تقييم الراحة الحرارية الخارجية في النسيج العمراني الإسلامي: دراسة حالة القصبة في الجزائر
Quantifying Outdoor Thermal Comfort in Islamic Urban Fabrics: A Case Study of the Algiers Casbah

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Acknowledgment

Department of Civil and Architectural Engineering
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UNIVERSITÉ DE LIEGE
COLLEGE DE DE DOCTORAT EN ART
DE BÂTIR ET URBANISME

UNIVERSITÉ DE BLIDA
INSTITUT D'ARCHITECTURE ET
D'URBANISME

Hicham Fawzi Arrar

Thermal analysis and environmental assessment of urban quality in a Mediterranean climate.
"Case of the medina of Algiers"

Introduction

Climate challenges and the conservation of historic Mediterranean cities

- **Ancient cities are sensitive to climate disruptions**

- **Increased risks: overheating, material vulnerability**

- **Need for an integrated climate/heritage approach**

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Climate challenges and the conservation of historic Mediterranean cities

- **A listed and fragile urban fabric**

- **Morphology inherited from bioclimatic urban planning**

- **Increasing exposure to thermal stress**

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Traditional Islamic Architecture

المسجد النبوي, المدينة المنورة

بيوت دمشق

جنة العريف, غرناطة

دير القمر, لبنان

عكّا ,خان الأعمدة

القاهرة ,بيت السحيمي

Climate challenges and the conservation of historic Mediterranean cities

• **Organic morphology, narrow alleys, patios**

• **Materials with high thermal inertia**

• **Spatial organization conducive to climate mitigation**

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Climate challenges and the conservation of historic Mediterranean cities

• **Rising temperatures, increased heatwaves**

• **Degradation of the thermal performance of historic fabrics**

• **Conflict between regulatory conservation and adaptation needs**
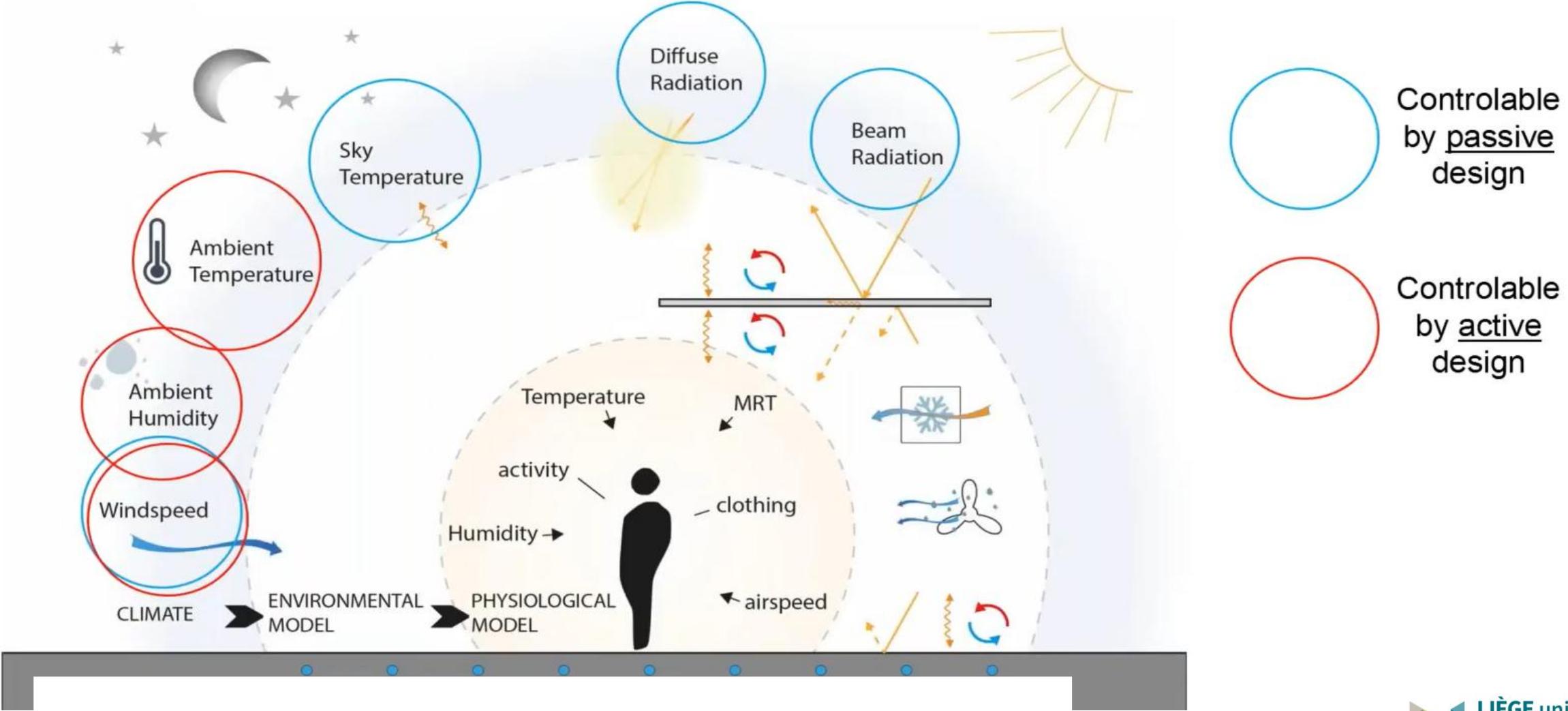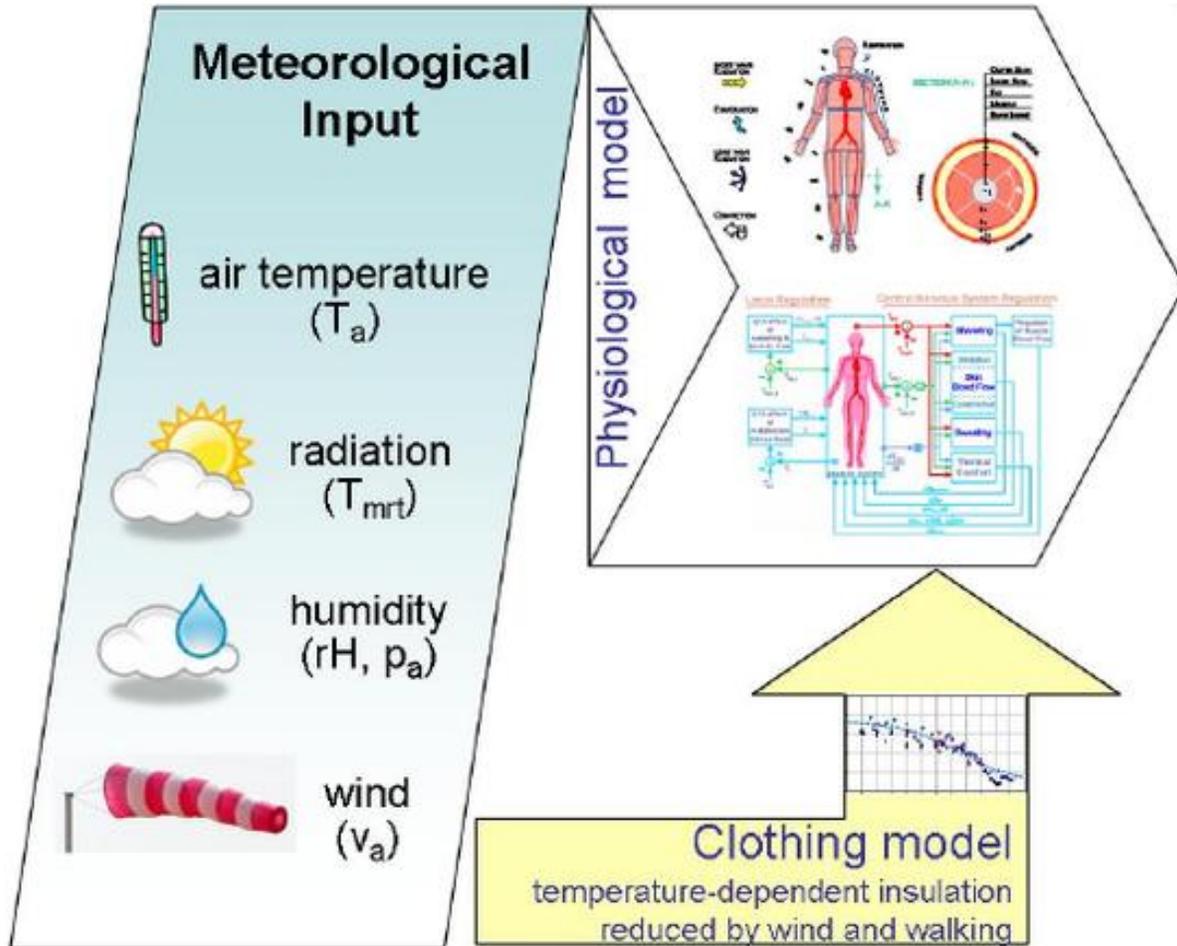

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Fundamentals of
Outdoor Thermal Comfort

Outdoor Comfort – Modelling Principles

Comfort Index – What is PET?

Thermo-Physiological Response of the human body

PET [°C]	Thermal sensation	Level of thermal stress
< 4°C	very cold	extreme cold stress
4.1 - 8°C	cold	strong cold stress
8.1 - 13°C	cool	moderate cold stress
13.1 - 18°C	slightly cool	slight cold stress
18.1 - 23°C	**neutral (comfortable)**	**no thermal stress**
23.1 - 29°C	slightly warm	slight heat stress
29.1 - 35°C	warm	moderate heat stress
35.1 - 41°C	hot	strong heat stress
41°C >	very hot	extreme heat stress

Influencing Factors

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Comfort Index – Why PET?

• **The PET index (Physiologically Equivalent Temperature) was chosen because it provides a realistic assessment of outdoor thermal comfort, particularly in Mediterranean climates.**

• **It is based on the MEMI model (Munich Energy Balance Model for Individuals), which considers the complete thermal balance of the human body, including radiative, convective, evaporative, and metabolic exchanges.**

• **Unlike other indices, PET integrates the key microclimatic parameters - air temperature, humidity, wind speed, and solar radiation - and allows for a detailed analysis of perceived comfort by accounting for the actual thermal behavior of individuals.**

• **It is also compatible with ENVI-met and expressed in degrees Celsius (°C), which makes its interpretation easier for urban planners and decision-makers.**

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Outdoor Comfort Strategies

SUN
NO WIND

①
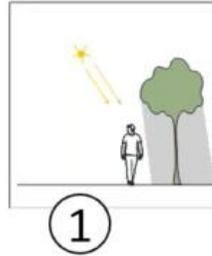
Air Temperature	30°C
Air Humidity	17.2 g/kg
Mean Radiation Temp.	**50°C**
Air Velocity	still
Clothing	0.5
Activity	135 W/m²

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Outdoor Comfort Strategies
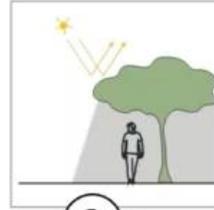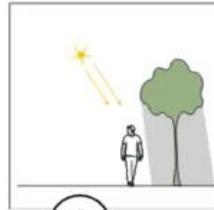
	SUN NO WIND	SHADE NO WIND
	①	②
Air Temperature	30°C	30°C
Air Humidity	17.2 g/kg	17.2 g/kg
Mean Radiation Temp.	**50°C**	**35°C**
Air Velocity	still	still
Clothing	0.5	0.5
Activity	135 W/m²	135 W/m²

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Outdoor Comfort Strategies
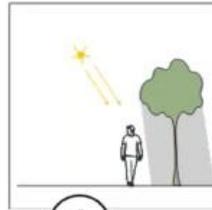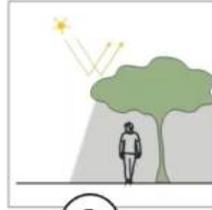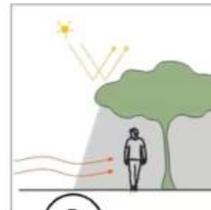
	SUN NO WIND	SHADE NO WIND	SHADE BREEZE
	①	②	③
Air Temperature	30°C	30°C	Reduce heat stress
Air Humidity	17.2 g/kg	17.2 g/kg	Reduce cold stress
Mean Radiation Temp.	**50°C**	**35°C**	35°C
Air Velocity	still	still	**breeze**
Clothing	0.5	0.5	0.5
Activity	135 W/m²	135 W/m²	135 W/m²

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Outdoor Comfort Strategies

	SUN NO WIND	SHADE NO WIND	SHADE BREEZE	SHELTERED DRY MIST
	①	②	③	④
Air Temperature	30°C	30°C	Reduce heat stress	26.5°C
Air Humidity	17.2 g/kg	17.2 g/kg	Reduce cold stress	18.6 g/kg
Mean Radiation Temp.	**50°C**	**35°C**	35°C	35°C
Air Velocity	still	still	breeze	elevated
Clothing	0.5	0.5	0.5	0.5
Activity	135 W/m²	135 W/m²	135 W/m²	135 W/m²
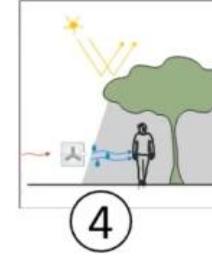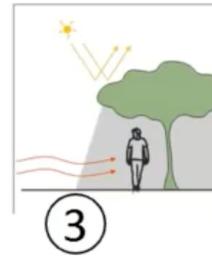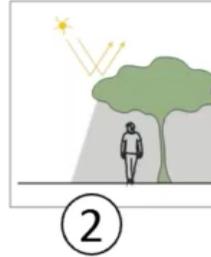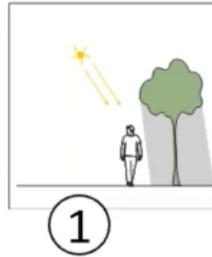
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Data Collection & Measurement

Measurement Period 1

Number of measurement points
- **14 representative points** in the Upper Casbah (considering **SVF** *[Sky View Factor]*, orientation, street width, etc.)
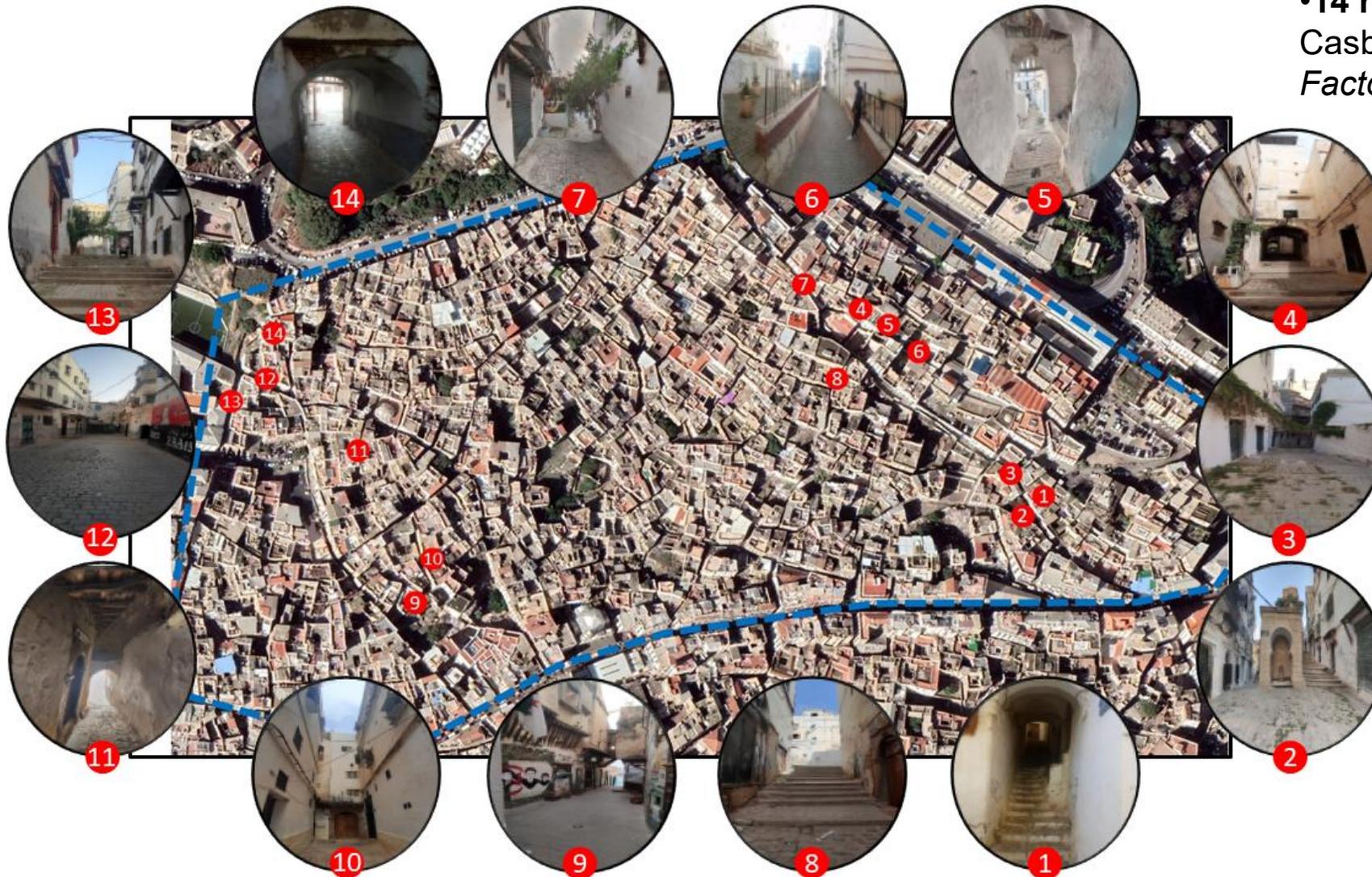
Microclimate Measurement Protocol

Fish-Eye Images Parameters				
Camera	**Focal length**	**Resolution**	**Dimensions**	**Colors representation**
(a) Canon EOS 1100 D	32mm	230000 pixels	4272 x 2848	sRGB

(a)

(b)

Meteorological Data Parameters				
Variable	**Device**	**Unit**	**Accuracy**	**Range**
(b) Air temperature (Ta)	Testo 175H1	°C	± 0.4 °C	-20 to +55 °C
(b) Relative Humidity (RH)	Testo 175H1	°C	± 2%	0 to 100 %RH*
(c) Wind Speed (Ws)	PEAKMETER PM6252A	m/s	± 0,1m/s	0.2 to 30.0 m/s
(d) Surface temperature (Ts)	Testo 830-T2	°C	±1.5 °C	-30 to +400 °C

(c)

(d)

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Microclimate Questionnaire

Renseignements personnels:

Genre

Homme ☐ Femme ☐

Résident ☐ Visiteur ☐

Âge: .... Poids: .... Kg Taille: ....cm

Données sur l'état de santé:

Évaluations de l'état de santé:

Faible ☐ Moyen ☐ Bon ☐

Vêtements:

Décrivez le type de vêtements que vous portez actuellement:

Vêtements légers ☐   Vêtements moyens ☐   Vêtements rugueux ☐

Paramètres climatiques :

Question : Paramètres influents sur votre confort quotidien :

- Température de l'air ① ② ③ ④ ⑤
- Humidité ① ② ③ ④ ⑤
- Vent ① ② ③ ④ ⑤
- Ensoleillement ① ② ③ ④ ⑤
- Ombrage ① ② ③ ④ ⑤

3 – Sabat :   Photo :

vous trouvez que température de l'air est ? :

| Insatisfaisant | -3 | -2 | -1 | 0 | 1 | 2 | 3 | Satisfaisant |

vous trouvez que l'humidité est ? :

| Insatisfaisant | -3 | -2 | -1 | 0 | 1 | 2 | 3 | Satisfaisant |

vous trouvez que le vent est ? :

| Insatisfaisant | -3 | -2 | -1 | 0 | 1 | 2 | 3 | Satisfaisant |

vous trouvez que l'ensoleillement est ? :

| Insatisfaisant | -3 | -2 | -1 | 0 | 1 | 2 | 3 | Satisfaisant |

vous trouvez que l'ombre est ? :

| Insatisfaisant | -3 | -2 | -1 | 0 | 1 | 2 | 3 | Satisfaisant |

Modeling and Calculation Methods

Software Used

RayMan Pro 3.1 - for calculating **Mean Radiant Temperature (Tmrt)** and **Physiologically Equivalent Temperature (PET)**.

Inputs:
•Meteorological data (air temperature, humidity, wind speed)
•**SVF (Sky View Factor)**
•Geographic coordinates (latitude, longitude, altitude)

Output:
•**Nine comfort classes**, ranging from **very cold** to **very hot**, representing different levels of outdoor thermal sensation.

				Summer	Day: 7	12 P.M
Unit	°C	%	m/s	°C	°C	°C
Points	Ta	HR	Ws	TGround	TWall 1	TWall 2
1	18.5	71.6	1.4	18.1	18.0	17.9
2	20.0	66.7	0.3	18.0	18.2	18.1
3	19.1	69.2	1.1	18.6	18.5	18.2
4	19.0	69.1	0.1	18.3	18.3	18.2
5	18.1	72.0	1.1	18.1	18.0	17.7
6	19.1	69.5	0.2	21.5	20.4	19.9
7	19.1	70.0	0.1	18.1	17.9	17.6
8	19.8	67.2	1.4	19.0	18.6	18.5
9	18.6	70.9	1.5	18.1	18.0	18.0
10	19.4	68.8	0.0	18.1	18.2	18.0
11	18.7	70.0	0.7	18.0	18.0	17.9
12	19.0	68.8	0.7	17.9	18.7	18.5
13	18.9	68.8	1.2	19.2	18.9	18.7
14	19	69.1	2.0	18.6	18.5	18.6

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Results

Assessment of the outdoor thermal comfort level stress via PET index in the 14 study cases in August 2021.

Thermal sensitivity	Grade of physiological Stress	Mid/West Europe	Csa Mediterranean
		(Matzarakis,1999) (Matzarakis A, et al., 1999)	**(Potchter et al., 2018)** (Potchter et al., 2018a)
		Cfb	Csa
Very Cold	**Extreme cold stress**	< 4	< 8
Cold	**Strong cold stress**	4 – 8	8 – 12
Cool	**Moderate cold stress**	8 – 13	12 – 15
Slightly Cool	**Slight cold stress**	13 – 18	15 – 19
Neutral	**No thermal stress**	18 – 23	19 – 26
Slightly warm	**Slight heat stress**	23 – 29	26 – 28
Warm	**Moderate heat stress**	29 – 35	28 – 34
Hot	**Strong heat stress**	35 – 41	34 – 40
Extremely hot	**Extreme heat stress**	> 41	> 40

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Results PET – January

Assessment of the outdoor thermal comfort level stress via PET index in the 14 study cases in January 2021.

District	Measurement point	PET 6:00 am	PET 8:00 am	PET 10:00 am	PET 12:00 pm	PET 2:00 pm	PET 4:00 pm	PET 6:00 pm	PET 8:00 pm
	1	18	17.4	21.3	25.5	24.5	22	17.6	15.9
	2	17.1	17.7	22	29.5	26.7	22.1	17	16.2
	3	17.3	16.5	22.7	28.7	25.1	21.8	16.9	17
	4	17.4	18.6	22.8	27.7	26	23.1	19	17.4
	5	17.6	16.1	19.4	25	23.8	21.5	17	16.4
	6	14.8	14.8	22.8	29	23.6	18.7	14.8	14.7
	7	16.5	16.6	21.9	26.9	28.2	22.3	16.5	16.6
	8	16.8	16.9	21.5	25.5	23.3	20.9	17.7	14.9
	9	18.5	18.5	22.7	26.5	24.9	22.7	18	18.4
Casbah of Algiers	10	18.8	18.7	24.4	28.8	28.4	24.1	18.5	18.9
	11	18.9	18.4	23.4	27.3	27.1	23.5	18.4	18.3
	12	16.4	15.3	19.8	24.9	23.4	21.2	15.5	14.5
	13	17.7	15.9	21.7	26.1	22.8	20	16.8	15.1
	14	17	15.6	20.6	25.2	22.3	20.3	17.1	15.4

|	12 − 15	15 − 19		19 − 26		26 − 28		28 − 34	
Thermal comfort	Cool	Slightly Cool		Neutral		Slightly warm		Warm	
Stress level	Moderate cold stress	Slight cold stress		No thermal stress		Slight heat stress		Moderate heat stress	

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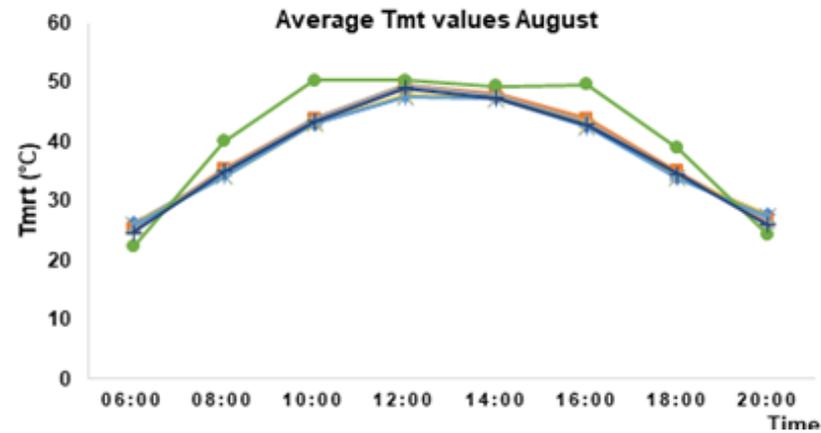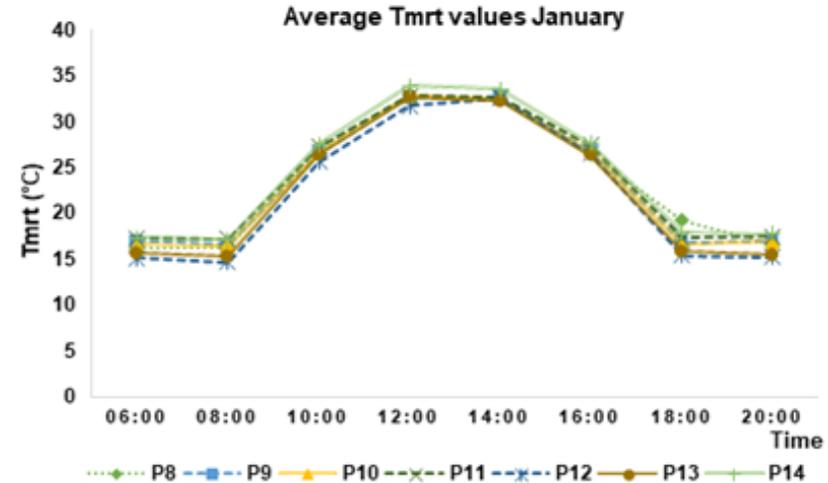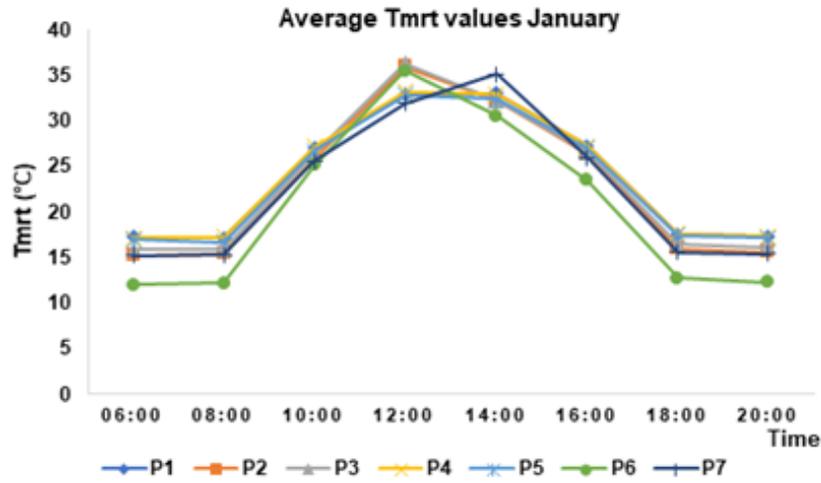SBD Lab

Results PET – August

Assessment of the outdoor thermal comfort level stress via PET index in the 14 study cases in August 2021.

District	Measurement point	PET 6:00 am	PET 8:00 am	PET 10:00 am	PET 12:00 pm	PET 2:00 pm	PET 4:00 pm	PET 6:00 pm	PET 8:00 pm
	1	27.2	32.8	38	41.1	41.2	37.9	32.7	29.1
	2	26.5	33.2	39.2	42.1	41.7	39.1	33.3	28.3
	3	27.1	33.1	38.8	42.3	40.4	38.3	33.1	28.4
	4	26.8	31.9	37.1	40.7	39.9	37.1	32.5	28.5
	5	26	32	37.7	39	39.5	37.3	32.5	28.6
	6	24.8	35.8	42.1	42.7	38.2	41.2	33.7	26.3
	7	26.2	32.9	37.8	41.4	40.8	37.4	33.1	27.8
	8	26.9	33	37.5	42.3	40.9	37.3	32.4	28.3
	9	27.1	31.6	36.6	39.8	38.4	36.7	32.7	28.7
Casbah of Algiers	10	27.8	32.8	38.7	42.2	41	38.3	32.9	28.8
	11	27.9	32.8	39.2	41.8	41.2	38	32.8	28.9
	12	26.6	34.9	40.6	41.5	40.6	41.3	34.9	28.2
	13	26.1	32.1	37.2	39.5	39.9	36.2	32	28.1
	14	27.4	32.1	37	40.2	40.4	38.1	32.7	28.4

19 - 26	26 - 28	28 - 34	34 - 40	> 40
Neutral	Slightly warm	Warm	Hot	Extremely hot

Thermal

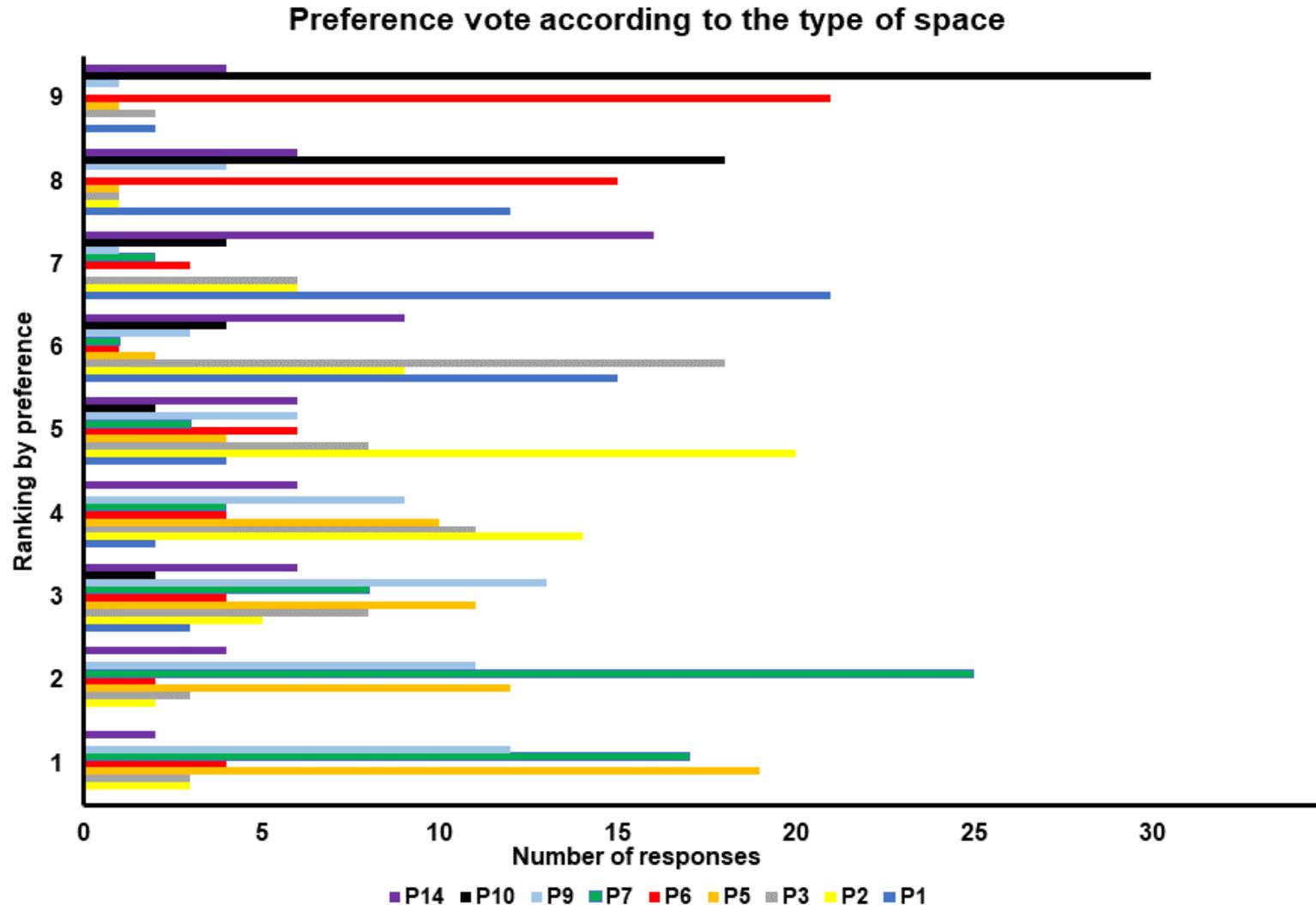reme heat stress

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Results PET – Tmrt

Assessment of the outdoor thermal comfort level stress via PET index in the 14 study cases in August 2021.
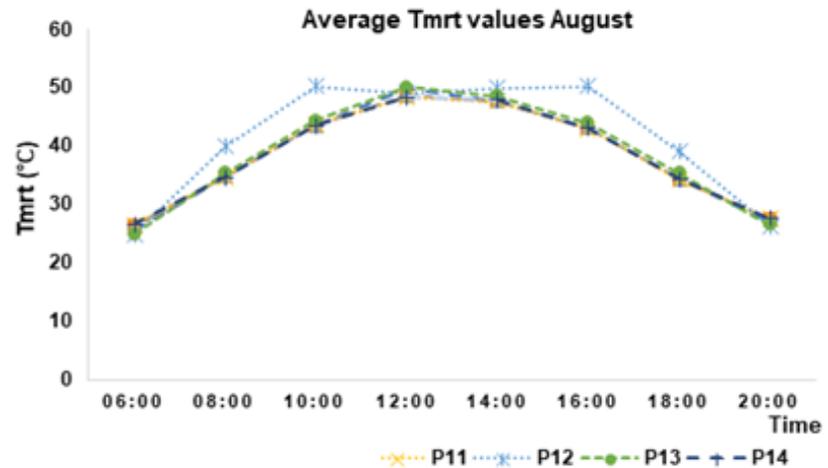
Results PET – Questionnaire

Assessment of the outdoor thermal comfort level stress via PET index in the 14 study cases in August 2021.

Preference vote according to the type of space

Results PET – Sky View Factor

Effect of the Sky View Factor on PET and Tmrt
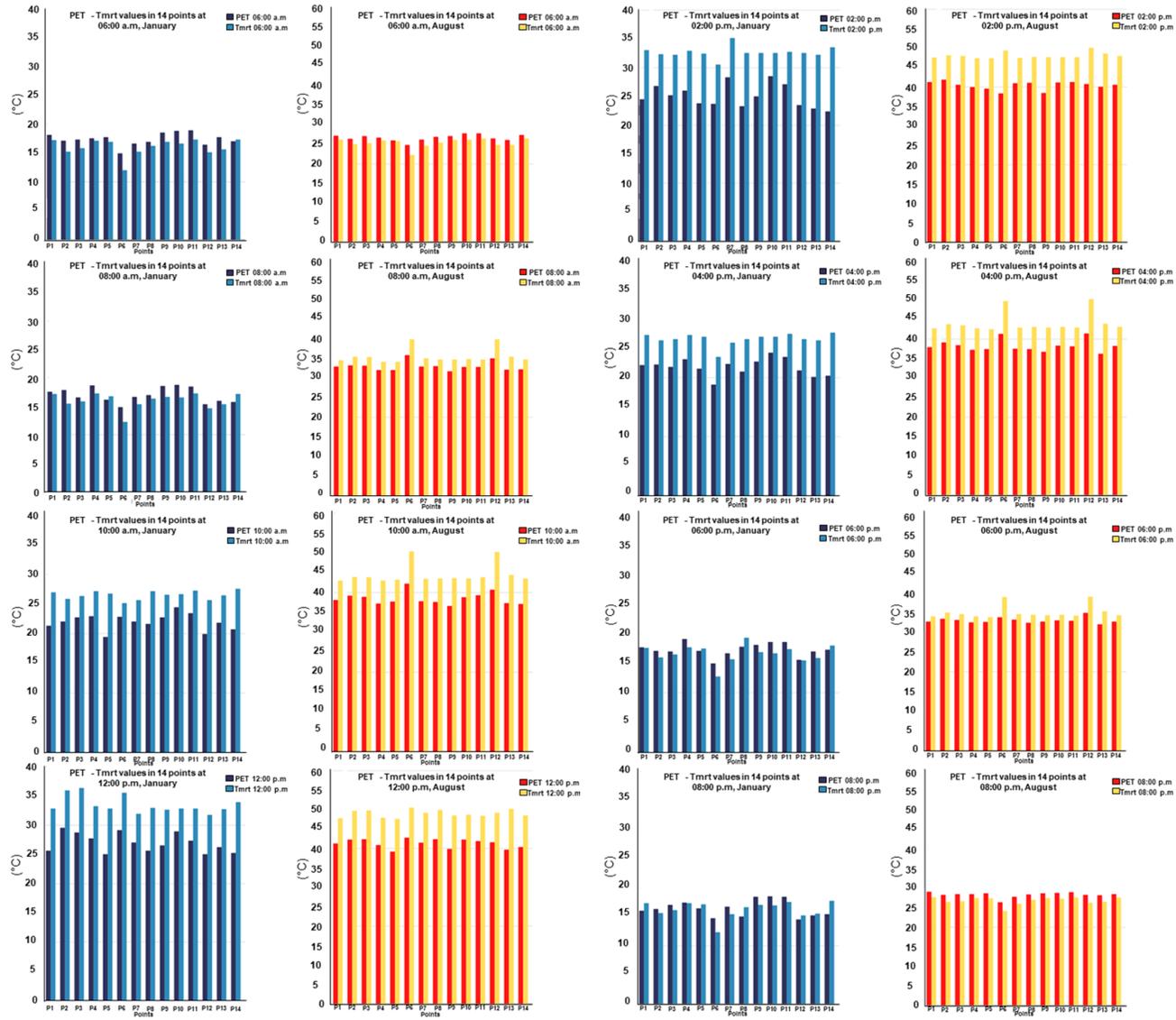
Discussion

In-situ measurements and local microclimatic analysis

Covered passages and low Sky View Factor (SVF): an optimal microclimate
Covered passages and streets with a low Sky View Factor (SVF) provide excellent thermal comfort in both summer and winter.
In summer, they are up to 2°C cooler than open spaces, thanks to shading and localized airflows.
In winter, heat is better retained through air destratification, with temperature differences reaching 3.7°C compared to other zones.

Open spaces: a source of thermal discomfort
Points 6 and 12 are identified as the most thermally uncomfortable, both in winter and summer.
Point 6 suffers from strong solar exposure due to collapsed buildings, while Point 12 combines a north–south orientation, high sky exposure, and multiple intersections.
A structural rehabilitation and the addition of hanging vegetation are strongly recommended to improve shading and reduce heat.

Correlation between Tmrt and SVF by season
In winter, a strong negative correlation (r = –0.96) indicates that more enclosed spaces are warmer, as they retain heat.
In summer, the correlation becomes positive (r = 0.82): the more open a space is, the more solar radiation it receives, increasing thermal stress.
These results highlight the importance of shading as a key factor in controlling mean radiant temperature (Tmrt).

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In-situ measurements and local microclimatic analysis

Limited effectiveness of the sea breeze at the local scale

Despite the proximity to the sea, the effect of the sea breeze remains limited. The measured wind speeds are low, leading to stagnant humidity. However, notable variations are observed between adjacent points (P12 and P13), influenced by orientation, wind velocity, and the presence of hanging vegetation, which demonstrates the impact of traditional urban morphology on local microclimate conditions.

Validation of results through a field survey

A survey conducted among residents confirmed the climatic data. Points 6 and 10 were perceived as the most uncomfortable, aligning with the recorded PET values.

Relative humidity emerged as the most disturbing factor for users, intensifying discomfort during hot periods.

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Conclusion

Conclusion

Comfort indices translate microclimate physics into human perception; reliability depends on accurate Tmrt and wind modeling.

1. Which parameters are most sensitive to design changes?
2. How can they be measured in a historical site?

References

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