WP7 Analysis of results and conclusions
Duration: 11/23-12/24

M7.1 Analysis of sensitivity study for local scale and scenarios

- SURFEXv9 proved as an effective tool to simulate most important measures for urban microclimate.
- For medium insulated buildings irrigated green roofs or street trees (without irrigation) can bring more than 1 K reduction in building indoor temperature each. Additional cooling can be achieved by window shading, ventilation during outdoor minimum temperatures or bright roofs. Although air conditioning can bring fast cooling, each air conditioning system has its limits of capacity. Additionally, air conditioning increases urban outdoor temperatures and electricity demand.
- The greatest reduction of the thermal comfort index °UTCI is achieved by the addition of trees at street level or unsealing and irrigation. Street trees reduce the amount of incoming solar radiation but reduce wind speeds as well – therefore are recommended in streets with wide profile.
- The highest levels of evapotranspiration can be achieved by irrigation of green roofs – ranging up to 8 mm/d – thus effectively cooling roof temperatures. Evapotranspiration of green roofs and low vegetation at street level can exceed evapotranspiration levels of street trees.
- Increase in reflectivity reduces roof temperatures, radiation temperatures, sensible heat flux and even thermal comfort in the street canyon.
- High traffic sites can cause an increase in air temperature by 1-2 K due to the wasted heat of combustion engines.
- Reduction of °UTCI is achieved by additional trees at street level (up to 4 °UTCI) or complete unsealing (up to 3 °UTCI).

M7.2 Analysis of simulation for scenarios performed
(see M6.2)

M7.3 Maps of Anthropogenic Heat
The anthropogenic heat emissions were then compiled from the data Annex A 8 created in WP3a using the underlying map material. As already described, maps were developed for current heat emissions based on the future scenarios and scenarios for 2030 and 2040 based on the climate roadmap. The 2030 scenario corresponds to the RCP 4.5 and the 2040 scenario to the RCP 2.6 climate scenario (Annex A 32-34).

M7.4 Maps of Evapotranspiration and Irrigation needs
To estimate the total irrigation need for green roofs and green areas different evaporation rates according to the project results are multiplied with the potential irrigation area to be compared to available water amounts:

- Green roof potential area: 1 813 ha (1068 ha (slight inclination) + 745 ha (strong inclination)
- Green areas on ground level: 12 600 ha (Stadt Wien 2025h)
- Total drinking water supply (HQ1+HQ2) = 375 000 m^3/d (during drought spells both the HQs but also the ground water sources for drinking water decrease and should not be used permissively.

When we assume strong drought during summer, so all water evaporated from green roofs originates from the drinking water inflow (on average supply 375.000 m^3: I. 173.000 m^3, II. 202.000 m^3), this would **mean a minimum of 10th up to 1/3 of the volume would be needed for full scale irrigation** only. According to the measurements within Imp_DroP, the daily evapotranspiration can go up to 7mm/d which would mean a **1/3 of the drinking water inflow**. Also, 1mm/d irrigation on green areas in Vienna would need 1/3 of the drinking water inflow (Annex A 35). An overview of evapotranspiration and irrigation needs in the entire study area for the heatwave in 2021 is shown in Annex A 36.

M7.5 Vegetation cooling potential and M7.6 Maps of Thermal Comfort

The cooling effect of irrigation has additional effects on the air humidity which can reduce the cooling effect. We have used the "Apparent Temperature" (Steadman, 1984), to quantify this effect. In Annex A 36 the cooling effect between optimized green infrastructure a realistic irrigation against non-irrigation for air temperature (Annex A 37 left) and the apparent temperature (Annex A 37 right) is shown. The cooling effect is reduced. In the spatial average over the city of Vienna the cooling effect of the air temperature is 1.5 K and for the apparent temperature it is 1.1 K.

M7.7 Final recommendations made

Recommendations were discussed during the stakeholder workshop and in the project group (Annex A38). The protocol of the stakeholder workshop can be found in Annex A39. The recommendations are summarized in 2.3 Conclusions.

1. Description of difficulties, if any, encountered in the achievement of project targets

- The construction and maintenance of the experimental sites, Admission to roofs, weatherproof insulation of the test containers.
- Environmental factors: wind tilting station, birds, rodents biting off cables.
- Personal changes led to a delay in the modelling progress. The numerical simulations could not be performed as planned, as Katharina Perny, the main employee working on the WRF-TEB simulation, left the working group and had to finish another project. Imran Nadeem, who recently joined BOKU-Met again, took over her work, but a delay of about 6 months was caused. This affected WP4, 5, 6 and 7 as the base run for Vienna during the measurement period had still not been completed and neither validation efforts nor offline simulations, which needed this base run for obtaining meteorological forcing information could begun. Further parameter adaptations and improvements of the model setup had been built on this work and could not be started either.
- The implementation of irrigation posed an additional unexpected challenge for the WRF-TEB base runs. A specific irrigation file needed to be produced.
- The accessibility of the experimental sites proved a challenge. It was difficult to find time slots to enter the sites at Kandlgasse and AKH. Our contact person at AKH fell sick, so access was restricted. The other two sites were easier to access, but the long travel distance posed a challenge for regular checks. Further the weatherproof insulation of the test containers was not stable and needed to be replaced. The collection of the run-off water from the tray continued to be error-prone and had to be exchanged with a tilting meter for future study sites.
- At Gartenbauschule Schönbrunn, the regular irrigation of one pair of pots did not work as expected. However, this additional information was not necessary.The existing data were sufficient to validate the FAO model

2. Description of project “highlights”

- Setup of stations on four green roofs, first measurement results.
- 2 seasons of lysimeter measurements at 4 roof sites within Vienna could be completed (May 2022 – Sept 2023).
- The anthropogenic heat flux for the future scenarios was calculated for the three urban categories.
- Municipal water data was acquired, an analysis performed and discussed with city officials.
- ARIS (FAO model based) results were used for validation of the climate model run.
- Setup of TEB and WRF-TEB. Meteorological files for WRF-TEB runs prepared. Compilation of the latest version of TEB within SURFEXv9 including irrigation with ECOCLIMAP Second Generation, new description of human behavior related to building energy consumption, TEB option for street trees.
- WRF-TEB simulations of heat stress during drought periods considering irrigation in and around Vienna.
- Microscale runs considering tree shade and irrigation in urban canyon.

3. Description and motivation of deviations from the original project application

- No rain measurements were carried out on site due to insufficient funds for accurate measurements. Excellent grid weather data (INCA) for Vienna are available and were used instead.

2.3 Conclusions to be drawn from project results (max. 5 pages)

- Which findings have been derived from the project by the project team?

- Irrigation Marchfeld
  - maximum cooling locally: -3 K (100% irrigation) (WRF-TEB)
  - maximum cooling in Vienna: -1 K (100% irrigation) (WRF-TEB)
- Maximum cooling achieved via vegetation within Vienna
  - cooling of indoor temperature via irrigated green roofs: 1 K (TEB/SURFEX)
  - air temperature: on average 1.5 K, maximum 3 K (WRF-TEB)
  - reduction of heat stress via tree shade: 4 °UTCI (TEB/SURFEX)
  - cooling of roof temperature via irrigated green roofs: 27 K (TEB/SURFEX)
- cooling via reduction of Anthropogenic Heat Flux
  - canyon air temperature: 1-2 K (TEB/SURFEX)
  - UTCI: 2° UTCI (TEB/SURFEX)

These maximum cooling values due to irrigation are not likely as too much drinking water would be necessary.

Recommendations regarding green roofs

The project has shown by means of measurements and modelling that the cooling effect of large-scale green roofs on the overall urban climate is very high. However, intensive green roofs with irrigation would be unaffordable for the entire city due to the high-water requirements and would exceed the capacity of Vienna's drinking water supply. Even if the green roofs do not reach their maximum capacity in extreme situations without irrigation, they still cool to a lesser extent. We therefore recommend:

- higher substrate layers for better storage / supply of rainwater
- optimization of water retention in intensive green roofs (use of substrates with high water storage capacity, installation of rainwater storage elements) to save drinking water
- technical rainwater storage elements (retention and detention roof structures with controllable drains) are very effective in compensating for extreme events (droughts/heavy rainfall events)
- possible use of grey water for irrigation should be investigated (need for research)
- use of light-colored substrate to increase the albedo when the ground is not completely covered
- promotion of biodiversity
- selective irrigation during heat extremes for buildings/locations with vulnerable population groups ("green air conditioning on demand")

Recommendations regarding greening in the street canyon:

The modelling showed the great importance of shading (at best by large-crowned trees) for thermal comfort in high solar radiation in the street canyon. Furthermore, sufficiently water-supplied low vegetation can also contribute effectively to cooling the public space, especially in the evening and at night.

We therefore recommend

- using trees for shading with the highest possible degree of canopy cover
- technical shading elements where tree planting is not possible
- use low vegetation in combination with tree planting over large areas
- selective irrigation during heat extremes in heat hotspots and in street areas with vulnerable groups ("green air conditioning on demand")
- during extreme heat and no wind conditions in narrow urban spaces take ventilation into account to ensure cooling effect of irrigation

Recommendation Electrification of traffic

Raise public awareness and discussion to prevent installation of air conditioning systems without attached alternative energy system (heat pump).

Raise public discussion and kick of more measurement studies to quantify the cooling of photovoltaic panels on the building envelope.

- cars using combustion engines significantly emit heat. Thus, traffic is the main driver of urban anthropogenic heat. About 75% of anthropogenic heat emission can be reduced by electrification of traffic. This should be talked about in public to raise awareness. Additional arguments against cars are environmental pollution and the prevalence of privately owned cars takes up a lot of urban space, which could be used for recreation.
- affordable options are leasing or shared mobility.
- speed limits only for combustion of cars, tax benefits (less emissions)
- standard air conditioning systems should be avoided due to waste heat emission.
- photovoltaic cells on the building envelope can help to cool the building as well as the surrounding area. The more efficient the solar panel is the higher its potential to cool down as the incoming solar energy is transformed into electricity and does not heat the city.
- the darker the present roof is, the more cooling can be achieved by installation of efficient photovoltaic panels. Advice on the spatial utilization of solar energy (e.g. roof albedo maps) can help.

Recommendation agricultural management

Aim of agricultural management in the Viennese surroundings should be not to irrigate to cool Vienna, but to transition to sustainable/ecological agriculture with little irrigation to prevent the areas from heating Vienna.

- water retention measures at field level (mulching, wind breaks, small dams etc.)
- construction of water retention tanks ("Zisternen") or retention basins for irrigation water.
- optimized irrigation methods and planning (e.g. precision farming methods)
- implementation of effective irrigation techniques (e.g. drip irrigation in suitable. crops)
- adaptation of crop rotations
- green manuring ("Gründüngung") in order to increase soil water holding capacity (water retention effect for the rooting zone of crops-more water available for transpiration) - sowing other cultivars who fertilize soil in between, is demanded in ecological agriculture) means additional time and money effort (sowing and irrigation!) it would only be done if there are subsidies or other economic profits -> economical studies are recommended.
- mulching ("Mulchen" - leaving stems/hay on field) is cheap but only brings cooling when albedo of soil is very low, so an increase in albedo is achieved. After harvest of cereals soil cultivation should be shifted to cooler periods (straw at the surface provides higher albedo on dark soils such as in the Marchfeld region).
- there are few fertilizer crops as Lupine ("Lupinie") and Alfalfa (Luzerne), who do not need irrigation, as they have deeper roots -> those are recommendable.
- generally ecological agriculture works with longer periods of vegetation cover, and less deep plowing -> which is good to keep moisture in deeper soil layers (and for soil life).
- application of minimum soil cultivation holds water in the soil better than ploughing (water retention effect).

Which further steps will be taken by the project team on the basis of the results obtained?

Due to the diverse feedback between the tackled cooling measures a system mapping approach is being investigated by the IIASA subcontractor to facilitate better understanding of the interlinkages and communication with stakeholders.

The project team has outlined several further steps based on the results obtained:

- Electrification of Traffic: This involves promoting the use of electric vehicles to reduce anthropogenic heat emissions and environmental pollution. Additionally, car-sharing models will be encouraged to reduce the prevalence of privately owned cars, which take up a lot of urban space.
- Public Awareness and Discussion: There will be efforts to raise public awareness and discussion to prevent the installation of air conditioning systems without attached alternative energy systems, such as heat pumps with ground regeneration.
- Measurement Studies: The team plans to initiate more measurement studies to quantify the cooling effects of photovoltaic panels on building envelopes. This will help in understanding the potential of solar panels to cool buildings and their surrounding areas.
- Urban Vegetation Management: The aim of urban vegetation within street canyons will be to provide shading without blocking air flow. Technical shading elements that can be easily set up and removed are also recommended.
- Agricultural Management: The focus will be on transitioning to sustainable and ecological agriculture with minimal irrigation to prevent the surrounding areas from heating Vienna. This includes implementing water retention measures, optimized irrigation methods, and effective irrigation techniques.

These steps are designed to address both the immediate and long-term challenges identified in the project, promoting sustainable practices and reducing the urban heat island effect.