Shading Affects the Latent Heat Flux in Vegetated Urban Areas

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1 INTRODUCTION

1.1. Motivation

It is a well-established fact that the world is undergoing rapid climate change and that this is leading to an increase in extreme weather events. Particularly there have been increases in warm-weather extremes [1] and urban areas are particularly vulnerable to such events. The urban heat island effect (UHI) is the well-documented phenomenon that temperatures in urban areas can be several degrees warmer than those in the surrounding rural areas. This means that cities are more susceptible to heatwaves than rural areas [2] the consequences of which can range from costly and inconvenient to fatal for those living in urban areas. When this is taken into consideration along with the fact that over 50% of the global population inhabits cities [3] (a figure that is predicted to rise throughout the 21st century) there is a pressing need to be able to understand and accurately model the urban microclimate and meteorology

1.2. Surface Energy Balance (SEB)

The surface energy balance (SEB) describes the way an urban area exchanges energy with the surrounding atmosphere, and it plays a key role in determining both the local microclimate and meteorological forcings. In this work the SEB of a surface is modelled as follows:

$$Q^{*} = H + E + G \tag{1}$$

where Q^{*} is the net radiative flux incident on the surface, H and E are the sensible and latent heat fluxes going from the surface into the atmosphere and G is the conductive heat flux away from the surface into the ground and buildings.

1.3 The Urban Surface

Urban areas are inherently heterogeneous and complex environments consisting of a wide range of materials. Surface variability impacts range of processes involved in urban atmospheric interaction; for example, the transport of heat and moisture [4], radiative interactions and momentum exchanges between the air and the urban surface. Given the complex nature of the urban surface land-surface models (LSMs), used for weather forecasts, tend to employ simplifications, often approximating the geometry as infinite canyons, parameterizing the flow and reducing radiative calculations to two dimensions. It has been shown that such models tend to struggle to accurately predict the latent heat flux and that models that decouple the buildings and vegetation perform worse across all of the fluxes. It has also been shown [5] that models that reduce the urban surface to an infinite canyon perform poorly in terms of partitioning the radiative energy across the urban surface – the ramifications for the SEB being evident.

This work aims to investigate the impact that shading has on the SEB in vegetated urban areas and hence quantify the uncertainty associated with fluxes calculated by LSMs that do not account for realistic shadow-casting effects.

2 METHOD

Two cases are simulated, both considering the same vegetated urban area but with different solar zenith angles and therefore different shade distributions. The SEBs arising from these two cases are compared.

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2.1 Setup

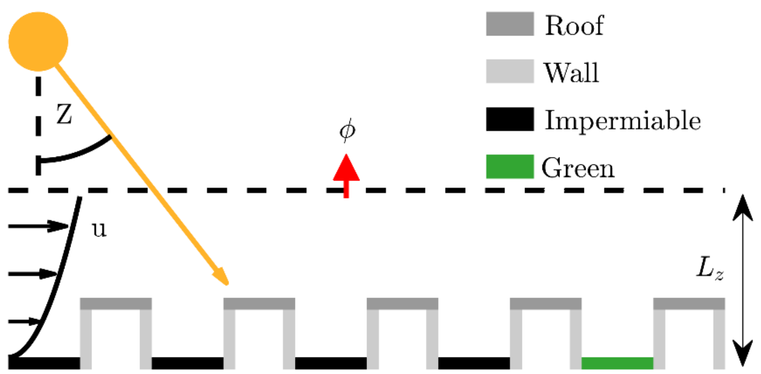

Figure 1, Schematic representation of the simulations.

Figure 1 shows how the simulations are setup, the solar zenith angle (Z) is fixed, a constant flow rate (u) is enforced such that the plane averaged streamwise velocity is 4 ms^{-1}, the domain height (L_z) is 384 m and the surface comprises of roofs, walls impermeable floor material (roads and pavements) and green spaces. The simulations experience a constant forcing and so are in a statistically steady state. This means the fluxes exhibit turbulent fluctuations about a constant mean.

The two zenith angles used are Z = 45^o (case 1) and Z = 0^o (case 2) which correspond to mod afternoon and midday respectively. Reducing the zenith angle by 45^o will increase the total radiative power incident on the surface by a factor of $\sqrt{2}$ which will significantly alter the buoyancy and turbulence. As this work focuses only on the distribution of shading this effect is negated by reducing the solar irradiance by $\sqrt{2}$.

2.2 Geometry

Figure 2 shows the geometry that is used in this work. The geometry is 1152 x 768 x 384 m^3 and is formed of 6 copies of a unit tile – this is done to reduce computational requirements. The geometry was produced using an urban landscape generator (ULG) similar to that presented by Sützl et al. [6]. The urban area is constructed such that it has morphometric indicator values that are within the ranges defined by Yu et al. [7] for mixed-type residential and commercial zones.

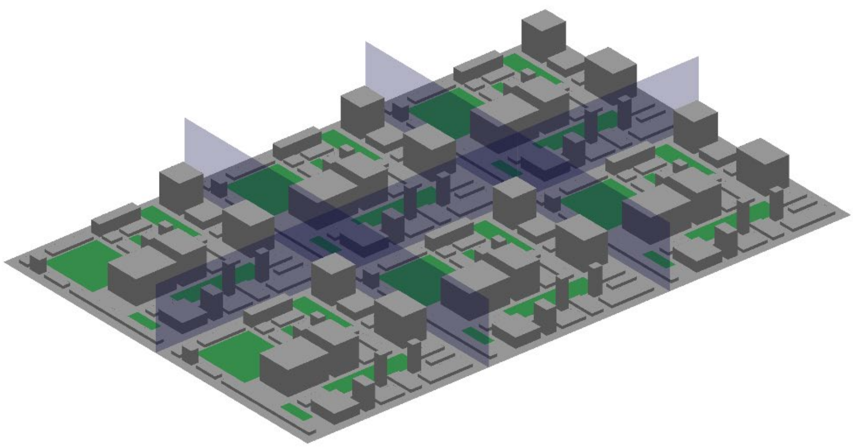

Figure 2, the urban geometry used, the blue planes highlight periodicity.

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2.3 uDALES

The simulations are run using the urban Dutch Large Eddy Simulation code (uDALES), a Fortran based large eddy simulation (LES) model that includes a two-way coupled SEB scheme [8]. Building on the work presented Grylls et al. [9] the code has been extended to allow for the simulation of radiatively forced convective boundary layers in periodic domains.

3 RESULTS

Figure 3 shows the area averaged SEB fluxes for both cases normalised by their values in case 1.

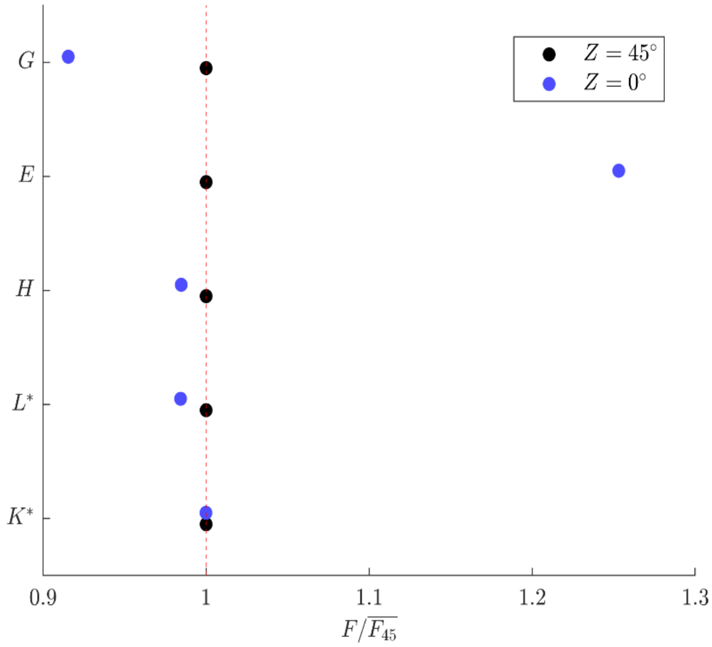

Figure 3, area averaged SEB fluxes for both cases, normalised by their case 1 values.

By definition, the Z = 45° results are 1 for each of the fluxes. There is almost no change in K* when Z = 0°, as discussed, the incoming shortwave is adjusted however this should not mean that there is no change in K*. When increasing the zenith angle more of the walls will be in direct sunlight and more of the roads and green space will be shaded. Additionally, there will be more reflections of direct shortwave between buildings as the walls are in general more illuminated than when the Sun is directly overhead. As a result, even though the total incident shortwave is the same we would still expect some change in K*. That the values are very similar suggests that the changes in shading, reflections and sunlit albedo happen to balance out. Both L* and H decrease by about 3% with the Sun directly overhead, G decreases by around 8% and E increases by approximately 25%. This suggests that E is sensitive to the distribution of shading and may explain why LSMs which simplify the geometry, and therefore do not correctly partition the radiative fluxes, tend to struggle to accurately reproduce E. That the other fluxes vary significantly less may suggest that they are not affected by the shading distribution, however, as the result has only been shown for one geometry and one pair of zenith angles it might be coincidental. It is possible that the combination of surface materials and the shape of the geometry used in this work are such that the changes in the fluxes across the surface almost exactly balance out. Furthermore, if the similarity in K* is not seen in other geometries then we would definitely expect larger variations in the other fluxes because K* is the most significant energy supply to the balance. For example, as the zenith angle increases less of the wall surface area is shaded but more of the floor is in shade. The same argument does not apply for E because green spaces only exist on the floor and so as Z increases the amount of green space that is in the shade can only increase.

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4 CONCLUSIONS

The SEB data obtained from running the two cases with different zenith angles highlights that shading plays a significant role in determining E, the average value varying by 25%. In this instance K* is essentially unchanged which is likely a coincidence of the materials and geometry used, with various effects cancelling out. Whilst such cancelling out may also contribute to reducing the changes in the other fluxes it is certain that if K* varied significantly then the other fluxes would too. To investigate this further a greater range of geometries and zenith angles should be investigated.

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