Sobre el impacto del balance de energía superficial urbano (SEB) evaluado mediante un gemelo digital CFD a escala de distrito

On the impact of the urban surface energy balance (SEB) assessed using a district-scale CFD digital twin

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RESUMEN

Understanding the urban Surface Energy Balance (SEB) is fundamental to characterising surface–atmosphere interactions in cities and to assessing the performance of urban mitigation and adaptation strategies under extreme climate conditions. The SEB controls the partitioning of radiative, convective, and conductive heat fluxes at urban surfaces and, therefore, governs buoyancy production, turbulence generation, and vertical exchange within the urban canopy, with direct implications for pedestrian-level thermal comfort and air quality. Through its coupling with building envelopes, the SEB also affects indoor thermal conditions and, consequently, cooling energy demand. In this study, a Computational Fluid Dynamics (CFD) model is applied to a representative area of the Salamanca district in Madrid (Spain) during a documented summer heat-wave episode to analyse the urban SEB under realistic extreme conditions. The objective is to assess the impact of the thermal cycling, surface optical properties, and material thermal properties on the hourly evolutions of roof- and façade-averaged surface boundary heat flux components. Particularly, on the net radiative (Qrad), convective (Qconv), and conductive (Qcond) heat fluxes. Anthropogenic and latent heat fluxes are neglected here. The CFD model explicitly resolves atmospheric flow, radiative exchanges, and Conjugate Heat Transfer (CHT) between building envelopes and the outdoor and indoor environments. Opaque building envelope elements are modelled as finite-thickness solids, allowing thermal inertia to be captured and enabling a physically consistent representation of thermal cycling across consecutive diurnal cycles. Short-wave and long-wave radiation processes are explicitly simulated. A scenario-based approach is adopted to investigate comparatively the impacts of (i) the initial thermal state of the building envelopes, (ii) the cool roofs, and (iii) the water walls on the temporal evolutions of SEB components. Unsteady simulations over two diurnal cycles enable the assessment of how these factors modulate the magnitude, timing, and persistence of Qrad, Qconv, and Qcond under heat-wave conditions, as well as their implications for indoor thermal comfort. The results demonstrate that thermal cycling plays a central role in the urban SEB, with thermal inertia strongly influencing both the redistribution of radiative gains into convective and conductive pathways and the persistence of heat release during evening and night time hours. Surface optical properties primarily govern peak radiative forcing, while material thermal properties control heat storage and delayed release, directly affecting indoor temperature dynamics during extreme heat events. This findings supports the evaluation of envelope-level mitigation strategies in heat-stressed urban environments.