



POLITECNICO
MILANO 1863

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URBAN HEAT ISLAND AND COMFORT

Applied GIScience for urban climate analysis, planning and design



The research of comfort in urban spaces is increasingly under the study of scholars, due to increasing concerns related to climate change

Citizens and city users, in towns and cities, are increasingly suffering from adverse climate effects caused by an increase of frequency and severity of heat waves. These effects are often related to human thermal

Among different approaches and variables used to understand comfort perception, the use of indices based on heat balance theory is key to guide the research and practice in urban planning, design, and management.

The limitations of a solely rational index-based approach reveal the necessity for a more comprehensive understanding of comfort by considering a wider range of influential factors from both individual and environmental perspectives during the assessing process ([Peng, et al. 2021](#))



Together with Air Temperature (T_a °C), the Mean Radiant Temperature (T_{MRT} °C) is the factor that most influences the sensation of heat. It is a synthetic variable with primary importance in the studies of thermal sensation.

T_{MRT} accounts for the temperature of all surfaces surrounding a point (or a person) within an environment. All long-wave and short-wave radiation are combined. It is defined as the weighted average temperature of the temperatures of the surfaces that delimit the environment including the effect of incident solar radiation. It affects the exchanges by radiation.

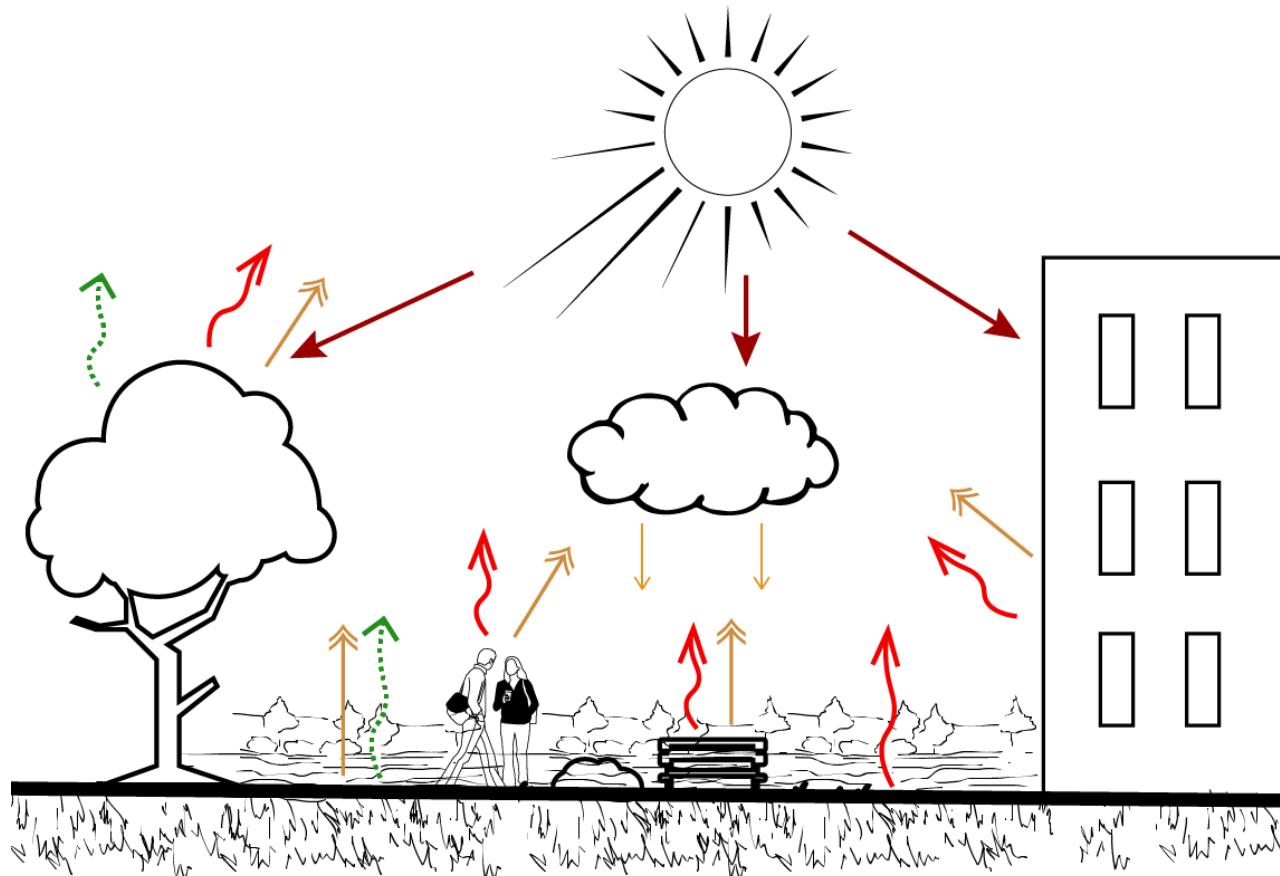
T_{MRT} can be calculated from the measured temperature of surrounding walls and surfaces and their positions with respect to a point in the space (or a person). If the body is exposed to cold surfaces, a significant amount of heat is emitted in the form of radiation towards these surfaces, producing a sensation of cold.

T_{MRT} has a strong influence on thermo-physiological comfort indexes such as Physiological Equivalent Temperature (PET)



Urban Comfort Measures and Modelling

T_{MRT} is among the most important and accurate meteorological parameters that can predict human outdoor thermal comfort, which calculates both direct and reflected of all short and longwave radiation fluxes



[Source](#)

Radiation fluxes and urban entities on the determination of outdoor T_{MRT}

- Direct solar radiation
- ⇒ Shortwave radiation reflected
- Shortwave radiation diffused by the sky
- ↔ Longwave radiation
- ↔ Evapotranspiration



Urban Comfort Measures and Modelling

T_{MRT} can be simulated/calculated with different software (CitySim Pro; ENVI-met; Grasshopper-Ladybug Tools; Autodesk CFD; UMEP-QGIS) or measured through mobile biometeorological instrument platforms.



#	Sensor	Variable(s)	Range	Accuracy	Height
1	HC2S3 Rotronic HygroClip2 T/RH Probe	Temperature	-50° to +100°C	± 0.1°C	1.5 m
		Humidity	0% to 100% RH	± 0.8% RH	
2	Omega Type T Thermocouple	Temperature	-250° to +350°C	± 0.5°C	1.5 m
3	Gill 2D WindSonic	Wind Speed	0 to 60 ms ⁻¹	± 2% @12 ms ⁻¹	1.7 m
4	GPS16X Garmin GPS	Lat/Lon	-	less than 3m	1.5 m
5	3 Hukseflux 4-Component Net Radiometers	SW Radiation	0 to 2000 Wm ⁻²	± 10%	1.1 m to 1.3 m
		LW Radiation	0 to 1000 Wm ⁻²	± 10%	

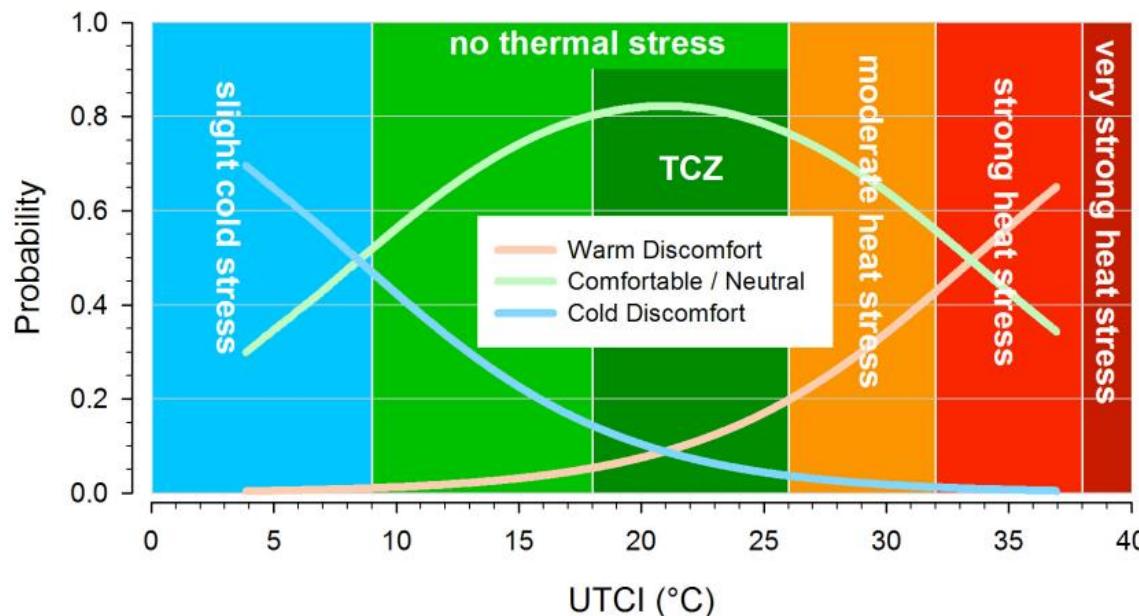
Mean Radiant Temperature cart with sensor specification

The calculation of T_{MRT} is based on the determination of the **radiation profiles of the all-surrounding surfaces and the visible section of the sky**. Temperature of all the surrounding surfaces, the absorptivity and emissivity of the outer surfaces and the pedestrian posture have an impact and needs to be defined.



In 2011, the International Society of Biometeorology (ISB; <http://www.biometeorology.org>) announced the Universal Thermal Climate Index - UTCI (<http://www.utci.org>) as a new **thermal index for outdoor thermal comfort** ([Park, et al. 2014](#)).

UTCI is a **human biometeorology parameter** that is used to assess the **linkages between outdoor environment and human well-being**. Thermal comfort indices describe how the human body experiences atmospheric conditions, specifically air temperature, humidity, wind and radiation.



Categories of thermal comfort predicted by ordinal logistic regression analysis with UTCI as explanatory variable
([Bröde et al. 2011](#))



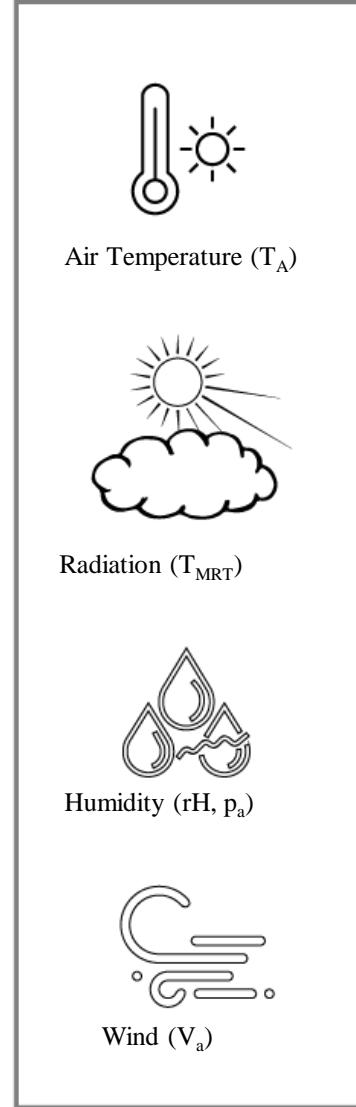
Urban Comfort Measures and Modelling

Universal Thermal Climate Index (UTCI) from Bröde et al. (2011)

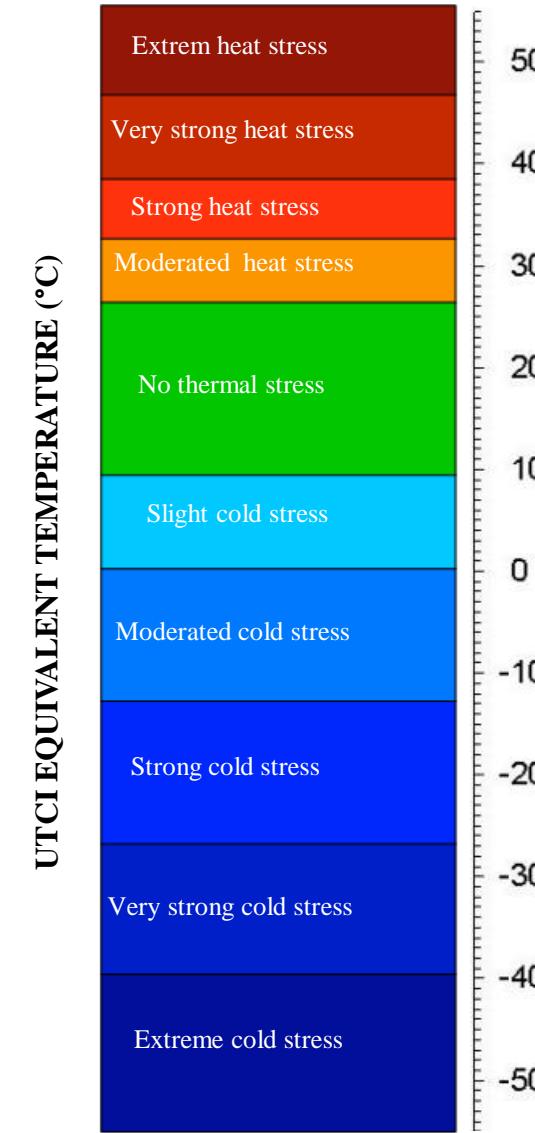
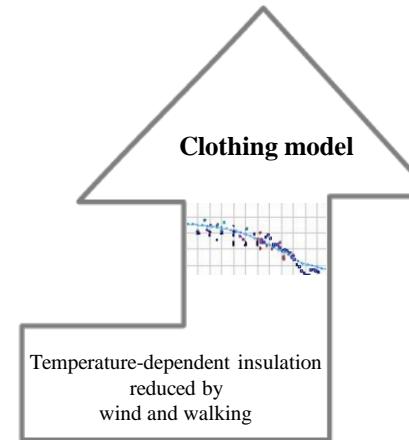
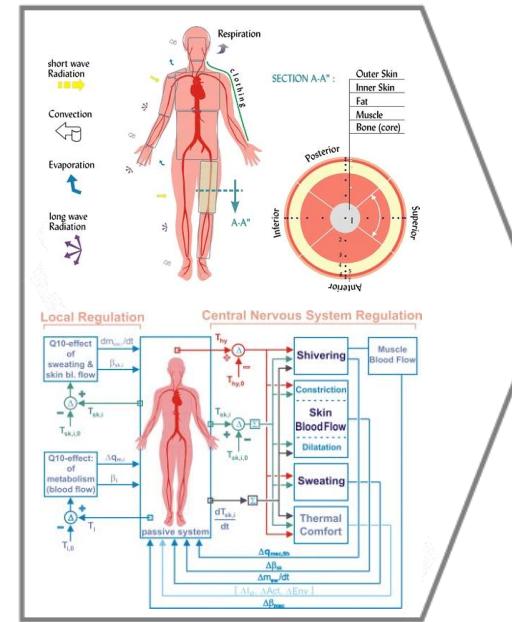


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METEOROLOGICAL INPUT

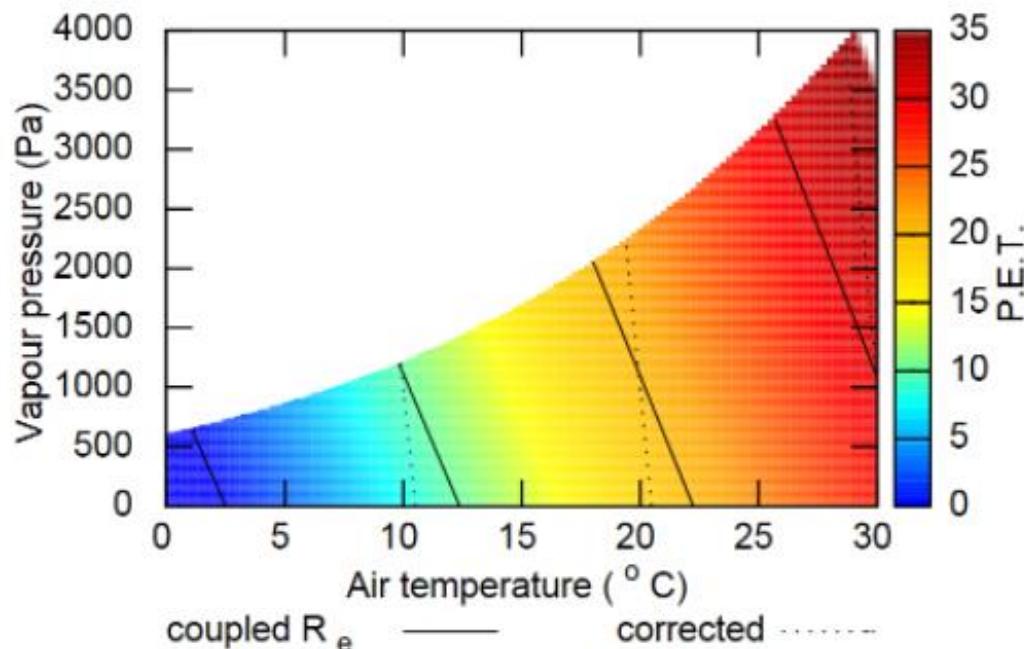


PHYSIOLOGICAL MODEL



Urban Comfort Measures and Modelling

The Physiological Equivalent Temperature (PET) index, derived from the human heat balance model, combines weather and thermo-physiological parameters (clothing and human activities). It is used to measure the thermal comfort of an individual in a given situation by comparing the physiological responses with respect to a reference environment, for example an office in which one feels generally comfortable.



PET. Iso-PET values: 20, 30, 40 and 50 $^{\circ}\text{C}$

Source: Walther and Goestchel, 2018

PET	Thermal perception	Grade of physiological stress
4°C	Very cold	Extreme cold stress
8°C	Cold	Strong cold stress
13°C	Cool	Moderate cold stress
18°C	Slightly cool	Slight cold stress
23°C	Comfortable	No thermal stress
29°C	Slightly warm	Slight heat stress
35°C	Warm	Moderate heat stress
41°C	Hot	Strong heat stress
	Very hot	Extreme heat stress

Ranges of the physiological equivalent temperature (PET) for different grades of thermal perception and heat stress

Source: Matzarakis and Amelung, 2008



PET is also defined as the air temperature at which, in a typical indoor setting (without wind and solar radiation), the heat budget of the human body is balanced with the same core and skin temperature as under the complex outdoor conditions to be assessed.

PET values can **vary based on the air temperature, and the conditions of the person indoor or outdoor**. As presented in the table, there are **large differences between air temperature and PET** also arise in winter-time on days with high wind velocities.

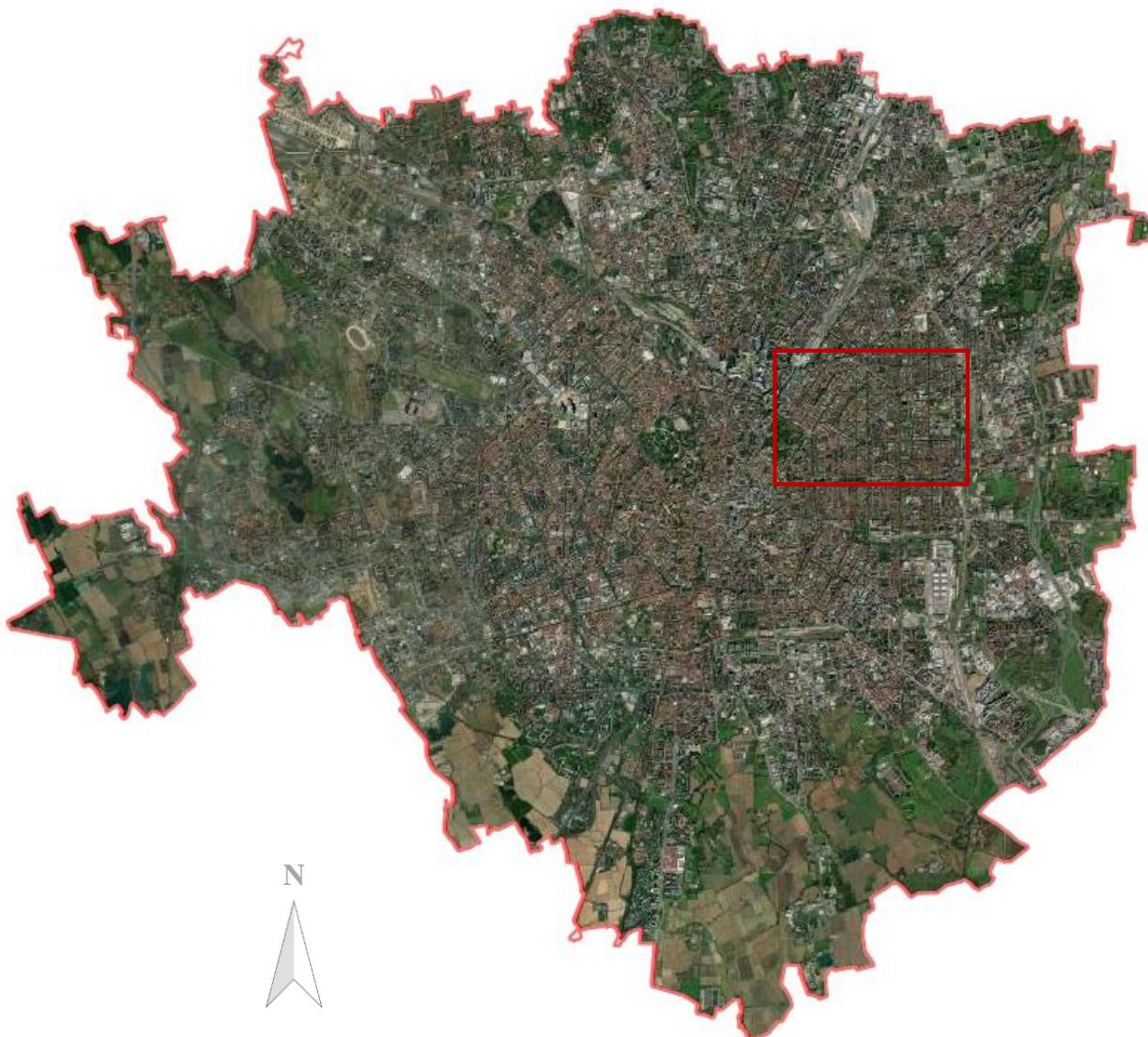
Scenario	T_a (°C)	T_{mrt} (°C)	v (m/s)	VP (hPa)	PET (°C)
Typical room	21	21	0.1	12	21
Winter, sunny	-5	40	0.5	2	10
Winter, shade	-5	-5	5.0	2	-13
Summer, sunny	30	60	1.0	21	43
Summer, shade	30	30	1.0	21	29

Examples of physiological equivalent temperature (PET) values for different climate scenarios.
Ta-air temperature, Tmrt-mean radiant tempertaure, v-air velocity, VP-water vapour pressure

Source: Höppe, 1999



Urban Comfort Measures and Modelling



The case study is the Municipality of Milan. Located in the north-western of Lombardy Region, it covers a space of 181.7 km² with around 1.3 million population.

From an urban climatic point of view, the region is framed as continental, characterized by cold winters and hot summers.

According to the Köppen climate classification scheme, this area is classified as 'Cfa' (humid sub-tropical), i.e. temperate, without dry season, and affected by hot summers.

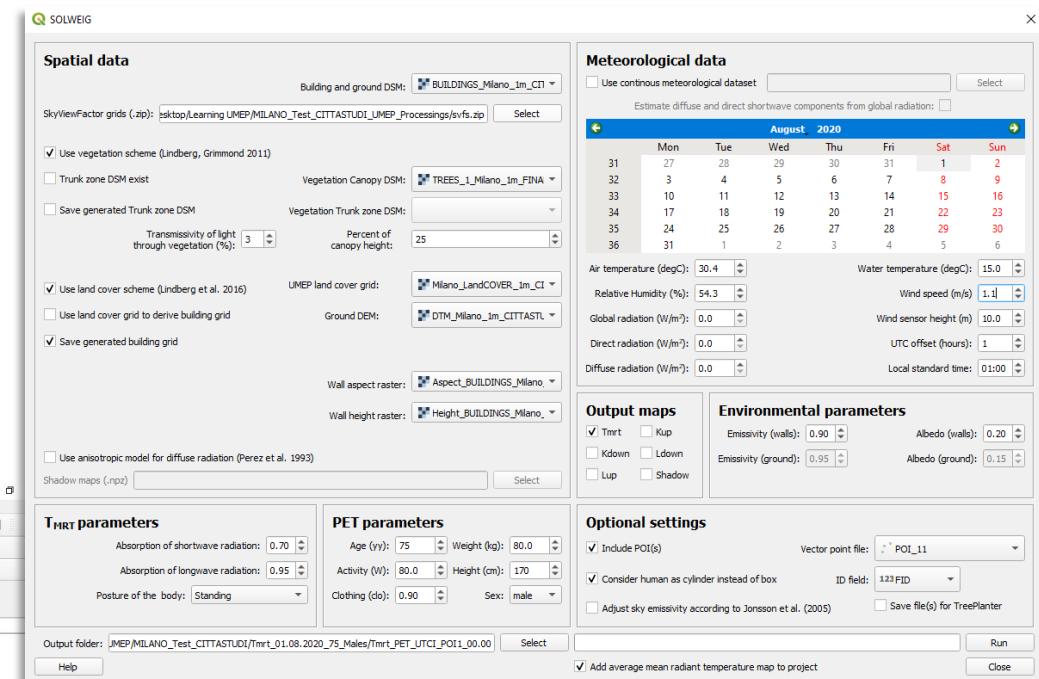
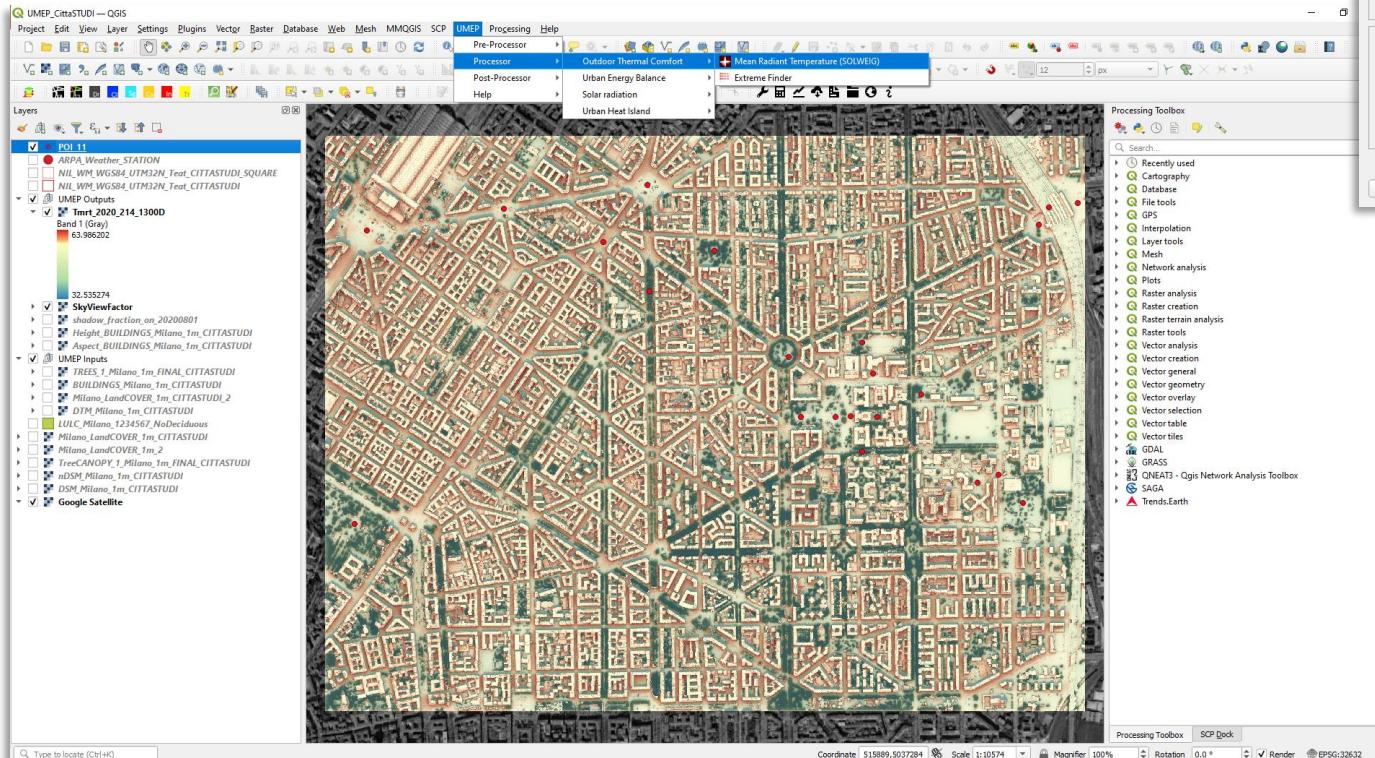
Köppen, 1936; Peel, Finlayson and McMahon, 2007



Urban Comfort Measures and Modelling

The Urban Multi-scale Environmental Predictor (UMEP) is a climate service tool, designed for researchers and service providers (e.g. architects, climatologists, energy, health and urban planners) presented as a plugin for QGIS.

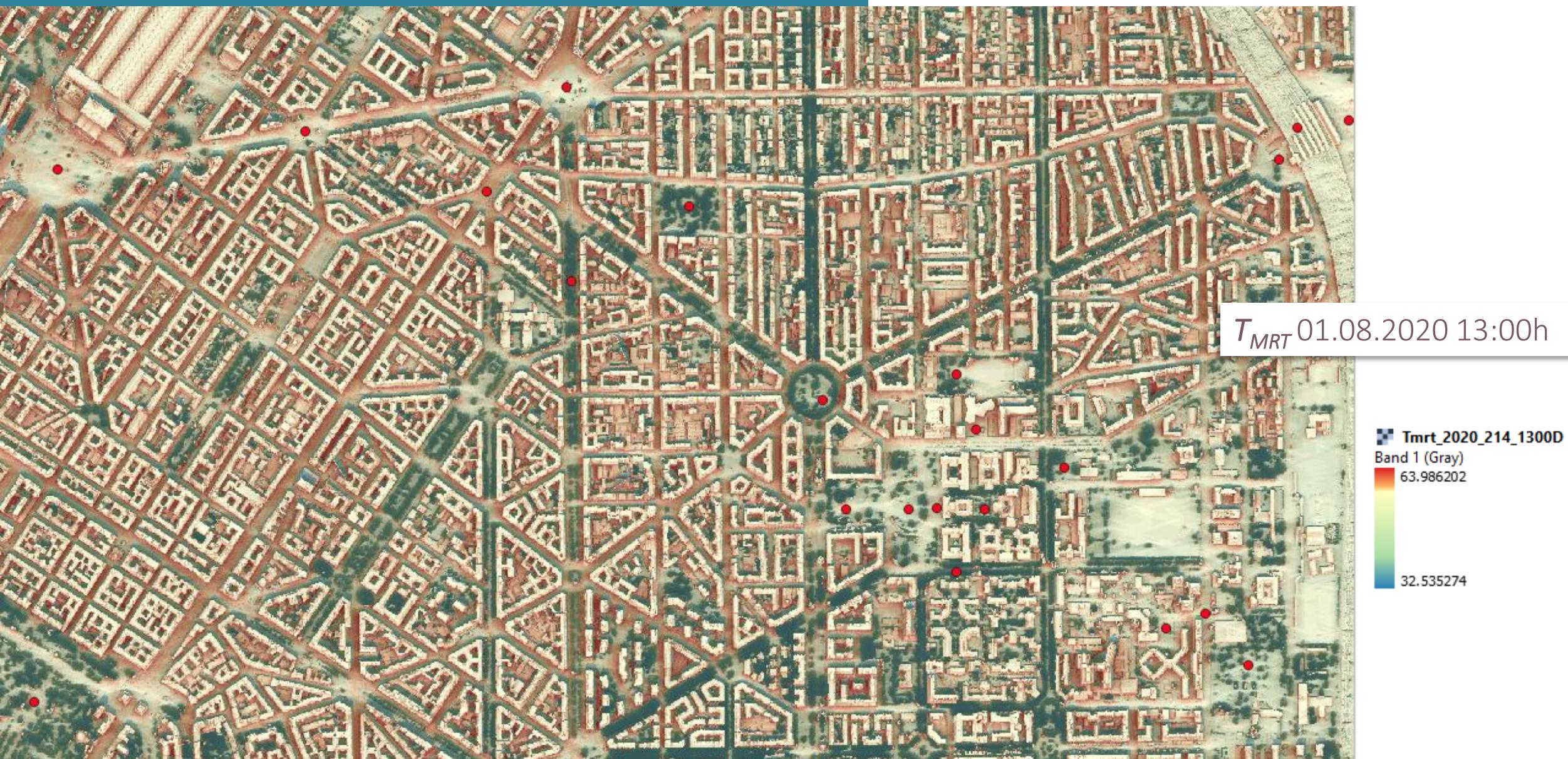
<https://umep-docs.readthedocs.io/en/latest/>



This tool can be used for a variety of applications related to outdoor thermal comfort, urban energy consumption, climate change mitigation etc. UMEP consists of a coupled modelling system which combines “state of the art” 1D and 2D models related to the processes essential for scale independent urban climate estimations.

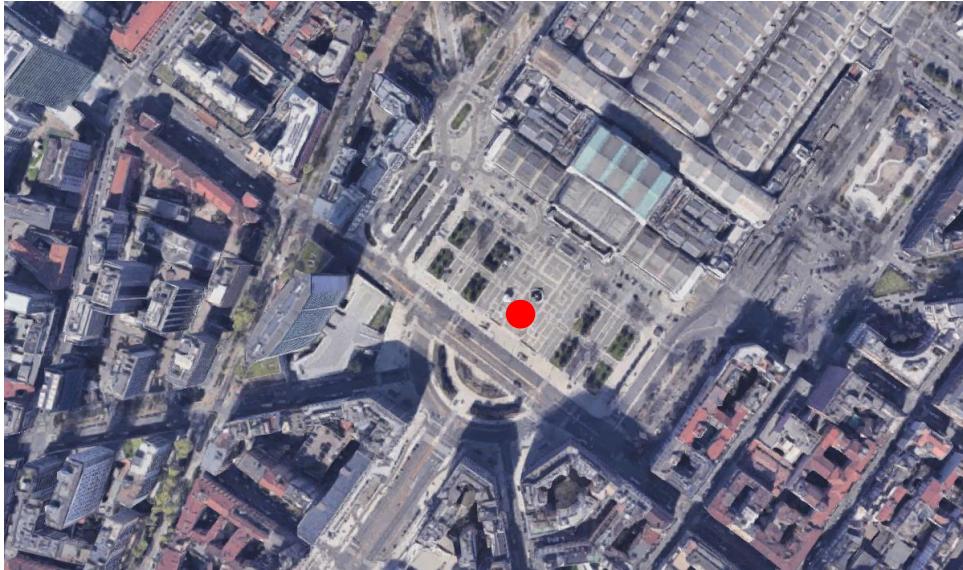


Urban Comfort Measures and Modelling

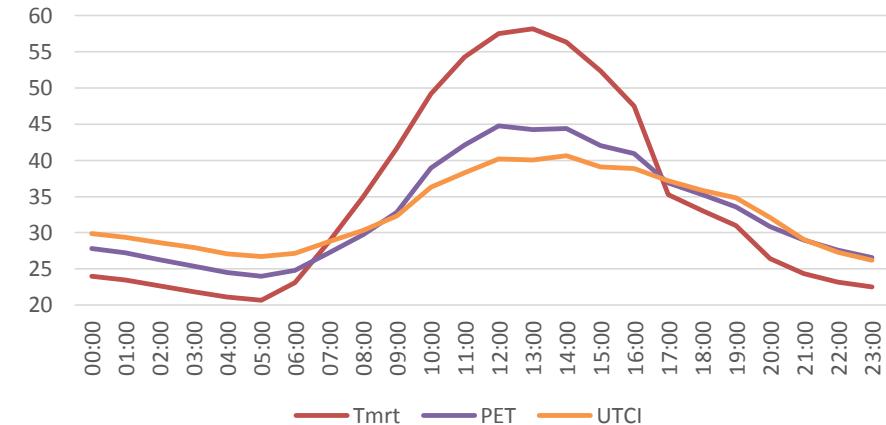


Urban Comfort Measures and Modelling

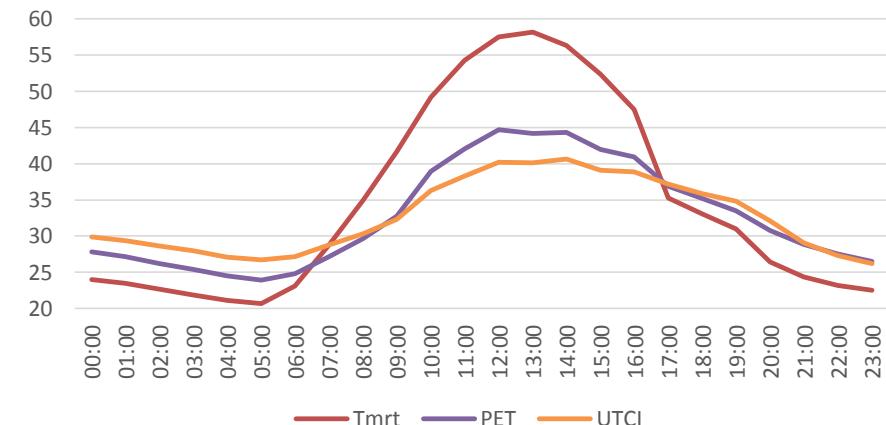
Centrale Station - Piazza Duca d'Aosta



UMEPI - Thermal Comfort for Male age 35

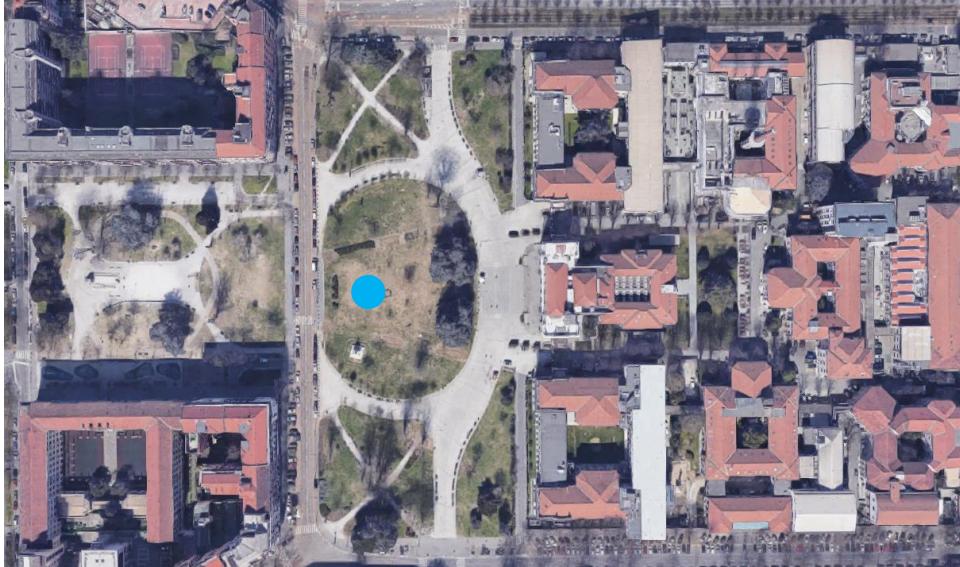


UMEPI - Thermal Comfort for Female age 35

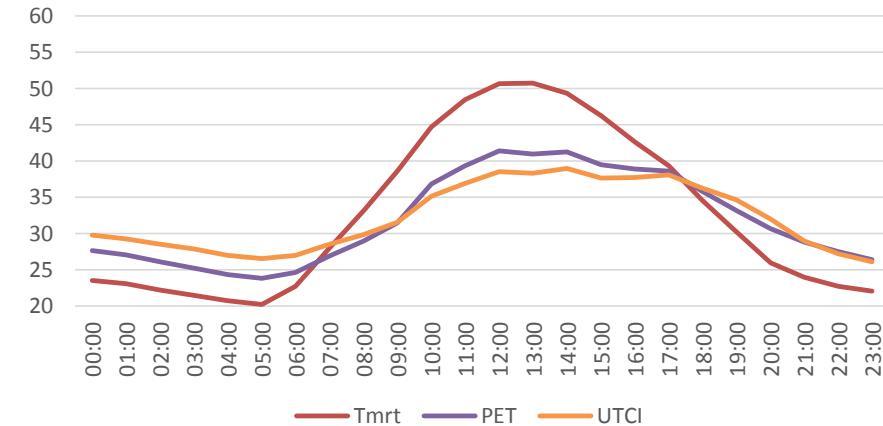


Urban Comfort Measures and Modelling

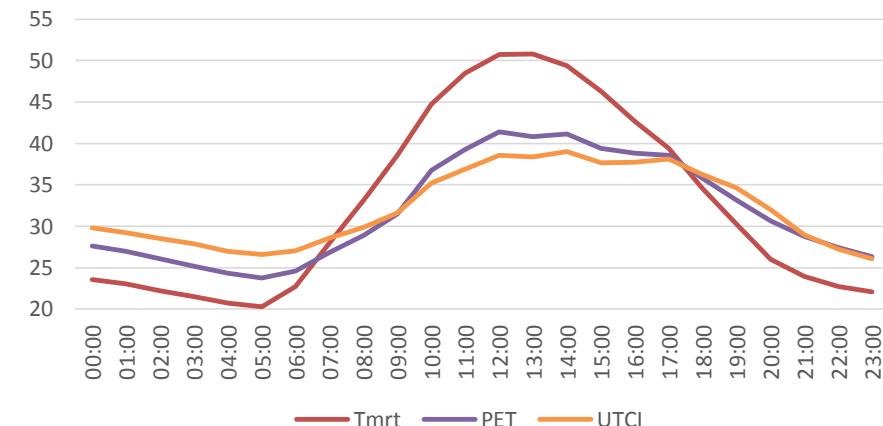
Piazza Leonardo da Vinci - Campus Leonardo



UMEП - Thermal Comfort for Male age 35



UMEП - Thermal Comfort for Female age 35

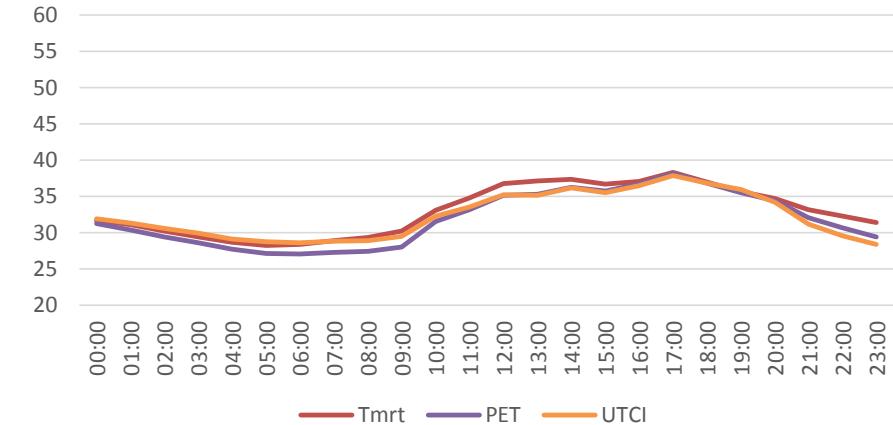


Urban Comfort Measures and Modelling

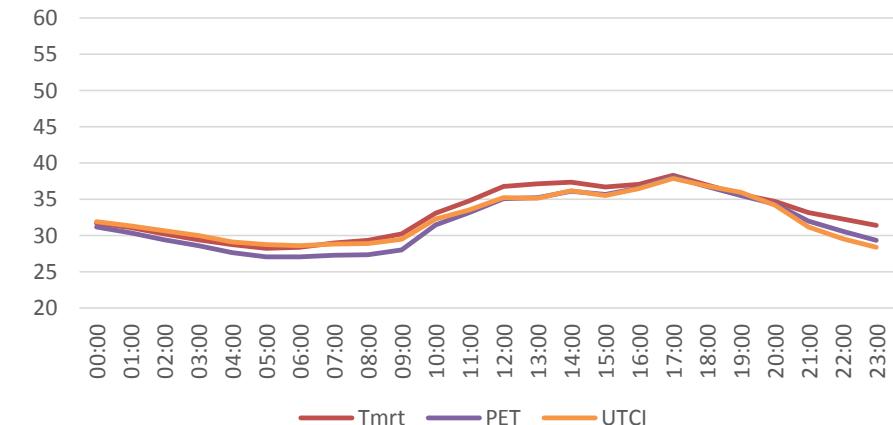
Viale Abruzzi



UMEP -Thermal Comfort for Male age 35



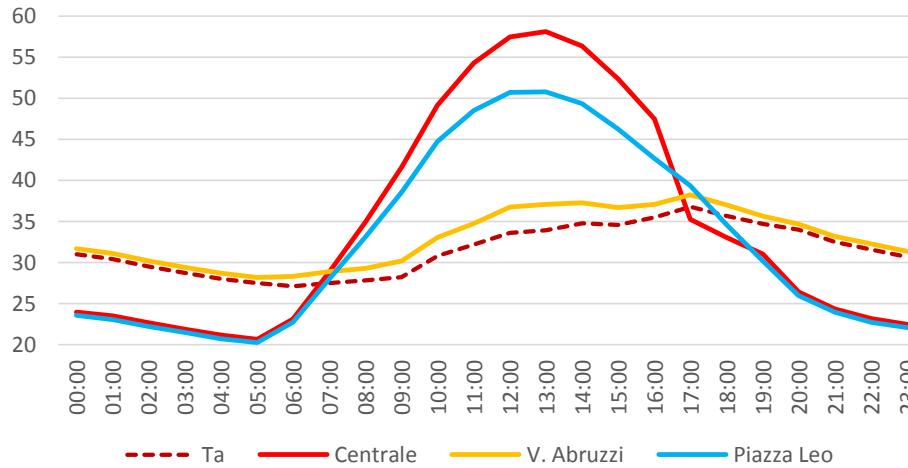
UMEP -Thermal Comfort for Female age 35



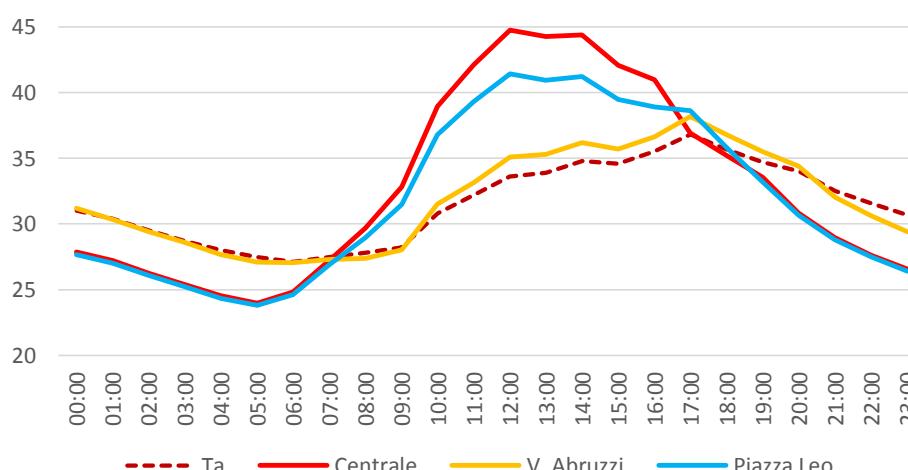
Urban Comfort Measures and Modelling

Male, 35

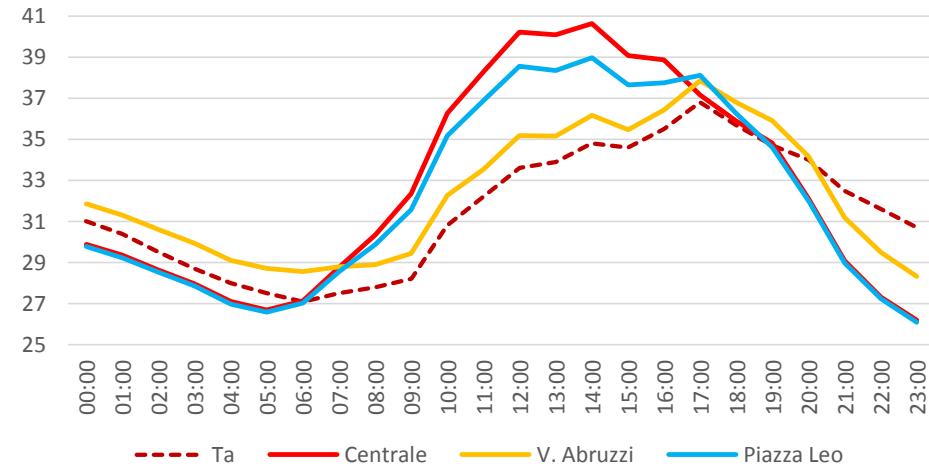
TMRT



PET



UTCI



Centrale

hour	F	M	Differ.
00:00	27.81	27.85	0.04
01:00	27.16	27.2	0.04
02:00	26.2	26.25	0.05
03:00	25.36	25.39	0.03
04:00	24.48	24.52	0.04
05:00	23.94	23.96	0.02
06:00	24.78	24.81	0.03
07:00	27.19	27.22	0.03
08:00	29.66	29.71	0.05
09:00	32.77	32.83	0.06
10:00	38.92	38.96	0.04
11:00	42.06	42.13	0.07
12:00	44.71	44.76	0.05
13:00	44.15	44.25	0.1
14:00	44.31	44.38	0.07
15:00	41.95	42.06	0.11
16:00	40.9	40.97	0.07
17:00	36.87	36.92	0.05
18:00	35.16	35.23	0.07
19:00	33.48	33.54	0.06
20:00	30.8	30.83	0.03
21:00	28.89	28.97	0.08
22:00	27.53	27.63	0.1
23:00	26.48	26.56	0.08



Piazza Leo

hour	F	M	Differ.
00:00	27.64	27.67	0.03
01:00	26.99	27.03	0.04
02:00	26.04	26.08	0.04
03:00	25.19	25.22	0.03
04:00	24.31	24.34	0.03
05:00	23.77	23.8	0.03
06:00	24.61	24.63	0.02
07:00	26.86	26.89	0.03
08:00	28.9	28.95	0.05
09:00	31.44	31.5	0.06
10:00	36.76	36.81	0.05
11:00	39.28	39.33	0.05
12:00	41.37	41.44	0.07
13:00	40.83	40.94	0.11
14:00	41.15	41.24	0.09
15:00	39.38	39.49	0.11
16:00	38.83	38.92	0.09
17:00	38.54	38.62	0.08
18:00	35.76	35.83	0.07
19:00	33.15	33.19	0.04
20:00	30.62	30.65	0.03
21:00	28.74	28.82	0.08
22:00	27.4	27.49	0.09
23:00	26.34	26.41	0.07



Viale Abruzzi

hour	F	M	Differ.
00:00	31.17	31.2	0.03
01:00	30.31	30.35	0.04
02:00	29.36	29.39	0.03
03:00	28.55	28.58	0.03
04:00	27.62	27.66	0.04
05:00	27.05	27.08	0.03
06:00	27.05	27.07	0.02
07:00	27.24	27.28	0.04
08:00	27.35	27.39	0.04
09:00	27.96	28.01	0.05
10:00	31.47	31.51	0.04
11:00	33.11	33.16	0.05
12:00	35.04	35.1	0.06
13:00	35.2	35.28	0.08
14:00	36.11	36.2	0.09
15:00	35.61	35.71	0.1
16:00	36.55	36.64	0.09
17:00	38.09	38.16	0.07
18:00	36.74	36.81	0.07
19:00	35.46	35.51	0.05
20:00	34.35	34.39	0.04
21:00	31.97	32.06	0.09
22:00	30.57	30.64	0.07
23:00	29.32	29.42	0.1

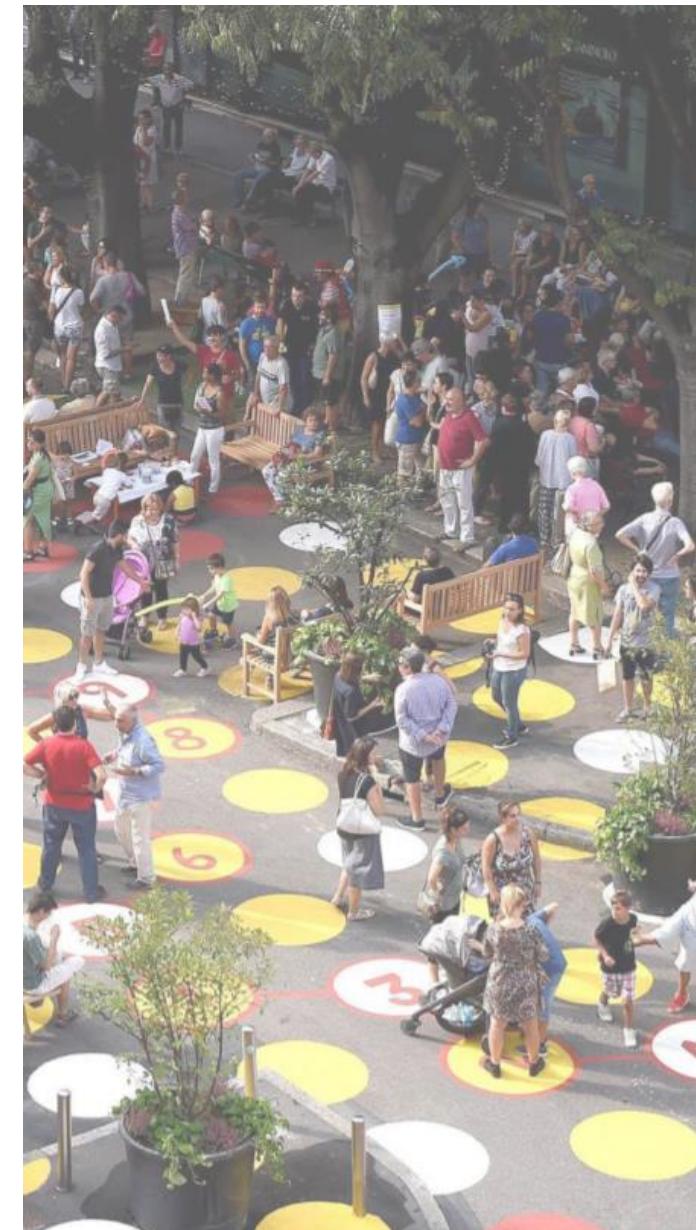


The Tactical Urbanism in Milan City

'*Piazze Aperte*' (Open Squares), launched in 2018 in collaboration with Bloomberg Associates, is aimed at pursuing the urban regeneration and sustainable mobility objectives of the **Milan 2030 Urban Plan (PGT - Piano di Governo del Territorio)** and the **Urban Sustainable Mobility Plan**

The project **focuses on public spaces** with the objective of increasing pedestrian accessibility and sustainable mobility for the environment, safety and quality of life in the city

65 places have been proposed, including squares and schools, to be addressed according to the **Tactical Urbanism approach**



https://www.comune.milano.it/documents/20126/71248910/200125_Piazze+Aperte_presentazione.pdf/ccedc101-46c4-b285-f1b8-f5835102f416?t=1581338482141



Piazzale Fabio Chiesa 'La PIANA', Milan

LA PIANA has been re-designed according to a Tactical Urban planning intervention that has transformed the square into a meeting space for the local community through re-painting the open space, the installation of new street furniture, potted plants and vegetable boxes

A micro-climatic measurement campaign was carried out before starting the project, mainly focusing on the land surface temperatures and the air temperature

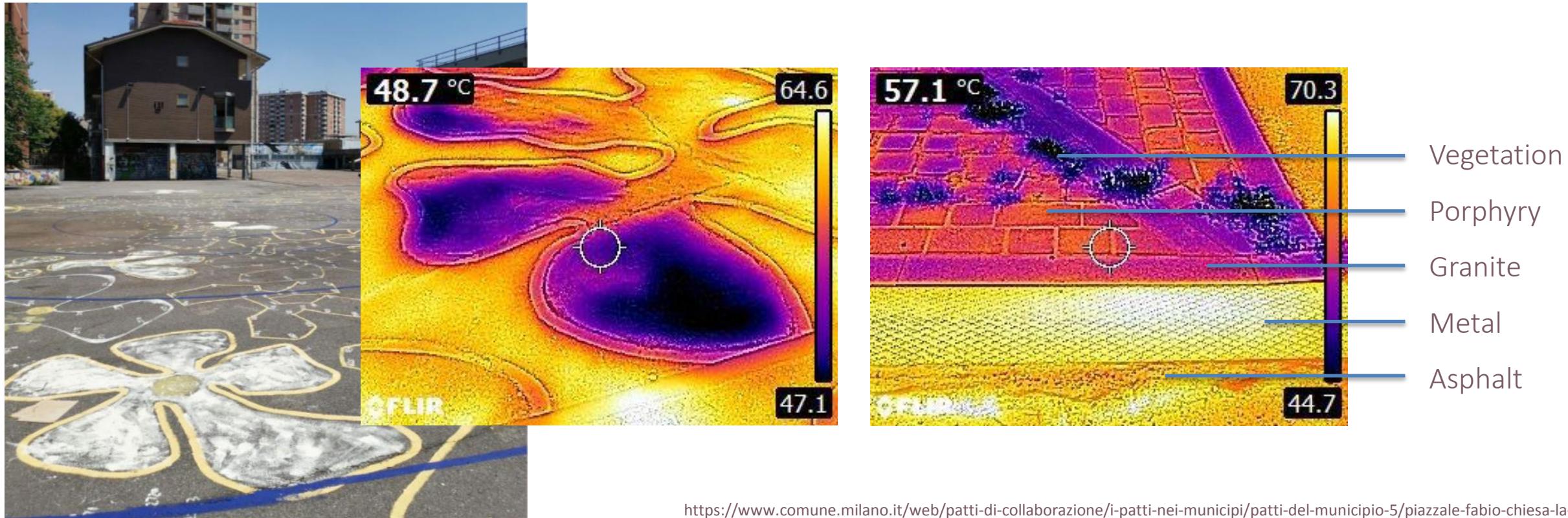


<https://www.comune.milano.it/web/patti-di-collaborazione/i-patti-nei-municipi/patti-del-municipio-5/piazzale-fabio-chiesa-la-piana>



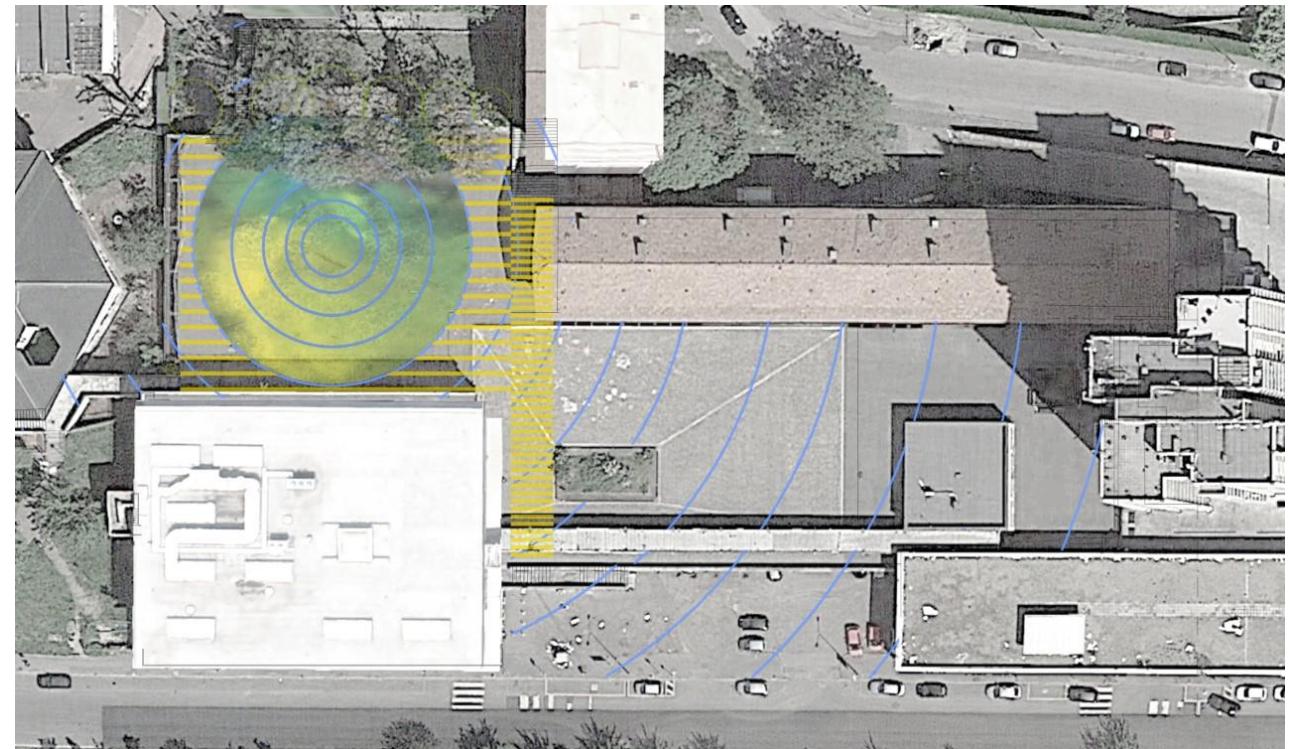
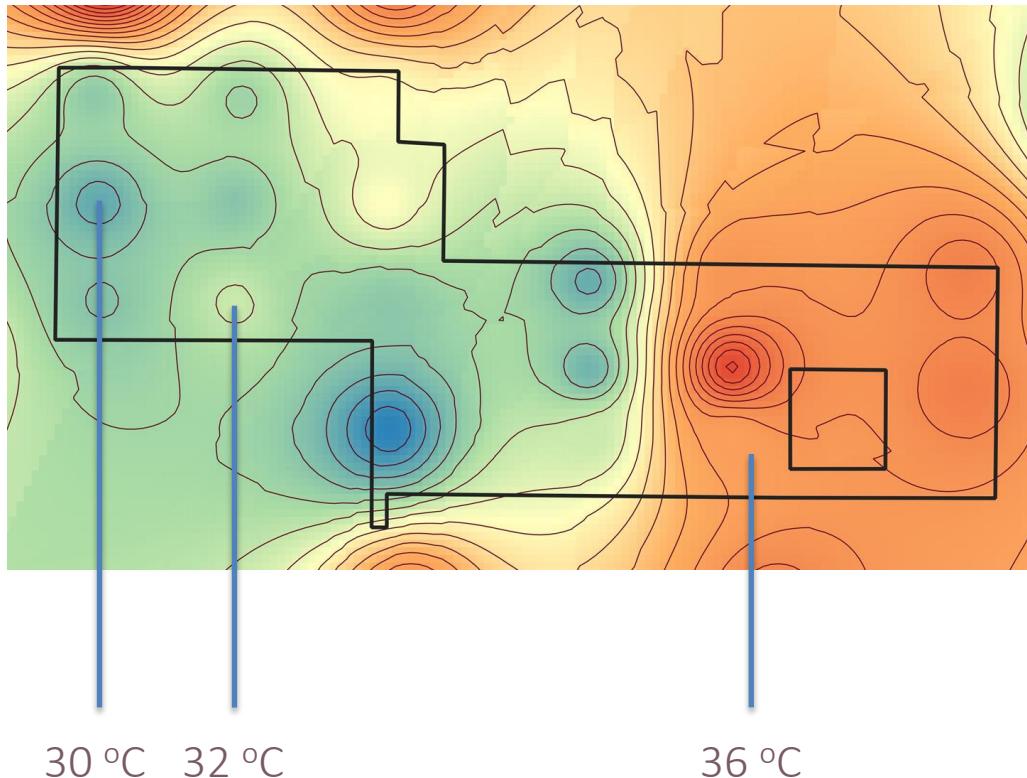
Piazzale Fabio Chiesa 'La PIANA', Milan

Surface temperature data has revealed the importance of using color as a key tool for reducing temperatures absorption by the materials, thus increasing mainly night-time comfort



Piazzale Fabio Chiesa 'La PIANA', Milan

While the **air temperature** maps have **inspired the re-painting** of the asphalt surfaces, in a manner similar to the temperatures behavior



<https://www.comune.milano.it/web/patti-di-collaborazione/i-patti-nei-municipi/patti-del-municipio-5/piazzale-fabio-chiesa-la-piana>

