HEat Robustness In relation To AGEing cities (HERITAGE) Program: First observations

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Abstract.

The HERITAGE research program intends to develop a high-tech sensing and design system aiming at detection, reduction and prevention (by monitoring and design) of urban heat-stress occurring due to ageing of built environmental settings and buildings in cities, through socio-technical solutions. This integral system will detect and forecast spatiotemporal patterns of heat stress at unprecedented resolutions (1m scale), aiming at technological solutions to reduce and mitigate indoor and outdoor heat stress through developing urban design guidelines and connecting the energy transition, housing demands, repurposing areas, climate adaptation and digitalization.

The HERITAGE system necessitates a multi-disciplinary approach involving earth observation, urban hydro-meteorology and climatology, urban design and sustainable infrastructural energy systems. Therefore, parallel to the sensing, long-term research lines are rolled out on robust hydro-meteorological, design and energy solutions, at multiple spatiotemporal scales and forms. Concretely, these research lines fill knowledge gaps in climate policies through innovative techniques for analysis, simulation, development and experimental testing of newly designed multiscale urban heritage canopy layer schemes for climate models, multiscale form-microclimatic relationships and sustainable energy systems, suited for application in aged neighborhoods and buildings.

Reflected and emitted solar and thermal radiation can be considered the main drivers for turbulent and radiative heat exchange and thus for urban heat. However, their use from remote sensing observations in urban areas is still in its infancy and rather simplistic in its modelling approach. The above-mentioned multiscale schemes and relationships will be developed in the cities of Amsterdam, Rotterdam, Eindhoven, Delft and Enschede, where we collect ground-based, air- and space-borne radiative observations and heat-exchanges at matching scales. We cover space-time resolutions from submeter to kilometer and from 100 Hz to hours, monitoring the exchange processes at the relevant scales. The observations will be employed to develop scale-dependent heat-exchange parameterizations, suitable for 3D city models at building-, street-, and neighborhood-level. In this contribution the first observations are presented.

Keywords: Urban heat, remote sensing, spatiotemporal modelling, building energy system, urban design

HEat Robustness In relation To AGEing cities (HERITAGE): First simulations

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Abstract.

Due to ongoing climate change and urbanization, societies face challenges concerning environmental quality, energy management and citizens' health. While many past observational and modelling studies concentrated on understanding urban microclimate and how humans experience this, focus has been on relatively modern infrastructure ("street canyons") regarding modelling and observational efforts which showed less success over historical districts. Many cities have a significant share of aged and historical buildings with unique and different street profiles from modern infrastructure, which raises additional challenges in the energy transition due to low energy-efficiency and restrictions to required interventions.

Within the HERITAGE research program we are developing a sensing system aiming at detection, reduction and prevention (by monitoring and design) of urban heat-stress in a realistic setting, where we aim at detecting (observations) and forecasting (simulations) spatiotemporal patterns of heat stress at resolutions down to 1 meter. This requires an observational modelling approach which ideally should utilize routinely collected urban hydro-meteorological observations and earth observation data that is operationally available. Utilizing our local urban observational infrastructure (in the city of Enschede), consisting of microwave and scintillometers, 4-component radiometer and turbulent flux (H_2O, CO_2 and heat) eddy-correlation sensors next to a spatially distributed urban micro-meteorological sensor network, we will develop such an approach.

Objective and generic determination of urban heat stress comes down to the determination of energy budgets. Calculating the energy budget at high resolutions depends on accurate representation building properties such as albedo, emissivity, and thermal capacity. The energy budgets relate to externally exposed thermal stresses on the human body by radiative, conductive and turbulent energy fluxes. The most relevant flux herein is the radiative flux, by emission and reflection, which can for a large part be provided by remote sensing. Future satellite missions, such as LSTM, CHIME, SBG and TRISHNA, have a more suitable temporal and spatial resolution for urban heat stress detection than current satellite constellations. Most urban climate simulations use generic values for building properties which are not representative of the realistic conditions, this gap can be bridged with inputs from remote sensing. In preparation thereof, quasi-synthetic simulations (employing the PALM4U model) of urban heat stress as experienced by humans, were performed over the city of Enschede, Netherlands to explore potential improvements. Results are shown for typically different Local Climate Zones, where use has been made of the above-mentioned observational infrastructure combined with readily available high-resolution imagery.

Keywords: Urban heat, remote sensing, spatiotemporal modelling, urban simulations

HEat Robustness In relation To AGEing cities (HERITAGE): First simulations

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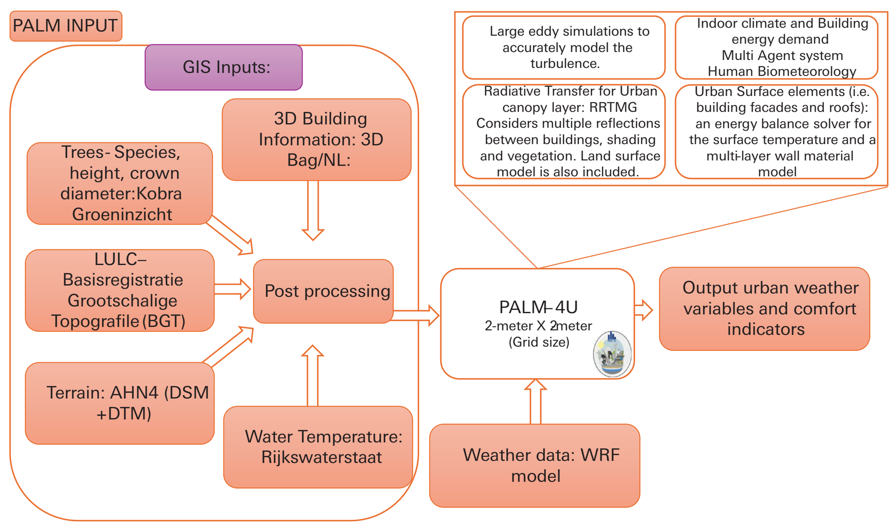
Introduction

Urban areas are increasingly experiencing extreme heat events, air pollution, and other climate-related challenges. Accurate modeling of urban climates is crucial for understanding these phenomena and developing effective mitigation strategies.

PALM-4U

The PALM 4U large eddy simulation (LES) model is a robust and versatile model for simulating urban climates by considering both turbulent and radiative fluxes, as well as complex 3D geometries.It allows to simulate the complex microclimate within cities by considering following aspects:



PALM 4U flowchart: Input, processing, and output.

Model Evaluation

To assess the model's accuracy, its predictions were compared against observational data collected from five EnvMon weather stations situated across Enschede, Netherlands. These stations are positioned 3.2 meters above ground. The comparison was conducted using data collected on a hot, sunny day, June 27, 2024. Focusing on two representative stations, a strong correlation between observed and modeled Air Temperature was evident. R^2 values of 0.93 and 0.95, respectively, confirmed this correlation. Moreover, the model accurately replicated the daily temperature fluctuations. The Root Mean Square Error (RMSE) values of 1.27 °C and 1.13 °C further indicated a close agreement between the observed and modeled data. Regarding Relative Humidity, a similar correlation was observed, though slightly weaker than for Air Temperature. R^2 values of 0.78 and 0.81 suggest a strong correlation. While the model captured the diurnal cycle of Relative Humidity, a dry bias was noted during evening hours.

Aerial View of simulation site

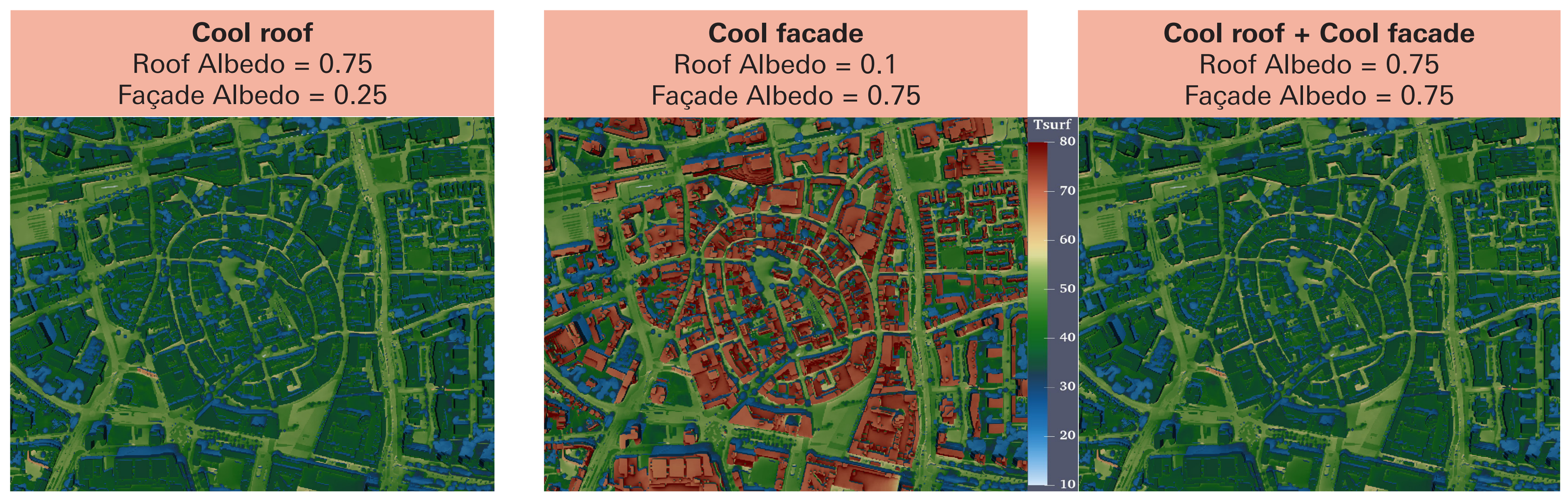
Surface Temperature for Control case: Roof albedo:0.1; Facade albedo:0.25

Sensitivity Assessment of surface radiative properties

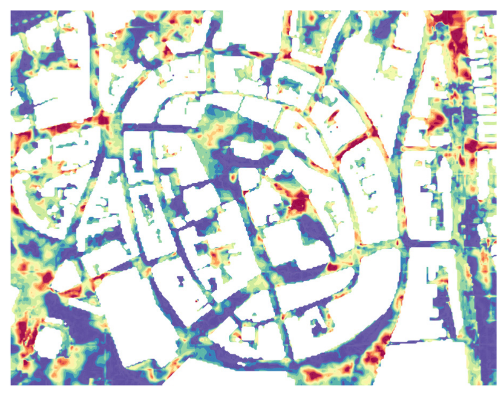
To examine how surface radiative properties influence urban climate variables, four different combinations of roof and façade albedo were simulated at midday (12:00 hours). The values for Solar Azimuth Angle and Solar Elevation Angle were 193.73 ° and 60.53°, respectively. The simulation results demonstrate a significant impact of roof and façade albedo on surface temperature. Here we refer to a cool roof/facade as roof/facade with higher albedo. When both roof and façade albedo were set to 0.75, a substantial reduction of 40 degrees Celsius in surface temperature was observed compared to the control case. This is primarily due to the increased reflection of solar energy, which reduces the amount of heat absorbed by the surface. Façade temperatures are reduced by up to 15 degrees Celsius.

Pedestrian thermal comfort : Physiologically equivalent temperature (PET)

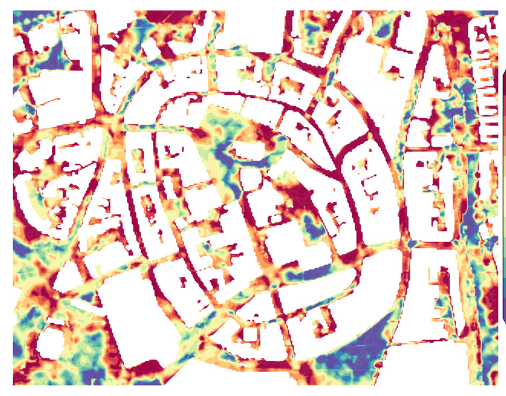
Model results show that cool roof reduces the PET at the street level and increases the pedestrian thermal comfort. However, using a cool façade increases the reflected radiation from the facades thereby worsening the PET. Case with both cool roofs and cool facades gives a mixed performance in terms of PET with regions of reduced PET interspersed with regions of increased PET.



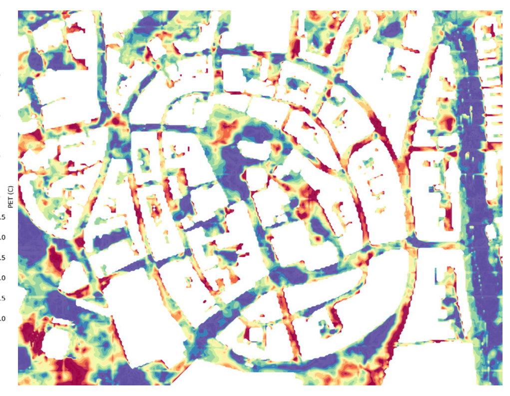
Surface Temperature for different roof and facade albedo values



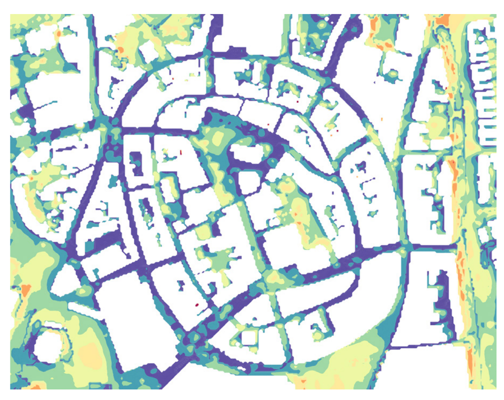
Δ PET: Cool roof – Control Case



Δ PET: Cool Facade – Control Case

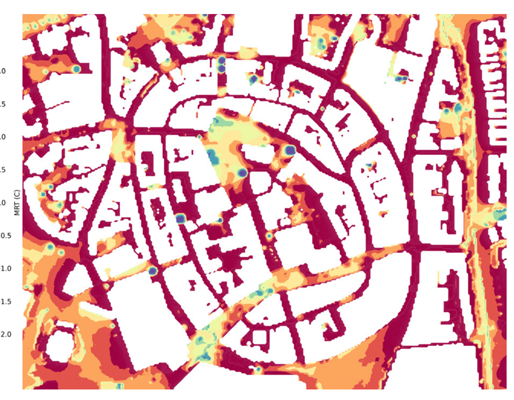


Δ PET: Cool roof + Cool Facade - Control Case



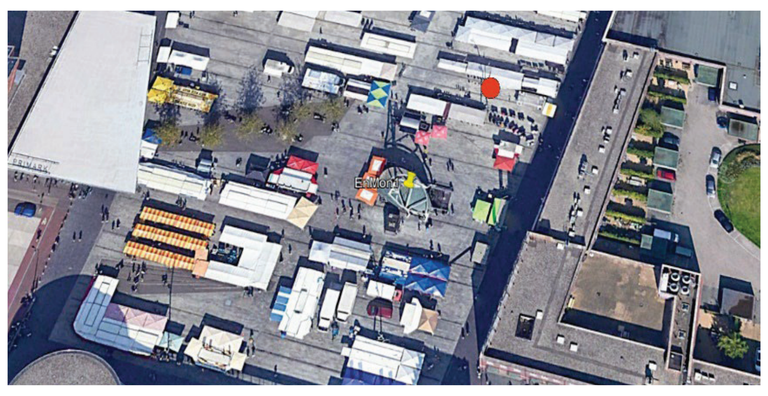
Δ MRT: Cool roof – Control Case

Δ MRT: Cool Facade – Control Case



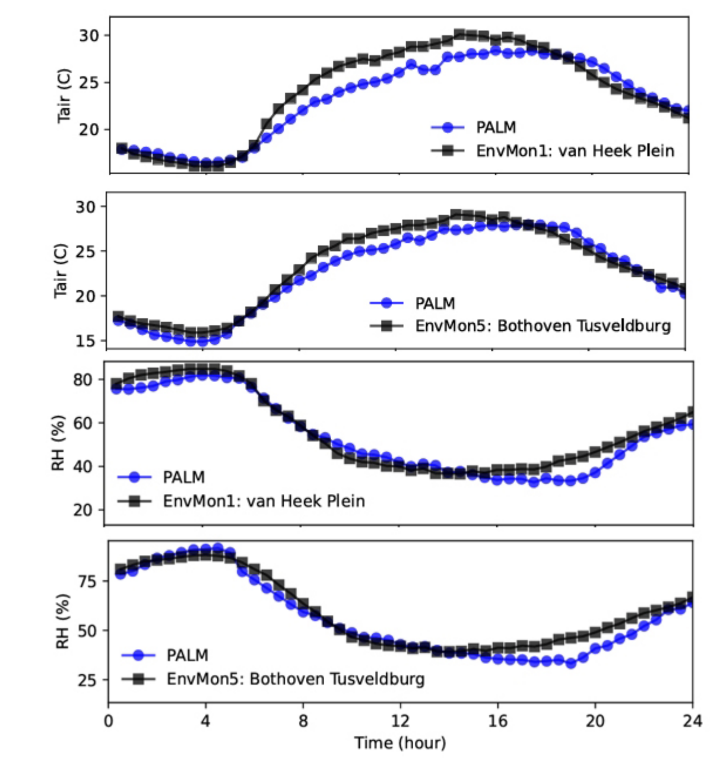
Δ MRT: Cool roof + Cool Facade - Control Case

Aerial View

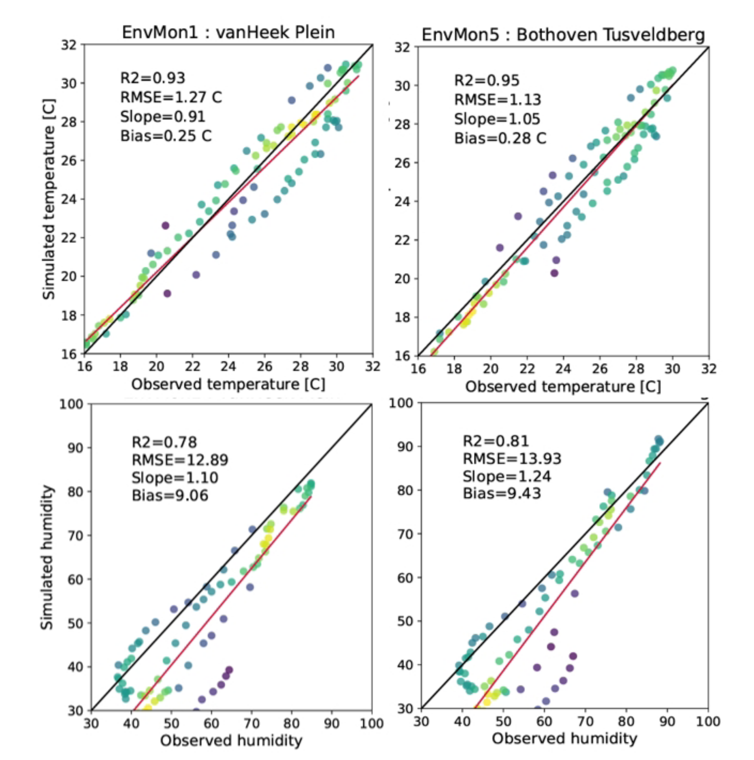


Aerial View of ground observation site: Van Heek Plein

Aerial View of ground observation site: Bothoven Tusveldberg



Diurnal variation of Tair and RH (%): In-situ Vs PALM



In-situ Vs PALM simulation: Model evaluation

Pedestrian thermal comfort : Mean radiant temperature

Model results show that cool roof reduces the MRT at the street level by upto 1 degree Celsius and increases the pedestrian thermal comfort. Using a cool façade increases the mean radiant temperature in most of the locations at the city center by upto 2 degree Celsius and indicates a worsening thermal comfort. Higher values were observed in areas with narrower street canyons compared to wider ones.

Conclusion:

1 The model demonstrated strong agreement with observed data for both Air Temperature and Relative Humidity, as evidenced by high R^2 values and low RMSE.

2 While cool roofs improved thermal comfort, cool facades had opposite effects, often increasing PET and MRT in areas with narrow street canyons. Future work will focus on simulating the effect of cool green facades (The façades with partially or fully covered with greenery).

3 Increasing roof and façade albedo significantly reduced surface temperatures, demonstrating the potential of reflective materials to mitigate urban heat islands.

For more information

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