CFD Modelling of the Urban Microclimate: a Portuguese Case Study

Diogo Nascimento [1], Ana Ascenso[1], Ana Miranda[1], Myriam Lopes[1] and Vera Rodrigues[1]*

[1]CESAM and Department of Environment and Planning, University of Aveiro, Portugal
*diogo.nascimento@ua.pt

universidade de aveiro
theoria poiesis praxis

HARMO 22

10-14 June 2024
Pärnu, Estonia

22nd International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes

Introduction

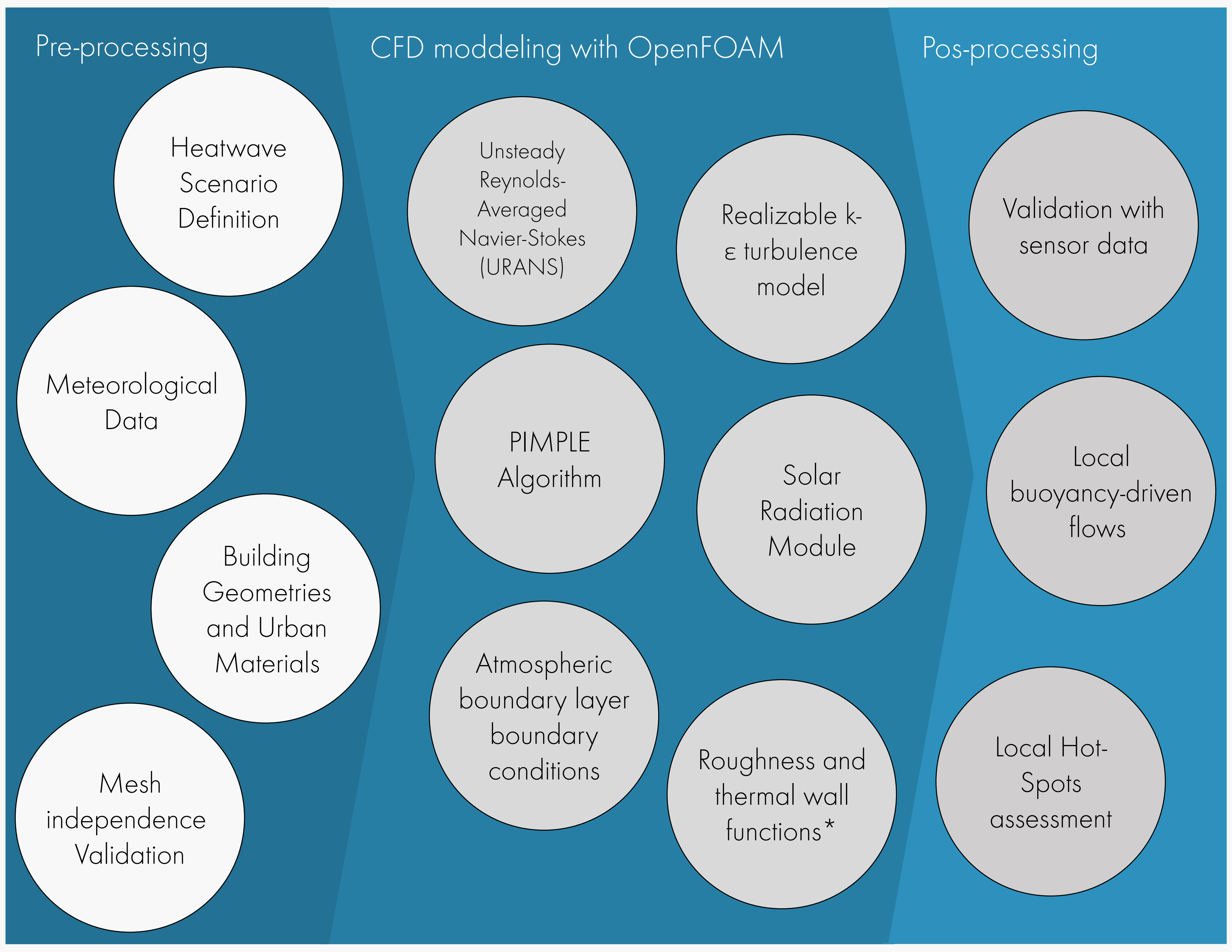
Urban areas increasingly suffer from extreme weather events, exacerbating the urban heat island effect and air pollution episodes (Pyrgou et al., 2020; Santamouris, 2020). High temperatures in cities can lead to the formation and spread of air pollutants, as heat accelerates chemical reactions that generate secondary pollutants like ground-level ozone and secondary particulate matter. Also, low wind speeds in densely built environments can worsen air pollution episodes.

In recent years, Computational Fluid Dynamics (CFD) modelling has established itself as a powerful tool for studying the complex dynamics of the urban atmosphere allowing for a comprehensive analysis of airflow patterns, temperature distributions, and pollutant dispersion within urban environments (Allegrini et al., 2014; Rodrigues et al., 2024).

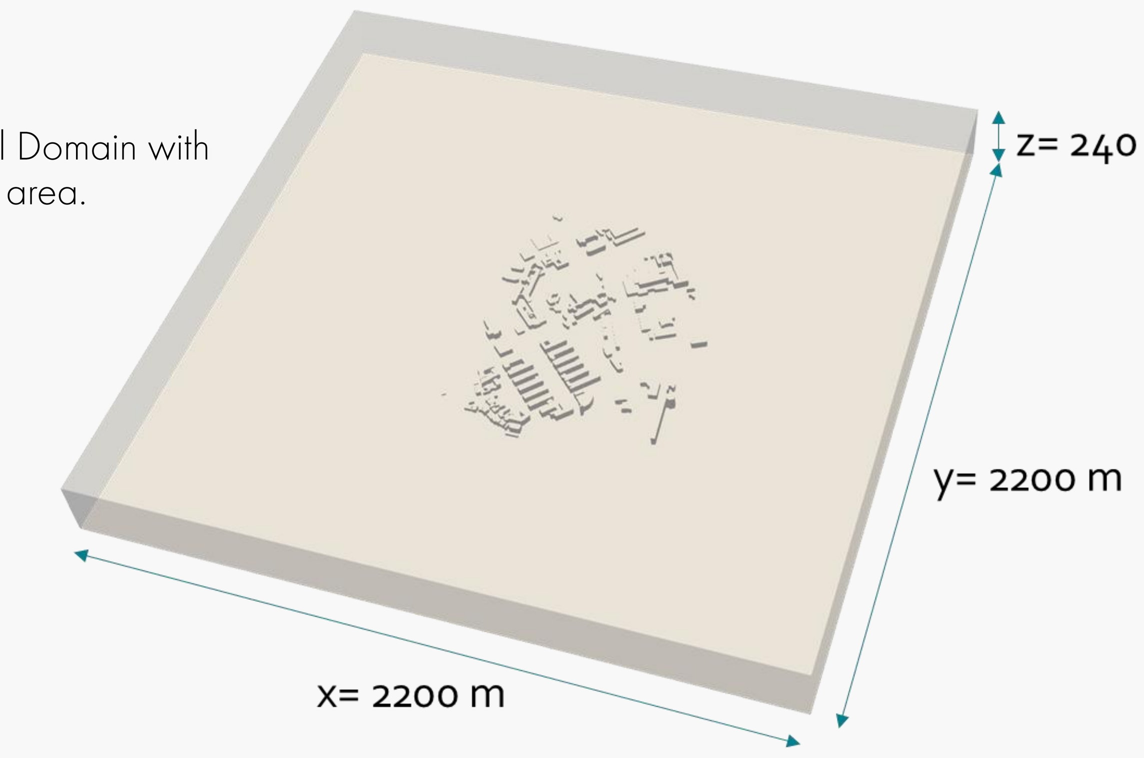
However, some CFD methodologies lack comprehensive treatment of heat effects or oversimplify temperature conditions, such as solar radiation interactions (Mirza et al., 2022; Mirzaei, 2021).

This study utilizes CFD simulations to model a portion of the city of Aveiro during a heatwave, considering material properties, heat exchanges between built environments and the urban atmosphere, and solar radiation interactions. The research focuses on analysing temperature patterns, the influence of near-wall temperatures on buoyancy, and the resulting impact on pollutant dispersion during peak radiation hours.

Methodology



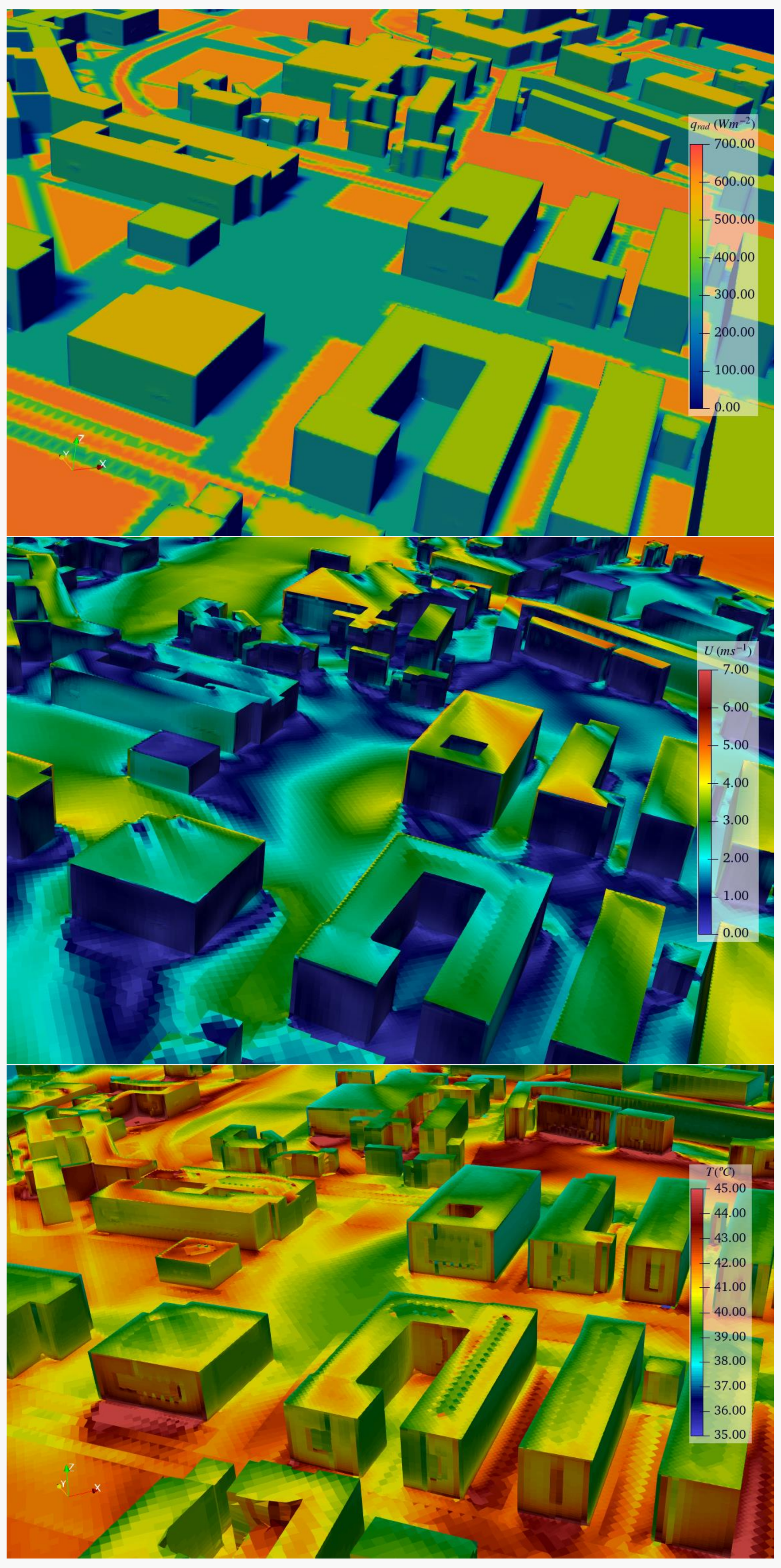
*more wall function details on extended abstract



Computational Domain with central interest area.

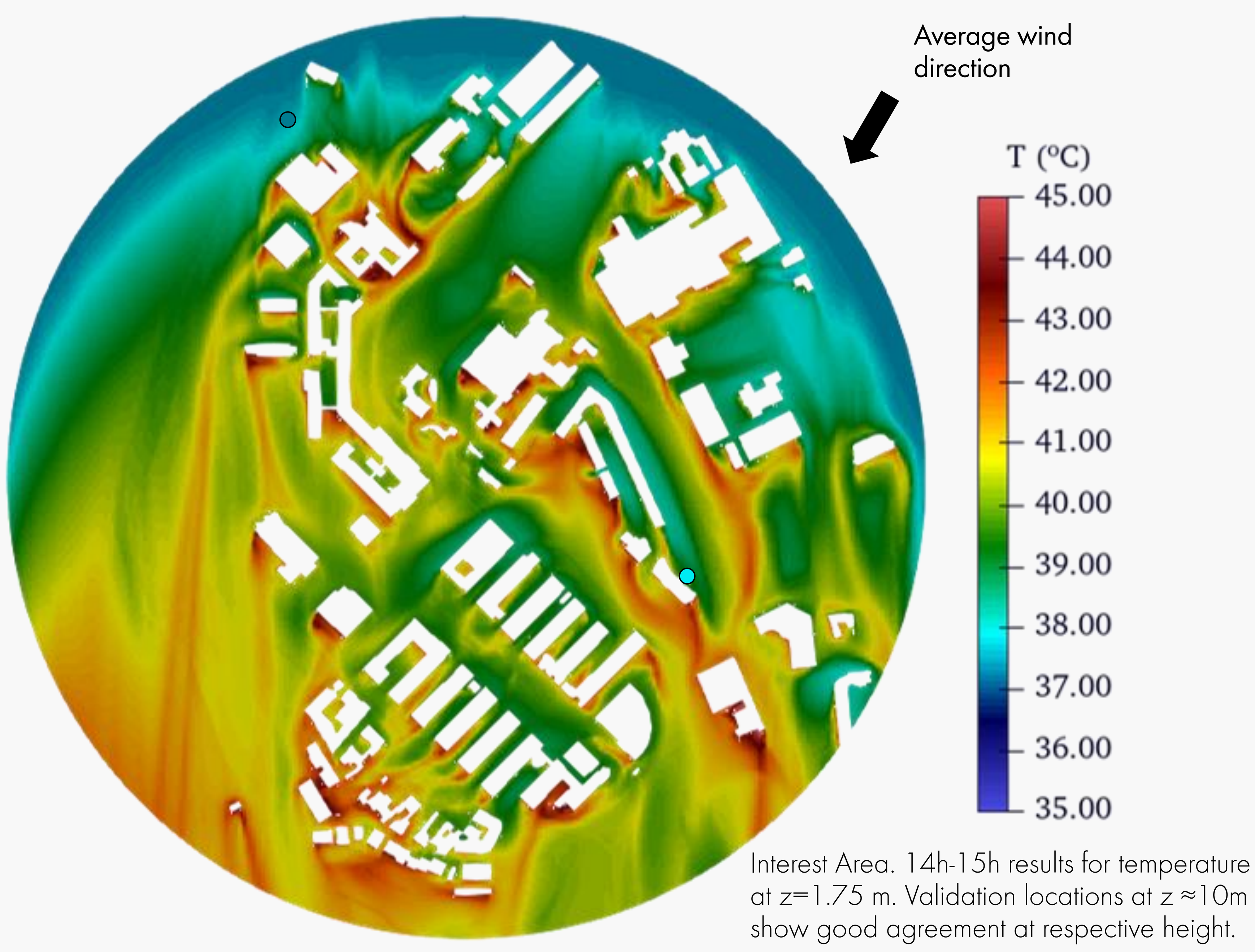
Results

The entire day was simulated, with results being saved every minute and then averaged every hour. However this poster only exposes and analyses the average temperature values between 14h and 15h. This hour was selected because it falls within the period of the highest accumulated heat in the area. Surface cell results show clearly the locations where lower wind speeds occur in conjunction with higher solar radiation (radiative heat exchanges) the modelling result is a local increase in near-wall air temperature. On the other hand, higher wind velocities promote cooler temperatures near the wall due to faster heat dissipation. Higher air temperatures occur within the cavity zone in the overall building wake region, closer to the ground where materials with higher absorptivity occur (asphalt) or in between buildings that are closer to each other with reduced spacing due to skimming flow that causes heat entrapment. The recorded maximum absolute temperatures for the day in the reference meteorological tower were of 37.8 °C at 10 m height.



Averaged 14h-15h results for Wind Speed, Temperature and Radiative Heat Flux.

- At z =1.75 m, results show near-wall air temperatures reach maximum values of 44.3 °C.
- Locally minimum temperatures modelled temperatures are 37.3 °C with an overall area mean temperature of 39.9 °C for the whole interest area.
- The cavity region of the building wake experiences higher temperatures due to lower wind speeds.
- Multiple materials directly impact temperature variation across the domain with an influence on radiation absorption and heat flux exchanges.
- Materials with higher absorptivity and higher emissivity promote higher near-wall temperatures.
- Green areas were considered as low vegetation surfaces based on their radiative and thermal properties.
- No vegetation evaporative cooling effect was modelled.



Interest Area. 14h-15h results for temperature at z=1.75 m. Validation locations at z ≈10m show good agreement at respective height.

Conclusions

This study presents a 3D CFD simulation of an urban microclimate during a heatwave event. Using OpenFOAM, the simulation accounts for material properties, heat exchanges, and solar radiation, revealing that near-wall air temperatures can achieve local maximum temperatures by up to 6.5 °C when compared to the reference locations. Key thermal interactions like solar radiation and surface heat exchanges, especially in low wind-speed areas should not be neglected or oversimplified. These results present essential steps for future CFD simulations of pollutant dispersion in urban areas, considering various stability conditions and buoyancy-driven/influenced dispersion behaviour.

References

Allegrini, J., Dorer, V., Carmeliet, J., 2014. Buoyant flows in street canyons: Validation of CFD simulations with wind tunnel measurements. Build Environ 72, 63–74. https://doi.org/10.1016/J.BUILDENV.2013.10.021

Mirza, S., Niwalkar, A., Anjum, S., Bherwani, H., Singh, A., Kumar, R., 2022. Studying impact of infrastructure development on urban microclimate: Integrated multiparameter analysis using OpenFOAM. Energy Nexus 6, 100060. https://doi.org/10.1016/j.nexus.2022.100060

Mirzaei, P.A., 2021. CFD modeling of micro and urban climates: Problems to be solved in the new decade. Sustain Cities Soc. https://doi.org/10.1016/j.scs.2021.102839

Pyrgou, A., Hadjinicolaou, P., Santamouris, M., 2020. Urban-rural moisture contrast: Regulator of the urban heat island and heatwaves' synergy over a mediterranean city. Environ Res 182. https://doi.org/10.1016/j.envres.2019.109102

Rodrigues, V., Augusto, B., Oliveira, K., Ascenso, A., Rafael, S., Nascimento, D., Miranda, A.I., 2024. Setting up a CFD model to evaluate the impact of green infrastructures on local air quality. Air Qual Atmos Health. https://doi.org/https://doi.org/10.1007/s11869-024-01567-6

Santamouris, M., 2020. Recent progress on urban overheating and heat island research. Integrated assessment of the energy, environmental, vulnerability and health impact. Synergies with the global climate change. Energy Build. https://doi.org/10.1016/j.enbuild.2019.109482

Acknowledgements

This work is part of the OptWire -Next-Generation Optical Wireless Communications Enabled by Artificial Intelligence project (PTDC/EEI-TEL/2697/2021), supported by FCT/MCTES. Thanks are due to CESAM (UIDP/50017/2020 + UIDB/50017/2020 407 + LA/P/0094/2020), through national funds, and the co-funding by the FEDER, within the PT2020 Partnership Agreement and Compete 2020. Thanks are also due to the advanced computing project (2022.59222.CPCA.A0) funded by the Foundation for Science and Technology, through the National Network for Advanced Computing. The OpenFOAM simulations were performed at the Cirrus platform center of the National Infrastructure for Distributed Computing (INCD).

OptWire
Optical Wireless Communications Enabled by AI

fct Fundação para a Ciência e a Tecnologia

REPÚBLICA PORTUGUESA