is not only beneficial—it is essential.

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Appendix 1
Direct Observation Notes [Observer 1]
Location: Building 14

Date/Time	**Weather Conditions**	**Activities Observed**	**Notes**
Tuesday, April 2210:00–10:30 AM	Sunny, 31°CWind: NNW 11 mph	Walking, Standing	Temperature was still tolerable but heat noticeable. Some students stood or sat under palm trees. Others waited for the bus using tree shade due to absence of shelter. Mostly male students observed. 22 people entered the college.
Tuesday, April 2212:00–12:30 PM	Sunny, 33°CWind: NW 14 mph	Walking, Standing	Students gathered under palm trees, many using sunglasses. Some jumped from sidewalks near cars to minimize sun exposure. Approx. 45 male students: 40 students, 5 faculty.
Tuesday, April 222:42–3:15 PM	Sunny, 34°C	Sitting, Walking, Talking	Students sat on stairs about 70 meters from bus stop. Cleaners began gathering for end-of-shift pickup. More people leaving than entering: 23 exiting, 7 entering. Mostly students.
Wednesday, April 232:40–3:00 PM	Sunny, 35°C	Walking, Standing	End of work period. Pedestrians preferred walking near palm trees or shaded areas. Conversations took place near building entrance. 74 observed: 35 students, 6 faculty, 18 cleaners leaving; 15 students arriving.
Thursday, April 2412:00–12:40 PM	Sunny, 35°CWind: NE 21 km/h	Walking, Standing	Low pedestrian volume. Students avoided central sidewalk. 30 students and 1 faculty entered; 35 students and 5 faculty exited.
Thursday, April 242:45–3:15 PM	Sunny, 37°C	Walking, Talking	People leaving post-class/work. Slow traffic observed. 11 students entered; 23 students, 12 faculty, and 20 cleaners exited.
Friday, April 2512:45–1:15 PM	Sunny, 36°C	None	No activity observed.

Monday, April 2810:30–11:00 AM	Sunny, 34°C	Walking	Rising heat seemed to impact pedestrian movement. Mostly students. 68 people entered (59 male students, 3 female students, 6 faculty); 15 students and 1 faculty exited.
Monday, April 286:45–7:30 PM	Nighttime, 32°CWind: NE 14 km/h	Walking	Calm and slightly dark. Cooler due to sunset. Mostly master's students observed. 10 people entered; 1 exited.

Appendix 2
Direct Observation Notes [Observer 2]
Location: Building 14

Date/Time	Weather Conditions	Activities Observed	Notes
Tuesday, April 2210:10–10:26 AM	Sunny, 31°C	Walking, Standing	Pedestrians moved slowly, many using phones. Some waiting for the bus. 15 people entered, 5 exited.
Tuesday, April 2212:05–12:24 PM	Sunny, 33°CWind: NW 14 mph	Walking, Standing	Students talking under palm trees. 24 entered; 18 exited.
Tuesday, April 222:30–2:47 PM	Sunny, 34°C	Sitting, Walking, Talking	Students sat on college stairs (70 meters from bus stop). Some parked in undesignated areas. 15 entered; 5 exited.
Wednesday, April 232:40–3:00 PM	Sunny, 35°C	Walking, Standing	End of work hours. Shade preferred along palm trees. Conversations held near entrances. 74 observed: 35 students, 6 faculty, 18 cleaners leaving; 15 students arriving.
Thursday, April 2412:00–12:40 PM	Sunny, 35°CWind: NE 21 km/h	Walking, Standing	Light traffic. Most avoided central sidewalks. 30 students and 1 faculty entered; 35 students and 5 faculty exited.
Thursday, April 242:45–3:15 PM	Sunny, 37°C	Walking, Standing, Talking	People leaving after classes or work. Low vehicular traffic. 11 students entered; 23 students, 12 faculty, and 20 cleaners exited.
Friday, April 2512:45–1:15 PM	Sunny, 36°C	None	No activity observed.
Monday, April 2810:30–11:00 AM	Sunny, 34°C	Walking	Heat building up. Mostly students observed. 68 people entered (59 male students, 3 female students, 6 faculty); 15 students and 1 faculty exited.

Monday, April 286:45–7:30 PM	Nighttime, 32°CWind: NE 14 km/h	Walking	Calm, slightly dark. Pleasant temperature. Mostly master's students. 10 entered; 1 exited.

Appendix 3
Physical features of the case study

Dimension	Parameters	Engineering college
Building height		Above 20
sidewalks length		70 meters
Street width		-
Sidewalk width		5 m
Road crossing		none
Pavement	Material	Interlock
	Condition	good
	Clutter	None
	Ramp	Tow in front edge of the sidewalk near to car parking And two at the college entrance but done unproperly.