MISSIONE 4
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RICERCA

CLIMATE RESILIENT STRATEGIES BY
ARCHETYPE-BASED URBAN ENERGY MODELLING

Future weather files with UHI effect

DELIVERABLE 2.3

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1. INTRODUCTION

1.1 Purpose

Climate files normally used to determine energy consumption for heating and cooling in buildings refer to weather data recorded by weather stations during past years. Weather data is used to develop weather files for simulation usually giving rise to Typical Meteorological Years (TMYs). In current project the process has been described in Deliverable 2.1. However, when applied to urban environments such files display two drawbacks, the former is that they refer to past years, while buildings are supposed to have a lifetime in the future, the latter problem is that the weather files refer to weather stations in open field, seldom in an urban environment. Simulation in an urban environment requires weather files referring to future times with embodied the effect of urbanization. This deliverable describes the methods used to generate TMY files using weather projections and incorporating Urban Heat Island (UHI) effects. The outcome of the project CriStAll will allow to study the Urban Environment and the resilience of this environment to climate change. The availability of future weather files incorporating heat island effects are prerequisites for other Work Package (WP) and task, such as WP4, "*Resilient and Mitigating Strategies*", and Task 4.1, "*Definition of Climate-Resilient and Mitigating Strategies*", where the climate files will be used for simulations.

1.2 Deliverable structure

This deliverable is structured into sections. The first section is an introduction to the deliverable, outlining the purpose (1.1), a description of the structure of the deliverable (1.2), followed by the description of the contribution of the partners (1.3). Section 2 describes how the future urban weather files were generated, starting from the future weather files without the UHI effect. Section 2 is dedicated to the description of the methods used to develop the future weather files incorporating UHI effects. Section 2.1 presents a description of the tools used for obtaining the future urban weather files starting from future weather files. Section 2.2 describes a model implemented in future weather files that, if activated, incorporates UHI effects in GCM-RCM simulations. Section 2.3 presents the results related to the sites of interest for the project: Turin (2.3.1), Rome (2.3.2), and Bari (2.3.3). Section 3 presents a summary of the results and comment on the developed method.

1.3 Contribution of partners

UniTS led the task and wrote the deliverable with contributions from the partners involved. It used the models developed by the other partners to create the weather files. unibz, with the cooperation of POLITO, developed the 3D models of the urban blocks for Turin and Bari and the larger urban areas selected for Rome. Specifically, for the case of Turin were considered 3 urban blocks while 2 were part of the case-study of Bari; as regards Rome, the analysis focused on larger areas extracted from four selected portions of the city (i.e., districts of EUR, Garbatella and Nuovo Salario). The choice of larger areas for Rome was due to the larger territorial extent of the capitol city and the diversified Urban Heat Island phenomena as documented also by previous researches and projects in the literature (Asdrubali et al., 2002). The unibz unit prepared also some preliminary versions of the JSON files of the selected urban blocks and areas used as input for the UWG simulations under different climate scenarios performed by the UniTS unit. All the partners reviewed and finalised the deliverable.

2. DEVELOPMENT OF FUTURE WEATHER FILES WITH UHI

Future weather files are generated using GCM-RCM simulations made available by research centres in CORDEX database, the combination of global models with regional models generates future weather projections, to allow a broader comparison of different models different RCM-GCM models could be used. One important issue about future weather models is if they incorporate some effect related to the urbanization. However, since weather stations are mainly located in areas external urban areas, the future weather files, bias corrected with the values of the historical data can be used to generate weather files incorporating the effect of urbanization. However, it must be pointed out that the spatial discretization used for generating future weather files, with a grid of 11-12 km of spacing, is too coarse to allow local analysis of UHI effects.

2.1 Tools for incorporating UHI in weather files

In the CRiStAll project the research teams decided to use the well-known Urban Weather Generator (UWG) tool to generate urban weather files. The model has already been described in previous deliverables (D2.1 "*Methods for collecting and checking weather data*"). The tool has already been used to generate future weather files. For example, Hostein *et al.* (2024) used UWG for defining future weather data for assessing indoor overheating in a French building. From this perspective, UWG has been the selected tool for defining urban environments also by Salvati *et. al* (2022) applied to a building in London, and by Hamdi *et al.* (2023) for a building in Toulose (France). The same approach is applied in this report, first the characteristic of the urban area is defined and a configuration file in JSON format is generated. The configuration JSON file is then used to generate UHI aware weather data using the already generated future weather data obtained in D2.2 "*Generation of future UHI weather data*".

2.2 UHI in future weather projections

Several GCM-RCM already contain information about UHI in generated files, the adopted method is similar to the one introduced in previous section, however the grid size used for simulations prevents a direct and efficient use for different parts of urban areas. The CLMU Community Land Model – Urban is a module of *Community Earth System Model* (Danabasoglu *et al.*, 2020) and based on the concept of urban canyon concept (Figure 1). However, the grid size, at least with a distance of 12 km prevents the direct use of the model for urban areas analysis. The model has been used for simulations with more fine grids, for example Wang *et al.* (2020) applied the model to study the effect of white roofs using a grid with a spatial resolution of 0.9° latitude by 1.25° longitude. The activation of the module in RCM simulations can provide some information on the urban areas, but with the limitation related to the coarse grid typical for the simulations.

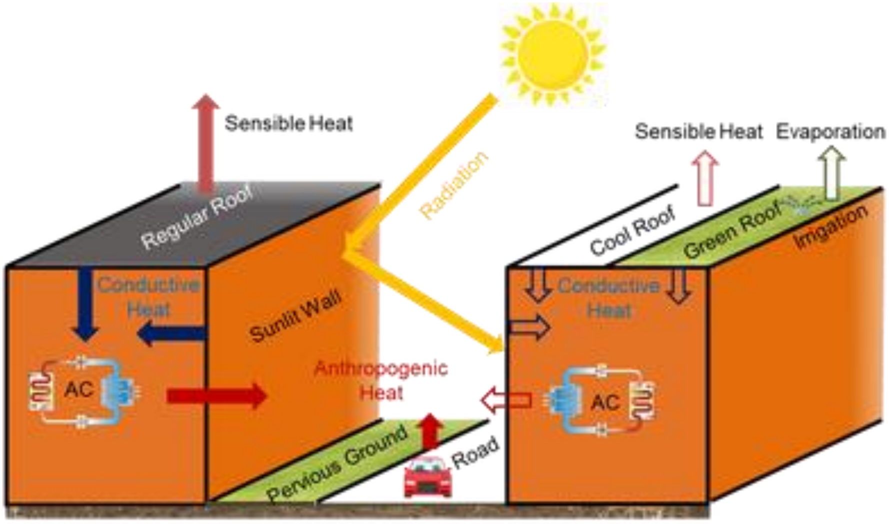


Figure 1: Canyon model for the CLMU module

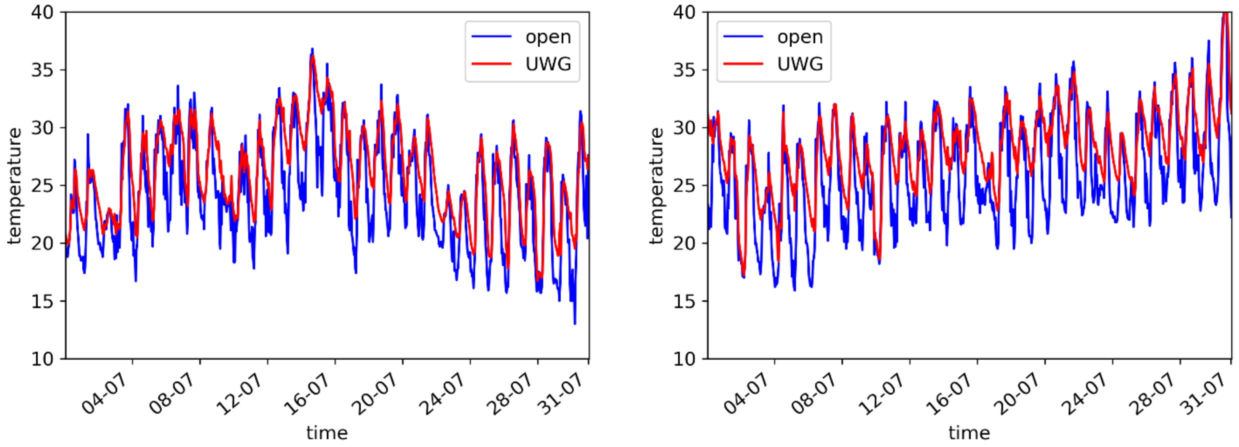
In addition, weather stations are usually located in open areas outside urban environments, therefore the future weather files modified with bias correction can be considered valid for undisturbed areas only, therefore the effect on urban areas can be obtained applying the methods of previous section, with a morphing of weather data depending on the urban environment. Present considerations could change if simulations on a finer grid will be available in future.

2.3 Incorporating the UHI in future projections

To incorporate the UHI in future weather file the capability of UWG software has been exploited. Starting from the bias corrected future weather files relative to open area weather files the UHI aware future TMY file can be obtained. Using the UWG configuration files therefore different weather data can be generated: current weather station files, without heat island, current weather files with UHI correction, future undisturbed TMY files, and future TMY files modified to consider the Urban environment. The obtained files can be used to compare the different environments related to the urban environment.

2.3.1 Urban future weather files for Turin

Different patches of the city of Turin have been computed, here are provided the results for block A, block B, block C, as presented in the project Deliverable 3.2 "*Atlas of the typical urban context configuration: model features*". Figure 2 reports the open field and modified weather file for Bauducchi station and two periods: the historical and the future weather files in 2050. It is of interest that the urban files are characterised by higher temperatures during the night. Table 1 reports the Heating Degree Days (*HDD*) and Cooling Degree Days (*CDD*) of the generated weather files. The values reveal the effect of climate change with a decrease of *HDD* and an increase of *CDD* from the values of historical values to the values related to 2050 period, but the inspection of the table shows the effect of UHI with higher values for *CDD* and lower for *HDD*. Table 1 reports also the number of tropical nights that is the number of days on which the minimum temperature is higher than the threshold of 20 °C. Inspecting Figure 2 appears that the effect of urban area affects more the minimum temperatures than the maximum ones, therefore UHI has a great effect on the number of Tropical Nights. This effect is particularly important because it hinders the possibility to reduce temperatures inside buildings using night cooling ventilation. It is worth noting that the number of tropical nights is more affected by the UHI than climatic change.



(a) (b)

Figure 2: Temperature comparison for Bauducchi weather station in July and block A: historical values (a), future weather for year 2050 (b)

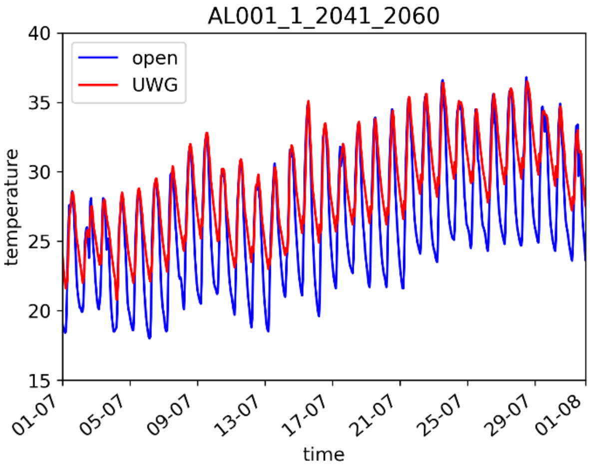
Table 1 - Heating and cooling degree days and tropical nights for Turin weather station

	HDD	***CDD***	**Tropical Nights**
Bauducchi 2010	2392	417	18
Bauducchi 2050	2270	558	33
Bauducchi 2010 block A	2050	578	73
Bauducchi 2050 block A	1921	768	83
Bauducchi 2010 block B	2038	582	73
Bauducchi 2050 block B	1909	772	83
Bauducchi 2010 block C	2055	578	73
Bauducchi 2050 block C	1926	767	83

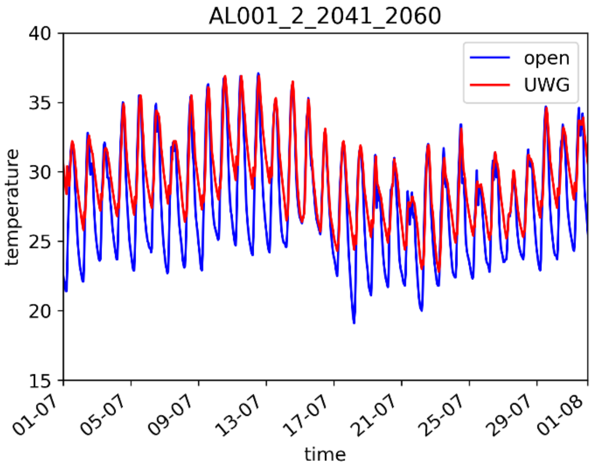
2.3.2 Urban future weather files for Rome

One area has been analyzed for Rome, the reference weather station is Tor Vergata with identifier AL001 which is the nearest of the selected patch whose characteristics were reported in D2.1. For this location, the analysis considered present values or historical cases, and future projections using the two models presented in D2.2.

Figure 3 presents the comparison between temperatures for the period 2041-2060 obtained in rural areas and in urban environments. Table 2 reports the synthetic data for the weather files generated considering heating degree days, cooling degree days and the number of tropical nights. Table 2 shows how climate change can affect urban areas, with a substantial increase in the number of tropical nights.



(a)



(b)

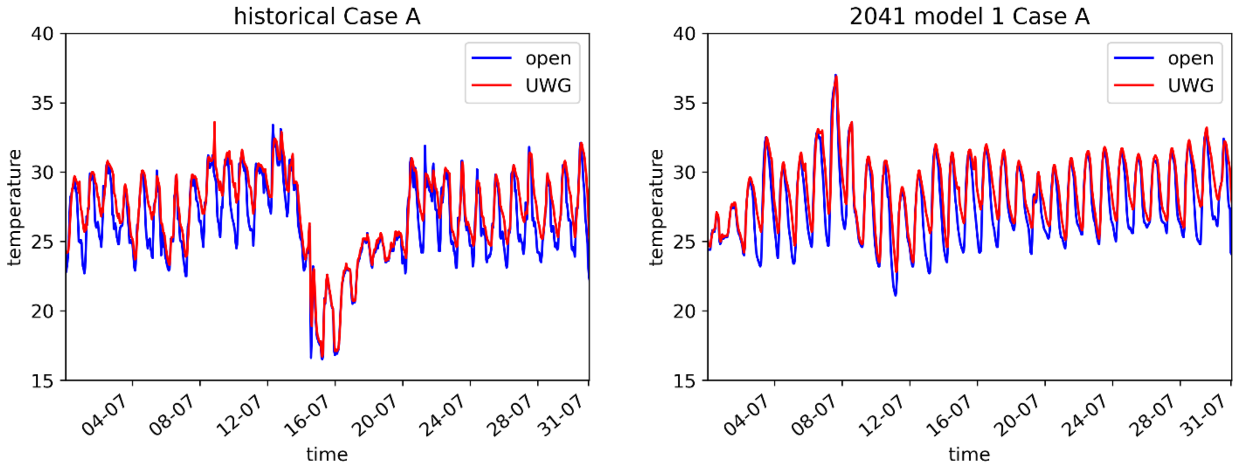
Figure 3: Temperature comparison for Rome station AL001 and future period 2041-2060 in July results for model 1 (a) model 2 (b)

Table 2 - Heating and cooling degree days, tropical nights for Rome weather station (AL001)

	HDD	***CDD***	**Tropical Nights**
Historical	1656	708	59
Historical Urban	1443	868	106
2041-2060 model 1	1318	686	58
2041-2060 model 2	1307	873	80
2041-2060 model 1 urban	1072	922	124
2041-2060 model 2 urban	1049	1132	133

2.3.3 Urban future weather files for Bari

Two patches of the city of Bari have been computed, the results will be presented as Case A and Case B. Figure 4 reports the open field and modified weather file for Bari station and two files, the historical and the future weather files for the period 2041-2060 for the month of July. As in the Turin case, the urban files are characterised by higher minimum temperatures. Table 3 reports the Heating degree days and Cooling degree days of the generated weather files. The effect of climate change is clearly visible with a decrease in *HDD* and an increase of *CDD* from the values of historical values to future periods. Furthermore, the inspection of the table shows the effect of UHI with higher values for *CDD* and lower for *HDD*. Table 3 reports also the number of tropical nights that is the number of days in which the minimum temperature is higher than the threshold of 20 °C. Figure 4 shows that the UHI has a great effect on the number of Tropical Nights. This effect should be taken into account when dealing with mitigation strategies and the effect of climate change on human health.



(a) (b)

Figure 4: Temperature comparison for Bari weather station in July and case A: historical values (a), future weather for year 2041 (b)

Table 3 - Heating and cooling degree days and tropical nights for Bari weather station

	HDD	***CDD***	**Tropical Nights**
Historical	1301	647	86
Future historical case A	1220	746	106
Future historical case B	1221	746	106
Future 2041 model 1 case A	923	1000	136
Future 2041 model 1 case B	923	999	136
Future 2041 model 2 case A	833	1169	142
Future 2041 model 2 case B	833	1169	142

3. SUMMARY AND CONCLUSION

The procedure described in this report is easily adoptable thanks to the use of Urban Weather Generator. The three cases showed similar results with a substantial temperature difference between rural and urban environments. However, it is worth noting the strong increase of the number of tropical nights in future periods, especially for urban environment. This parameter is quite important, because this could force people at installing new cooling systems to cope with the high temperatures. But this could accelerate the temperature increase in urban environments. From this emerges the urgency to develop mitigation plans at city level to reduce the effect of rising temperatures.

It is worth mentioning also the limitations and difficulties encountered when dealing with future weather files in urban environment. Future urban files depend on the description of the urban environment and the quality of future weather files. Different projection models were considered in this report, other models could be added as well, but it is expected that the main results will not change. The advantage in using additional GCM-RCM models is that this can reduce the uncertainty intrinsic to the use of future projections. Furthermore, the method proposed here will beneficiate by the availability of new GCM-RCM projections with an increased spatial resolution. The data used in this work had a resolution of about 11 km higher resolutions could allow a better mapping of weather data inside the urban area.

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