7th AIGE/IIETA International Conference

16th AIGE 2022 Conference

Parma, June 8th – 9th, 2022

GEOSPATIAL ASSESSMENT AND MODELING OF OUTDOOR THERMAL COMFORT AT URBAN SCALE

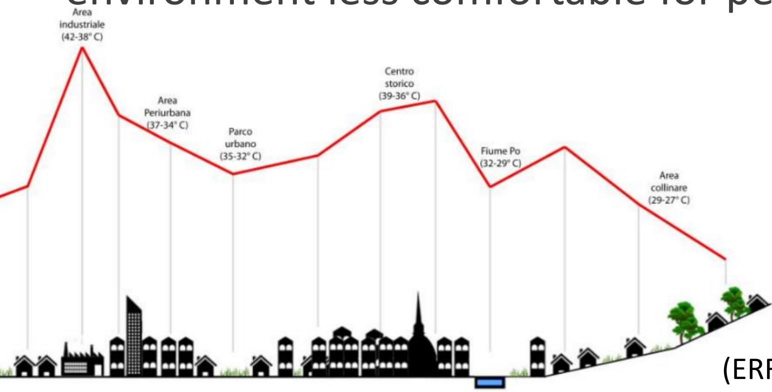
Guglielmina Mutani[1] and Simone Beltramino[2]

[1]Responsible Risk Resilience Centre – R3C, Department of Energy, Politecnico di Torino. Turin, Italy

[2]Responsible Risk Resilience Centre – R3C, Interuniversity Department of Regional and Urban Studies and Planning, Politecnico di Torino. Turin, Italy

Research background and objectives

Climate changes and **urban population growth** are increasing the **heat island effect** in cities causing environmental impacts and making the urban outdoor environment less comfortable for people.



(ERRIS)

Heat island over Turin (Marco Diana)

Urban spaces are a limited and precious resource that must be exploited to the fullest.

(Urban space of Turin)

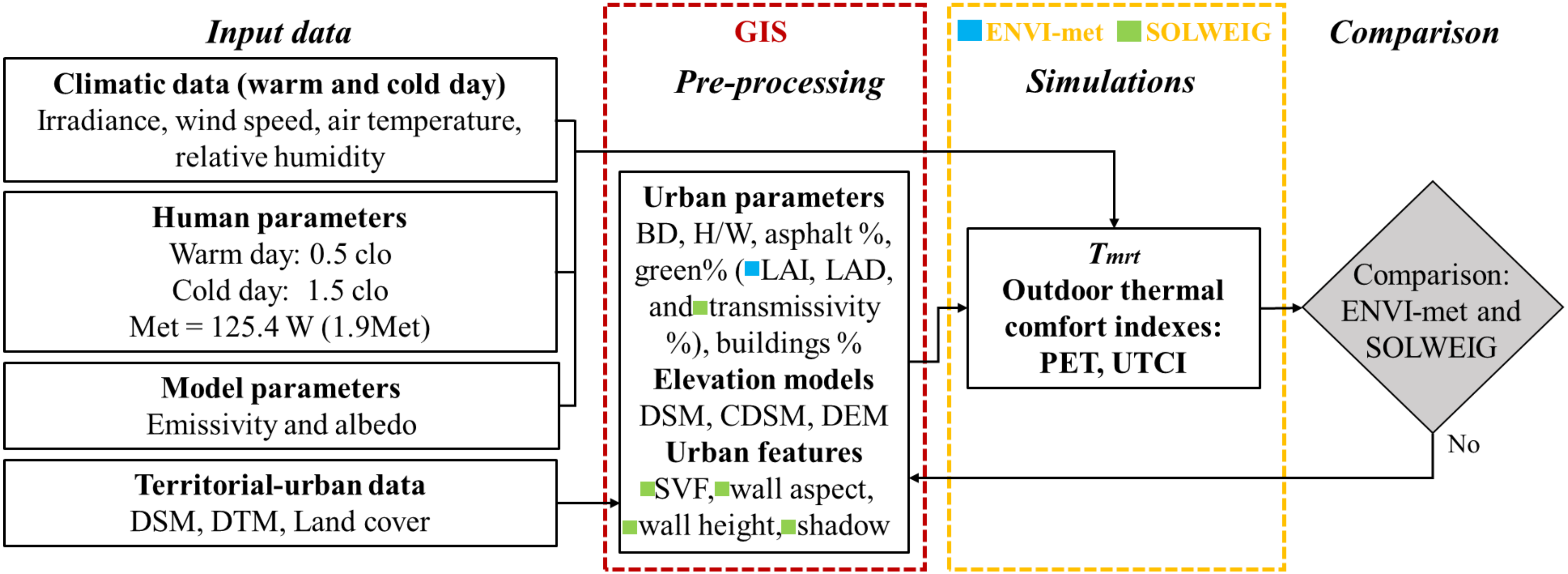
GOAL OF WORK: provide an overview of the current **tools to evaluate local climate conditions** in cities, helping to define the most appropriate type of tool.

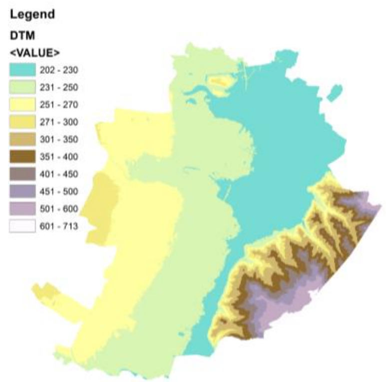
CASE STUDY: **two neighborhoods** with different urban morphologies located in the **city of Turin** (Italy).

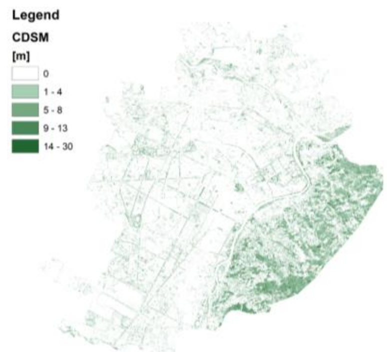
OBJECT OF WORK: the results of this work provide **urban thermal comfort maps** and **graphs** to support urban planners, useful to implement guidelines for checking and improving the livability of outdoor spaces.

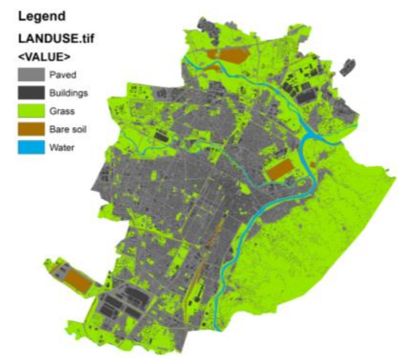
REF: "How to Improve the Liveability in Cities: The Effect of Urban Morphology and Greening on Outdoor Thermal Comfort" G. Mutani, V. Todeschi, S. Beltramino. TECNICA ITALIANA-Italian Journal of Engineering Science. Vol. 65, No. 2-4, July, 2021, pp. 361-370

Methodology







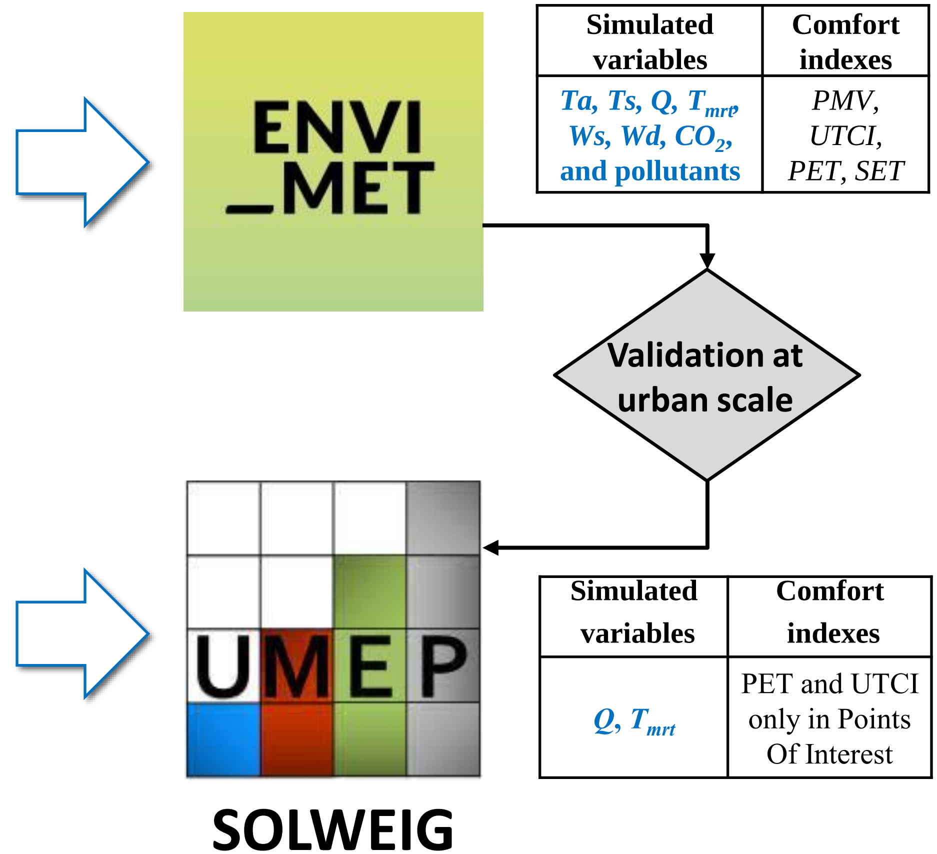


Thermal comfort tools for outdoor spaces

The tools used to evaluate thermal comfort conditions can be classified based on the **spatial scale** analyzed:

- **Local scale tools** use very **accurate**, **complex**, and **time-consuming models** are useful for **advanced feasibility studies**, and for the design phase of blocks of buildings and little neighborhoods.

- **Urban scale tools** are less common in literature and most of them are based on **GIS** (Geographic Information Systems) tools. They are based on more **simplified models** for the calculation of thermal comfort variables, returning **lower accuracy** results, but the possibility to consider a **larger urban area with faster simulation times**.



Simulated variables	Comfort indexes
Ta, Ts, Q, T_{mrt}, *Ws, Wd,* CO_2, **and pollutants**	*PMV, UTCI, PET, SET*

Simulated variables	Comfort indexes
Q, T_{mrt}	PET and UTCI only in Points Of Interest

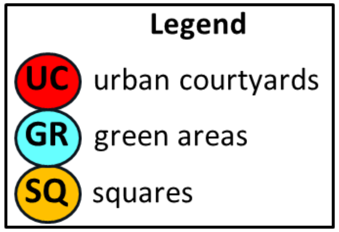
REF: "Improving Outdoor Thermal Comfort in Built Environment Assessing the Impact of Urban Form and Vegetation". " G. Mutani, V. Todeschi, S. Beltramino. International Journal of Heat and Technology Vol. 40, No. 1, February, 2022, pp. 23-31

Comparison between ENVI-met and UMEP-SOLWEIG

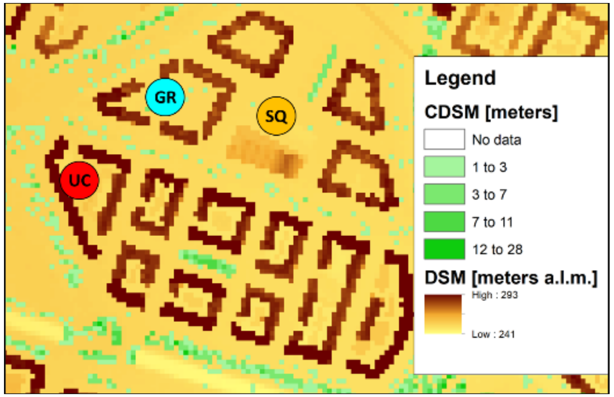
ENVI-met was compared with UMEP-SOLWEIG to validate this last tool under extreme summer and winter weather conditions, analyzing thermal comfort conditions:

Models	Wind	Ta and RH	Radiative fluxes	Pollutant	Soil	Vegetation	Built environment
ENVI-met	Reynolds-averaged non-hydrostatic Navier-Stokes equations	Determined by the different sources and sinks of sensible heat and vapor in the model	Radiation fluxes (avg) consider shading, reflections, building materials, and the effect of vegetation	Pollutant dispersion model is developed by ENVI-met	The heat conductivity considers the soil water content (Darcy's law). A 3D root model calculates water extraction from the soil	All plants are treated solving the energy balance of the leaf surface	Complex buildings can be constructed with no limitations, represented by a thermodynamical model of 7 prognostic calculation nodes
UMEP-SOLWEIG	Hourly weather data	Hourly weather data	Diffuse and direct solar radiation calculation from the global radiation using the approach	Not calculated	Grass and natural surfaces have been parameterized considering the DSM	*Tveg* is equal to *Ta*; shortwave and longwave transmission is taken from literature.	Derived from DSM of buildings and ground

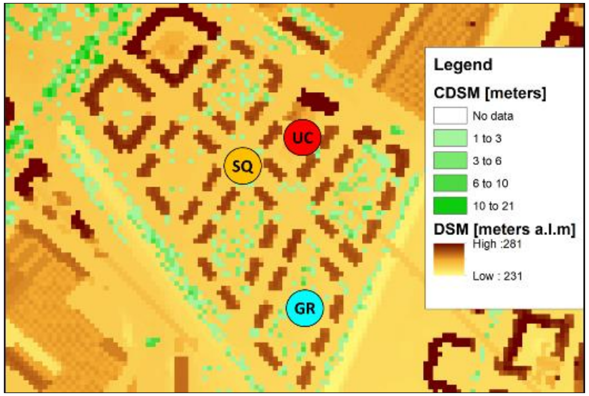
Case study



Mediterraneo



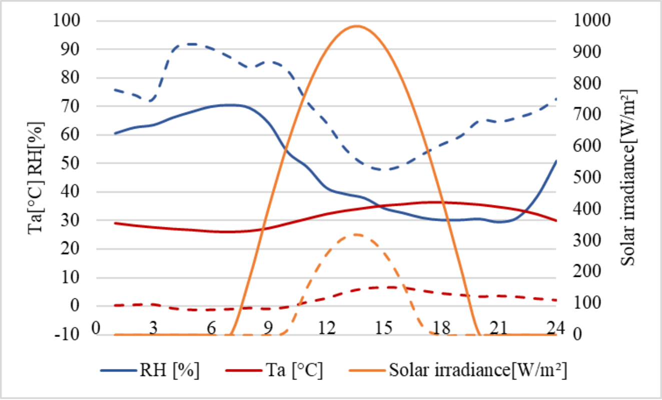
Arquata



Emissivity	Albedo	Deciduous trees seasonal leaf trend parameters
Asphalt 0.9; Concrete pavement 0.9; Walls and roofs 0.9; Grass: 0.95.	Asphalt 0.2; Concrete pavement 0.4; Walls and roofs 0.4; Grass 0.2.	ENVI-met: spherical shape, height of 5-15 m: LAI=5.0 in summer; LAI=0.6 in winter. SOLWEIG: from a 3D model “CDSM”, τ_s = 2% in summer and τ_s = 64% in winter.

Climate data

Regarding local climate conditions, a set of **hourly meteorological data** from the ‘Politecnico di Torino’ weather station was used to investigate local climate conditions.



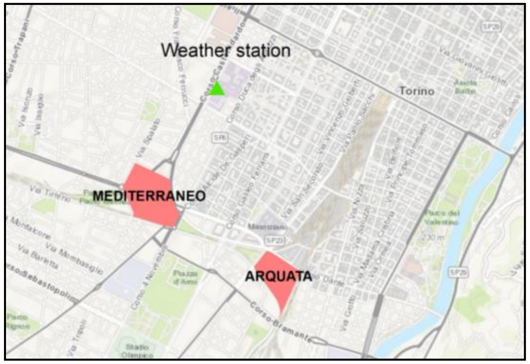
The assessment was done for:

- the **hottest day** (summer, August 7th);
- the **coldest day** (winter, January 1st).

Results and discussion

Comparison between SOLWEIG and ENVI-met for two neighborhoods

Neighborhoods	Arquata	Mediterraneo
Building density (BD) [m^3/m^2]	3.56	6.96
Height-to-width ratio (H/W) [m/m]	0.27	0.62
Asphalt [%]	43.50	49.72
Grass [%]	10.31	8.08
Buildings [%]	19.44	17.32



1. Average daily values on three points of interest

2. Hourly values on three points of interest

3. Spatial analysis

4. City-scale analysis

Comparison between SOLWEIG and ENVI-met

Average daily values on three points of interest

The average values of PET and UTCI for August 7th, 2015 (8 am - 8 pm) and for January 1st (10 am - 6 pm) are shown.

	Summer						Winter					
	PET (°C)			*UTCI* (°C)			*PET* (°C)			*UTCI* (°C)		
Mediterraneo	**GR**	**SQ**	**UC**	**GR**	**SQ**	**UC**	**GR**	**SQ**	**UC**	**GR**	**SQ**	**UC**
ENVI-met	45.29	44.70	42.14	39.77	39.00	38.54	2.12	2.46	1.99	4.78	5.35	4.07
SOLWEIG	45.51	44.90	41.27	39.31	39.01	37.27	2.42	3.09	1.89	5.72	6.40	5.14
Arquata	**GR**	**SQ**	**UC**	**GR**	**SQ**	**UC**	**GR**	**SQ**	**UC**	**GR**	**SQ**	**UC**
ENVI-met	42.24	45.57	44.61	39.05	41.08	36.88	2.98	2.50	2.59	4.92	5.55	5.02
SOLWEIG	40.45	44.72	43.86	36.97	38.94	38.52	3.46	2.98	2.55	6.78	6.28	5.83

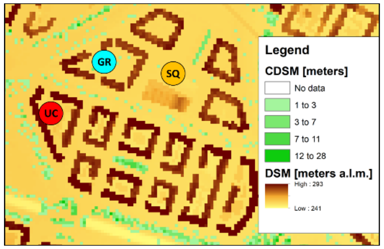
PET (°C)	Stress Category	UTCI (°C)	Stress Category	PET (°C)	Stress Category	UTCI (°C)	Stress Category
over 41	extreme heat stress	38 to 46	very strong heat stress	Under 4	high cold	9 to 0	slight cold stress
35 to 41	strong heat stress	32 to 38	strong heat stress				

The **mean relative absolute error (MRAE)** varies in summer from **0.03 to 5.34 %** and in winter from **1.63 to 37.76%** and the main errors can be observed in wintertime and with UTCI (i.e., **MRAEavg = 22%**).

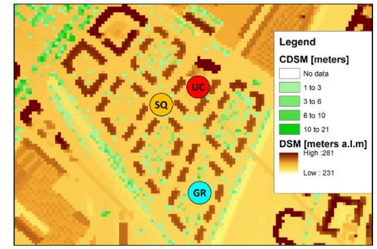
Comparison between SOLWEIG and ENVI-met

Hourly values on three points of interest

ENVI-met 5 m	SOLWEIG 5m
9-11 h	20 min

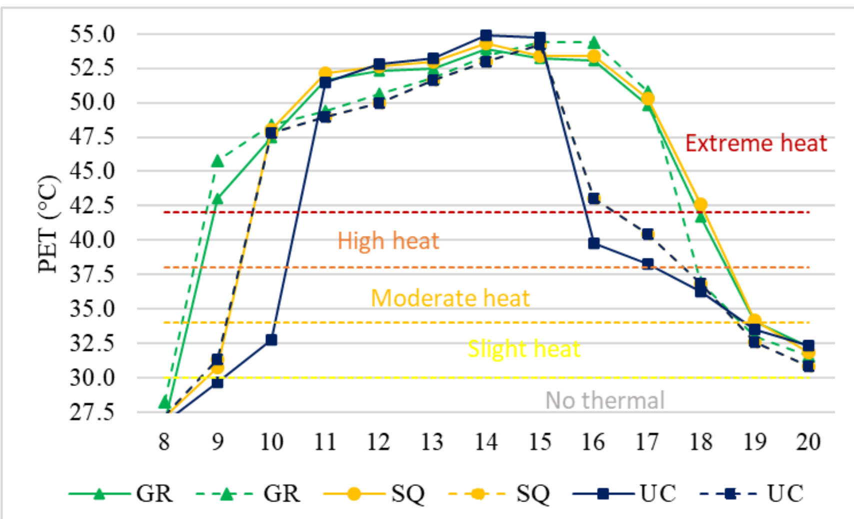


Legend
- UC urban courtyards
- GR green areas
- SQ squares

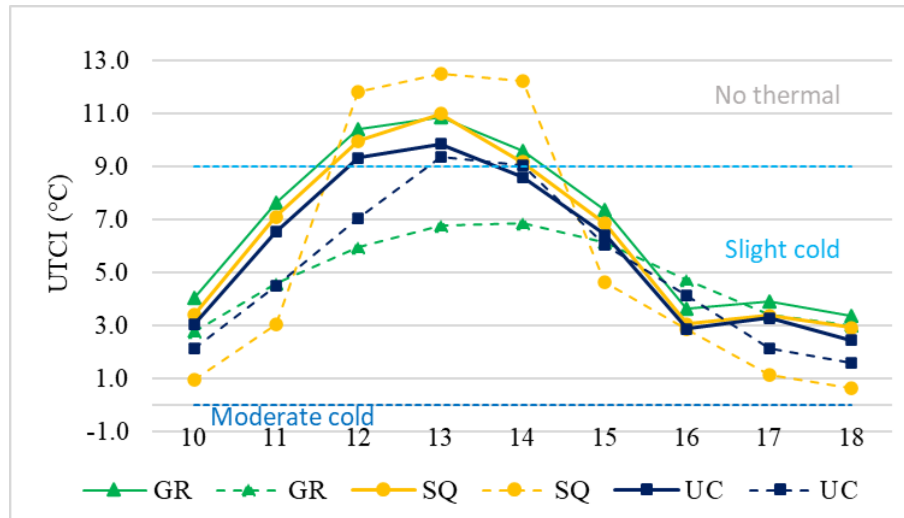


SOLWEIG (solid line)

ENVI-met (dashed line)



PET in Mediterraneo on **August 7th**, 2015.



UTCI in Arquata on **January 1st**, 2015.

The results presents **similar trends** emphasizing the reliability of SOLWEIG.

Comparison between SOLWEIG and ENVI-met

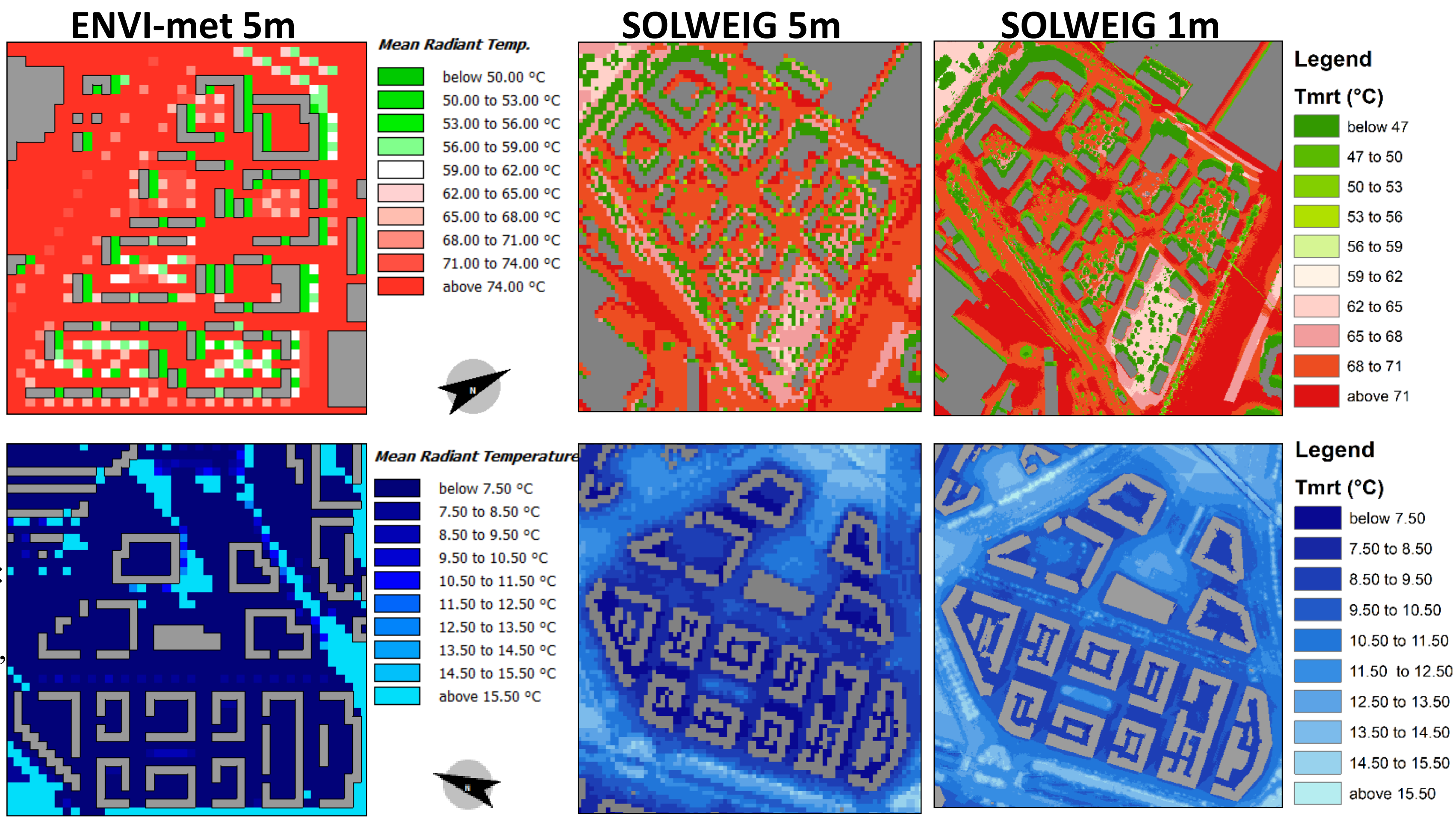
Spatial analysis

Simulation time

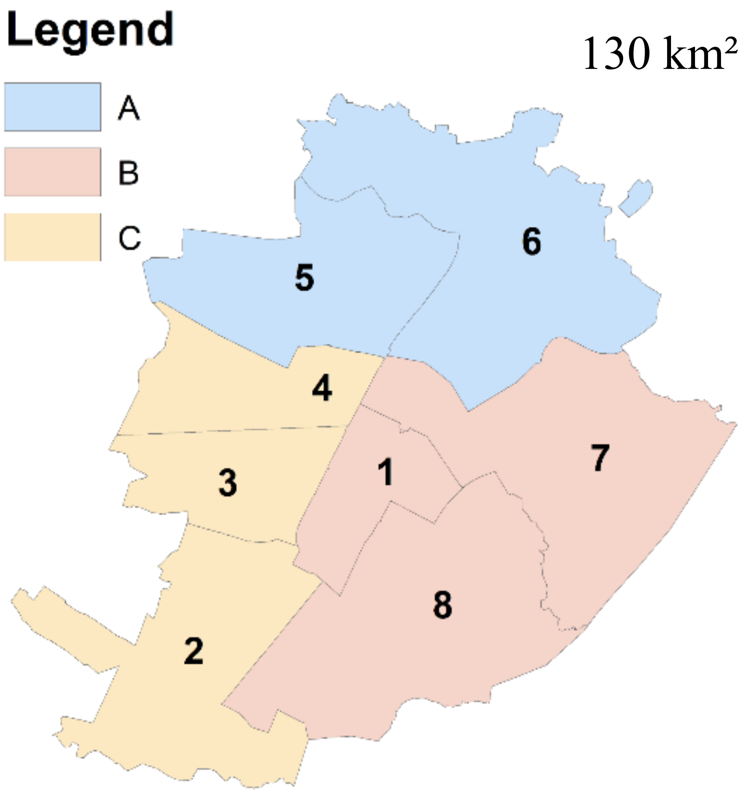
ENVI-met 5 m	SOLWEIG 5m	SOLWEIG 1m
9-11 h	20 min	1h

Arquata: T_{mrt} at 1 pm on August 7th, 2015

Mediterraneo: T_{mrt} at 3 pm on January 1st, 2015



City-scale analysis



Area dimensions

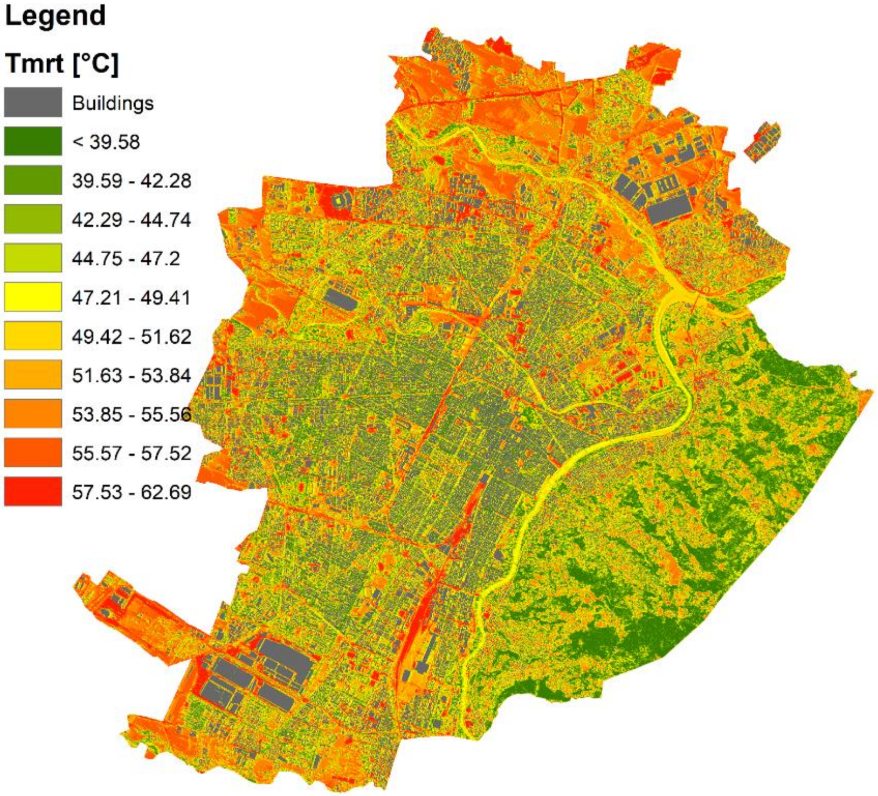
Group	Width	Height	Cell size
A	2210	1353	2.990.130
B	2197	1720	3.778.840
C	1593	2073	3.302.289

Simulation time SVF and *Tmrt*

Group	Summer (h)	Winter (h)
A	**9.32**	**10.54**
B	**12.19**	**11.43**
C	**12.37**	**11.17**

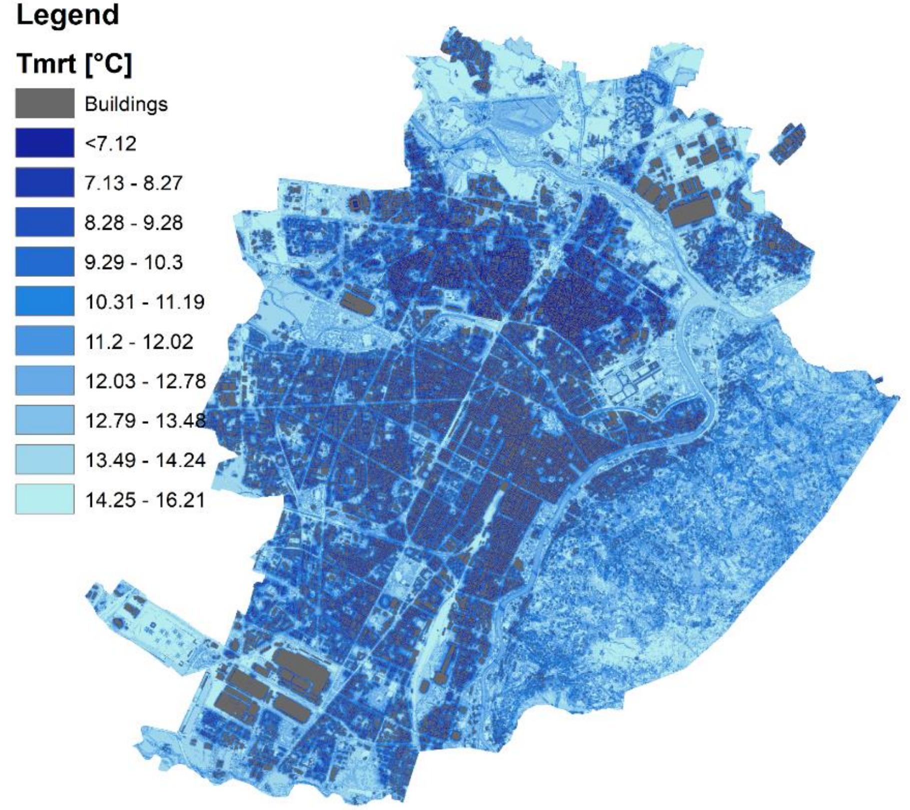
Total simulation time: 67 hours

City-scale analysis



Summer T_{mrt}
Average values from
8 am to 8 pm

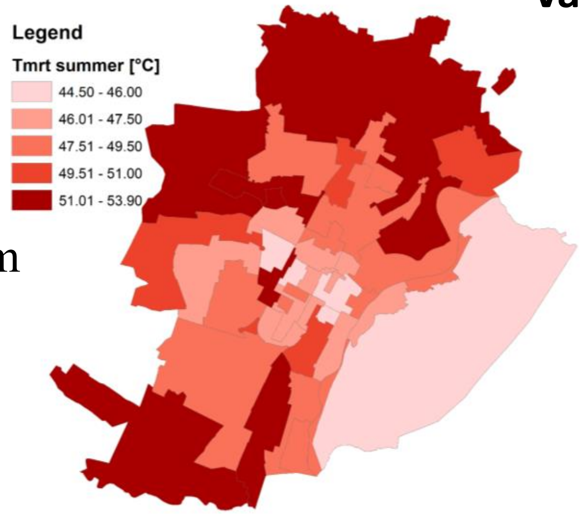
Winter T_{mrt}
Average values from 10
am to 6 pm

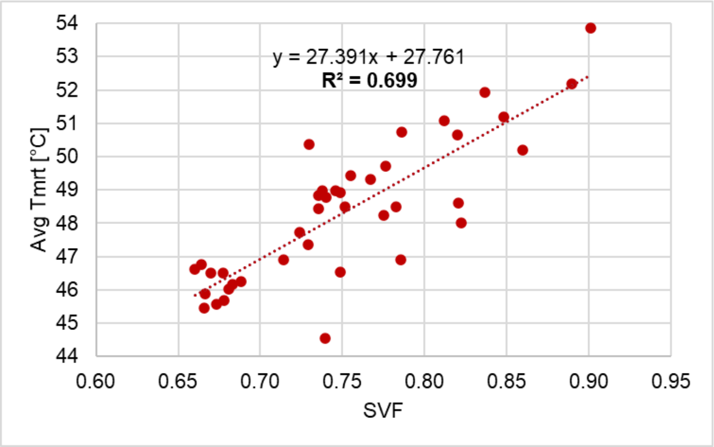


City-scale analysis

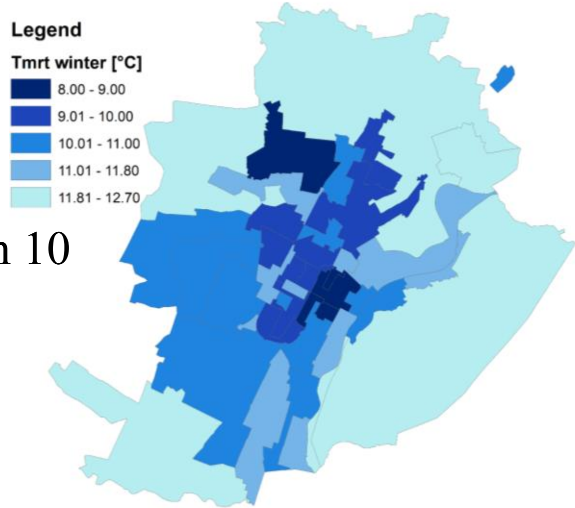
Simplified relations with urban variables

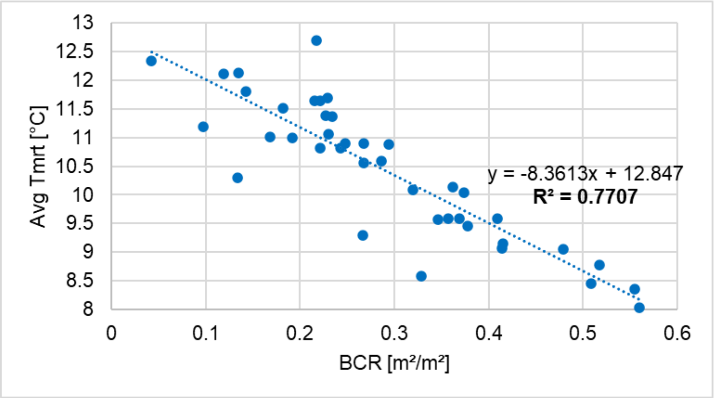
Summer T_{mrt}
Average values from 8 am to 8 pm





Winter T_{mrt}
Average values from 10 am to 6 pm





Future works

- Evaluation of **outdoor thermal comfort indexes** (*PET* and *UTCI*) **spatially** by implementing new models
- Evaluation of **scenarios** to observe the **effect of the interventions at the urban scale** (e.g., increase in greenery, change in climatic conditions such as rising temperatures)

Web-GIS Platform

Evaluate the effect of interventions

Define priority of interventions

Establish design metrics

Integration within the planning process.

Conclusion

Comparison between SOLWEIG and ENVI-met:

- ❑ Since it offers the **best compromise between simulation time and accuracy**, we found that **SOLWEIG** seems to be more suitable, especially for assessment and analyses at the **urban scale**, to assess the overall impact of interventions for the sustainable development of the urban environment.

- ❑ **ENVI-met** is more useful for **feasibility studies with high spatial and temporal resolution**, or for the pre-design phase of neighbourhoods.

These results show a good similarity between ENVI-met and SOLWEIG; SOLWEIG has a **good quality of accuracy** despite the simplified assumptions used in the computational models. However, some limitations are noteworthy: **forced meteorological data limit the accuracy**, especially in winter conditions and with UTCI index.

Thanks for your attention!

simone.beltramino@polito.it