M6.1 Modelling with TEB (sensitivity studies for small scale)

To assess the effectiveness of various urban heat mitigation strategies during summer drought conditions, multiple simulations were conducted, each representing different adaptation measures. These scenarios include variations in vegetation cover, urban surface modifications, ventilation strategies, photovoltaic installations, air conditioning, insulation improvements, and traffic heat emissions. The baseline scenario (S_STQ) represents the present-day urban environment with existing vegetation, while S_NO_TREE considers a case without any tree cover. Green infrastructure strategies include green roofs with varying vegetation types and substrate depths (S_GR, S_GRSEDUM), street tree implementations (S_TREE, S_TREELAI2), and unsealed roads covered with grass (S_LV). Urban surface modifications focus on increasing roof albedo (S_ALB), integrating photovoltaic panels with different efficiencies and configurations (S_PV, S_PVAIR, S_PV09, S_PV40, S_GRPV, S_GR1PV), and improving building insulation (S_INS). Additionally, passive cooling measures such as night ventilation (S_VEN), shading (S_VENSD), and combined strategies incorporating reflective roofs (S_VENSDALB) were tested. The impact of active cooling through HVAC (S_HVAC) and the influence of increased anthropogenic heat emissions from traffic (S_HTR) were also evaluated. Optimal irrigation was assumed for scenarios involving vegetation to ensure maximum evapotranspiration, and traffic emissions were normalized based on diurnal patterns from previous studies. The results of these simulations provide insights into the potential effectiveness of different mitigation strategies in reducing urban heat stress during extreme summer conditions. Different urban measurements to cool during summer drought were defined and simulated (see Table 6).

Table 6. Overview of simulated urban measures.

S_STQ	**present day situation and vegetation cover**
S_NO_TREE	no measures, no tree cover
S_GR(i)	green roof, grass 15 cm substrate (irrigated)
S_GRSEDUM(i)	green roof, Sedum 6 cm Substrate (irrigated)
S_TREE(i)	street trees, height=12 m, crown width= 10 m, LAI=6 (irrigated)
S_TREELAI2	street trees, height=12 m, crown width= 10 m, LAI=2
S_LV(i)	all road unsealed with grass, irrigated, no trees
S_ALB	roof albedo = 0.6
S_VEN	night ventilation only
S_VENSD	night ventilation and shading
S_VENSDALB	night ventilation, shading, white roof
S_PV	100% photovoltaic cover of roof, efficiency=18%, albedo=0.1
S_PVAIR	like PV, but with airgap
S_PV09 90%	photovoltaic, efficiency=18%, Albedo=0.1
S_PV40 100%	photovoltaic, efficiency =40%, Albedo=0.1
S_GRPV 50%	photovoltaic, 50% green roof, gras 15 cm
S_GR1PV	50% photovoltaic, 100% green roof, gras 15 cm
S_HVAC	air condition on, setpoint: 24 °C
S_HTR	sensible + latent energy flux caused by traffic is increased by factor 10
S_INS	insulation increased
S_ALL	combination of PV and INS

Irrigation: Irrigation values are assumed to assure optimal water availability and maximum evapotranspiration.
High traffic: For H_traffic a weekly and hourly normalization was applied and the normalization supplied by Météo-France adapted according to the NOx traffic diurnal cycles published in (Schreier et al., 2020): XPAR_TRAF_DAILY=1.15, 1.15, 1.15, 1.15, 1, 0.7, 0.7; XPAR_TRAF_HOURLY=0.72, 0.47, 0.36, 0.35, 0.41, 0.71, 1.36, 1.56, 1.6, 1.56, 1.41, 1.21, 1.1, 1.06, 1.01,1,1.01, 1.05, 1.1, 1.15, 1.15, 1, 0.85, 0.8; the mean background value of 13 W was taken from the results of WP3b.

Thermal comfort indoors: Indicator indoor air temperature

When we talk about heat stress during the summer – the main parameter affecting us is presently the indoor temperature, as here people spend most of their time. Therefore, this value should be looked at. The main competitor of all cooling measures is the technical solution of air conditioning. As we see in Fig. 12 air conditioning provides effecting cooling until the capacity of the appliance is reached. Beyond this point, indoor temperatures rise in air-conditioned houses too. Another notable. measure is ventilation during hours when there is a notable. temperature difference between indoor and outdoor temperatures. With this measure an effective cooling can be achieved. White roofs need to be mentioned as cheap measures as well. Further window shading is very efficient. Compared to those measures, which neither relieve electricity nor water, the use of vegetation has a minor but reducing influence on the indoor temperature Fig. 12 and Annex A 22.

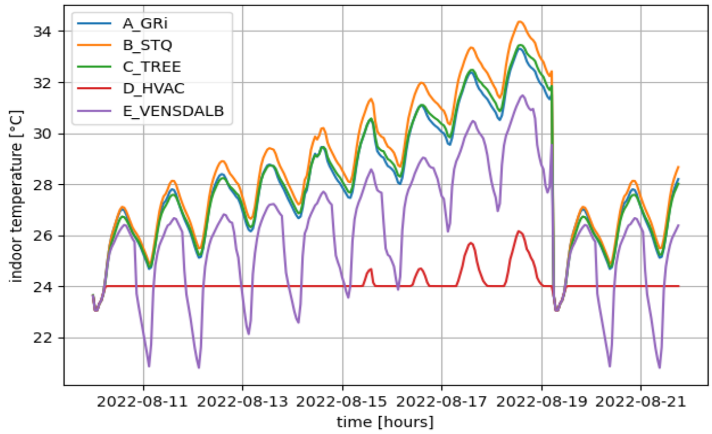

Fig. 12 Evolution of indoor temperature during the hot and dry observed episode (hourly values) under different scenario assumptions (irrigated intense green roofs (A_GRi), no measures (B_STQ), street trees (C_TREE), air condition (D_HVAC), night time ventilation, shading and bright roofs (E_VENSDALB)).

Thermal comfort street canyon microclimate: UTCI at street level

If indoor temperatures exceed thermal comfort levels, as well as for general recreation purposes, thermal relief is sought in the near urban free spaces. Therefore consecutively, we present results for the urban canyon. When we move outdoors, next to the air temperature incoming solar radiation and wind speed play an increasing role in pedestrian thermal comfort. Therefore, we show the Universal Thermal Comfort index (UTCI), which includes those parameters next to air temperature and humidity. Here the strongest reduction can be achieved by tree shading (Fig. 13). Even trees with low leaf area density (LAI) show a strong reduction of UTCI. Irrigation can add additional cooling. Irrigation of low vegetation in the canyon without shading provides little cooling during the morning, but notable changes during afternoon and night hours.

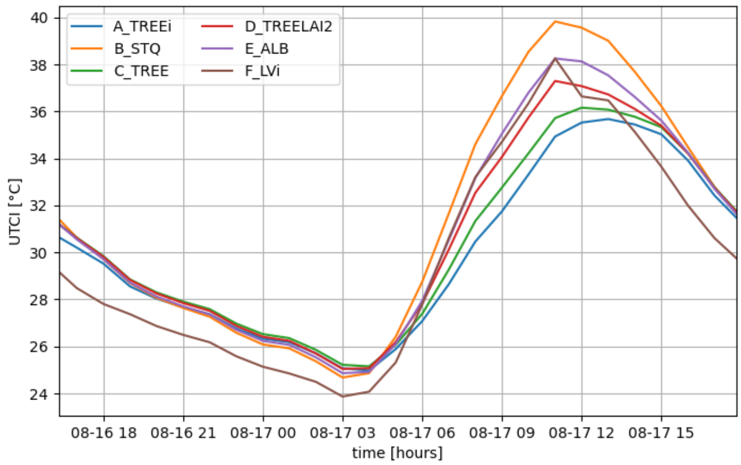

Figure 13. UTCI (hourly values 16-17 Aug 2022) for different measures (irrigated street trees (A_TREEi), no measures (B_STQ), street trees (C_TREE), light street trees (D_TREELAI2), bright roofs (E_ALB), low irrigated vegetation in the street canyon (F_LVi).

During a heat wave (Annex A 23), the cooling effect of irrigated laws accumulates to make it the most efficient measure due to its strong nighttime cooling.

Here it needs to be pointed out, that a dense city quarter is simulated – in urban areas of wider street profiles therefore higher ventilation/higher irradiation the shading effect is likely to be more effective during longer periods. In the simulated geometry the wind speed can be nearly halved by inclusion of trees (Annex A 24).

Whether the weather is perceived as humid depends crucially on the water content of the air, also known as absolute humidity (AF). Sultriness begins when the dew point exceeds the limit value of 16 °C, which corresponds to an absolute humidity of 13.5 g of water vapor per cubic meter of air under normal conditions. At 25°C, 30°C and 35°C this threshold is reached at about 59%, 45% and 35% relative humidity.

This means that during full irrigation of whole street canyons (LVi) sultriness levels are in reach during the morning (Annex A 25) and good ventilation should be ensured.

Thermal comfort urban climate: local heat contributing to mesoscale

When we want to know how much an urban area contributes to the general heat stress of a city via increases in temperature we need to look above the roof level. Roof temperatures (Annex A 26) influence radiant temperatures (Annex A 27) and further sensible heat flux (Annex A 28). The less radiation is reflected, used for evapotranspiration or the generation of electricity, the more energy is available to heat the air above the roof – which affects larger areas of the city. If additional heat is released from roof mounted air condition systems, this adds even more heat to the urban boundary layer. The evapotranspiration of green roofs (Annex A 29) is higher than from the unsealed areas at street level. The low vegetation scenarios at street level have higher maximum evaporation rates than street trees as well. The irrigated versions are higher in all cases. The type of green roof (sedum/grass) and tree (sense/light crown) is secondary.

For the anthropogenic heat scenarios, the highest effect is seen when a 10-fold increase in turbulent fluxes is assumed within the streets, as is likely on a high traffic and traffic jam site, with 1-2K air temperature and more than 2K UTCI increase compared to the STQ scenario (Annex A 30).