



Deliverable 5.1

Practical Climate Database for PED Transition Scenarios

Responsible partner: UPC

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Executive summary

1. Purpose and scope

Deliverable 5.1 establishes the foundational meteorological and climate baseline required to conduct advanced building energy performance simulations, microclimate analysis, and climate resilience assessments across five European university campuses participating in the eduPED project. These five "Living Labs" represent diverse geographical regions, urban morphologies, and Köppen–Geiger climate zones across Europe, serving as bounded real-world testbeds for transitioning academic infrastructure toward Positive Energy District (PED) status.

To accurately evaluate how urban built environments respond to global climate change and extreme thermal stress, Deliverable 5.1 develops a standardized, bias-corrected climate dataset covering two distinct 20-year time horizons:

- Present Baseline Conditions (2020s): Representative of the historical observational period 2005–2024 / 2009–2028.
- Mid-Term Future Conditions (2050s): Representative of projected future climate conditions for the period 2041–2060 under a high-emission global climate scenario

For each Living Lab and each time period, two distinct categories of simulation-ready weather files are produced in the standard EnergyPlus format (.EPW):

1. Typical Meteorological Years (TMYs): Constructed according to the standard EN ISO 15927-4:2011 to reflect average, statistically representative monthly weather parameters for evaluating baseline energy demand, HVAC sizing, and annual net energy balances.
2. Extreme Heat Wave Years (HWYs): Generated using advanced statistical threshold detection algorithms (Ouzeau et al., 2016) to capture severe, long-duration thermal shock events necessary for evaluating building thermal resilience, peak cooling demand, indoor overheating risk, and occupant thermal comfort.

These datasets are delivered in formats directly compatible with **building energy simulation tools** (e.g., EnergyPlus), ensuring their practical applicability for testing PED resilience and guiding climate adaptation measures.

The results indicate that **annual mean air temperature increases** in all cities in the mid-term future (2050s) compared to the present period (2020s), while **solar irradiation slightly decreases**. However, the variations are **not evenly distributed across the year**, with varying patterns depending on the city.

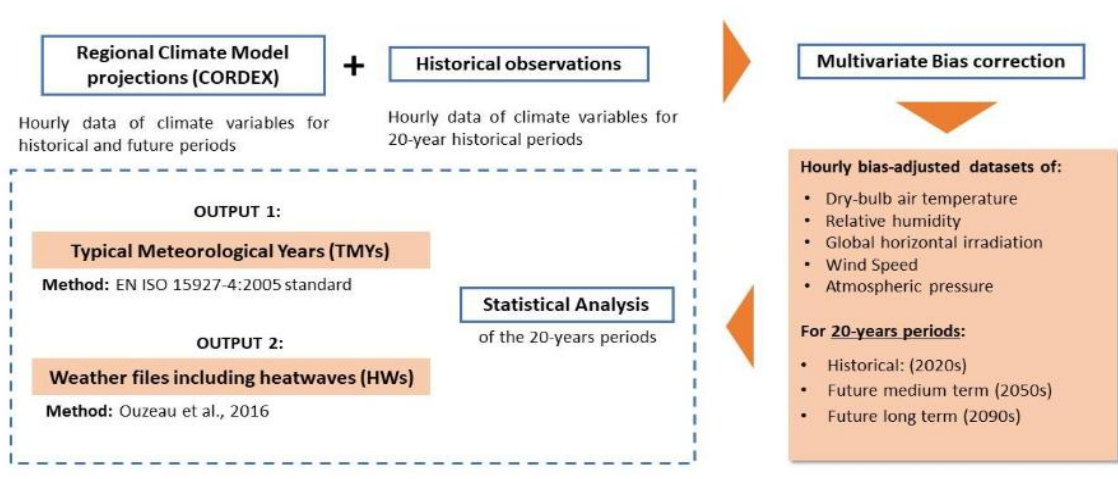
All cities will experience a **significant increase in the number of heatwaves** in the 2050s compared to the 2020s. Of the characteristics of historical and future heatwaves that can be compared (i.e. intensity, severity and duration), **duration** is the one that **will increase most clearly in the future**.

In summary, Deliverable 5.1 provides the essential climate datasets that will guide the upcoming simulation tasks, ensuring a solid basis for assessing PED resilience and adaptation strategies.

2. Climate Modeling Methodology and Data Pipeline

The generation of future climate datasets relies on dynamic downscaling methodologies to achieve higher spatial and temporal accuracy than traditional simplified morphing techniques (e.g., WeatherShift or CCWorldWeatherGen), which fail to capture non-linear shifts in extreme weather frequencies and thermal duration. The Figure 1 shows the methodology used in this task

Figure 1: Methodological pipeline linking regional climate modeling, observational bias correction, and statistical generation of TMY and HWY simulation files.



2.1 Regional Climate Projections and Data Extraction

Climate model data were extracted from the EURO-CORDEX framework (Coordinated Regional Climate Downscaling Experiment – European Domain) at a high spatial resolution of 0.11° (~12.5 km, EUR-11 grid). The global climate model selected was MPI-M-MPI-ESM-LR downscaled with the regional climate model REMO.

The core simulation pathway selected corresponds to RCP 8.5 from the IPCC Fifth Assessment Report (AR5), representing a "business-as-usual" high-emission trajectory leading to approximately +2.0 °C global warming by 2050 relative to pre-industrial levels. This scenario aligns closely with current global GHG emission trends (SSP5-8.5 in IPCC AR6) and provides a rigorous upper-bound test for district climate resilience.

The raw hourly climatic variables extracted from CORDEX projections were:

- TAS: Near-surface air temperature (°C)

- HURS: Near-surface relative humidity (%)
- SFCWIND: Near-surface wind speed (m/s)
- RSDS: Surface downwelling shortwave radiation / Global horizontal irradiance (W/m²)
- PS: Surface atmospheric pressure (Pa)

2.2 Bias Correction Protocols

To eliminate systematic model discrepancies and align Regional Climate Model (RCM) outputs with site-specific observational reality, a two-pronged bias-correction methodology was applied using local meteorological station data:

1. Multivariate Distribution-Based Bias Correction (MBC): Applied to temperature, relative humidity, wind speed, and surface pressure. MBC preserves the complex inter-variable physical dependencies essential for dynamic building energy simulation.
2. Quantile Delta Mapping (QDM): Applied specifically to surface solar radiation (RSDS). QDM corrects quantile systematic biases while preserving projected future relative changes without introducing non-physical reshuffling of diurnal solar curves.

Because wind direction is not produced by CORDEX RCMs, vector-averaged hourly wind direction profiles were computed from 10 to 20 years of local station observations for each month and embedded into both present and future EPW files.

Table 1 reports if the weather station used as reference for each city for the bias-correction step is located in an urban area or rural area and the baseline observational period.

Table 1. Details of the meteorological stations used as sources for the observational data.

City	Latitude	Longitude	Weather station location (urban/rural)	Baseline Observational Period
Cluj-Napoca	46,7838 N	23,8449 E	Rural	2005 – 2024
Graz	47,0776 N	15,4489 E	Urban	2005–2024
Terrassa	41,5656 N	2,0695 E	Rural	2015–2024
The Hague	51,9655 N	4,4348 E	Rural	2005–2024
Torino	45,0758 N	7,6783 E	Urban	2005–2024

3. Typical Meteorological Years (TMY) Results

Statistical comparison between the 20-year bias-corrected multi-year time series and the synthesized TMY files confirms high statistical fidelity across all Living Labs. Table 2 summarizes the projected shifts in fundamental climate variables between present (2020s) and mid-term future (2050s) periods.

Table 2. Average values and projected changes in weather variables in the 20-year period datasets for the present conditions 2020s (2006–2025) and future mid-term conditions 2050s (2041–2060).

	Air Temperature (°C)		Relative Humidity (%)		Global Hor. Rad (W/m ²)		Wind Speed (m/s)	
	2020s	2050s	2020s	2050s	2020s	2050s	2020s	2050s
Cluj-Napoca								
Average	10.53	11.71	75.29	74.97	155.35	150.55	2.24	2.23
Change		1.18		-0.32		-4.80		-0.01
Graz								
Average	11.34	12.18	72.85	73.58	142.66	139.78	1.39	1.38
Change		0.83		0.73		-2.88		0.01
Terrassa								
Average	15.69	16.54	70.94	70.77	187.45	186.37	2.06	2.10
Change		0.85		-0.17		-1.08		0.04
The Hague								
Average	11.36	11.79	80.32	80.56	123.11	120.32	4.36	4.35
Change		0.42		0.24		-2.79		-0.01
Torino								
Average	15.12	15.97	64.88	63.81	148.25	146.73	1.32	1.32
Change		0.85		-1.07		-1.52		0.00

3.1 Temperature Dynamics and Seasonal Discrepancies

While annual mean air temperatures increase universally across all five campuses—ranging from **+0.42 °C (+3.7%)** in The Hague to **+1.18 °C (+11.2%)** in Cluj-Napoca—the monthly distribution of warming exhibits significant geographical variance:

- **Mediterranean & Subtropical Climates (Terrassa & Torino):** Temperature increases are strongly concentrated in the warm summer season. In Torino, August experiences a mean temperature rise of **+3.11 °C**, while September in Terrassa increases by **+2.11 °C**. This

localized summer spike will drastically escalate space cooling energy demands and summer peak electrical loads.

- **Continental Climates (Cluj-Napoca & Graz):** Temperature increases occur across most months. Cluj-Napoca exhibits extreme warming in spring (April rising by **+5.35 °C**, from 14.73 °C to 16.96 °C), alongside late-summer and autumn increments. Graz exhibits marked winter/autumn warming (November rising by **+2.46 °C** and February by **+2.16 °C**).
- **Temperate Oceanic Climates (The Hague):** Warming is moderate overall but concentrated in autumn/winter (October rising by **+1.49 °C**), whereas late spring and early summer show minor temperature reductions.

4. Extreme Heat Wave Years (HWY) Assessment

To evaluate district thermal resilience under extreme events, heatwaves were identified using the daily mean temperature threshold method established by Ouzeau et al. (2016). Three site-specific temperature thresholds were computed from the 2009–2028 baseline dataset:

- Spic (99.5th percentile): The daily mean temperature threshold required to trigger a heatwave event.
- Sdeb (97.5th percentile): The threshold establishing the formal start and end dates of the heatwave.
- Sint (95.0th percentile): The interruption threshold. If temperatures drop below Sdeb for fewer than 3 days but remain above Sint, separate hot spells are merged into a single prolonged event.

Table 3. Thresholds used over the present period (2009–2028) for heatwave selection and number of heatwaves found per period: Present (2009 – 2028) and 2050s (2041 – 2060) in each city.

City	CORDEX Domain	Threshold to detect heatwaves over 2009–2028			Number of heatwaves detected	
		Sint 95	Sdeb 97.5	Spic 99.5	Present	2050s
		Threshold (°C)	Threshold (°C)	Threshold (°C)		
Cluj-Napoca	EUR	23.8	25.3	27.7	7	19
Graz	EUR	23.6	24.8	26.4	8	22
Terrassa	EUR	26.3	27.5	29.6	9	20
The Hague	EUR	20.1	22.0	24.6	8	14

Torino	EUR	27.1	28.2	29.8	8	33
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4.1 Heatwave Surge and Extreme Metrics

Applying present-day thresholds to future 2050s projections reveals a dramatic surge in both the frequency and severity of heatwaves across all Living Labs:

- **Torino:** Experiences the most extreme expansion, with heatwave frequency escalating **more than fourfold** (from 8 to 33 events per 20-year period).
- **Graz & Cluj-Napoca:** Heatwave frequency nearly **triples** (surging from 8 to 22 events in Graz, and 7 to 19 events in Cluj-Napoca).
- **Terrassa:** Heatwaves more than double (9 to 20 events), with individual event durations expanding up to **29 consecutive days** in the 2050s.
- **The Hague:** Increases from 8 to 14 events, accompanied by a sharp threefold rise in heatwave severity (cumulative temperature exceedance above threshold).

Table 4. Heatwave Detection Thresholds (2009–2028 Baseline) and Total Event Frequency Surge

Living Lab	Period / Scenario	Heatwave Type	Max Daily Mean Temp (°C)	Duration (Days)	Severity (°C·hours)
Cluj-Napoca	Historical (2020s)	Most Intense / Severe	31.2	15	18.8
	Future (2050s)	Most Intense	33.0	12	16.7
Graz	Historical (2020s)	Most Intense	30.5	10	23.3
	Future (2050s)	Longest	29.5	21	14.6
Terrassa	Historical (2020s)	Most Severe	31.7	20	17.0
	Future (2050s)	Most Severe / Longest	32.5	29	23.6
The Hague	Historical (2020s)	Most Severe	27.4	17	9.6
	Future (2050s)	Most Intense	30.6	15	30.2
Torino	Historical (2020s)	Most Intense / Severe	34.0	27	56.0
	Future (2050s)	Most Severe	33.3	20	32.4

5. Conclusion

This deliverable presents the characteristics of the weather datasets generated to represent current and future climate conditions at the EDUPED Living Lab sites: Cluj-Napoca, Graz, Terrassa, The Hague and Turin.

The adopted methodology enables a consistent analysis of the impact of climate change on the energy performance and climate resilience of PEDs. The climate dataset generated for each city comprises two different types of weather files: Typical meteorological years (TMYs) and years containing extreme heatwaves (HWs). Each type of file is generated based on historical period data (2020s) and future period data (2050s). The files are generated in the EnergyPlus EPW format, ready to use to run energy performance simulations.

The TMY files are particularly valuable for evaluating the impact of refurbishment strategies for PEDs under typical present and future climate conditions, considering the expected average change in climate variables in a mid-term future period. The HW files are representative of more extreme climate conditions, that are set to become more and more frequent in the future. Therefore, they can be used to assess the climate resilience and potential of climate adaptation strategies for PEDs even in the most challenging future climate scenarios.

The weather files are generated based on detailed Regional Climate Model projections from the CORDEX database. Observational data from local weather stations in each city are used to bias-correct the climate projections and enhance the accuracy of the results.

The main results of the climate analysis can be summarised as follow:

In the mid-term future (2050s), the annual mean air temperature increases in all cities compared to the present period (2020s). The increase in mean annual temperature ranges between +0.42 °C (+3.7%) in The Hague to +1.18 °C (+11.2%) in Cluj-Napoca. However, the temperature variations are not constant throughout the year. The cities of Terrassa and Torino show a higher increase in summer temperature than winter temperature, while the other cities show increments more evenly distributed across

the year. Regarding the mean solar irradiance, a general reduction is observed across all locations. Cluj-Napoca shows the largest decrease of 4.80 W/m^2 (-3%), whereas Terrassa presents the smallest change with 1.08 W/m^2 (-0.57%).

The climate projections indicate a significant increase in number of heatwaves in 2050s (2041-2060) compared to 2020s (2009-2028). Torino is set to experience the highest increase in number of heatwaves by more than four times in 2050s compared to 2020s (from 8 to 33 HWs). Heatwave events will also surge in Graz and Cluj, with a significant increase in the duration of the events in Graz. The longest future HW is expected to occur in Terrassa, with a duration of approximately one month. The Hague is the city with the lowest number of heatwave events in both present and future periods, but the severity of future HWs is particularly enhanced compared to present conditions.

In summary, Deliverable 5.1 provides the essential climate datasets that will guide the upcoming simulation tasks in WP5, ensuring a solid basis for assessing PED resilience and adaptation strategies.