Reviewer 1 – Heat flux profiles (Line 333)

1) A more systematic explanation of the heat-flux profiles is needed in relation to Eq. (16) and the framework of Martilli et al. (2002). The newly added sentence appears to restate the preceding point (reduced heat flux near the roof level) without clarifying the underlying mechanism. Please make the causal chain explicit—i.e., how the terms in Eq. (16) lead to the observed profile features around the roof layer. If possible, please use the full and exact equations used in heat flux calculations of each parameterizations.

We sincerely appreciate your expertise in highlighting the questions regarding our manuscript. In the revised version, we have referenced and cited the relevant equations for calculating the heat flux between the horizontal and vertical surfaces and the atmosphere.

The revised texts can be found in below, as well as in lines 269 to 280 in the revised manuscript.

It is important to emphasize that the heat flux forcing caused by urban effects, represented by term (F) in Eqn.3, consists of the heat flux between the vertical surfaces of the building and the air $(\overline{w'\theta'}_{\text{vert}})$ as well as the heat flux between the horizontal surfaces and the air $(\overline{w'\theta'}_{\text{hor}})$, as noted by [Martilli et al., 2002]. A scale analysis based on [Martilli et al., 2002] (see Eqn.10) reveals that $\overline{w'\theta'}_{\text{vert}}$ is proportional to $-(\theta - \theta^{\text{wall}})\eta/c_p \approx -\mathcal{O}(10^{-5})\Delta\theta$, where η is $\mathcal{O}(10)$ and $c_p = 10^{-6}$ J/m^3/K.

$$\overline{w'\theta'}_{i,\text{vert}} = -\frac{\eta}{c_p}\left[\left(\theta_i - \theta_i^{\text{West wall}}\right) + \left(\theta_i - \theta_i^{\text{East wall}}\right)\right] S_i \tag{10}$$

where the superscript of θ^{wall} indicates the orientation of walls for an exemplary North-South street direction. In contrast, the heat flux at the roof $(\overline{w'\theta'}_{\text{hor}})$ scales with $-\frac{k^2}{(\log(0.5\Delta z_i/z_{0I}))^2}U\Delta\theta$ according to Eqn.13, which is approximately $-\mathcal{O}(10^{-3})\Delta\theta$.

$$\overline{w'\theta'}_{I,\text{hor}} = -\frac{k^2}{(\log(0.5\Delta z_i/z_{0I}))^2}U_i\Delta\theta f_h S_I \tag{11}$$

where f_h is a stability correction factor used in [Louis, 1979]. Therefore, -$\overline{w'\theta'}_{\text{hor}}$ is by orders of magnitudes greater than -$\overline{w'\theta'}_{\text{vert}}$ at the roof level, the resultant heat flux observed a significant decrease of at $z/H = 1$.

2) The manuscript suggests that heat conduction is the primary source of the warm bias in bulk models. However, it is not clear whether conduction is actually parameterized in the present configuration. Please clarify which processes are represented (e.g., slab heat storage, conductive transfer through roof/wall/ground layers) and how they enter Eq. (16). If conduction is not parameterized, the explanation should be revised accordingly.

In the revised manuscript, we clarified that different mechanisms dominate heat exchange between different surfaces and air.

Between vertical surfaces (wall) and the air, the heat exchange is modeled as fully conductive, which is shown in Eqn.10 in the revised manuscript using the temperature difference $\Delta\theta$ and thermal diffusivity.

In contrast, the heat exchange between the horizontal surface and the air is dominated by forced convection as modeled using the bulk aerodynamic method suggested by [Louis, 1979] (see Eqn.11 in the revised manuscript).

However, it should be distinguished that the above-mentioned conduction is different from that which happens at the interior of the materials of buildings. This conductive transfer within the layers of materials is solved using the diffusion equation of heat,

$$\frac{\partial T_i}{\partial t} = \frac{\partial}{\partial z}\left(K_s \frac{\partial T_i}{\partial z}\right) \tag{12}$$

where K_s is the substrate thermal conductivity of the material. At the boundary, an energy budget equation is supplemented,

$$\frac{\partial T_n}{\partial t} = \frac{\left(HF - K_s \frac{\partial T}{\partial z}\big|_{n-1}\right)}{\Delta z g_n} \tag{13}$$

where $\Delta z g_n$ is the thickness of the material layer, and HF is:

$$HF = \frac{(1-\alpha)R_s + \varepsilon R_l - \varepsilon\sigma T_n^4 + H}{C_s} \tag{14}$$

where α is the albedo of the surface, R_s is the direct and reflected solar radiation received by the surface, ε is the emissivity of the surface, R_l is the long wave radiation received by the surface, H is the sensible heat flux, and C_s is the specific heat of the material. The representation of Eqns.12, 13, and 14 are identical in WRF simulations (Bulk and BEP), as well as in PALM LES.

The 'conductive heat transfer' used throughout the manuscript refers to the direct contact of the wall and atmosphere represented by Eqn.10 and is not related to Eqns.12, 13, or 14..

3) This subsection is currently difficult to follow; a concise rewrite that connects equations, physical interpretation, and figures would greatly improve clarity.

We have revised the structure of the manuscript by incorporating additional subsections to clearly distinguish the different parts of the results being discussed. For instance, we added subsections:

- *3.1 Turbulence characteristics and runtime parameters*

- *3.2 Case 10WC results: vertical profiles of* $\theta, u, \overline{w'\theta'}$, *and* $\overline{w'u'}$
- *3.3 Case 24SC results: vertical profiles of* $\theta, u, \overline{w'\theta'}$, *and* $\overline{w'u'}$

to guide readers.

We have also enhanced coherence by referencing equations and figures when needed, e.g., lines 267 to 283. Finally, we improved the clarity of the discussion by providing physical interpretations immediately following the sentences that present the results.

4) Please also demonstrate—quantitatively—that the two bulk models produce different magnitudes of sensible heat flux (e.g., by referencing specific panels/figures and providing summary statistics).

Thanks for the suggestion. We have added the following texts to enrich the understanding of the different magnitudes of sensible heat flux produced by the two Bulk models.

The TKE-ACM2+Bulk simulation produced a heat flux of $0.124\,\mathrm{K\,m\,s^{-1}}$ ($0.207\,\mathrm{K\,m\,s^{-1}}$) at the ground in Case 10WC (Case 24SC) according to Fig.5a (Fig.5c), which is approximately 1.17 (0.817) times the magnitudes simulated by Boulac+Bulk.
Reviewer 2 – Momentum flux profiles (Line 333)
1) The authors' response to the previous comment remains unclear and partially redundant. Please provide a streamlined, explicit explanation of the momentum-flux behavior and incorporate the key points into the main text at Line 333 (rather than only in the response letter).

We have revised the explanation for the momentum flux behavior with the addition of the following texts in lines 314 to 324:

The two Bulk methods produced monotonically increasing momentum flux from the ground to the top of the boundary layer. The $\overline{w'u'}$ in TKE-ACM2+Bulk was less negative than that in Boulac+Bulk (Fig.5b and Fig.5d), corroborating a relatively larger u/u_g (Fig.4b and Fig.4d) in both cases. In contrast, the momentum flux profiles simulated by BEP models had a local minimum value at or above the roof level. Below the roof level, TKE-ACM2+BEP yielded slightly more negative $\overline{w'u'}$ than Boulac+BEP (Fig.5b and Fig.5d) consistently in the two cases, resulting in a lower wind speed (Fig.4b and Fig.4d). From the roof level to the top of the boundary layer, TKE-ACM2+BEP produced massively larger magnitudes of $\overline{w'u'}$ due to the addition of the non-local flux, yet the u/u_g were lower in $[18H, 27H]$ ($[16H, 21H]$) in Case 10WC (Case 24SC) only compared to Boulac+BEP, indicating an inconsistent correlation between u/u_g and $\overline{w'u'}$ within $Z = 1H$ to $Z = 18H$ ($Z = 16H$). This inconsistency is likely due to the fact that TKE-ACM2+BEP produced a more well-mixed boundary layer, resulting in u/u_g profiles within the mixed layer that exhibited less variability compared to those in Boulac+BEP, which appeared to have a stronger shear.

Reviewer 2 – Momentum flux profiles (Lines 414–415)
1) Please add more detailed information about the observation stations (e.g., coordinates, elevation, LCZ/surface type, instrument height, averaging period) and include explicit cross-references to the relevant figures in the Supplementary Materials.

The elevation at which the LiDAR units measure the wind speeds is described in line 185. Additionally, we have added descriptive texts to elucidate in detail about the information about the observation stations, including the coordinates, elevation, and LCZ type in lines 189 to 204, which can also be found below.

Lines 189 to 194:

The LiDAR unit at the Hong Kong University of Science and Technology Supersite (USTSS_LCZ5) is located on the east coast of Kowloon Island (22.333 °N, 114.267 °E), where the nearest model grid center falls within LCZ 5 (open mid-rise). The second LiDAR, installed on the southeastern peninsula of Hong Kong Island (Hok Tsui, 22.209 °N, 114.253 °E), is surrounded by natural vegetation and referred to as HT_rural. Lastly, the LiDAR at King's Park (22.312 °N, 114.170 °E) in downtown Kowloon, where the average building height is 60 m [Kwok et al., 2020], is located within an LCZ 1 model grid (compact high-rise), and designated as KP_LCZ1.

Lines 195 to 204:

The coordinates corresponding to each automated weather station (AWS) are retrieved from the little-r formatted files and outlined in the figures in the supplementary material, e.g., Fig.S6 to Fig.S98. The elevation of each AWS is 10 m above the ground. The landuse type of each AWS and LiDAR unit is identified using the nearest model grid point, which is also outlined in the figures in the supplementary material. All observational data presented in this work is 1-hour averaged.

References

[Kwok et al., 2020] Kwok, Y. T., De Munck, C., Schoetter, R., Ren, C., and Lau, K. (2020). Refined dataset to describe the complex urban environment of Hong Kong for urban climate modelling studies at the mesoscale. *Theoretical and Applied Climatology*, 142.

[Louis, 1979] Louis, J.-F. (1979). A parametric model of vertical eddy fluxes in the atmosphere. *Boundary-Layer Meteorology*, 17(2):187–202.

[Martilli et al., 2002] Martilli, A., Clappier, A., and Rotach, M. W. (2002). An Urban Surface Exchange Parameterisation for Mesoscale Models. *Boundary-Layer Meteorology*, 104(2):261–304.