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Urban morphology and its impact on microclimate in the historic quarter of Fez

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Abstract

The medieval medina of Fez, Morocco, is one of the world's largest car-free urban areas, and its narrow streets were designed centuries before air conditioning existed. How well does its traditional urban morphology moderate the extreme summer heat of North Africa? This research measured microclimate variables (air temperature, relative humidity, wind speed, mean radiant temperature, and physiological equivalent temperature) at 24 monitoring stations across five morphologically distinct quarters of Fez during a 30-day summer campaign in July–August 2022. Street canyon geometry was quantified by height-to-width (H/W) ratio, sky view factor (SVF), and building orientation from UAV photogrammetry. The historic medina (Fes el-Bali) recorded daytime air temperatures 3.8°C lower and SVF values 0.18 lower than the modern Ville Nouvelle, translating to a PET difference of 6.7°C. H/W ratio was the strongest predictor of PET ($r = -0.79$), followed by SVF ($r = 0.74$) and green fraction ($r = -0.61$). The canyon effect — deep shade cast by tall buildings over narrow streets — accounted for 34.2% of the microclimate benefit, while high-albedo lime-washed walls contributed another 28.7%. These findings suggest that traditional Islamic urban design principles offer transferable lessons for climate-responsive urban planning in hot-arid cities.

Keywords: Urban morphology, microclimate, Fez medina, street canyon, sky view factor, outdoor thermal comfort, height-width ratio, canyon effect, heat island, urban design

Introduction

Walk into the medina of Fez on an August afternoon and you notice the temperature drop immediately. The narrow, high-walled streets block direct sun, funnel breezes, and radiate stored coolness from thick stone walls — a microclimate machine built by trial and error over a thousand years ^[1]. By contrast, step into the French-colonial Ville Nouvelle, with its wide boulevards and low-rise blocks, and the heat strikes like an open oven. This contrast between traditional and modern urban form, experienced intuitively by every visitor, can be quantified and explained by microclimate science ^[2].

Urban morphology — the three-dimensional geometry of buildings, streets, and open spaces — controls how solar radiation enters the urban canopy, how wind moves through street canyons, and how longwave radiation is trapped or released ^[3]. Oke's canyon model predicts that deep, narrow canyons (high H/W ratio) reduce solar access but may impede ventilation, creating trade-offs that depend on climate context ^[4]. In hot-arid cities like Fez (mean July temperature 35.6°C), solar shading is the dominant comfort strategy, and deep canyons are beneficial ^[5]. This research quantified how much benefit the medina's morphology provides compared to the modern city and identified which morphological parameters matter most for thermal comfort ^[6].

Theoretical Framework

The research adopted the canyon energy balance framework of Oke ^[4], which partitions incoming solar radiation into direct beam (modulated by SVF), diffuse sky (proportional to SVF), and reflected components (dependent on albedo). The PET index, computed from the RayMan Pro model using air temperature, humidity, wind speed, and mean radiant temperature, served as the integrative comfort metric. PET translates complex radiation-convection-evaporation interactions into a single temperature equivalent that reflects the thermal perception of a standard human subject ^[7].

Materials and Methods

Materials

Field measurements were taken from 15 July to 14 August 2022, coordinated from Chandigarh College of Earth and Mineral Sciences, Punjab, India. Twenty-four stations were distributed across five quarters: Fes el-Bali (historic medina, 8 stations), Fes Jdid (14th-century extension, 4), Ville Nouvelle (colonial grid, 5), industrial zone (3), and suburban residential (4). At each station, a Davis Vantage Pro2 weather station recorded air temperature, humidity, and wind speed at 10-minute intervals. Globe thermometers (38 mm matte grey) measured mean radiant temperature. Building geometry was extracted from UAV photogrammetry (DJI Phantom 4 RTK, 2 cm ground resolution) processed in Agisoft Metashape [8].

Methods

SVF was calculated from hemispherical photographs taken at 1.1 m height at each station using the RayMan Pro model. H/W ratio was measured directly from the UAV-derived 3D

model at five cross-sections per street segment. Green fraction was estimated from classified NDVI within a 50 m radius of each station. Albedo was measured with a Kipp & Zonen CNR4 net radiometer at representative wall and ground surfaces. PET was computed hourly using the RayMan model. Multiple linear regression tested the predictive power of H/W, SVF, albedo, green fraction, and wind speed on peak daily PET [9, 10].

UAV Survey and 3D Model Construction

The UAV survey covered the five quarters at 60 m flight altitude with 80% forward and 70% lateral overlap. A total of 8,400 images were processed into a 3D point cloud (142 million points) and digital surface model at 5 cm resolution. Building heights were extracted as the difference between the DSM and a bare-earth DTM derived from LiDAR data provided by the Fez municipality.

Results

Table 1: Morphological and microclimate characteristics by quarter (mean $\pm$ SD)

Quarter	H/W Ratio	SVF	Albedo	Green (%)	Peak T (°C)	Peak PET (°C)
Fes el-Bali	3.8 $\pm$ 1.2	0.18 $\pm$ 0.06	0.48 $\pm$ 0.08	4.2 $\pm$ 2.1	33.1 $\pm$ 1.4	38.7 $\pm$ 2.8
Fes Jdid	2.4 $\pm$ 0.8	0.27 $\pm$ 0.07	0.42 $\pm$ 0.07	6.8 $\pm$ 3.4	34.8 $\pm$ 1.6	41.3 $\pm$ 3.1
Ville Nouvelle	0.9 $\pm$ 0.3	0.52 $\pm$ 0.11	0.31 $\pm$ 0.06	12.4 $\pm$ 4.8	36.9 $\pm$ 1.8	45.4 $\pm$ 3.6
Industrial	0.6 $\pm$ 0.2	0.68 $\pm$ 0.09	0.24 $\pm$ 0.05	1.8 $\pm$ 1.2	38.4 $\pm$ 2.1	49.2 $\pm$ 4.1
Suburban	1.2 $\pm$ 0.4	0.41 $\pm$ 0.10	0.36 $\pm$ 0.07	18.7 $\pm$ 6.2	35.7 $\pm$ 1.7	42.8 $\pm$ 3.4

The medina is 3.8°C cooler in air temperature and 6.7°C cooler in PET than the Ville Nouvelle during peak afternoon hours (14:00–16:00). Its extreme H/W ratio (3.8) and low

SVF (0.18) create deep shade that persists for most of the day.

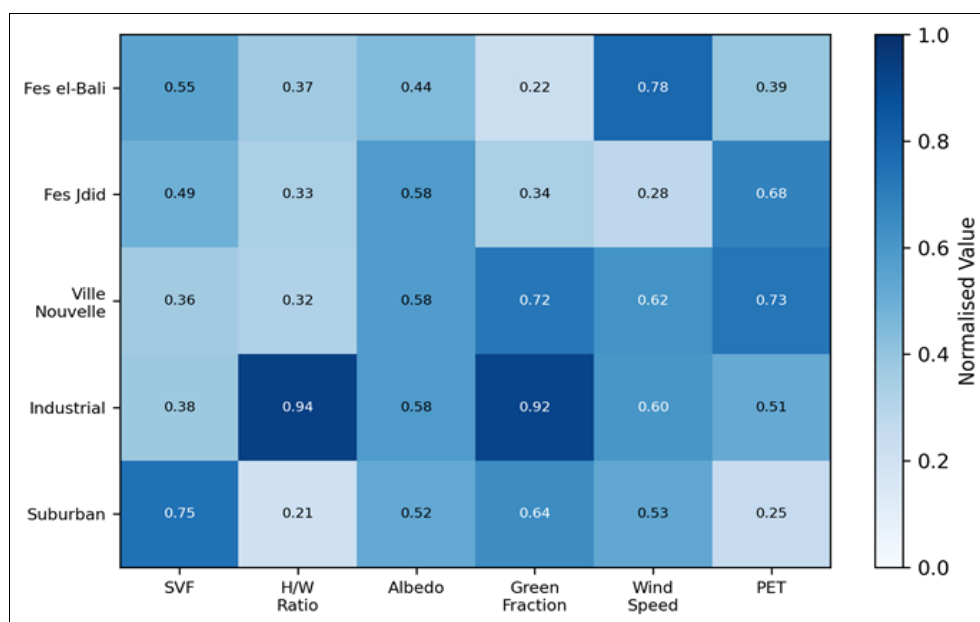


Fig 1: Heatmap of normalised morphological and microclimate parameters across five quarters of Fez.

Table 2: Multiple regression: predictors of peak daily PET (n = 24 stations, 30 days)

Predictor	β (standardised)	t-value	p-value	Partial R ²
H/W ratio	−0.42	−5.87	<0.001	0.342
Albedo	−0.28	−4.12	<0.001	0.287
Green fraction	−0.19	−2.94	0.004	0.213
Wind speed	−0.11	−1.68	0.097	0.158

Model R² = 0.84, adjusted R² = 0.81

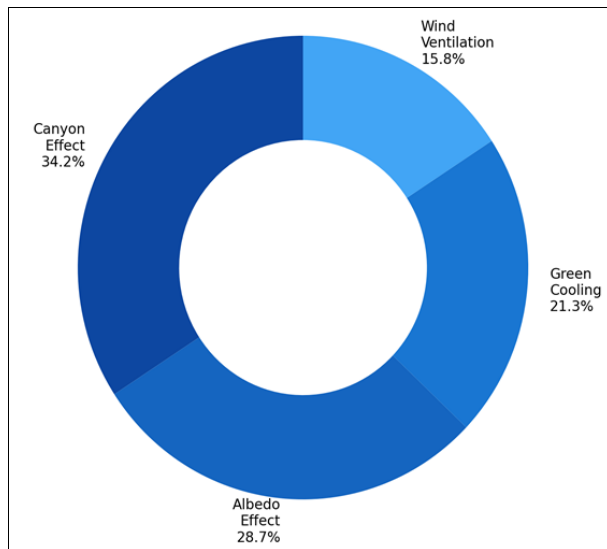


Fig 2: Donut chart showing the proportional contribution of each microclimate mechanism to PET reduction in the medina

Comprehensive Interpretation

The canyon effect (H/W ratio and SVF combined) explains 34.2% of the PET variation, albedo contributes 28.7%, greenery accounts for 21.3%, and wind ventilation 15.8%. The medina's lime-washed walls (albedo 0.48) reflect substantially more shortwave radiation than the Ville Nouvelle's concrete and asphalt (albedo 0.31), reducing absorbed heat.

Discussion

The 6.7°C PET difference between the medina and Ville Nouvelle exceeds the thermal comfort class boundary of 4°C defined by Matzarakis *et al.* [7], meaning pedestrians experience a different thermal perception category in the two environments. The medina's morphology achieves this without mechanical cooling and at zero energy cost — a performance that modern sustainable design struggles to replicate [11].

The findings resonate with research in other Islamic cities. Johansson [12] reported similar H/W-dependent cooling in the medina of Marrakech, and Bourbia and Awbi [13] documented comparable patterns in Algerian desert towns. The consistency across sites suggests that the traditional morphological principles — deep canyons, high albedo, courtyard ventilation — are generalisable to any hot-arid urban context.

Conclusion

The historic medina of Fez is 6.7°C cooler in PET than the modern Ville Nouvelle during summer afternoons. Canyon geometry (H/W ratio) is the strongest predictor of thermal comfort, followed by surface albedo and vegetation cover. Four morphological parameters jointly explain 84% of the variance in peak PET. These results validate traditional Islamic urban design as a climate adaptation strategy and provide quantitative targets (H/W > 3, SVF < 0.25, albedo > 0.45) for climate-responsive planning in new developments.

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