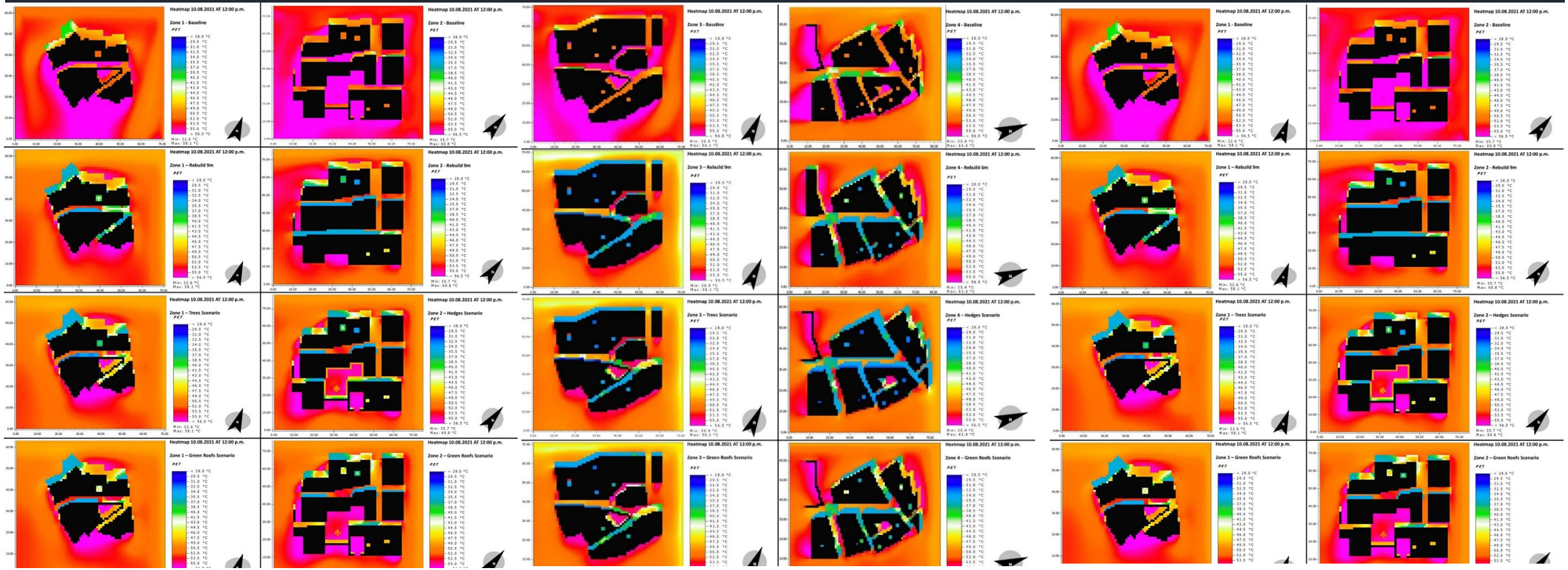
نمذجة المناخ الحضري ومرونة النسيج العمراني في العمارة الإسلامية

Urban Climate Modelling and Morphological Resilience in Islamic Urban Fabrics



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Acknowledgment

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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

Motivation and expected impacts

- **Reconcile heritage conservation and outdoor thermal comfort**

- **Develop a reproducible and quantifiable methodological framework**

- **Provide operational recommendations for rehabilitation stakeholders**

Fawzi Hicham Arrar

Milestones

- **On-site measurements and local microclimatic analysis**
- **Study of future climate scenarios**
- **Integration of nature-based solutions**

Fawzi Hicham Arrar

Objectives

Methodological development

1. Develop an innovative methodology for the urban rehabilitation of historic fabrics, based on a multicriteria algorithm integrating thermal comfort and heritage constraints.

Quantification of thermal comfort

2. Measure the current levels of outdoor thermal comfort in the Casbah of Algiers using on-site observations and numerical simulations.

Evaluation of adaptation strategies

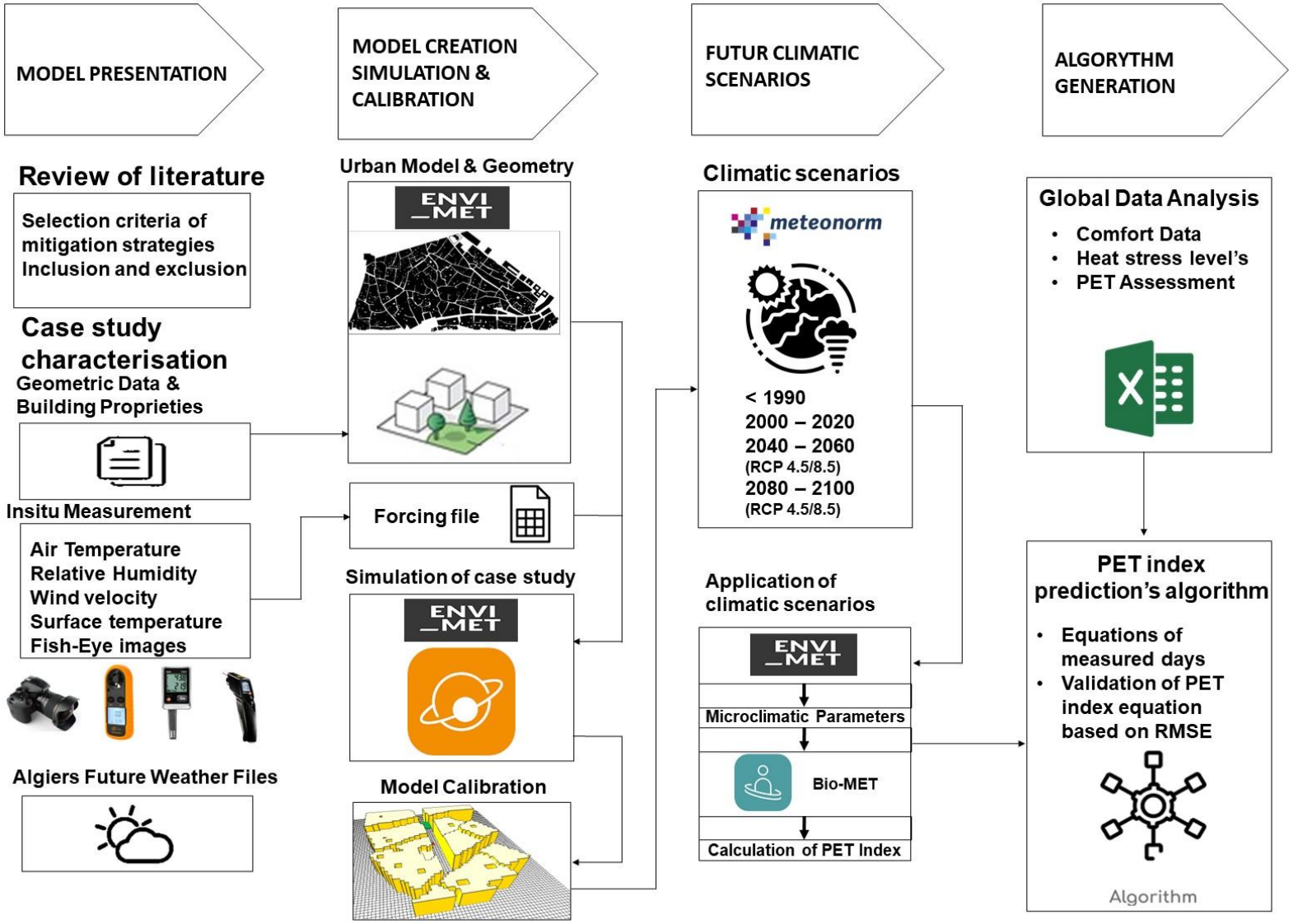
3. Analyze the effect of passive strategies and nature-based solutions (NBS) on thermal comfort and environmental impacts in a historical context.

Sustainable decision-making framework

4. Propose a decision-making framework applicable to sustainable rehabilitation, reconciling heritage conservation with resilience to climate change.

Modelling Urban Climate

Methodology



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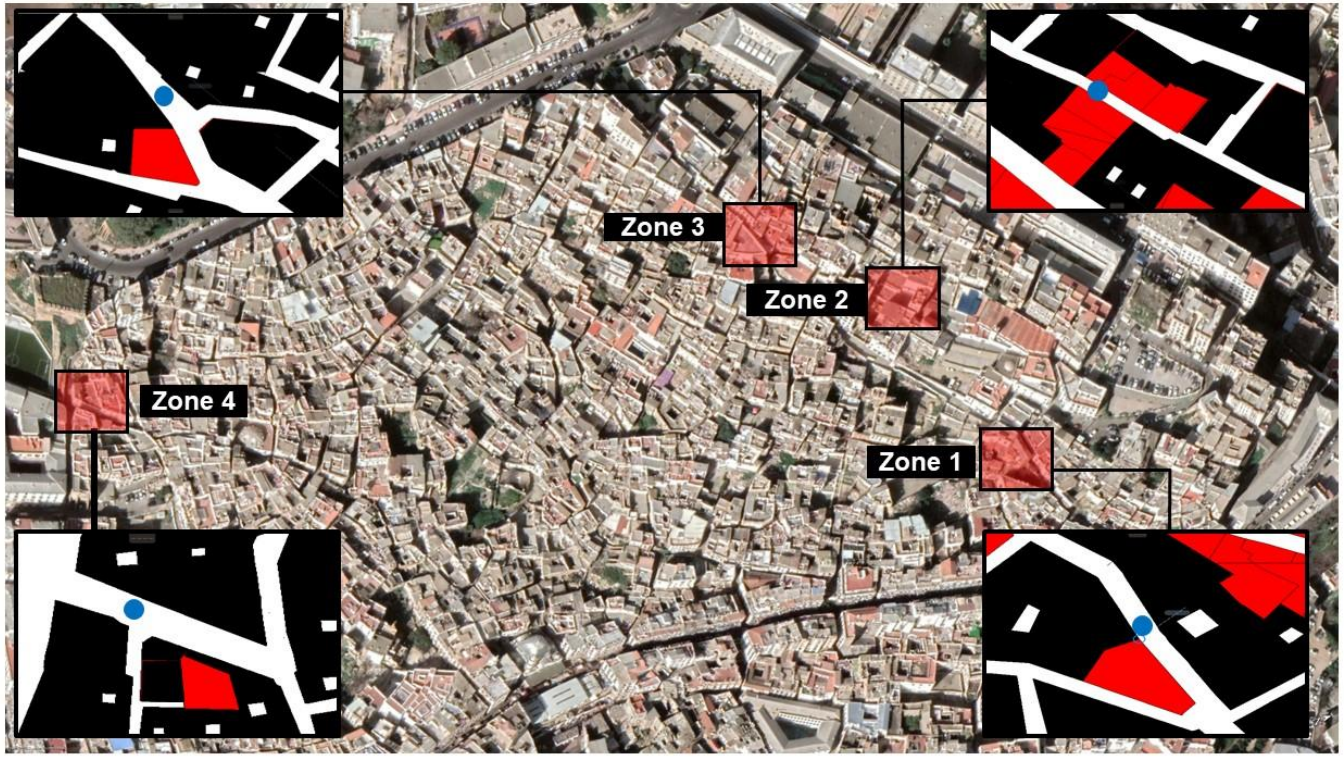
Methodology – Measurements Campaign

Measurement location	Morphological characteristics	Sky view factor	
		Image	Value
Zone 1	Street direction: E-W Width: 2.80 m Height: 11.30 m Canyon Hard surface texture (Granite)		0.18
Zone 2	Street direction: N-S Width: 18.6 m Height: 8.10 m Exposed to direct solar radiation Hard surface texture (Granite/Concrete) Small Palm		0.56
Zone 3	Street direction: E-W Width: 3.95 m Height: 8.20 m Canyon Hard surface texture (Granite) Small vegetation		0.24
Zone 4	Street direction: N-S Width: 4.90 m Height: 8.95 m Exposed to direct solar radiation Hard surface texture (Granite)		0.29



On-site measurement campaigns: August 2021

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Methodology – Measurements Campaign

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

Meteorological Data Parameters					
	Variable	Device	Unit	Accuracy	Range
(b)	Air temperature (T_a)	Testo 175H1	°C	± 0.4 °C	-20 to +55 °C
(b)	Relative Humidity (R_H)	Testo 175H1	°C	± 2%	0 to 100 %RH*
(c)	Wind Veloc(Bruse 2004)ity (V_a)	PEAKMETER PM6252A	m/s	± 0,1m/s	0.2 to 30.0 m/s
(d)	Surface temperature (T_s)	Testo 830-T2	°C	±1.5 °C	-30 to +400 °C

The study areas were selected according to the following criteria:

•Vulnerability of zones during the summer period based on the thermal comfort quantification study in the Casbah of Algiers (Arrar et al., 2022)

•The main and most frequented street of the neighborhood

•Presence of collapsed houses – potential for rehabilitation

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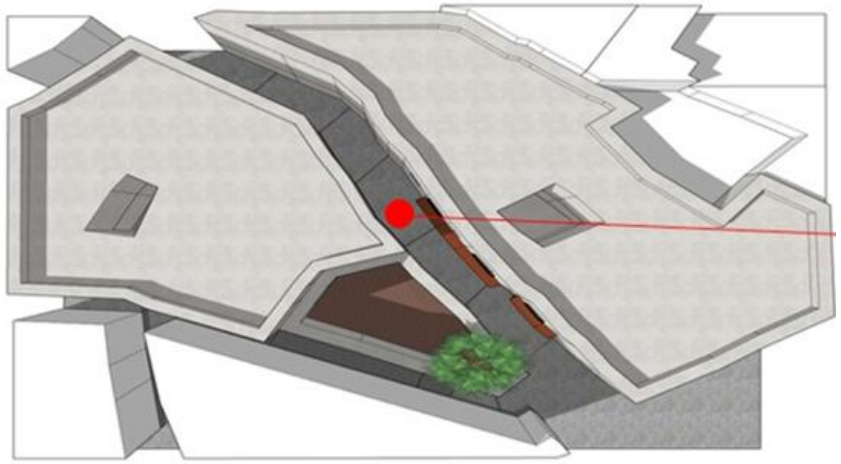
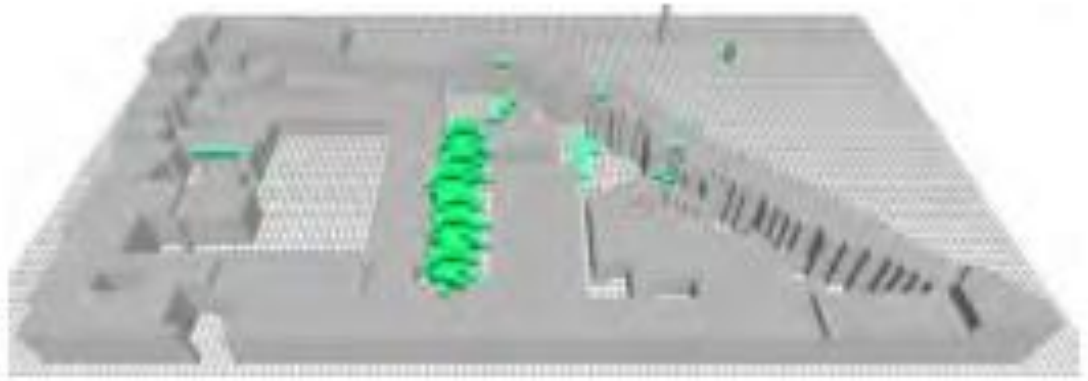
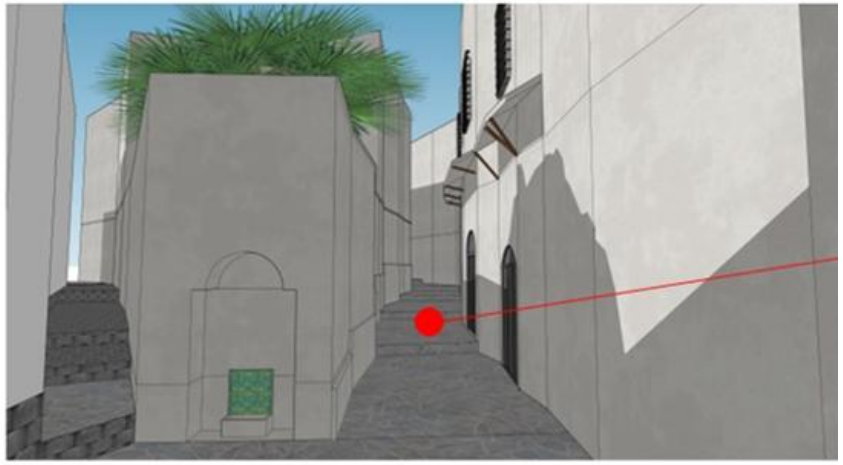
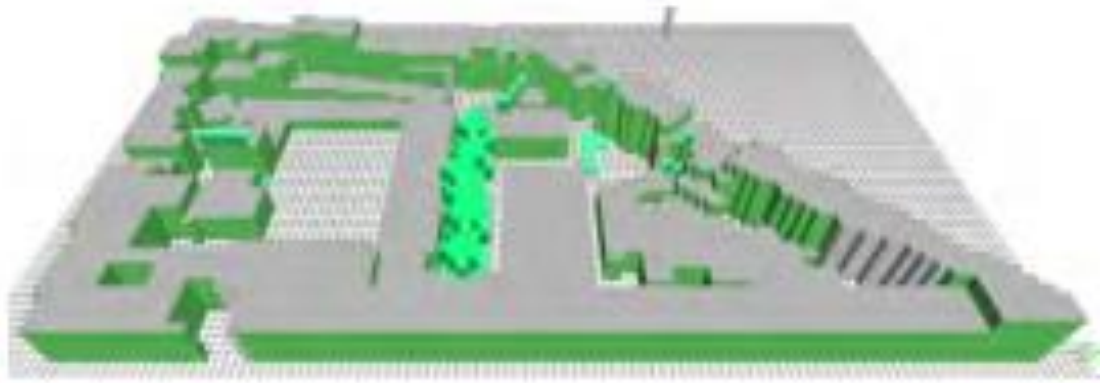
Model Representation

ENVI-met

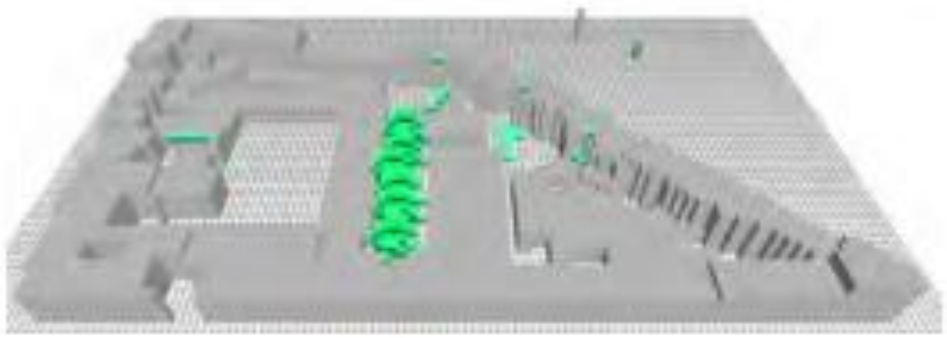








Model Representation



Air temperature
Sun / shade
Radiant temperature (walls, etc.)
Wind
Humidity
Metabolism, clothing, etc.

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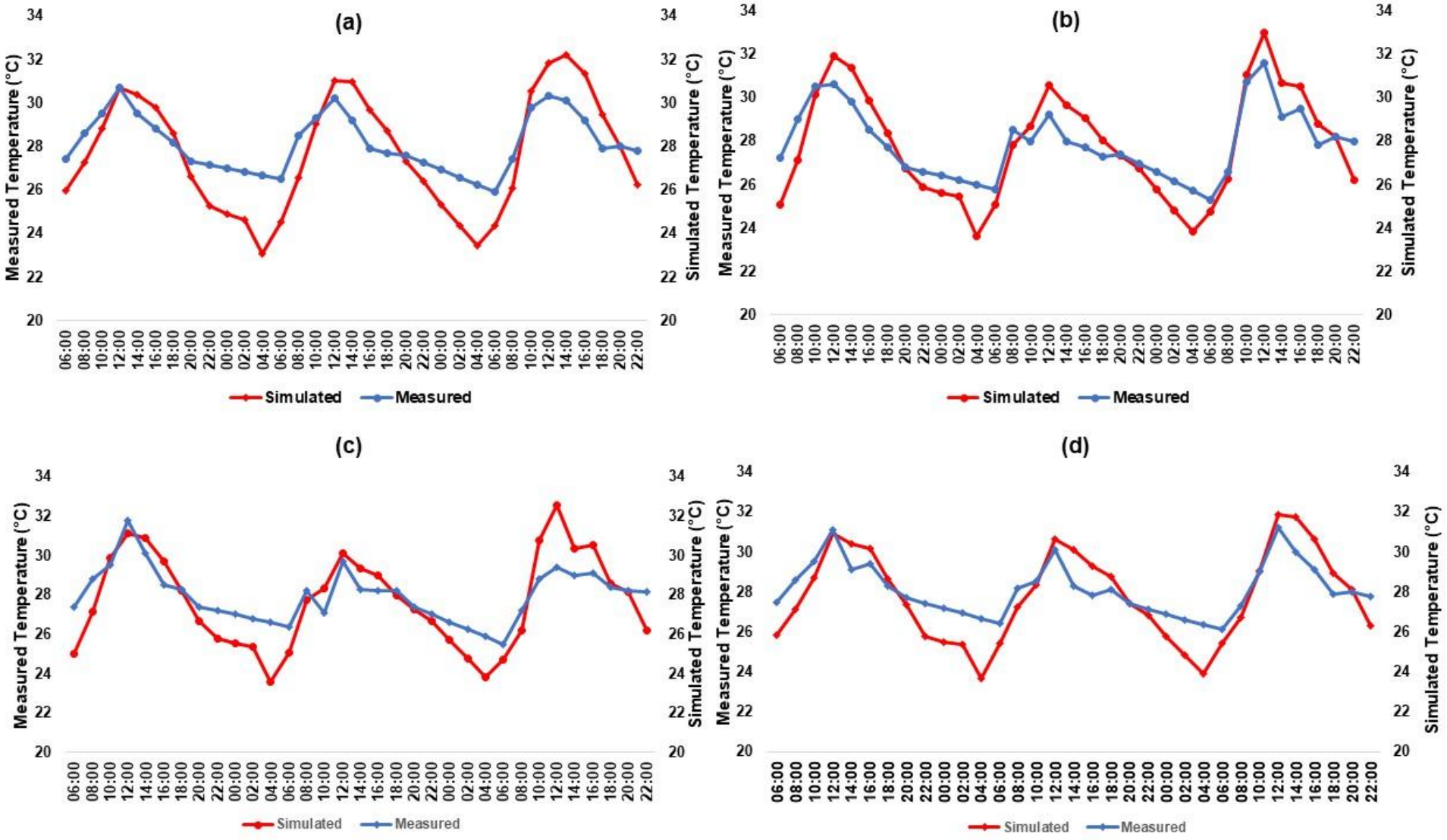
Model Calibration



Validation of measurements and simulations from August 8 to 10, 2021

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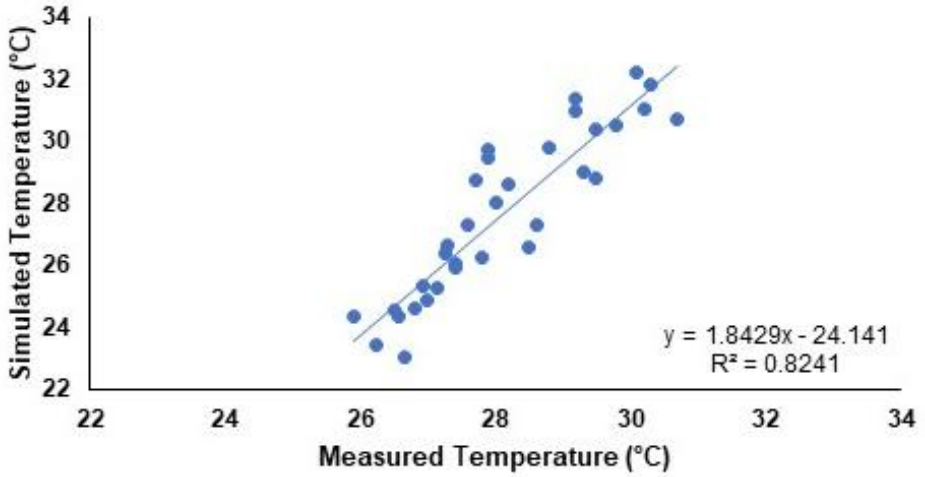
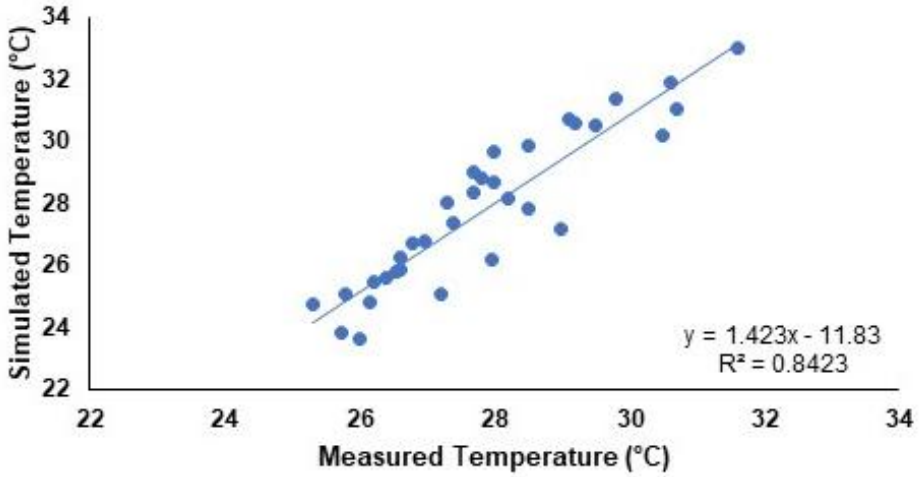
Model Calibration

Zones	Zone 1	Zone 2	Zone 3	Zone 4
RMSE	1.61	1.19	1.39	1.28
	5.72%	4.26%	4.96%	4.55%
MBE	- 0.44	- 0.05	- 0.30	- 0.32
	- 1.56%	- 0.16%	- 1.06%	- 1.15%

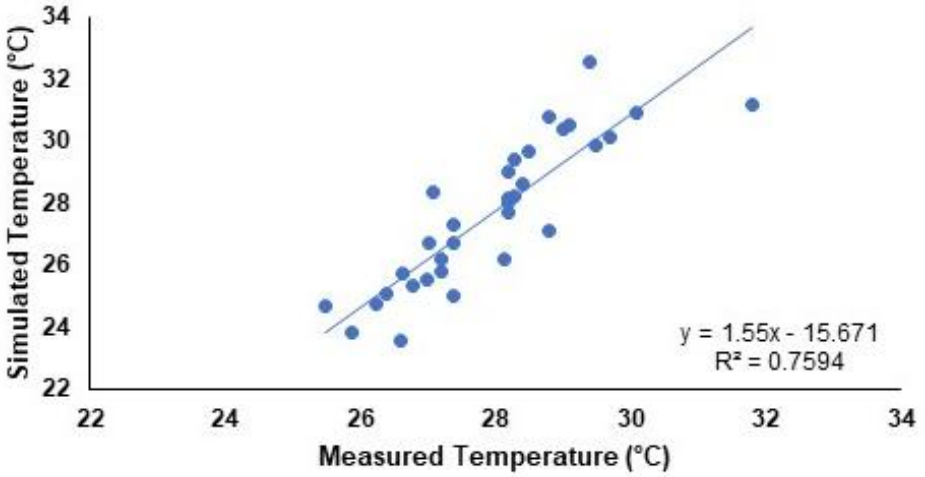
(a)



(b)



(c)



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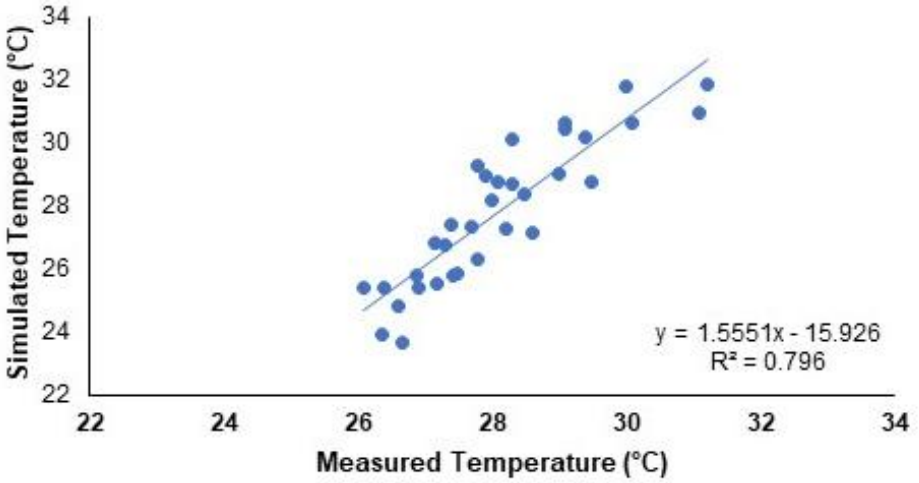

Calibration in compliance with ASHRAE 140

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Scenario Simulation & Climate Futures

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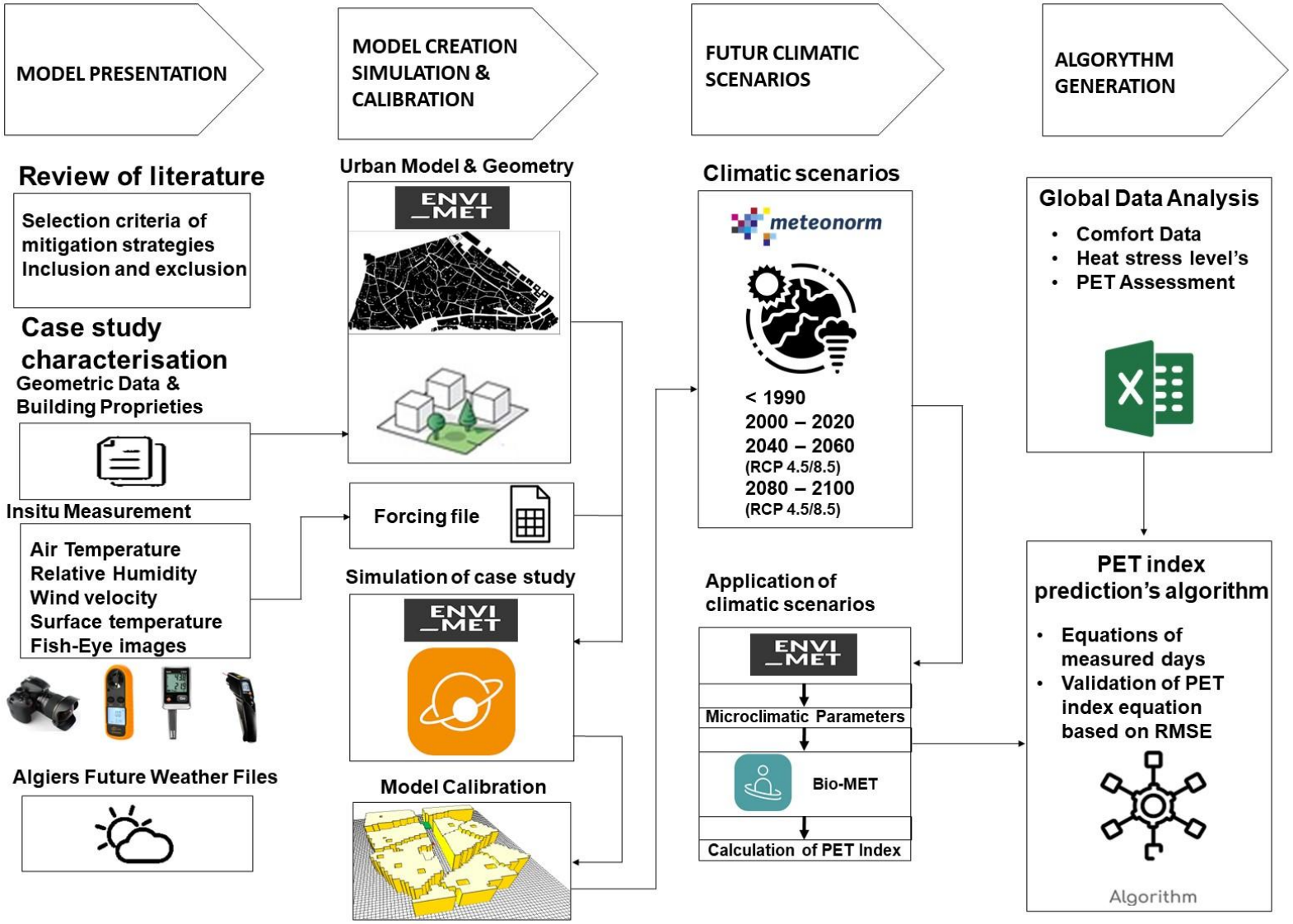
Study of future climate scenarios

- **How can an integrated approach combining on-site measurements and numerical simulations improve the quantification and prediction of outdoor thermal comfort in the context of climate change?**

Methodology



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Methodology

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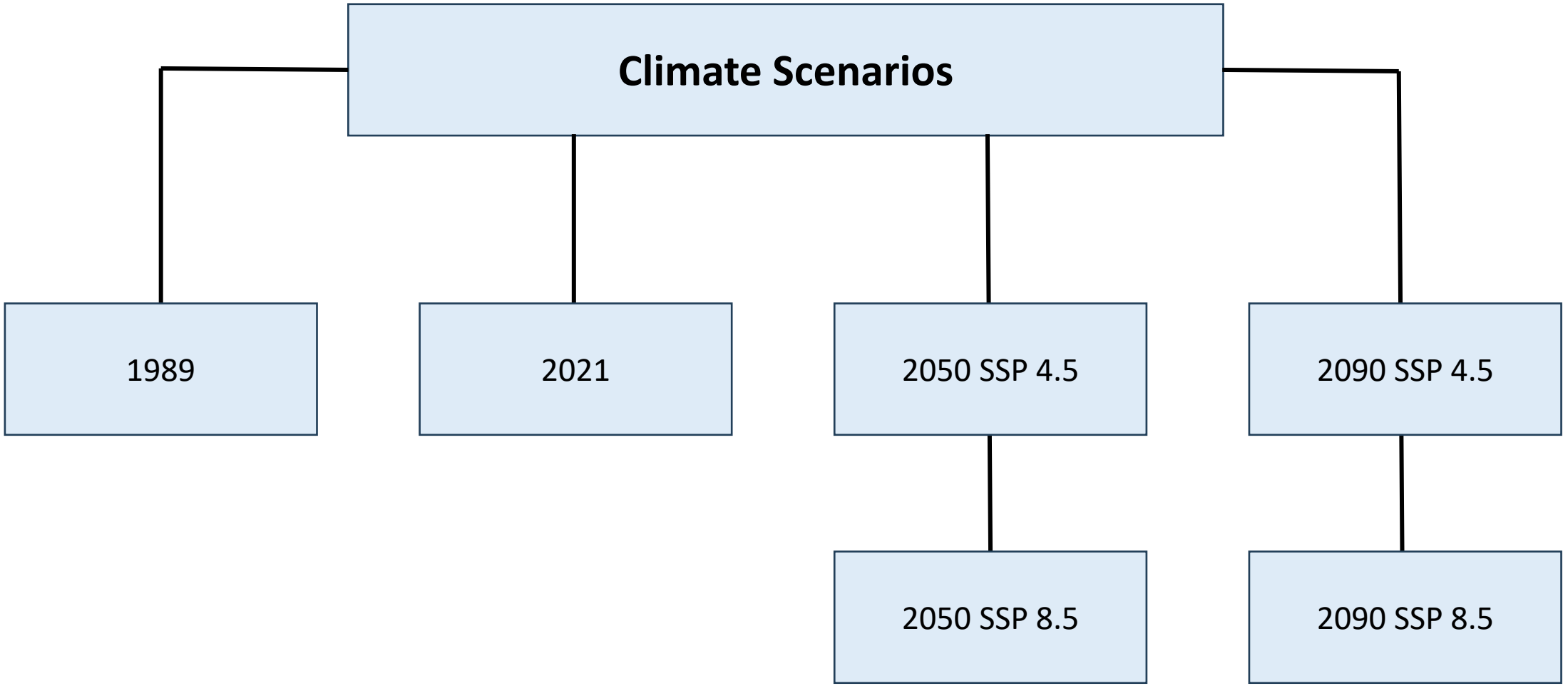
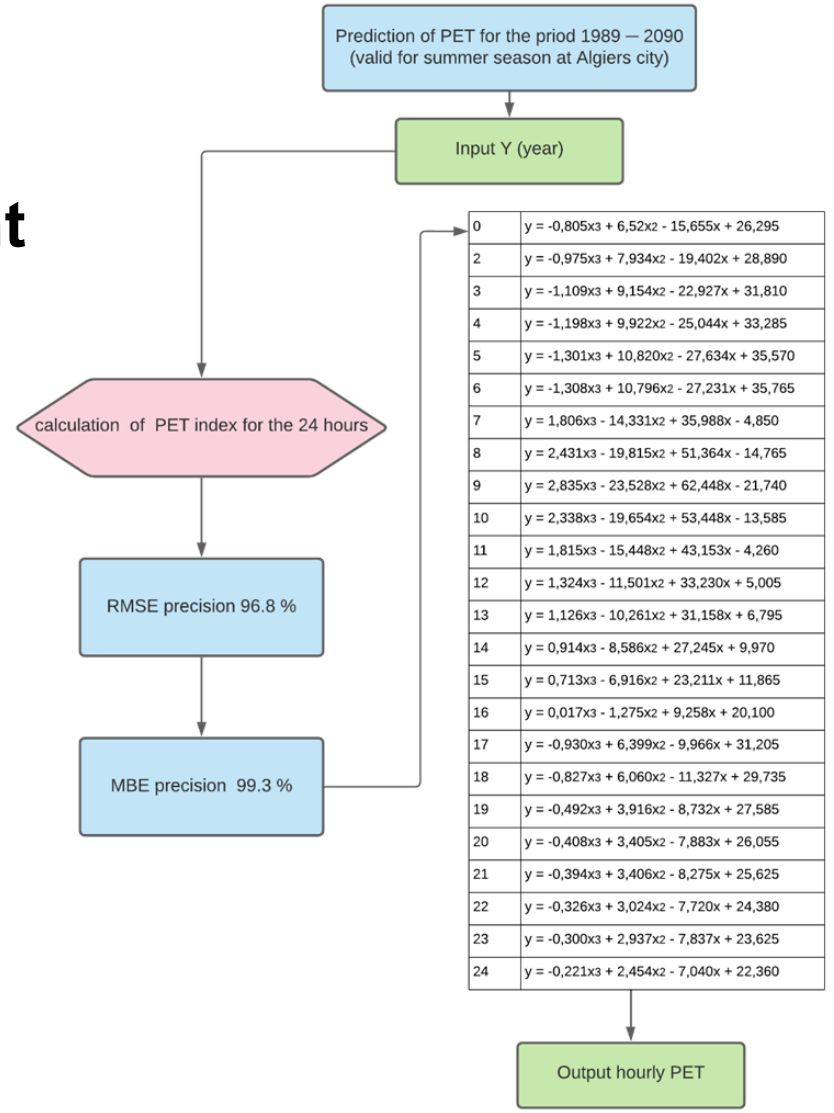
Future Scenarios



IPCC 2021 SSP scenarios

Future Scenarios

- **Development of a third-degree polynomial model to estimate PET (Physiological Equivalent Temperature) for each hour of the day.**
- **Based on simulated data for the years 1989, 2020, 2050, and 2090, at four measurement points.**
- **Hourly predictions of thermal comfort**
- **Support for sustainable urban design** (shading, vegetation, ventilation)
- **Guidance for planning in response to climate change scenarios**



0	y = -0,805x3 + 6,52x2 - 15,655x + 26,295
2	y = -0,975x3 + 7,934x2 - 19,402x + 28,890
3	y = -1,109x3 + 9,154x2 - 22,927x + 31,810
4	y = -1,198x3 + 9,922x2 - 25,044x + 33,285
5	y = -1,301x3 + 10,820x2 - 27,634x + 35,570
6	y = -1,308x3 + 10,796x2 - 27,231x + 35,765
7	y = 1,806x3 - 14,331x2 + 35,988x - 4,850
8	y = 2,431x3 - 19,815x2 + 51,364x - 14,765
9	y = 2,835x3 - 23,528x2 + 62,448x - 21,740
10	y = 2,338x3 - 19,654x2 + 53,448x - 13,585
11	y = 1,815x3 - 15,448x2 + 43,153x - 4,260
12	y = 1,324x3 - 11,501x2 + 33,230x + 5,005
13	y = 1,126x3 - 10,261x2 + 31,158x + 6,795
14	y = 0,914x3 - 8,586x2 + 27,245x + 9,970
15	y = 0,713x3 - 6,916x2 + 23,211x + 11,865
16	y = 0,017x3 - 1,275x2 + 9,258x + 20,100
17	y = -0,930x3 + 6,399x2 - 9,966x + 31,205
18	y = -0,827x3 + 6,060x2 - 11,327x + 29,735
19	y = -0,492x3 + 3,916x2 - 8,732x + 27,585
20	y = -0,408x3 + 3,405x2 - 7,883x + 26,055
21	y = -0,394x3 + 3,406x2 - 8,275x + 25,625
22	y = -0,326x3 + 3,024x2 - 7,720x + 24,380
23	y = -0,300x3 + 2,937x2 - 7,837x + 23,625
24	y = -0,221x3 + 2,454x2 - 7,040x + 22,360

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Scenarios Coupling

Equation for converting a year from binary to decimal

PET predictor		
input year	2090	4.1

RMSE precision	96.80%
MBE precision	99.30%

Équation de conversion d'année

Du binaire aux décimales

$y = 0{,}0299x - 58{,}39$

$R^2 = 0{,}9953$

Hour	PET
1:00	16.2
2:00	15.5
3:00	15.3
4:00	14.8
5:00	14.5
6:00	15.4
7:00	26.3
8:00	26.3
9:00	34.2
10:00	36.3
11:00	38.1
12:00	39.2
13:00	39.7
14:00	40.3
15:00	39.9
16:00	37.8
17:00	33.8
18:00	28.2
19:00	23.7
20:00	22.9
21:00	21.8
22:00	21.1
23:00	20.2
0:00	19.5

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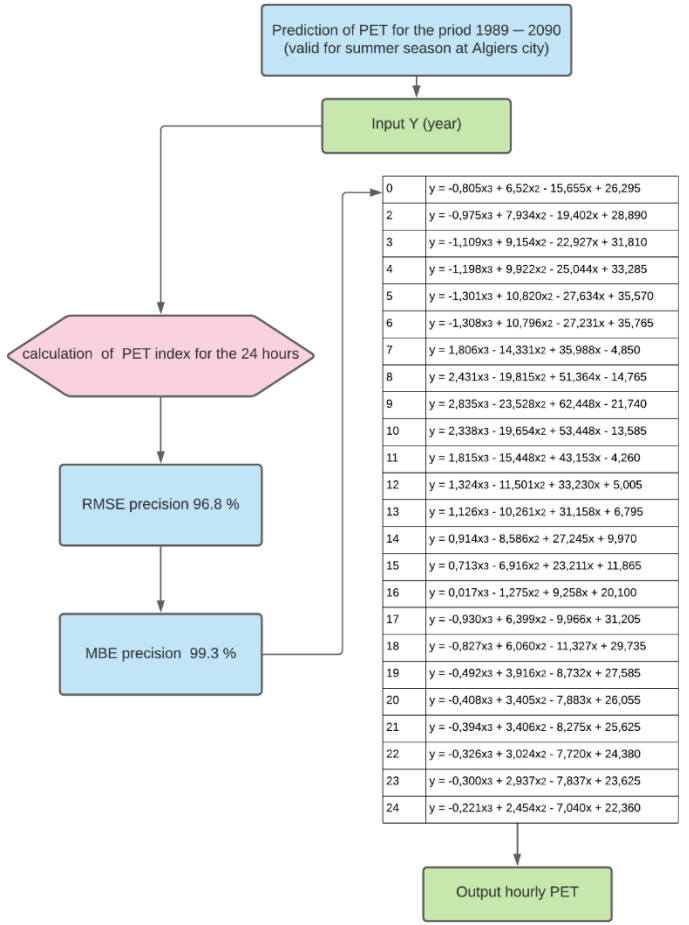

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Results

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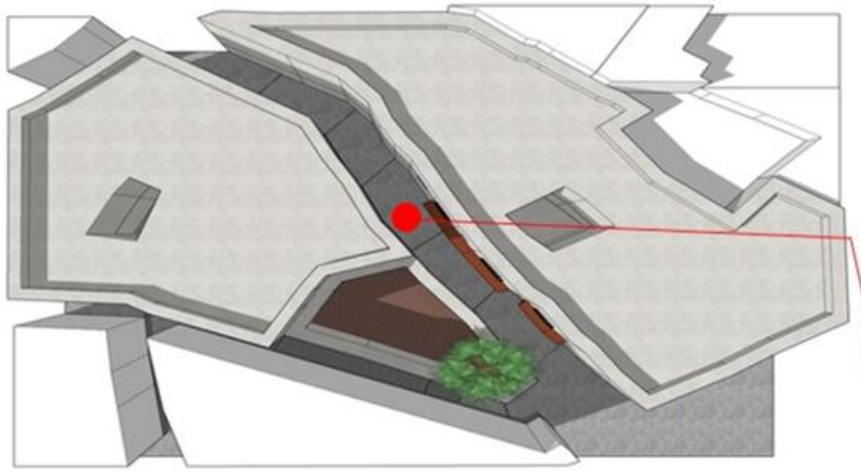
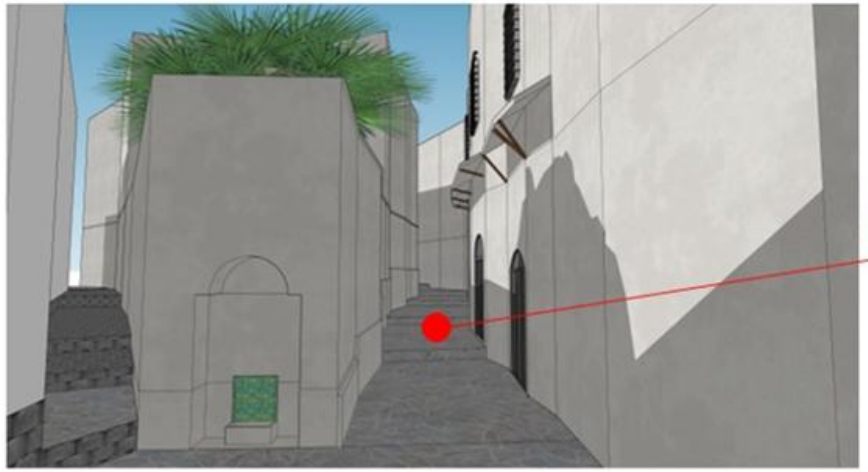
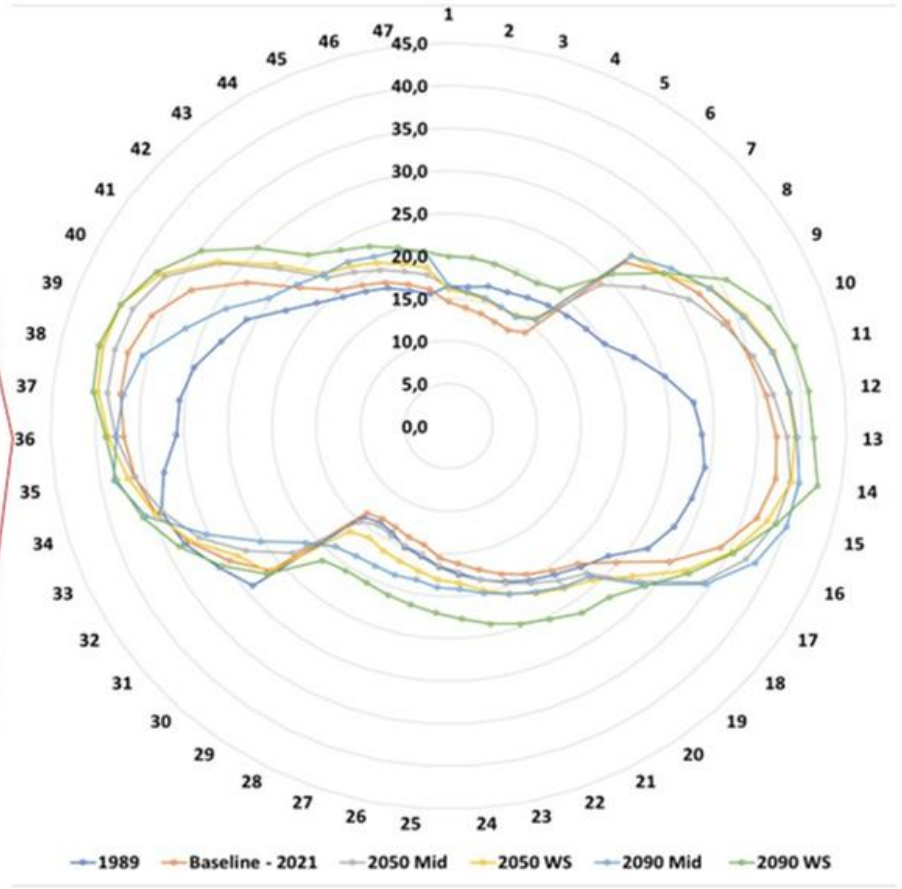
Comfort Characterisation Zone 1







Climate scenarios radar

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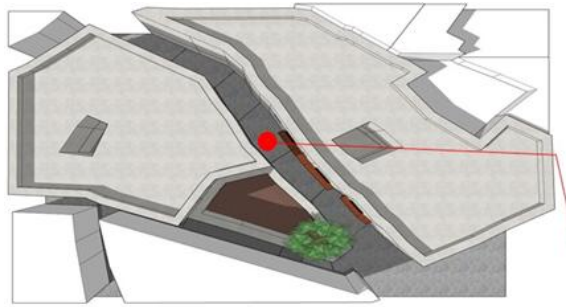
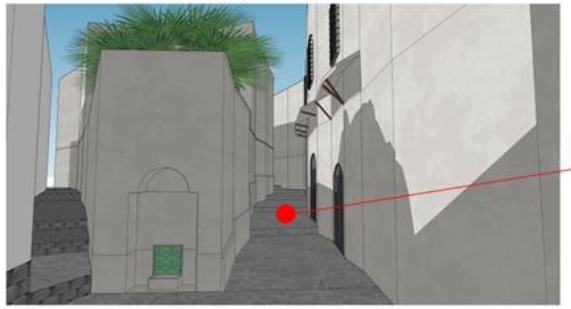
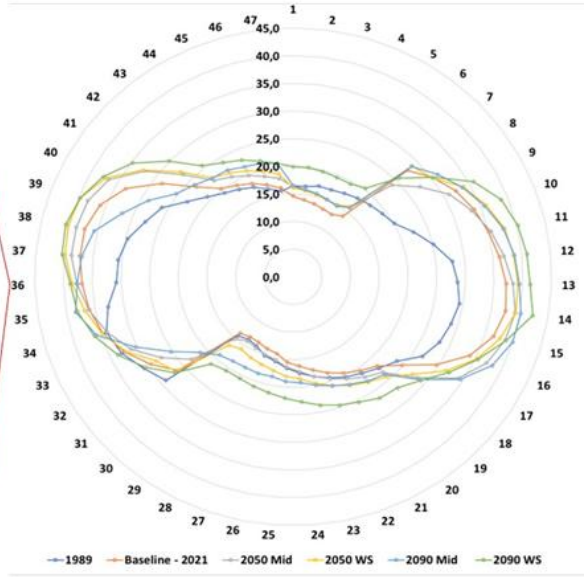
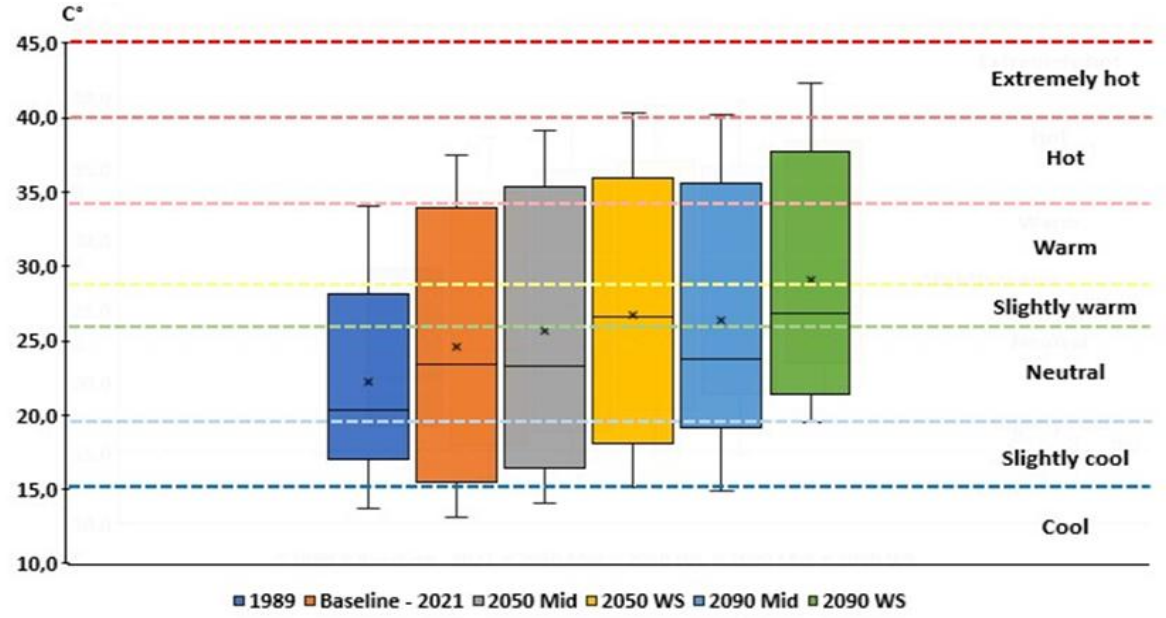
Comfort Characterisation







Climate scenarios radar



	1989	2021	2050 Mid	2050 WS	2090 Mid	2090 WS
Maximum temp	34,1	37,5	39,2	40,3	40,2	42,3
Average Temp	22,2	24,6	25,7	26,7	26,4	29,1
Minimum Temp	13,7	13,1	14,1	15,1	14,9	19,5
Average temperature difference	5,2	8,3	8,1	8,0	7,4	7,0

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Comfort Characterisation

Time	1989		Baseline - 2021		2050 Mid		2050 WS		2090 Mid		2090 WS	
	08th	09th	08th	09th	08th	09th	08th	09th	08th	09th	08th	09th
00:00		17,6		16,5		17,5		18,7		19,4		22,8
01:00	16,3	16,7	14,7	15,8	16,3	16,8	16,1	18,2	16,5	19,2	19,5	22,1
02:00	16,4	15,8	14,1	14,5	15,8	15,8	15,7	17,5	15,8	18,6	19,5	21,5
03:00	16,8	15,3	13,7	14,1	15,5	15,3	15,4	17,0	15,6	18,7	19,3	21,1
04:00	16,9	14,3	13,3	13,6	15,1	14,8	15,2	16,6	15,2	18,4	19,1	20,6
05:00	17,4	14,0	13,2	13,4	15,0	14,5	15,1	16,1	14,9	18,6	19,1	20,6
06:00	18,0	14,7	14,1	14,1	16,0	15,5	16,2	16,9	15,9	19,2	20,2	21,4
07:00	18,6	21,6	20,7	20,5	22,0	21,9	22,4	22,8	22,1	21,3	24,4	25,8
08:00	19,2	24,9	24,0	24,4	25,9	26,1	25,8	25,9	25,2	24,8	28,0	29,6
09:00	20,0	31,5	31,0	30,7	29,6	29,8	32,7	31,0	32,4	29,6	34,8	33,0
10:00	22,6	33,4	33,1	33,7	32,7	33,1	35,4	34,1	35,1	35,1	38,2	35,7
11:00	25,4	32,6	34,8	35,3	35,2	35,6	37,7	36,2	37,4	37,6	40,0	37,6
12:00	28,3	31,2	36,4	36,4	37,3	37,4	38,9	38,2	39,0	37,3	41,1	38,6
13:00	29,0	31,0	37,3	36,7	38,6	38,3	39,4	39,3	39,5	36,6	41,5	39,9
14:00	29,8	30,0	37,6	36,8	39,4	38,4	39,4	39,8	40,2	35,3	42,1	40,3
15:00	29,0	27,9	36,4	35,4	38,5	37,6	37,7	39,1	39,6	31,8	38,8	39,2
16:00	28,2	26,2	33,5	32,5	36,7	35,7	35,0	36,4	37,6	28,7	35,3	37,1
17:00	26,8	23,1	29,3	28,1	33,5	31,6	31,3	32,0	33,9	25,4	32,0	34,3
18:00	23,7	21,0	24,7	23,5	27,7	26,4	27,3	26,9	28,0	24,0	28,9	29,6
19:00	22,3	19,4	22,0	20,6	23,5	22,4	24,4	23,0	23,9	22,9	26,9	25,7
20:00	21,2	18,5	20,8	19,5	22,2	21,3	23,1	22,1	23,0	22,5	26,4	24,3
21:00	20,4	17,8	19,7	18,5	21,0	20,2	22,1	21,1	21,9	21,7	25,3	23,1
22:00	19,4	16,7	18,5	17,5	19,8	19,2	21,0	20,0	21,1	21,4	24,5	22,0
23:00	18,5	15,8	17,4	16,5	18,6	18,2	19,9	19,1	20,2	20,8	23,6	21,0

	12 – 15	15 - 19	19 - 26	26 - 28	28 - 34	34 - 40	> 40
Thermal Comfort	Cool	Slightly Cool	Neutral	Slightly warm	Warm	Hot	Extremely hot
Stress Level	Moderate cold stress	Slight cold stress	No thermal stress	Slight heat stress	Moderate heat stress	Strong heat stress	Extreme heat stress

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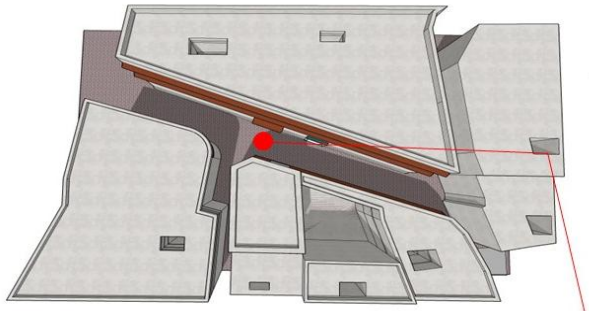
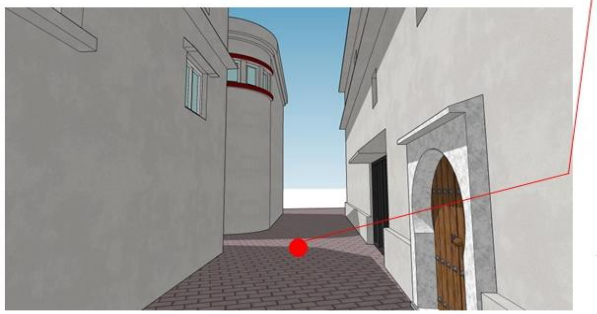
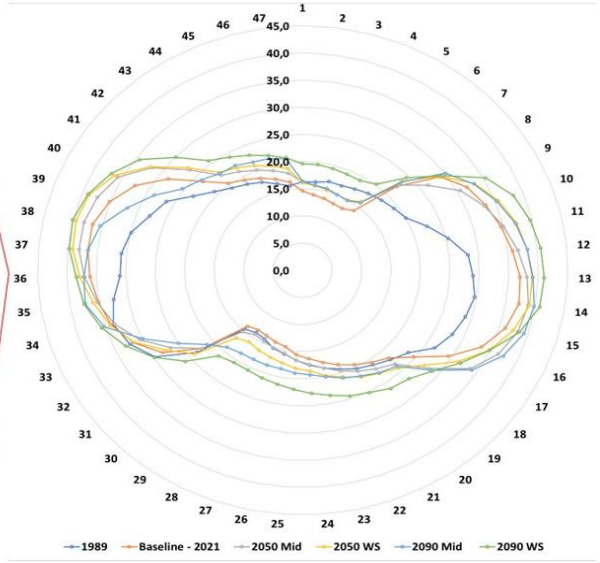
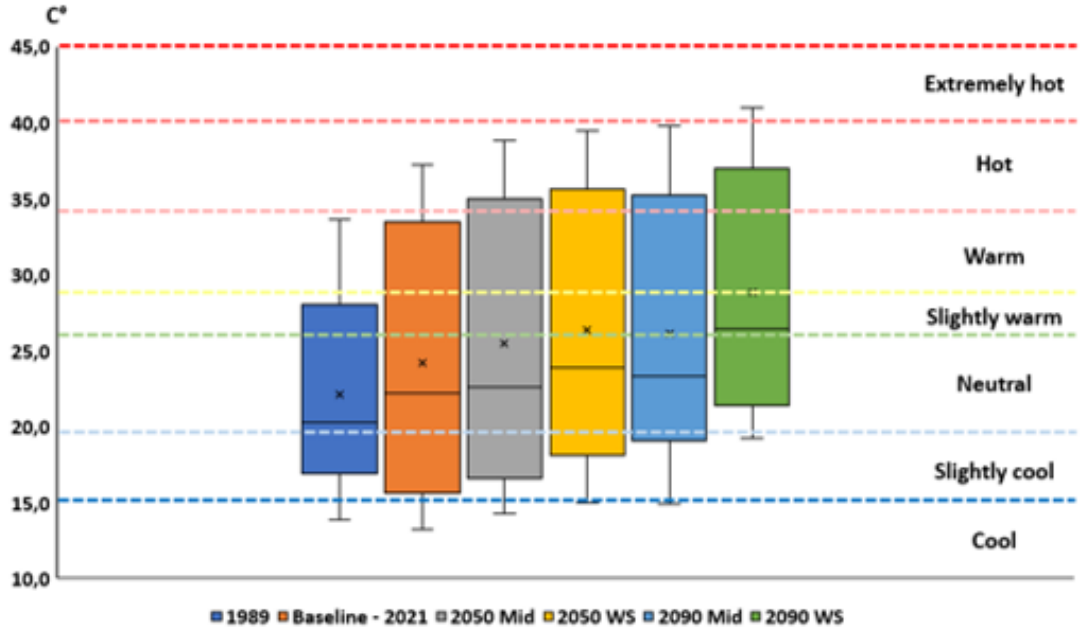
Comfort Characterisation Zone 4







Climate scenarios radar



	1989	2021	2050 Mid	2050 WS	2090 Mid	2090 WS
Maximum temp	33,4	37,6	39,4	39,8	40,2	42,1
Average Temp	22,0	24,0	25,5	26,3	26,0	28,8
Minimum Temp	14,0	13,2	14,5	15,1	14,9	19,1
Average temperature difference	5,0	7,8	7,8	7,8	7,1	6,9

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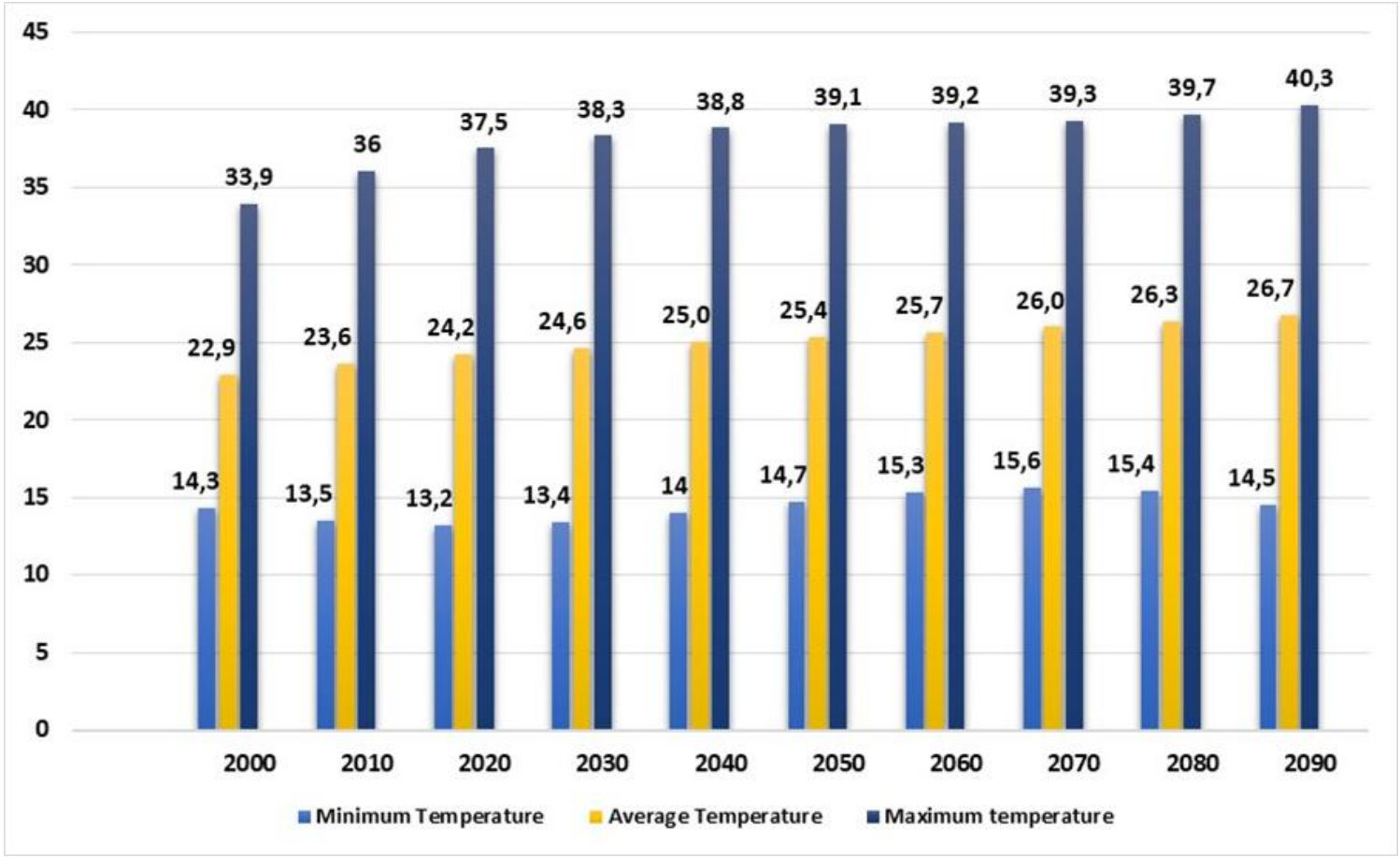
Comfort Characterisation Zone 4

Time	PET / Year									
	2000	2010	2020	2030	2040	2050	2060	2070	2080	20
01:00	14,9	14,6	14,6	15,0	15,5	16,1	16,6	16,9	16,8	16
02:00	14,6	14,0	14,0	14,4	15,0	15,6	16,1	16,4	16,2	15
03:00	14,6	13,8	13,7	14,0	14,6	15,3	15,8	16,2	16,0	15
04:00	14,3	13,5	13,3	13,6	14,2	14,9	15,5	15,8	15,7	14
05:00	14,5	13,5	13,2	13,4	14,0	14,7	15,3	15,6	15,4	14
06:00	15,2	14,2	14,0	14,3	15,0	15,7	16,3	16,6	16,4	15
07:00	22,5	23,8	24,3	24,1	23,6	23,0	22,7	23,0	24,1	26
08:00	22,5	23,8	24,3	24,1	23,6	23,0	22,7	23,0	24,1	26
09:00	27,5	30,4	31,7	31,9	31,4	30,6	30,1	30,2	31,4	34
10:00	29,3	32,0	33,4	33,8	33,6	33,1	32,8	33,0	34,0	36
11:00	31,0	33,4	34,8	35,4	35,4	35,2	35,1	35,4	36,3	38
12:00	32,7	34,8	36,1	36,7	36,9	36,9	37,0	37,2	37,9	39
13:00	33,5	35,7	37,1	37,9	38,2	38,3	38,3	38,4	38,8	39
14:00	33,9	36,0	37,5	38,3	38,8	39,1	39,2	39,3	39,7	40
15:00	32,8	34,9	36,4	37,4	38,0	38,4	38,7	39,0	39,3	39
16:00	30,7	32,3	33,7	34,9	35,9	36,7	37,2	37,6	37,8	37
17:00	27,3	28,2	29,5	30,9	32,2	33,5	34,4	34,8	34,7	33
18:00	23,5	23,9	24,7	25,7	26,7	27,7	28,5	28,9	28,8	28
19:00	21,7	21,6	21,9	22,2	22,7	23,2	23,6	23,9	24,0	23
20:00	20,6	20,5	20,7	21,0	21,4	21,9	22,3	22,7	22,9	22
21:00	19,6	19,5	19,6	19,8	20,2	20,7	21,1	21,5	21,7	21
22:00	18,6	18,4	18,4	18,7	19,0	19,5	20,0	20,4	20,8	21
23:00	17,6	17,3	17,3	17,5	17,8	18,3	18,8	19,3	19,8	20
00:00	16,7	16,4	16,3	16,5	16,8	17,2	17,7	18,3	18,9	19
	12 – 15	15 - 19	19 - 26	26 - 28	28 - 34	34 - 40	> 40			
Thermal Comfort	Cool	Slightly Cool	Neutral	Slightly warm	Warm	Hot	Extremely			
Stress Level	Moderate cold stress	Slight cold stress	No thermal stress	Slight heat stress	Moderate heat stress	Strong heat stress	Extreme h stress			



This section shows the hourly PET forecasts from 2000 to 2090 generated by our algorithm. It allows anticipating the evolution of thermal comfort and identifying critical periods related to climate change.

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Nature-Based Mitigation

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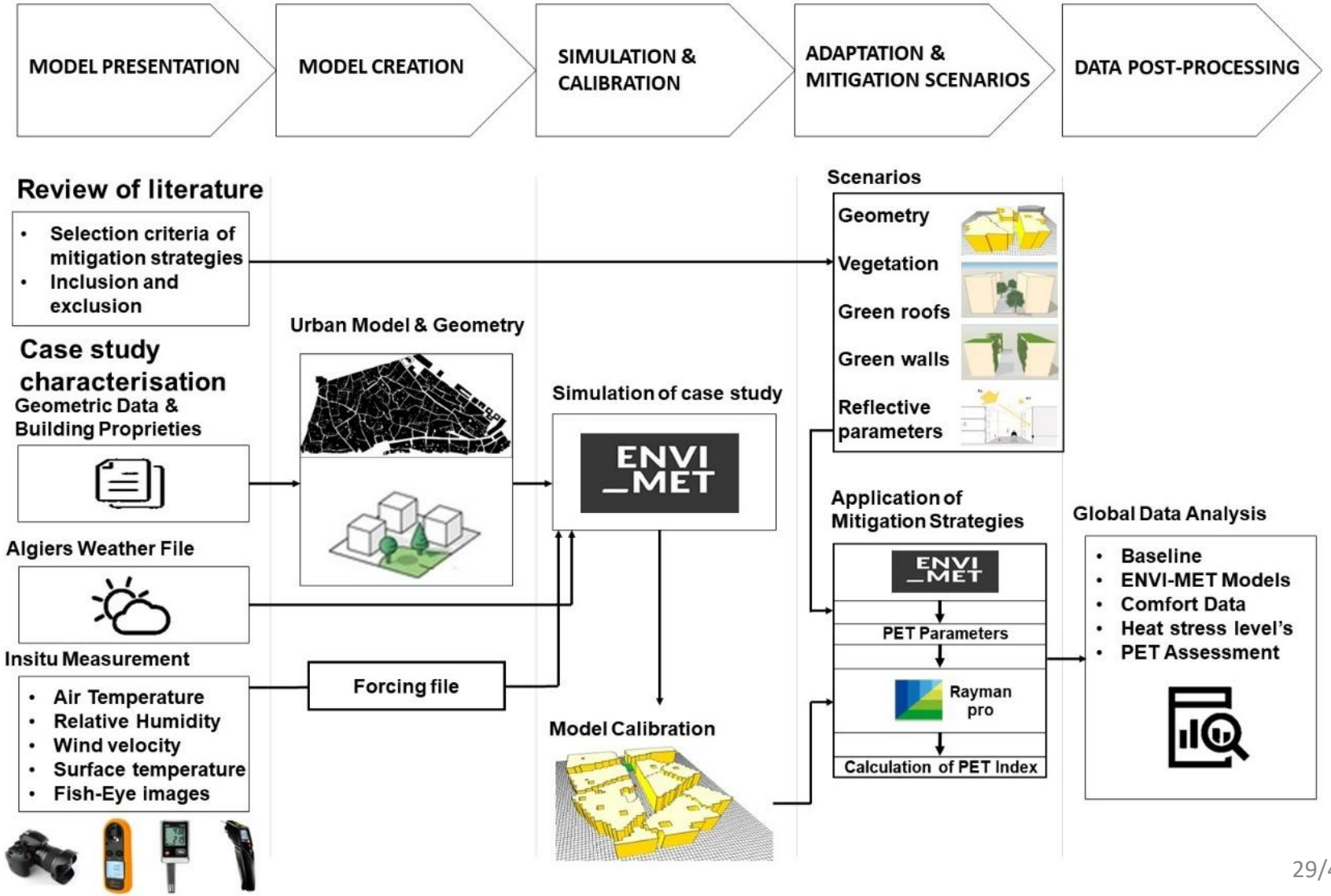
Methodology



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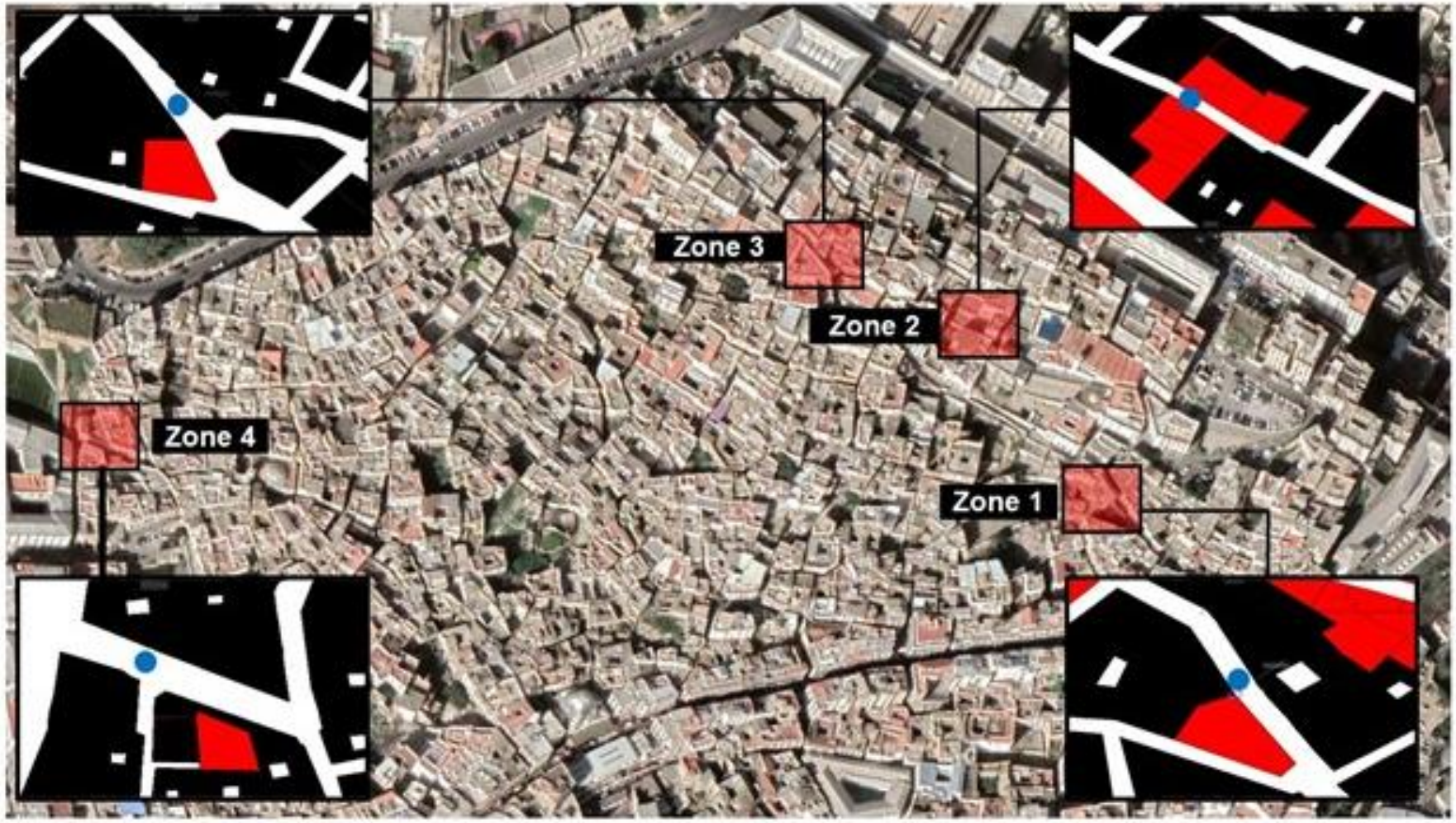
Methodology



(A)

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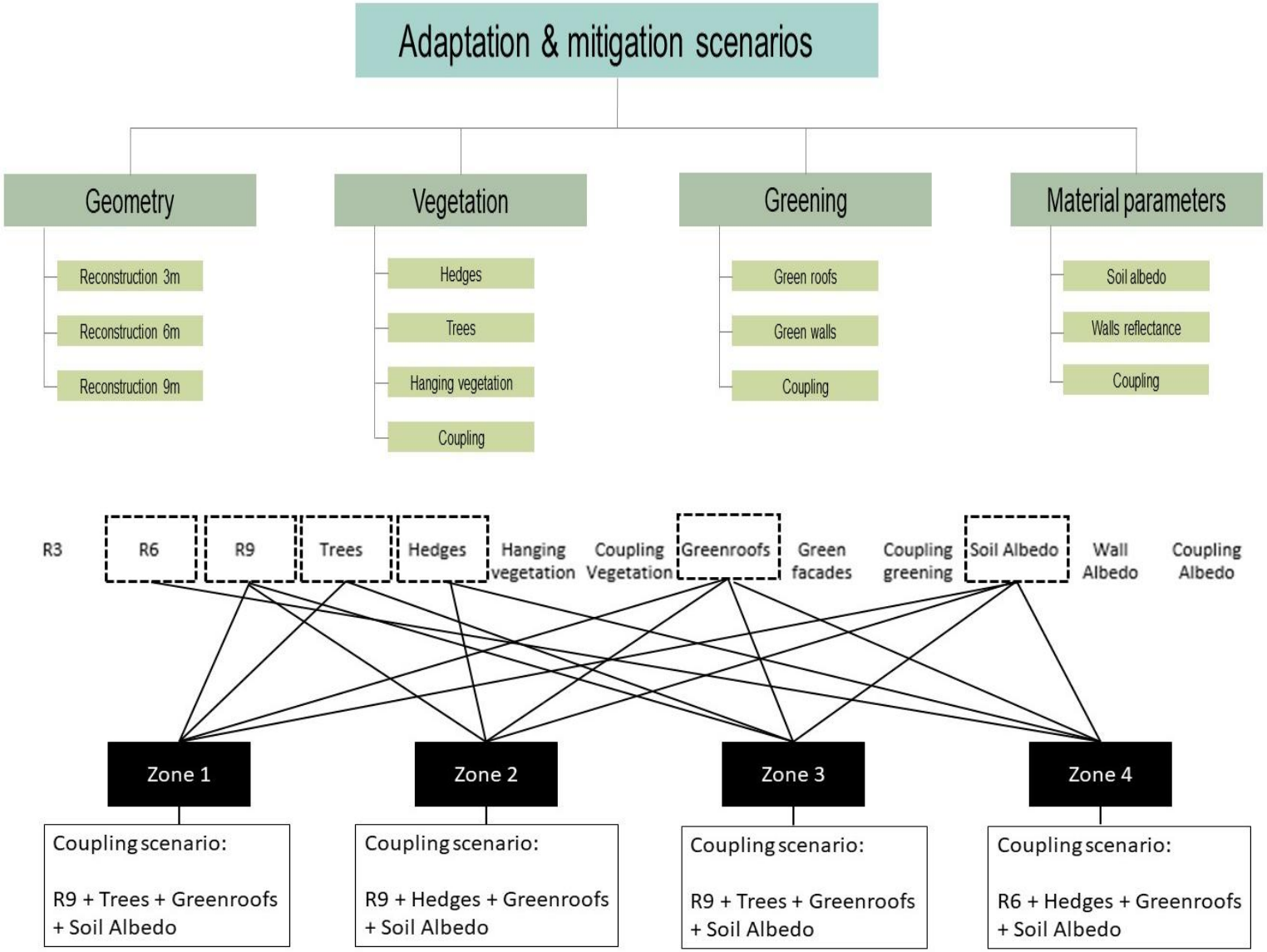
Methodology



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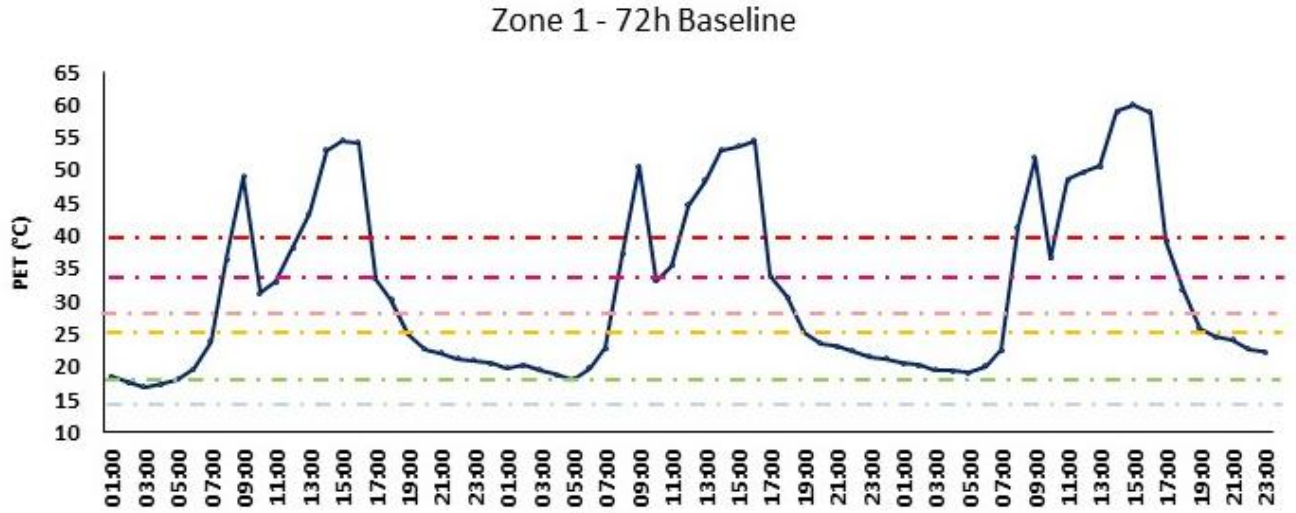
PET Values for the Zone 1



(a)

District	Days	PET 5:00 am	PET 8:00 am	PET 10:00 am	PET 12:00 pm	PET 3:00 pm	PET 5:00 pm	PET 8:00 pm	PET 10:00 pm
Zone 1	Baseline	19.1	41.3	36.5	49.8	59.9	39.2	24.6	22.8
	Rebuild 9m	17.3	34.9	31.5	34.6	56.3	33.7	23.0	21.3
	Trees	18.3	35.0	30.5	33.0	54.2	32.1	23.2	21.5
	Greenroofs	18.1	35.2	31.7	35.1	56.7	33.5	23.1	21.3
	Soil Albedo	18.1	35.2	31.8	34.9	56.0	33.4	23.0	21.3
	Coupling scenarios	17.4	34.6	30.5	32.7	55.0	32.1	23.0	21.3
	15 - 19	19 - 26		26 - 28	28 - 34		34 - 40	> 40	
Thermal comfort	Slightly cool	Neutral		Slightly warm	Warm		Hot	Extremely hot	
Stress level	Slight cold stress	No thermal stress		Slight heat stress	Moderate heat stress		Strong heat stress	Extreme heat stress	

(b)

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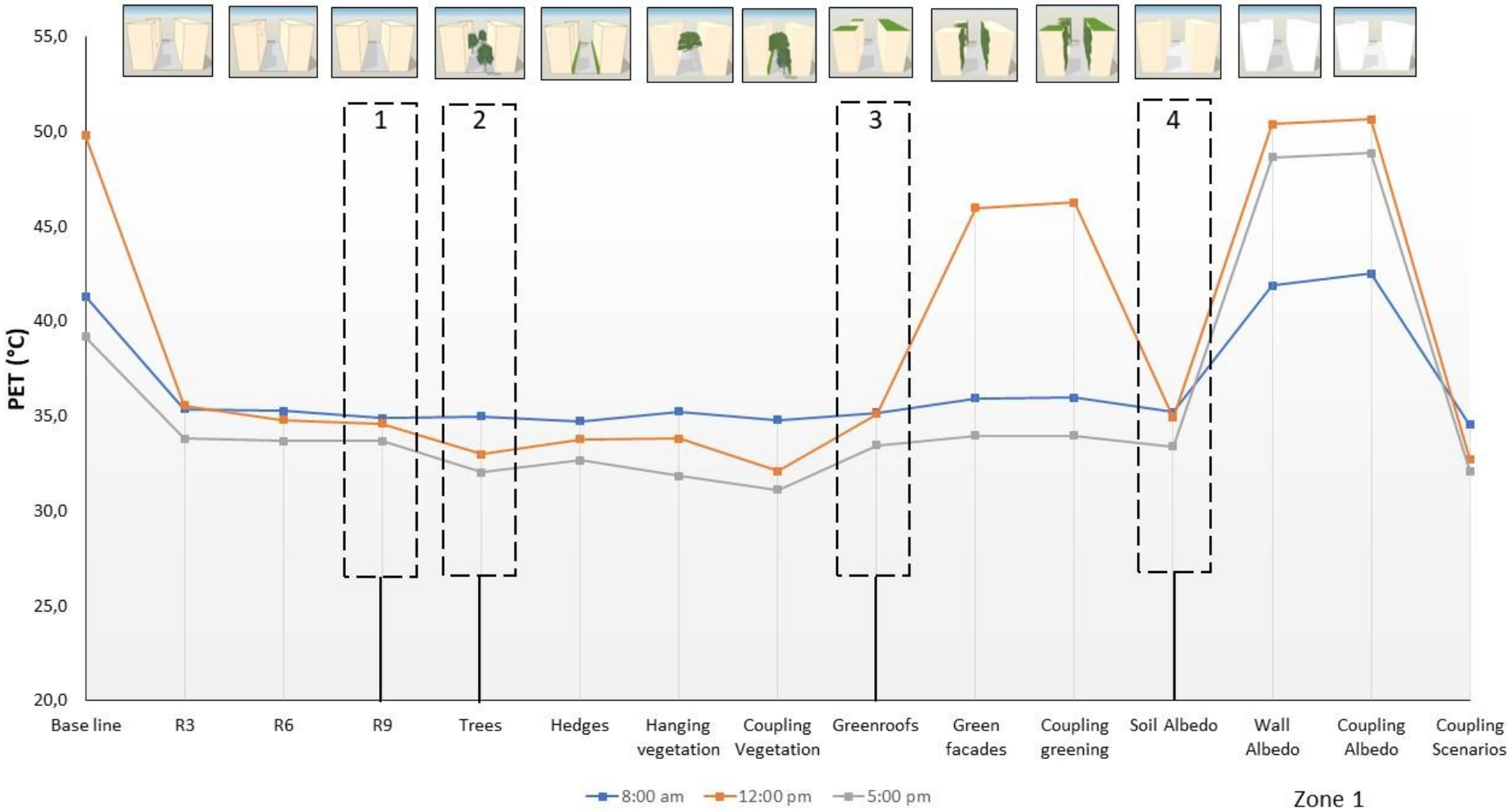
PET Values for the Zone 1



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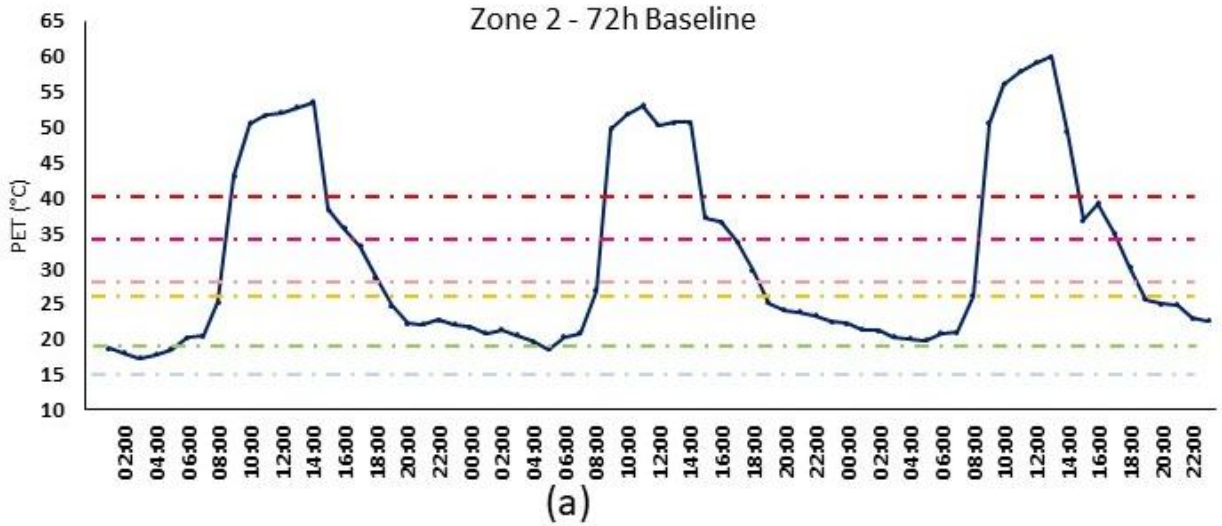
PET Values for the Zone 2



(a)

District	Days	PET 5:00 am	PET 8:00 am	PET 10:00 am	PET 12:00 pm	PET 3:00 pm	PET 5:00 pm	PET 8:00 pm	PET 10:00 pm
Zone 2	Baseline	19.9	26.1	56.1	59.1	36.8	35.1	25.1	23.0
	Rebuild 9m	17.4	23.1	31.4	36.1	35.4	33.9	23.5	21.7
	Hedges	19.2	24.2	51.5	53.5	37.2	33.2	24.7	22.7
	Greenroofs	18.8	24.2	52.1	54.0	39.5	33.6	24.2	22.2
	Soil Albedo	18.8	24.3	52.2	54.8	42.9	33.6	24.0	22.0
	Coupling scenarios	18.6	23.8	30.9	35.2	33.8	32.8	24.3	22.7
	15 - 19	19 - 26		26 - 28	28 - 34		34 - 40	> 40	
Thermal comfort	Slightly cool	Neutral		Slightly warm	Warm		Hot	Extremely hot	
Stress level	Slight cold stress	No thermal stress		Slight heat stress	Moderate heat stress		Strong heat stress	Extreme heat stress	

(b)

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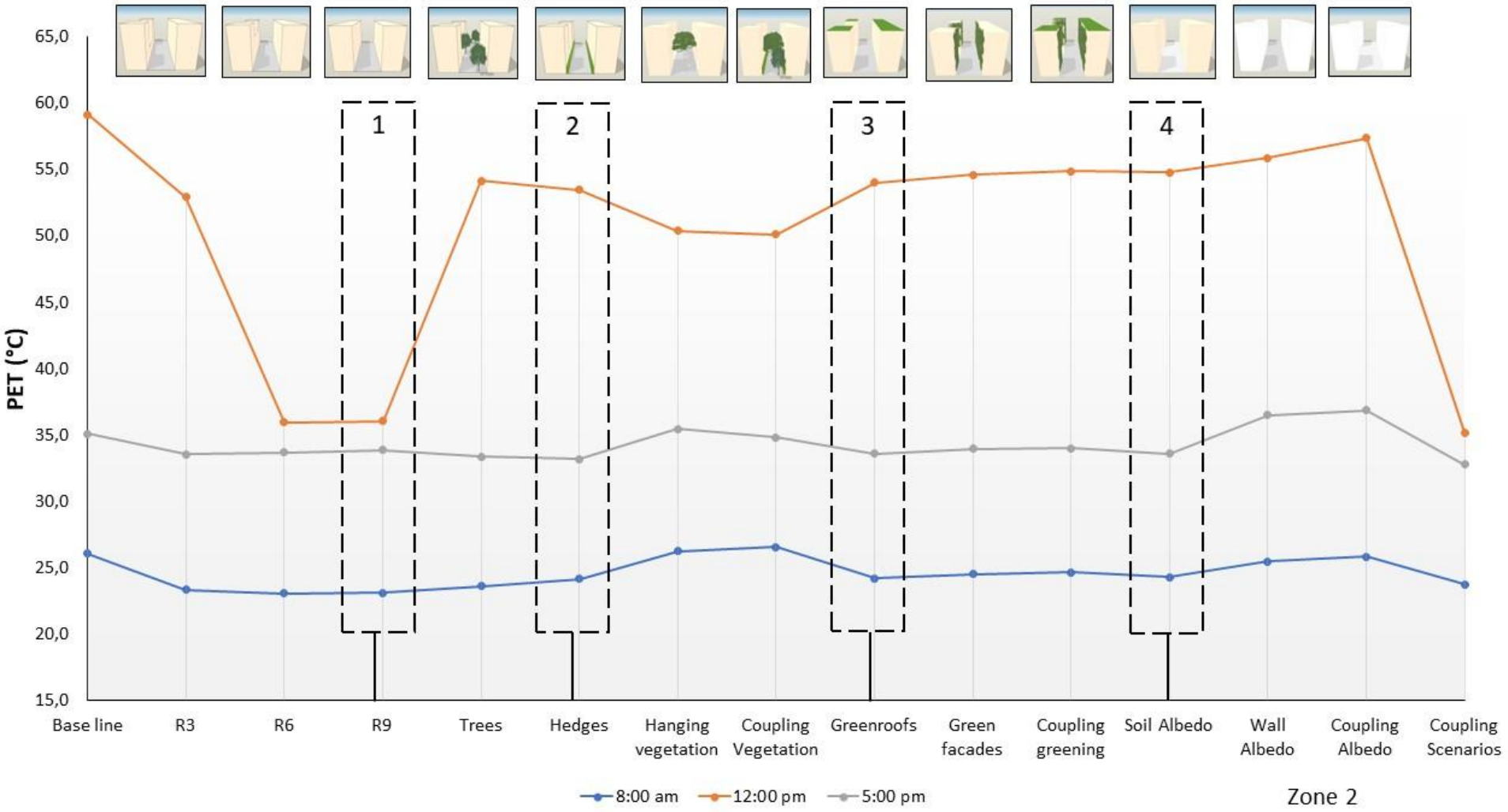
PET Values for the Zone 2



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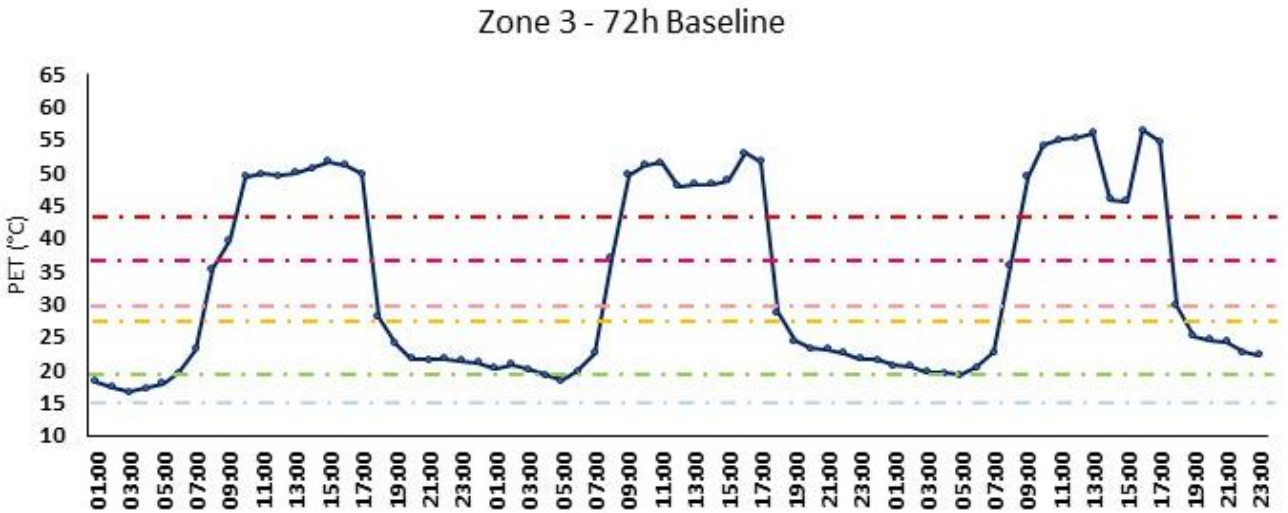
PET Values for the Zone 3



(a)

District	Days	PET 5:00 am	PET 8:00 am	PET 10:00 am	PET 12:00 pm	PET 3:00 pm	PET 5:00 pm	PET 8:00 pm	PET 10:00 pm
Zone 3	Baseline	19.3	36.0	54.2	55.4	55.7	54.6	24.5	22.6
	Rebuild 9m	17.7	34.0	48.7	49.2	51.5	50.7	23.0	21.3
	Trees	17.9	33.8	48.4	48.3	50.4	50.1	23.2	21.5
	Greenroofs	17.7	34.1	49.5	49.8	52.0	51.2	23.0	21.2
	Soil Albedo	17.7	34.1	49.2	49.8	52.1	50.8	23.0	21.2
	Coupling scenarios	17.7	34.0	49.2	49.3	51.3	50.7	22.9	21.3
	15 - 19	19 - 26		26 - 28	28 - 34		34 - 40	> 40	
Thermal comfort	Slightly cool	Neutral		Slightly warm	Warm		Hot	Extremely hot	
Stress level	Slight cold stress	No thermal stress		Slight heat stress	Moderate heat stress		Strong heat stress	Extreme heat stress	

(b)

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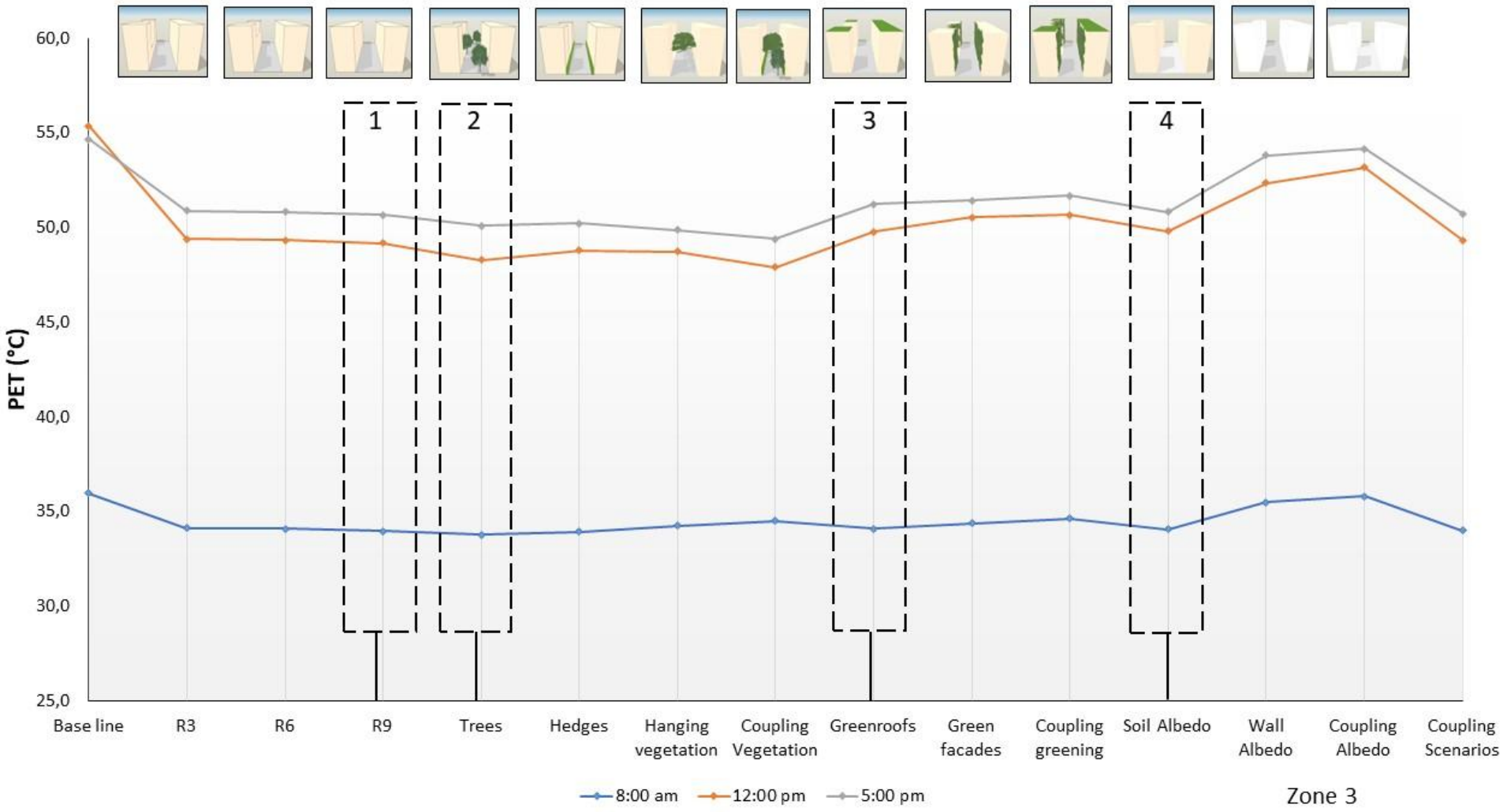
PET Values for the Zone 3



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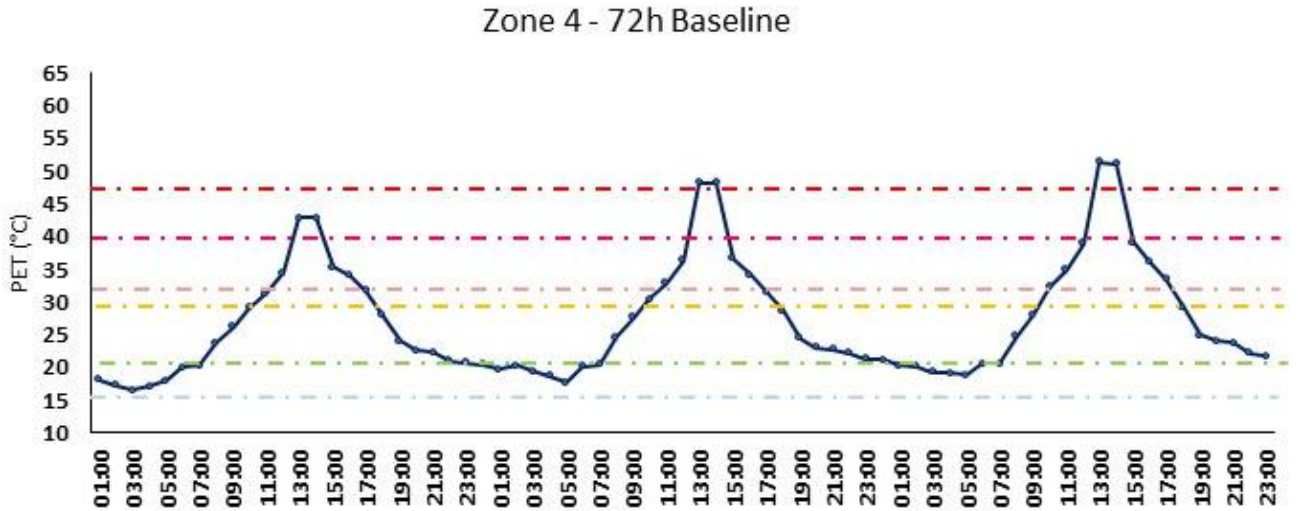
PET Values for the Zone 4



(a)

District	Days	PET 5:00 am	PET 8:00 am	PET 10:00 am	PET 12:00 pm	PET 3:00 pm	PET 5:00 pm	PET 8:00 pm	PET 10:00 pm
Zone 4	Baseline	18.9	24.8	32.2	39.0	39.1	33.5	24.1	22.1
	Rebuild 9m	17.8	23.2	29.6	35.3	36.8	32.3	23.1	21.2
	Hedges	18.1	23.0	28.8	34.2	35.4	31.3	23.6	21.7
	Greenroofs	17.8	23.3	29.7	35.3	36.9	32.3	23.0	21.1
	Soil Albedo	18.2	23.7	30.1	35.8	36.9	32.2	22.9	21.1
	Coupling scenarios	18.6	24.0	30.1	35.5	36.0	31.9	23.4	21.7
	15 - 19	19 - 26		26 - 28	28 - 34		34 - 40	> 40	
Thermal comfort	Slightly cool	Neutral		Slightly warm	Warm		Hot	Extremely hot	
Stress level	Slight cold stress	No thermal stress		Slight heat stress	Moderate heat stress		Strong heat stress	Extreme heat stress	

(b)

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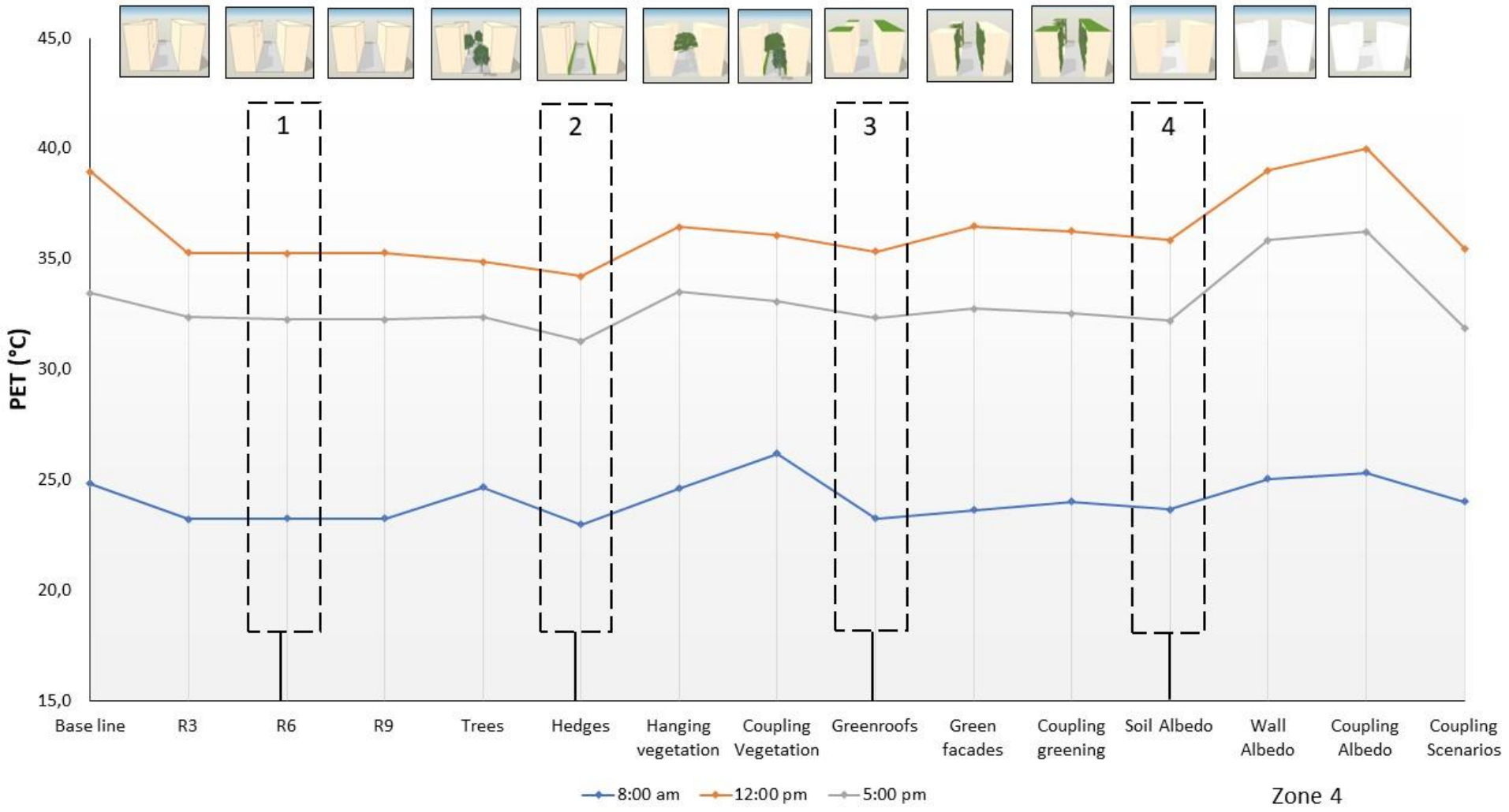
PET Values for the Zone 4



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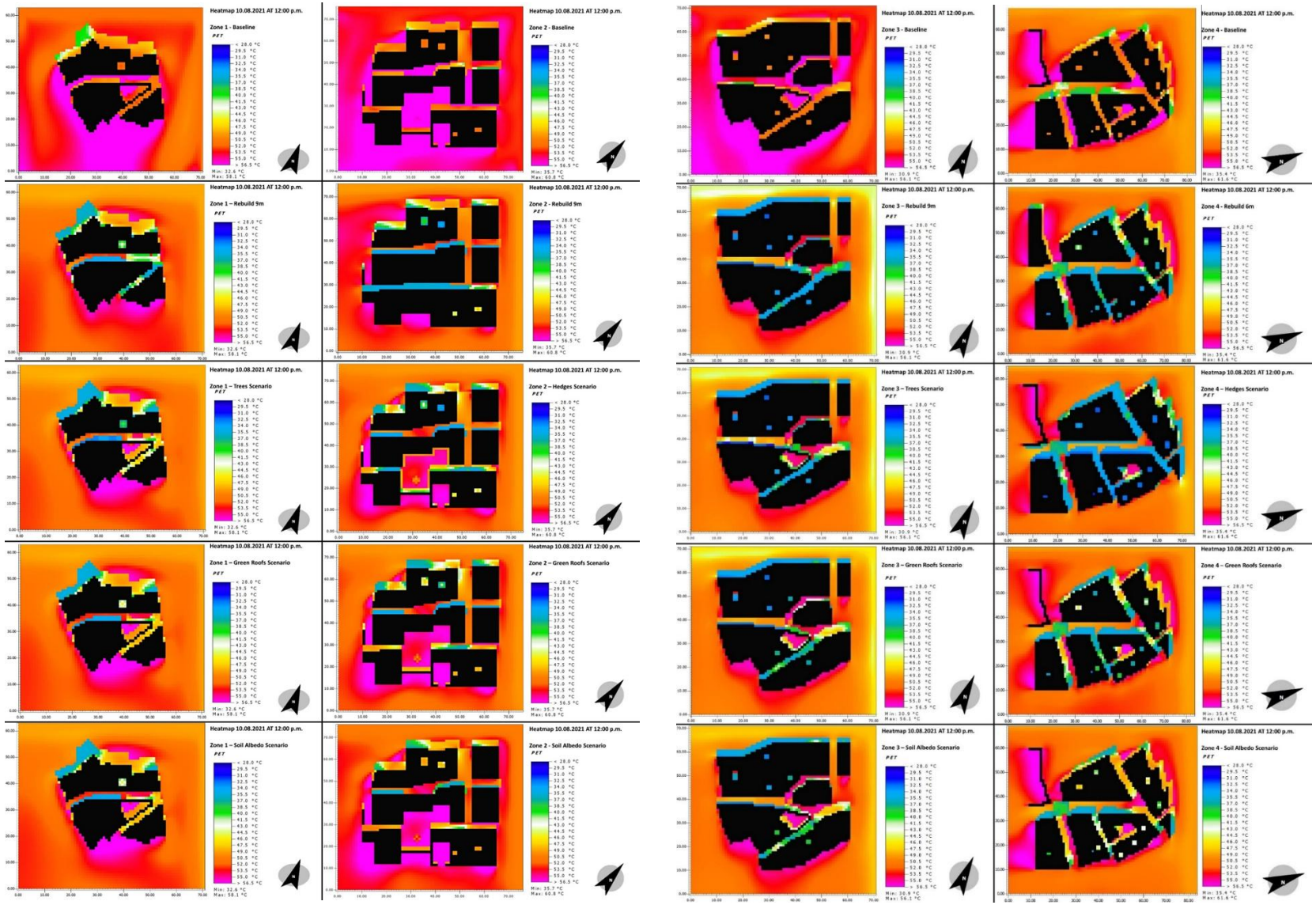
Heat maps of different mitigation strategies on the four zone at 12:00 p.m



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Discussion & Conclusion

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Discussion & Conclusion

What is the current level of thermal comfort in the Casbah of Algiers, and how do microclimatic variations influence the use of outdoor spaces?

The Casbah experiences high thermal stress in summer, with 52% of daytime hours in August characterized by strong to extreme thermal discomfort. The mean radiant temperature (Tmrt) exceeds 60°C in open, unshaded areas. In contrast, sabat and narrow alleys reduce temperatures by 2 to 3°C, demonstrating the effectiveness of traditional morphology. The sea breeze is barely perceptible due to urban density, and modern materials (asphalt, concrete) worsen discomfort, unlike vernacular materials that offer better thermal inertia.

Discussion & Conclusion

Marked rise in daytime temperatures
Maximum temperatures increased from 34.1°C in 1989 to 42.3°C in 2090 (RCP 8.5 scenario), with up to six hours of extreme heat stress per day. This rise reflects an increased risk to public health.

Less cool nighttime temperatures
Nighttime temperatures rose from 16.7°C in 1989 to 22.7°C in 2090 under the most pessimistic scenario, reducing the duration of nighttime thermal recovery phases, which are essential for residents' well-being.

Evolution of PET between 1989 and 2090
In 1989, daytime temperatures reached 34.1°C, compared to 42.3°C in 2090 under the extreme (RCP 8.5) scenario. Nights also became warmer, with increases ranging from 1.4°C to 5.1°C across scenarios. This trend indicates an intensification of thermal stress, especially during the hottest hours of the day.

Evolution of PET between 1989 and 2090
From 1989 to 2090, the annual average temperature increases by +4.5°C in the extreme scenario. Daily maxima rise from 34.1°C to over 42°C, potentially multiplying the frequency of heatwaves. The daily thermal range narrows slightly by 2090, but the overall heat level remains very high.

Discussion & Conclusion

Targeted effectiveness of cooling strategies
Selecting a single, well-targeted and effective strategy is more relevant than implementing complex combinations. Combined scenarios (e.g., vegetation + albedo) do not yield any significant gain over well-chosen individual scenarios. For example, the ΔPET between vegetation combinations and the best single options does not exceed 0.9°C. Therefore, a targeted strategy adapted to the local morphology is more effective than stacking multiple techniques.

Maximum cooling through reconstruction
Urban reconstruction to 9 m in Zone 2 produces the greatest cooling effect, with a PET reduction of 23.2°C at 12 p.m. This strategy outperforms all others in terms of thermal impact.

Green roofs are more effective than green walls
Green roofs demonstrate a stronger cooling effect, especially in Zone 1, with a PET decrease of 10.9°C at noon, compared to an average of 1°C in other zones. Their effectiveness is enhanced in urban canyons with high height-to-width (H/W) ratios.

High-albedo ground: a simple and efficient strategy
Increasing ground albedo results in a cooling of 14.9°C in Zone 1 and 5.5°C in Zone 3. This solution is particularly relevant in dense areas with limited sky view.

Discussion & Conclusion

Limits of combined scenarios
Scenarios combining multiple strategies do not provide significant benefits over simple scenarios (e.g., combined ΔPET in Zone 1 is only 0.9°C), except in very specific cases. Therefore, strategies should be targeted according to morphological characteristics.

Zone 3: extreme thermal discomfort despite interventions
Despite the implemented measures, PET reaches 55.4°C at 12 p.m. in Zone 3, confirming that the east–west orientation and an H/W ratio of 2.07 make this area particularly vulnerable. Additional measures are required.

Variable cooling effects throughout the day
Cooling effects peak at 12 p.m., the time of maximum solar exposure, and then decrease by 5 p.m. At 8 a.m., effects are present but moderate. North–south oriented areas cool more quickly after sunset than east–west oriented ones.

Negative effects of reflective walls in narrow canyons
The use of high-albedo wall materials was counterproductive in areas with high H/W ratios, increasing reflections and reducing thermal comfort.

References

Arrar FH, Kaoula D, Matallah ME, Abdessemed-Foufa A, Taleghani M, Attia S. Quantification of Outdoor Thermal Comfort Levels under Sea Breeze in the Historical City Fabric: The Case of Algiers Casbah. Atmosphere. 2022; 13(4):575. https://doi.org/10.3390/atmos13040575

Matzarakis, A., Mayer, H., & Iziomon, M. G. (1999). *Applications of a Universal Thermal Index: Physiological Equivalent Temperature (PET). International Journal of Biometeorology, 43*(2), 76–84. https://doi.org/10.1007/s004840050119

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نمذجة المناخ الحضري ومرونة النسيج العمراني في العمارة الإسلامية

Urban Climate Modelling and Morphological Resilience in Islamic Urban Fabrics

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