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CFD simulation of an idealized urban environment: Thermal effects of geometrical characteristics and surface materials

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ABSTRACT

Numerical fluid flow and heat transfer simulations of a street-scale urban environment are utilized to investigate the diurnal cycle of the urban thermal environment. Unsteady simulations forced with realistic solar load and wind and temperature profiles are performed based on Reynolds-averaged Navier–Stokes equations in the finite volume solver ANSYS/FLUENT 14.5. The simulations are carried out over an idealized geometry for a clear summer day in southern California. In comparison with previous studies, our model considers dynamic coupling of heat transfer and the flow field as well as non-uniform surface heating caused by solar insolation and building shadowing. Relative importance of urban design parameters, including urban aspect ratio (height-to-width of H/W = 1/3–3/2), surface albedo (0.18–0.35), and wind direction (0°, 45° and 90°) and speed (2 and 3 m s^{-1} bulk flow) are investigated. Ground surface albedo is found to have the most influence on the urban facade temperature and the energy balance. Replacing asphalt with concrete as ground material decreased ground surface temperature by up to 8 K and increased building wall temperature by 3.5 K. In agreement with surface temperature Urban Heat Islands observations, high urban built-up density, specified by larger canyon H/W, increases the peak building wall temperature during the day, while the ground surface temperature is more sensitive to aspect ratio at night. Although the higher H/W decreases the penetration of direct solar radiation, an energy balance analysis suggests the wall temperature increase to be the result of decreasing convective cooling. For compact building

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configuration (canyon H/W of 1), rotating the wind direction 45° away from the canyon axis and increasing average bulk velocity at the inlet did not significantly influence the wind speed inside the canyon and therefore ground temperatures, while peak roof temperature is strongly influenced. Therefore urban built-up density outweighs the effects of wind speed and direction on the ground temperature.

Nomenclature

AR	canyon aspect ratio, AR = H/W
As	asphalt
C	concrete
Cp	effective heat capacity
F	view factor
H	building height
h	Convective Heat Transfer Coefficient (CHTC)
k	effective thermal conductivity
L	net longwave radiation flux
L_{inc}	total longwave radiation incident on the surface
Q_c	conduction heat flux
Q_h	sensible heat flux
R_{net}	all-wavelength net radiation flux
S	total shortwave radiation incident on the surface
S_{abs}	shortwave radiation absorbed by the surface
T_a	inlet air temperature
T_{sky}	sky radiation temperature
U_b	average bulk wind velocity at inlet
W	building spacing

Greek letters

α	surface albedo
ϵ	surface emissivity
σ	Stephan–Boltzmann constant

Subscripts

gr	ground surface
$gr-w$	from ground to wall
r	roof surface of the center building
w	average of 4 walls of the center building
ww, we, ws, wn	west wall, east wall, south wall, north wall of the center building respectively

1. Introduction

Understanding of urban climate requires consideration of complex relationships between various factors. Urban morphology, natural land cover, moisture availability, anthropogenic heats and built materials alter air flow and heat transfer in the urban environment, and therefore determine urban microclimates, strength of the Urban Heat Island (UHI) and the ensuing environmental effects