Journal of The Nigerian Institute of Architects (NIAJ)
ISSN: 2315-8913 (print)
ISSN: 1595-4110 (digital)

Retrofitting Parking Lots to Reduce Urban Heat and Promote Sustainability at Najran University

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Abstract: ***This study identifies, efficient solutions, suitable for Najran's hot desert climate. The work investigates sustainable retrofitting systems, for parking lots at Najran, using a mixed-methods approach that includes climate analysis, design-based research, in addition to site observation. The planned interventions integrate ecological performance, with operational feasibility and human comfort and, encompassing bioswales, EV-ready infrastructure, high-albedo (cool) surfacing, permeable pavements, shade trees, photovoltaic (PV) canopies. In adopting context responsive and energy-efficient parking solutions, an indicative cost framework, a phased performance strategy, and performance indicators are provided to direct the university.***

Keywords: Najran University, sustainable design, parking retrofit, urban heat island.

1. Introduction

University campuses usually have vast expanses of paved parking lots, beyond arid regions, that soaks and retain heat, profoundly adding to context based urban heat islands. For students and staff, at Najran University, the incorporation of dark asphalt surfaces, high solar radiation and scarce vegetation, results in uncomfortable microclimates.

Retrofitting provides practical and sustainable path to mitigate surface heating, manage stormwater more effectively, and enhance user comfort, in the existing parking areas. It also aligns with global and regional sustainability targets in the built environment.
This paper presents climate-sensitive retrofit strategies designed specifically for Najran University, with a focus on affordability, durability, and long-term environmental benefit.

For clarity and ease of reference, Table 3 summarises all figures and tables included in this paper, indicating their placement within the manuscript and the type of content presented.

Table 3: Summary of Figures and Tables Included in the Paper.

No.	Title	Section Placement	Type
Figure 1	Existing Parking Lot Conditions	After Introduction	Photograph or site map illustrating present shading conditions and parking layout.
Figure 2	Proposed Retrofitted Parking Lot Concept	After Retrofitting Strategies	Conceptual illustration, schematic, or render showing proposed interventions
Table 1	Performance Comparison of Existing and Retrofitted	Results and Discussion	Comparative analysis of environmental, thermal,

	Parking Lot Conditions		and user comfort parameters
Table 2	Indicative Cost Framework for Retrofitting Measures	Cost and Implementation Considerations	Cost analysis table with typical unit costs and key considerations

Figure 1 illustrates the current conditions of Najran University's parking lots, highlighting asphalt surfaces and minimal shading that contribute to heat accumulation and reduced user comfort

Figure 1: Existing Parking Lot Conditions
Photograph or site map showing current parking layout, surface materials, and shading coverage

2. Climate Context: Najran's Hot Desert Environment
Najran's climate is defined by very hot summers, mild winters, and extremely low rainfall, an annual average of about 40–45 mm. During July, average high temperatures reach around 39°C, while winter nights can drop to 9–12°C. In summer, with reduced humidity levels, the area receives up to, 13 hours of sunshine, per day.

Extreme heat, as this, in addition to strong solar exposure, effects traditional asphalt pavements to reach surface temperatures, exceeding 60°C. These situations in addition to accelerating pavement deterioration, also reduces pedestrian comfort.
In contrast a great possibility for combining solar energy systems, like photovoltaic shade canopies, is provided, by the region's abundant sunshine.

While rare, rainfall, usually occurs, in intense, short bursts. Runoff management is quite critical, that designs must rank bioswales and permeable paving, to absorb sudden rain events, while saving water.
A successful retrofit design for Najran University parking lots, must stabilise thermal mitigation, water efficiency, and energy generation, in this context, as well as, using native vegetation and reduced-maintenance materials.

3. Retrofitting Strategies for Najran University
Practical, modular solutions that can be phased, in overtime, form the focus of the proposed retrofit framework. A major part of environmental performance, energy use, thermal comfort or hydrology, is addressed, by each strategy.

3.1. Surface and Material Interventions
High-Albedo (Cool) Surfacing: To lower heat absorption and advance pavement lifespan, replace or coat existing asphalt with reflective materials or light-color.

Permeable Pavements: In select contexts, during storm events, introduce interlocking concrete pavers or porous asphalt, to improve infiltration, minimise runoff, and reduce puddling.
Reinforced Turf Systems: To lower impervious surface coverage and maintain natural infiltration, use grass-grid modules, for overflow parking zones.

3.2. Shading and Vegetation
Native Shade Trees: To ensure shade, improve comfort, and lower reflected heat, plant drought-tolerant species, along parking rows and pedestrian paths.

PV Canopies: To generate electricity, while protecting cars and pedestrians from heat, add structural shading with renewable energy, through installation of solar panels over major parking areas.

Planted Bioswales: To collect runoff, filter pollutants, and support biodiversity, with minimal irrigation needs, establish vegetated islands and infiltration strips.

3.3. Stormwater and Hydrology Management

Infiltration Trenches and Tree Trenches: Through subsurface channels, promoting groundwater recharge, trap and filter stormwater.

Rain Gardens and Filter Strips: To treat and save runoff naturally, before it enters the drainage system, incorporate shallow planted basins.

3.4. Energy and Mobility Enhancements

EV-Ready Infrastructure: Powered by PV canopies, furnish select bays with electric vehicle charging points,

Efficient Lighting and Wayfinding: For energy effectiveness, install LED luminaires,
with reflective signage and shaded pedestrian walkways, for improved accessibility and safety. Figure 2 presents the proposed retrofitted design, including permeable paving, shade trees, bioswales, and photovoltaic canopies, demonstrating interventions aimed at reducing heat and enhancing sustainability

Figure 2: Proposed Retrofitted Parking Lot Concept
Render of the proposed retrofitted parking lot design or conceptual illustration, or schematic.
Source: Author's illustration 2025.

4. Results and Discussion

The present state of Najran University, greatly contributes to surface heat accumulation, and diminished user comfort; as revealed, based on the University's existing parking lot. Majority of parking areas provide little to no shading, from trees or other forms of vegetation, and are paved with traditional asphalt. Surface temperatures on peak summer days, can increase to around **54 °C**, as shown by field observations and thermal readings; establishing unfavorable thermal conditions for users, highlighting the **urban heat island** effect, around the campus. Additionally, the impermeable surfaces limit groundwater recharge, causing immense **stormwater runoff**, as well as stressing nearby drainage systems.

In order to improve user experience and environmental performance, the proposed **retrofitting measures** were assessed for their potentials. Incorporating **permeable paving, bioswales, high-albedo coatings and shade trees. were suggested to** reduce surface temperatures, to an estimated **37 °C,** by comparable field studies and simulation-based projections. To greatly enhancing pedestrian comfort and reduced heat exposure for parked vehicles, shade coverage is expected to increase beyond **60%**. The introduction of permeable surfaces would also improve infiltration, and elevate local cooling, through evapotranspiration, in addition to decrease stormwater runoff; majorly consisting routine surface cleaning and vegetation care; maintenance needs under the proposed design, remain moderate. Further supporting energy conservation, in nearby buildings, is the integration of reflective materials and vegetative shading; through moderation of ambient temperatures. The solutions not only provide broader **sustainability gains**, such as improved microclimate regulation and lowered energy demands, but also guarantee direct thermal benefits.

Summarised in **Table 1**, are the main outcomes of this assessment, contrasting the current and reconstructed parking lot conditions, beyond comfort-related, environmental and thermal parameters. Major environmental, thermal, and user comfort parameters are compared in Table 1, with the existing parking lots and proposed retrofitted models, that emphasise the anticipated growth

Table 1: Performance Comparison of Existing and Retrofitted Parking Lot Conditions at Najran University.

SN	Parameter	Existing Parking Lot	Retrofitted Parking Lot (Proposed)
1	Surface Material	Conventional asphalt	Permeable paving and reflective coating
2	Vegetation/Shade Coverage	< 10 %	> 60 % with trees and solar canopies
3	Surface Temperature (Peak Day)	54 °C	37 °C (estimated)

4	Stormwater Runoff	High	Greatly reduced due to permeable surfaces
5	Maintenance Requirement	Frequent re-asphalting	Moderate (surface cleaning, vegetation care)
6	User Thermal Comfort	Poor (high heat exposure)	Good (improved shading and air movement)
7	Sustainability Rating	Low	High

Comparative analysis of Najran University's existing, and retrofitted parking lot conditions.

The reconstruction model offers computable growth, beyond multiple proportions, as shown in Table 1. To enhance strength, comfort, and contextual efficacy, the integration of green and reflective infrastructure, modifying the parking areas, into **climate-responsive zones**. In dry regions conclusively, findings indicate, that while Najran University's parking reconstruction, combines environmental responsibility and practical functionality, it could be a **benchmark for sustainable campus development**.

5. Cost and Implementation Considerations

Retrofitting is most effective when implemented in phases, starting with high-impact, low-cost interventions and scaling up based on performance outcomes and budget availability.

6. Phased Implementation Plan

The implementation is provided in three progressive phases, to guarantee that the retrofitting solutions are effective and viable.

Phase 1. Pilot Project (Year 1):
As a testable site*; an* average-sized parking space, is chosen. The pilot stage is premised on evaluating methods, consisting planting shade trees, application of high-albedo surface coatings, installing permeable paving in select bays and introduction of a small bioswale. Before a broader adaptation, the objective is to evaluate practicability, refine the approach, collect user feedbacks.

Phase 2. Expansion (Years 2–3):
The retrofit program, will grow to larger parking areas. after positive findings is got from the first phase. The second phase, consists upgrading signage, lighting, introducing photovoltaic shade canopies, furnished with EV-ready charging points, as well as, pedestrian pathways. In addition to improving functionality and user experience, beyond campus, the solutions strive to enhance environmental benefits.

Phase 3. Full Integration (Year 3+):
Retrofitting measurements will be selected, for all resurfaced, new campus parking spaces. In the last phase, schedules of repairs is integrated, to provide lasting sustainability. Furthermore, to assess the environmental, energy and thermal outcomes, performance metrics will be observed. A well-coordinated, climate-responsive parking system, that improves sustainability and user comfort, will be possessed by the campus, at this level.

Summary of usual unit costs, including major reviews for executing the project retrofitting solutions, is shown in Table 2, guiding planning and budgeting.

Table 2: Indicative Cost Framework for Proposed Retrofitting Measures

	Retrofit Measure	Typical Unit Cost Range (USD)	Key Considerations for Najran
1	High-albedo coating (per m²)	8–12	Reduces surface temperature; fast to implement and affordable.
2	Permeable paving (per m²)	45–60	Increases infiltration and reduces runoff; suitable for moderate-use areas
3	Grass/turf-grid system (per m²)	30–40	Ideal for overflow or low-frequency parking zones
4	Shade trees + planter islands (per tree)	400–700	Use drought-tolerant native species; install drip irrigation.
5	PV shade canopies with EV chargers (per bay)	2,500–4,000	High initial cost but provides renewable energy and long-term shade benefits.
6	Bioswales / bioretention islands (per metre) .	250–400	Manage runoff naturally; low maintenance once established
7	LED lighting and wayfinding (per lot)	8,000–15,000	Improves visibility, safety, and energy efficiency.

Note. *Regional averages and sustainability-based construction data reflect cost estimates (Author's compilation, 2025).*

7. Expected Benefits

For the campus space and its users, the reconstructed parking lot framework, provides numerous benefits. The model lowers surface weather degrees and prevents, urban buildup of heat, through replacement of old asphalt, with surfaces that are breathable and reflective. To create a cooler and more inviting spaces; the addition of green islands and shade trees, increase convenience for visitors, students, staff. Through the use of permeable paving and bioswales, stormwater control is improved, reducing the potential for flooding and runoffs. Because of the reduced dependence on artificial cooling, in nearby buildings, energy consumption is lowered. The interventions altogether, show how thoughtful design, transfigures daily infrastructure, into climate-responsive benefits, leading to more aesthetically pleasing, sustainable, resilient, campus environment.

8. Conclusion

This work elevates the significance of retrofitted parking lots; as an aspect of a wider technique, to mitigate urban temperature, as well as improve sustainability in campus. Besides integrating reflective surfaces, permeable paving, solar canopies, and vegetation, the proposed model, addresses temperature control, as well as improved user comfort and promotion of sustainable energy use. Najran University can be a model, for climate-sensitive infrastructure development, through choosing these techniques, explicating how ordinary facilities, such as parking spaces, plays a central role, in establishing more resilient, livable campuses.

Acknowledgments

The kind assistance of Najran University, is sincerely acknowledge, by the authors; for permitting access to the site, data and facilities. Further appreciation is extended to the Nigerian Institute of Architects, and the University of Jos; for their academic collaborations.

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