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SURFACES TEMPERATURE AND TURBULENT PROPERTIES OF HEAT TRANSFER WITHIN THE URBAN ROUGHNESS SUB-LAYER

S. Pistinner [*], E. Fattal and E. Gavze
Israel Institute for Biological Research

1 INTRODUCTION

The urban environment is both turbulent and morphologically heterogenous. Turbulent boundary layers over heterogenous canopy or terrain are expected to generate complex flow, temperature and turbulent fields. Such boundary layers can be treated statistically, provided the dimensions of the roughness elements are small. If we eliminated the heterogeneity of the canopy by forming an ideal city in which buildings are of the same shape, size and are equally and symmetrically spaced, it appears we obtain a homogeneous boundary layer over large size roughness elements. This conjecture is correct when the stability is neutral. However, when heat transfer processes are involved, field experiments and wind tunnel experiments differ even for boundary layers over flat plates and open terrain (Kader 1990), implying that once heat transfer is involved, a homogeneous boundary layer can rarely be found. Yet, this does not imply that with a proper parameterization of temperature or heat flux, an heterogeneous terrain can not be parametrized via homogeneous like boundary layer parameterization.

Large size roughness elements turbulent boundary layers are schematically divided into several sublayers. The sub layer which contains the large size roughness elements is the so called canopy layer. The roughness sub-layer contains the canopy layer, and is about three times higher than the canopy layer (cf. Roth 2000 for more details). Above the roughness sub layer one expects to find the inertial sub layer where turbulent fluxes are constant. Schematically this layer is expected to form above 2.5 to 3 roughness elements height. Indeed this has been confirmed for the momentum flux in field experiments (Feigenwinter 1999, Roth 2000).

In most cases of interest the dimensions of the roughness sub-layer are so small that the details of the flow field within them are not important for a modeler. However, when large size roughness elements are involved, even if one is interested only in the inertial layer, it is still necessary to predict the input turbulent fluxes into this layer. Naturally, the turbulent fluxes are expected to depend on the morphology of the canopy layer and the physical process which take place in the roughness sub-layer.

When momentum transfer is considered, the usual way to parameterize the velocity field above a given height is with the displacement height and the roughness length. These properties determine the velocity and momentum flux and visa versa provided that the similarity functions are given. If the roughness elements and the plane on which they are mounted are isothermal, it is expected that that a similar approach with another roughness length would provide good results. Some authors drawing the analogy between heat and mass transfer have computed these so called roughness lengths invoking reasonable physical assumptions (cf. Brutsaert 1996, Voogt 2000 and references therein). However, in some cases it was believed that spatial averaging and utilizing similarity theory on local scale might provide good quantitative results (Masson 2000).

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[*] *Corresponding author address: S. Pistinner, Dept. of Math, IIBR, POB 19 Ness-Ziona, 90410 Israel. e-mail: shlomi@math.iibr.gov.il*

The field experiment reported here aim to test the validity of this assumption quantitatively by checking the assumptions of the theory on the microscale level, namely, whether an inertial layer forms on the averaged over a single roof top. Said differently, the problem that we are interested in is: what kind of microscopic theory should be used to compute a thermal roughness length and a thermal displacement height?

2 EXPERIMENTAL SETUP

A schematic description of the experimental set up and the distribution of the measuring devices is shown in Fig. 1. The data, discussed in this paper, were collected above the roof on which poles T1, T2,T3 were mounted on. Tethered balloons provided additional information. Measurements on poles T1,T2 & T3 were taken from two heights, 2m & 6m above the roof, i.e. z/h=1.2, 1.6. The balloons height was 20 m above the roof level, i.e. at z/h=3. The measurements devices were identical ultrasonic anemometers with 17cm path length and 10Hz sampling times (USA-1 Metek Gmbh). Data from all anemometers were collected on a single computer and card to ensure synchronization. Temperatures were measured with thermocouples on poles and surfaces and by thermistors on the balloons. The measurements were taken during four days during summer 2001. Here we present hourly averages of two days: 31/7 - 1/8/2001. During the day the wind regime was controlled by the sea breeze which blew mainly from the west, i.e., perpendicular to the street between the two buildings. At night the wind changed direction and blew mainly from the south-east.

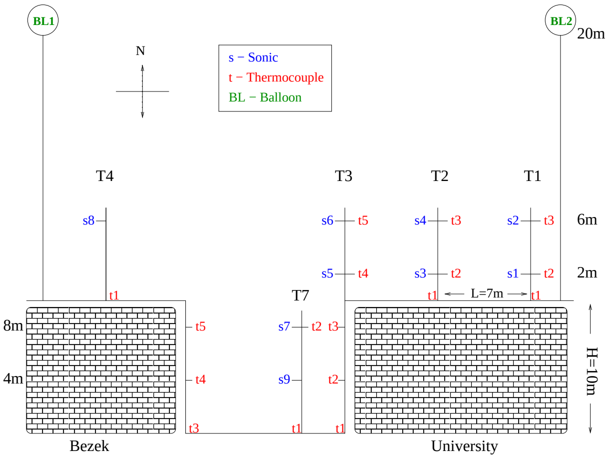

Figure 1: Experimental setup.

3 RESULTS

Air temperatures are shown in Fig 2. The differences between the air temperatures measured by the tethered balloon are within the range of the measurements device errors. Generally the temperatures at the height of 6m are intermediate between the 20m and the 2m height, thus implying unstable conditions even during night times. Fig. 3 reveals that the roof surface is heterogenous. A close look at Fig 2. and Fig 3. shows that the air temperatures generally follows the trend of the surface temperatures. As we shall see later the heat flux and the turbulence exhibit an independent behavior. We move to the assumption of local similarity invoked by Masson (2000). The bottom panel of Fig 4. clearly demonstrates that this assumption does not hold for the horizontally averaged heat fluxes. From the top panel of Fig 4. it is clear that dispersive heat fluxes

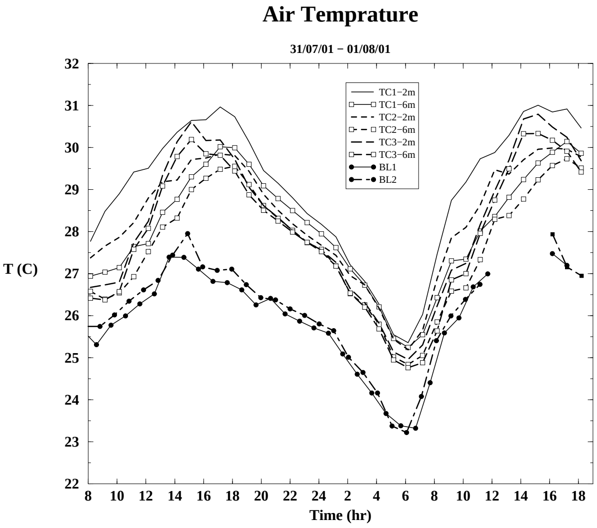

Figure 2: Air Temperatures on poles T1-T3 and the Balloons

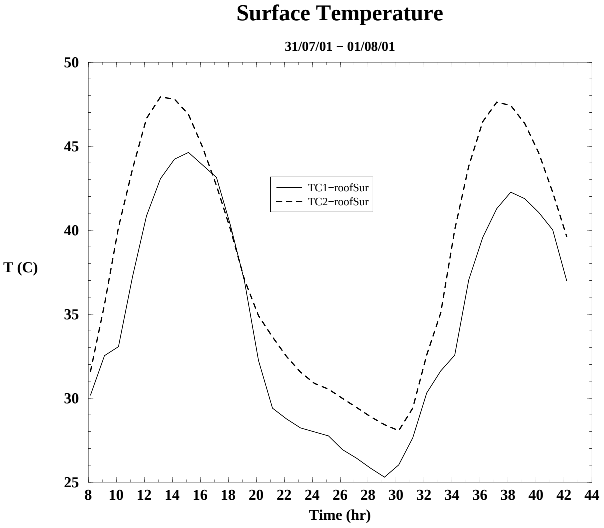

Figure 3: Surface Temperatures below poles T2 and T3

can not compensate for the lack of similarity. Thus, the assumptions of similarity on a single roof scale can not be invoked to calculate, or parameterize the heat fluxes.

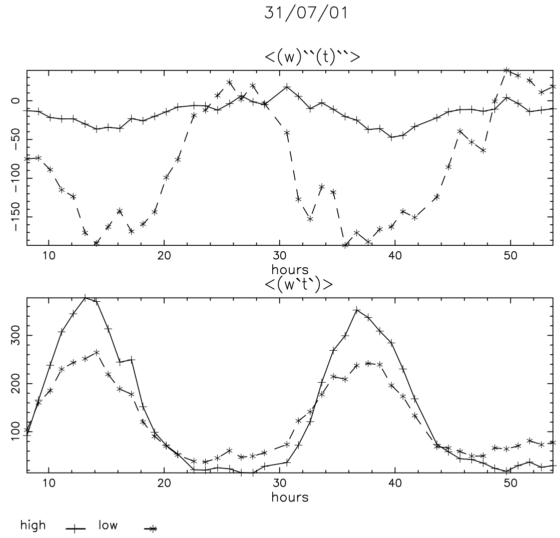

Figure 4: Horizontally averaged vertical velocity temperature co variances (bottom), and their dispersive counter parts (top).

4 ANALYSIS

We now proceed to the turbulent quantities. These seem to exhibit an evolution that is independent of the surface temperatures. Fig 5. shows the temperatures fluctuations at the top panel, and the heat fluxes at the bottom panel. It is unequivocally clear that during the time an internal boundary layer (IBL) type of behavior is found both for the heat flux and the temperature fluctuations during the day time. During night times, when light wind conditions are found, the IBL type of behavior is lost for the heat flux but is preserved for the temperatures fluctuations. Yet, we note that the differences of the temperature fluctuations are 0.1^oC, which is the resolution of the measurement devices. Thus, one could hold the position that the temperature fluctuations are spatially homogeneous. It is now instructive to take a look at the vertical velocity fluctuations that are shown in Fig 6. These again reveal the IBL type of behavior during day time, and are consistent with the similarity theory assumption during night time when light wind conditions are encountered. This type of behavior is well above the measurement device errors. Thus, it seems that the heat flux is controlled by the mechanical properties of the turbulence. Fig. 7. shows again the heat fluxes at the bottom panel and the correlation coefficient of the temperature and velocity fluctuations, which ranges

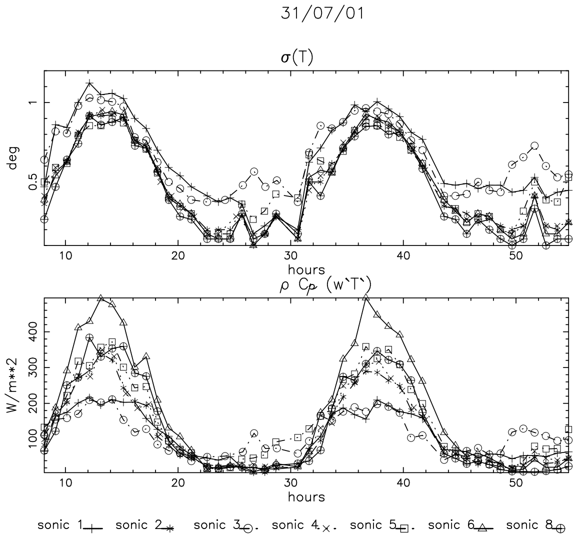

Figure 5: Correlation of vertical velocity and temperature fluctuations (bottom panel) and temperature variance (top panel).

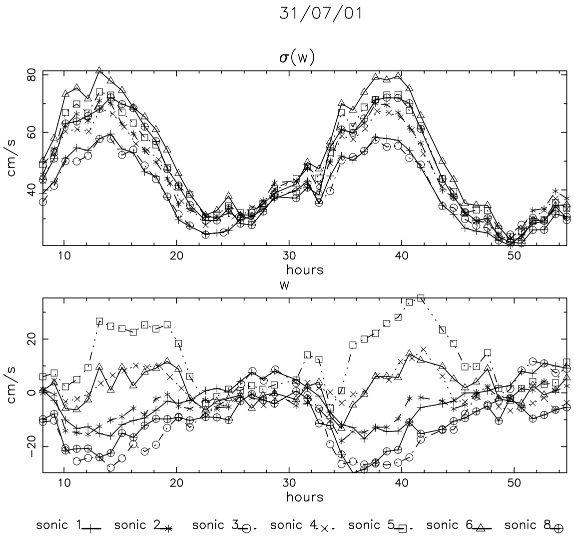

Figure 6: Vertical velocity fluctuations (top panel) and vertical velocity (bottom panel)

around 0.5, as found in wind tunnel experiments. Thus, it seems that heat transfer is controlled by the mechanical properties of the turbulence. This conclusion is strengthen from Fig 2. and Fig 5. where the heat flux seems to be temperature gradient independent, but varies due to the variability in the turbulence mechanical properties. Fig 7. shows that the correlation between these quantities is universal and weakly depends on the shape of the surfaces.

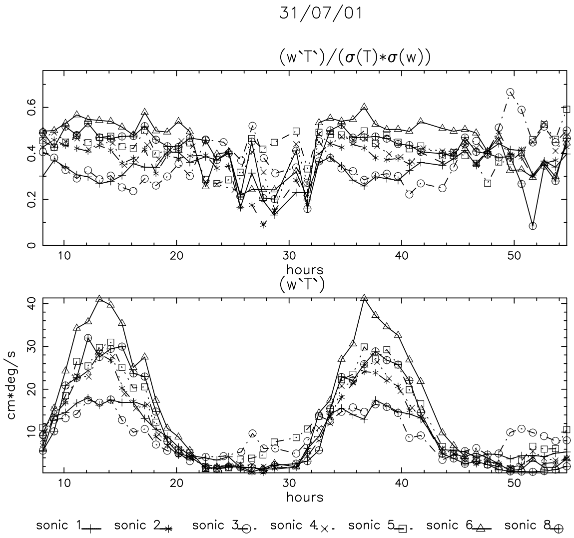

Figure 7: Correlation of vertical velocity and temperature fluctuations (bottom panel) and correlation coefficient (top panel)

The statistics of the vertical velocity and the temperature fluctuations are now considered. The results are not shown here for sake of brevity. During the day the skewness of these fluctuations nearly vanishes and the flatness value is around four, implying Gaussian statistics. During night time, the temperature fluctuations lose Gaussian statistics.

The findings of these field experiment might imply that close to surfaces the Boussinesq assumption for the heat flux does not hold. Rather, the heat flux behaves seems to be adventive rather then diffusive. The temperatures carried from hot to cold in this case from the surfaces to the air are via a convective type of behavior. This agrees well with the assumption that near the surfaces heat can be regarded as a passive scalar and that the heat flux is determined by the mechanical properties of the turbulence which is this case are likely to be strongly affected by the large size roughness elements.

5 REFERENCES

1. Brutsaert, W., and Sugita, M., 1996: Sensible heat transfer parameterization for surfaces with anisothermal dense vegetation., J. Atmos. Sci., **53**, 209-216.

2. Feigenwinter C., Vogt, R., and Parlow, E. 1999: Vertical structure of selected turbulence characteristics above an urban canopy. Theor Appl. Climatol. **62**, 51-63.

3. Kader, B.A., and Yaglom, A.M. 1990: Mean fields and fluctuation moments in unstably stratified turbulent boundary layers., J. Fluid Mech., **212**, 637-662.

4. Masson, V., 2000: A physically based scheme for the urban energy budget in atmospheric models. Bound. Layer Meteor. **94**, 357-397.a

5. Roth, M., 2000: Review of atmospheric turbulence over cities. Qurt. J. Roy. Meteorol. Soc. **126**, 941-960.

6. Voogt, J. A., and C. S. B. Grimmond, 2000: Modeling surface sensible heat flux using surface radiative temperatures in a simple urban area., J. Appl. Meteor. **39**, 1679-1699.