Response to reviewers comments for 'Coupling the urban canopy model TEB (SURFEXv9.0) with the radiation model SPARTACUS-Urbanv0.6.1 for more realistic urban radiative exchange calculation', EGUSphere, https://doi.org/10.5194/egusphere-2024-1118

Reviewer #1

General Comments

The paper outlines a new development to the building/urban representation within the Town Energy Balance model. This new approach replaces the currently used street-canyon assumption with the urban geometry assumptions behind the SPARTACUS-Surface model that suggest that the separation between buildings can be described using an exponential distribution. The new model iteration does not utilize many other capabilities of SPARTACUS, and instead retains the assumption from the street-canyon that buildings and trees are all of one height (although does implement the multiple layers of SPARTACUS). This omission impacts some of the results shown within this paper, such as a lack of roof shadowing, which would be addressed if the full form of SPARTACUS-Surface was utilized. Despite this, the work here is a useful development, and shows movement towards more realistic urban representation than the current street canyon approach.

Thank you for taking the time to provide such a careful revision of our manuscript. The responses to the specific comments are given below.

Specific Comments

1. The three model setups (TEB, TEB-SPARTACUS, and HTRDR-Urban) use different urban form/tree inputs which if changed would alter the motivation and results within the paper. It is clear that the two TEB simulations differ only through their building separation (street canyon vs. exponential separation) assumptions and tree representation (a turbid block vs. a SPARTACUS tree), however within the HTRDR-Urban simulations the building height and tree representation are different from either TEB model. A further point is that the HTRDR-Urban simulations sometimes include pitched roofs – a feature that SPARTACUS-Urban could represent. It may be fairer to conduct simulations that are more similar, as when you compare two scenes that are different, both models will give different answers. The statement at L370 – 'SPARTACUS-Urban is perfectly suited for dealing with such a variety of building height; the TEB geometrical input parameters would have to be modified' does reflect this, but the authors should consider mentioning this earlier in the paper, perhaps with a test to show what differences would have arisen if the full SPARTACUS version was used. Thank you for pointing this out. We now also display the results obtained when using the original SPARTACUS-Urban outside of TEB with a 1 m resolution vertical grid (Section 3.4) to represent the variety of building heights in the Figures showing the dependency of results on the solar elevation angle (Figures 2, 5, B1, B2, B3, C1). Furthermore, we agree that the pitched roofs lead to a lot of confusion. Therefore, only the results for morphologies with flat roofs are now shown in the detailed Figures 2, 5, B1, B2, B3, C1. However, in the figures summarising the results for all morphologies (Figures 3, 4, 6, 7, 8, 9), also the results for the morphologies with pitched roofs are shown. This has been made for purpose, since real world districts usually have pitched roofs, thus the performance of the urban radiation models shall be measured under these conditions. The flat roof equivalent has been added to allow for a fair intercomparison of the radiation models. These aspects are now better explained in Section 3.2. Furthermore, we would like to point out that it is clear that the

HTRDR-Urban morphology is different from the TEB-SPARTACUS and TEB-Classical ones since it represents the true 3D buildings and trees whereas the urban canopy models need to simplify the geometry for the sake of computational cost limitation. The comparison of the results for TEB-SPARTACUS and TEB-Classical with the *Truth* HTRDR-Urban is made to quantify the uncertainty of the morphology simplifications. This is also now better explained at the beginning of Section 3.

2. The calculation of mean radiant temperature (MRT) for the new model configuration is discussed, however no results are given within this paper. It would be interesting to see the MRT values that are obtained from the new model, as well as a comparison – either to observations or to other modelled MRT, if this is dedicated a whole section within the paper. The calculations of MRT in TEB-SPARTACUS (L155-160) themselves need more explanation, and some decisions made are not well justified. For example, the authors state (L175) that the radiative fluxes for the MRT calculation are determined at ground level, rather than at 1 m. What are the differences between the MRT if this is not neglected? As the TEB-SPARTACUS fluxes are computed at regular intervals (default 1 m) then would be an easy change to make? Finally, in L162 it is unclear why the values of the body albedo and emissivity are chosen.

   Thank you for this very constructive suggestion. We are able to use the HTRDR-Urban model to create a reference map of MRT, therefore it is possible to compare the spatial distribution of MRT simulated in a district by HTRDR-Urban with the values for MRT in the sun and shade given by TEB-Classical and TEB-SPARTACUS. The methodology for this MRT validation is now explained in the new Section 3.5. We choose the open high-rise LCZ4 district and a solar elevation angle of 30° to validate the TEB-Classical and TEB-SPARTACUS MRT, the results are given in the new Section 4.4. The values for albedo and emissivity of the human body are the standard values for MRT calculation given for example by Thorrson et al. (2007). This article is now cited at the appropriate place.

   We also investigate the sensitivity of extracting the radiative fluxes at 1 m above ground level instead of at ground level in SPARTACUS-urban for the LCZ4 district and find a MRT difference of 0.6 K when using the fluxes at 1 m above ground instead of at ground level. It would however not be such an easy change to take the 1 m fluxes into account since the vertical profile of the diffuse fluxes into the horizontal direction are not outputs of SPARTACUS-Urban. They could become outputs in potential future versions. We now briefly mention these aspects in the Sections 2.2 and 4.4.

3. What is the reasoning behind choosing the morphologies tested and LCZ parameters? Some LCZs have large variations in urban form across them, so what is the rationale in choosing the combinations that are tested here? Further, could you have used real-world geometries rather than the scenes that have been created? Some LCZ types that have been created for the previous work but are no standard LCZ classifications, e.g., a-b or af, could be explained in the text. Please introduce some more discussion on the scenes themselves – the tree properties are given in the text but not any urban form properties – and then use these to aid discussion within the results sections (e.g., for Figure 3).

   Table 1 showing the district-average morphological parameters and a rendering of the morphologies using HTRDR-Urban has been added to help the reader understand the simulated morphologies. We disagree that the investigated morphologies have large variations whithin them. Each one has been generated by sampling from the same distribution of building footprint area, building height for the entire 800 m x 800 m district.

This is now stated in Section 3.2. The motivation for the additional (non-standard) LCZ has been explained by Nagel et al. (2023), which we indeed failed to cite. In fact, Tornay et al. (2017)'s inventory of frequent urban morphologies in France has revealed that the standard LCZ2 (compact mid-rise) and LCZ6 (open low-rise) should be subdivided into block-type morphologies with an internal courtyard (LCZ2a, LCZ6a) and row-type morphologies (LCZ2b, LCZ6b). Wind circulation and radiative transfer might differ between the block-types and row-types, which is the rationale to investigate them separately. LCZ7 is not investigated, since it differs from LC3 only via the construction materials. This is now briefly explained in Section 3.2. It would be highly beneficial to investigate real urban districts, however the processing of the building data would be complicated, it would not always be clear which urban facet belongs to a roof, a wall, or the ground, and the representativity of the selected real districts would have to be investigated. These aspects are now also discussed in Section 3.2. In the results section, more reference to the morphology parameters and the pitched/flat roofs is now made.

4. The authors state that the TEB levels are different to the SPARTACUS levels. Could this be modified to keep consistency rather than interpolating between the two and introducing error?
   The TEB canopy levels are set in a way to have a smaller grid width close to the surface, because the meteorological parameters like air temperature and wind speed have the strongest gradients close to the surface. For SPARTACUS, this does not make sense because the radiation fields are relatively homogeneous close to the surface, especially since most buildings are higher than 3 m, there is thus only little variation of building density with height in the lowest meters. This is now better explained in the manuscript (Section 2.2).
5. In the terrestrial radiation section there is little explanation of the surface temperature representation in each model, and whether they incorporate both sunlit and shaded surface temperature. How are these prescribed? Additionally, there is no explanation of why the chosen temperature is used. Please expand on the assumptions made in these calculations.
   Thanks for pointing this out. There is no distinction between sunlit and shaded surfaces in this study, which means that all urban surfaces have the same temperature. The objective is to investigate only the change in the urban geometry. In the simulations, the difference between the surface temperature and near-surface air temperature is prescribed and the values of -10 K, 0 K, 10 K, 20 K, and 30 K are investigated. These values should span the range of plausible differences with -10 K corresponding to a nocturnal situation with clear sky and negative surface energy balance leading to a surface temperature lower than air temperature, and +30 K a situation with strong solar irradiation leading to much higher surface temperature than air temperature. This is now explained in Section 3.4.

Technical Comments

1. There are some grammatical issues throughout the paper, such as misspellings of ‘leave’ and ‘plane area fraction’. Please go through the paper and check for grammatical errors.
   Thanks for catching these errors. The entire paper has been checked.
2. I am unsure how useful Tables 1 and 2 are, given that they mostly contain information that can be found in the SPARTACUS-Surface user manual. Also, most columns are stated ‘Set to 0’ which is user-specified. Please consider altering these to make them more useful to the reader.

These large tables have been moved to the Appendix (A1 and A2). However, the column stating to which values the parameters are set is kept to help a potential developer or model user know which model parameters are currently still hardcoded instead of being initialised via databases (like the tree diameter or the fraction of specular reflections from the walls) or via the coupling to a radiation model (like the single scattering albedo and extinction coefficient of air).

3. Why were optical properties of buildings (0.3, L237) and trees chosen? It is also unclear why the albedo of buildings changed in the simulations with trees (L240).
   The same albedo value is chosen for all surfaces in the scene, because the objective is to investigate only the effect of the changed urban geometry assumptions. For the urban geometries without trees, a value of 0.3 is chosen, because this is a value typical for most urban surfaces. For the geometries with trees, a value of 0.4 is chosen because this corresponds to the broadband single scattering albedo of a leave. This is now explained in Section 3.4.
4. The results in the sections of direct-only and diffuse-only radiation are very similar and could be combined or mentioned and added to the supplementary material. Each discussion of the results in this section is very short.
   This is true, the sections for direct-only and diffusive-only radiation have been combined to become Sections 4.1 and 4.2.
5. Much of the paper is structured into bullet points, which makes the paper more challenging to read. Particularly this is the case in the discussion section of the paper, which reads more like a conclusions section. I would advise altering this in some sections of the paper.
   The bullets points have been removed from the discussion section (Section 5).
6. Quantitative error values would be useful in the results, discussions, and conclusions sections, rather than just describing decreases and increases in error. Where numerical values are given in the conclusions, e.g., L355 – ‘a factor of 5 less uncertainty’ it is unclear, and the full results for all the morphologies are not included.
   Thanks a lot for this suggestion that makes the article much more rigorous. Quantitative error values on the uncertainty reduction due to TEB-SPARTACUS are now given in Sections 4 and 5.
7. The conclusions section outlines a restriction of ‘only urban districts with one building type and morphology have been investigated’ – this is untrue as the scenes you use are heterogenous (buildings are not identical with one prescribed height. This is also mentioned in line 410 in the conclusions. Please rephrase this.
   The scenes used in this article have been selected as homogeneous districts in the sense that they are composed of one single Local Climate Zone (LCZ). For example, the LCZ9 district consists only of detached houses. These do not all have the same height or size, but this would also not be the case in a real LCZ9 district. However, in the LCZ9 district, there is not one single mid-rise, high-rise or large low-rise building that would correspond to a considerably different urban morphology. This is now stated more clearly in the methodology Section 3.2 and also in the conclusions.
8. Some of the variable symbols used are non-standard, so in the results section it would be good to have a reminder of these for the reader.
   Thanks, we now remind the reader of the meaning of the radiative observables in the discussion section.

9. In some of the figures (e.g. Figure 2) it is hard to tell the difference between some of the lines. Please consider altering the line colours and styles so that all results are easily seen.
   Thanks for this very useful suggestion. The Figures 2, 5, B1, B2, B3, C1 have been changed to include also a symbol at the location of the value, making it more easy to distinguish them. The new figures will also be more easy to distinguish if printed in black and white.
10. In L292 you use Q_T/Q_D where in other places this would be just Q_T (e.g. L295). Please modify this and check for any other occasions in the text.
   Thanks, to avoid confusion, the radiative observables normalised by the downwelling solar radiation are now discussed consistantly in the text, since it is this quantity that is displayed in the figures (unitless and with a range from 0 to 1).
11. For the readers, it would be useful to add the plots for the solar zenith angles tested into the supplementary material for the other morphology types.
   Done, these are the new figures B1, B2, B3, and C1.

Reviewer #2

This study coupled the urban canopy model TEB with the radiation model SPARTACUS-Urban to improve both the urban geometry simplification and radiative transfer calculation. With SPARTACUS-Urban, the mean radiant temperature is calculated in a more realistic way by using the radiative fluxes in vertical and horizontal direction incident on a human body. TEB-SPARTACUS was validated by comparing the solar and terrestrial urban radiation budget observables with those simulated by the Monte-Carlo-based HTRDR-Urban reference model, which showed improved model performance for almost all radiative observables and urban morphologies for direct solar, diffuse solar, and terrestrial infrared radiation. Overall, this study represents an important model development effort to improve urban radiative processes and can potentially contribute to future urban climate studies. The manuscript overall reads fine but there are a few key places that lack clear descriptions and sufficient details. I would suggest the authors address those issues before this study can be considered for potential publications. Please see my specific comments/suggestions below.

Thank you for taking the time to provide such a careful revision of our manuscript. The responses to the specific comments are given below.

Specific comments:

1. Section 2.1: The authors did not change the geometrical complexity and input parameters of TEB in this study. Have the authors tested how sensitive the urban simulation results are to these parameters? This would be a good model uncertainty quantification exercise.
   Thanks, we have now added the results obtained when applying SPARTACUS-Urban in Offline mode with a 1~m vertical discretisation of building density and building perimeter (Section 3.4) in the Figures 2, 5, B1, B2, B3, C1. This helps to quantify how much the TEB results could be improved by considering for a variety of building height in the selected homogeneous urban morphologies. The SPARTACUS-Urban results are also mentioned in the results (Section 4) and discussion (Section 5).
2. Section 2.2 and Figure 1: Should the parameter be “delta_spts,max” (used in Figure 1) or “delta_sps,max” (used in the text). Please double check to make sure this is consistent. Also, the text description of the setup of “delta_spts,max” (or “delta_sps,max”) is not very clear to

me based on Figrue 1 demonstration. In the text, it says that “delta_sps,max” is set up to the height from the ground to tree height, which is not the case demonstrated in Figure 1a.
Thanks, “delta_SPTS,max” is now also used in the text. Furthermore, Section 2.2 has been reformulated to better explain what is done. In fact, three parameters determine the SPARTACUS-Urban vertical grid : “delta_SPTS,max”, building and tree height. The vertical grid is defined such as to not have to interpolate the building and tree cover in the vertical direction and to not have vertical levels coarser than “delta_SPTS,max”.

3. Equation (6): Should it be “Tagg^4 = ….”?
   Thanks, this mistake has been corrected. The code was correct.
4. Lines 125-130: (1) Does SPARTACUS-Urban solve surface energy balance for each type of urban surface covers (such as the Figure 1 example) and then aggregate the fluxes together, or directly use the aggregated surface properties (e.g., albedo, emissivity, etc.) to solve the energy balance for the “effective” aggregated surface as a whole? This needs to be clarified. (2) It may be very useful if there is a simple diagram to demonstrate the surface energy balance and key processes considered for different surface types (e.g., building, tree, air).
   We agree that we missed to provide a more general overview of how SPARTACUS-Urban is used within TEB. In fact, TEB-Classical and TEB-SPARTACUS only differ in terms of outdoor radiative transfer calculation. With TEB-Classical, the radiosity method is used to calculate the radiation absorbed by the roofs, walls, ground, trees, whereas for TEB-Classical it is SPARTACUS-Urban that is used. SPARTACUS-Urban uses the aggregated radiative properties of the individual surfaces (e.g. the roofs that might be covered by the structural roofing material and partly by green roofs) to calculate the outdoor radiative exchanges. The results of SPARTACUS-Urban are then used in TEB for the calculation of the roof, wall, ground, and vegetation energy balances. The new Figure 1a gives a very simple overview of how SPARTACUS-Urban is embedded in TEB as an alternative to the classical radiosity method.
5. Section 2.3: (1) There needs to be a description of data sources or references that indicate how the current TEB input parameters and the SPARTACUS-Urban parameters came from (e.g., those in Table 1). (2) Also, based on the description here, currently the model does not account for radiative interactions between trees and buildings (e.g., multi-reflection between trees and walls), right? This needs to be clarified in the text. (3) There is also a need to clarify how the SPARTACUS-Urban output parameters (Table 2) are coupled with other TEB energy calculations. This is related to my #4 question above in terms of how the surface energy balance and budget are solved in this coupled SPARTACUS-Urban-TEB system. Does SPARTACUS-Urban just return the aggregated “effective” radiative flux and parameters to TEB for the entire surface energy balance calculation or does it solve for the energy balance in each surface type/facet individually?
   (1) The TEB input parameters can be specified by the user to simulate any urban morphology, building materials or inhabitant behaviours. For TEB simulations in France, maps of the building morphology parameters can be calculated based on administrative datasets (Bocher et al., 2018), building construction materials via a database on building archetypes (Tornay et al., 2017), and parameters related to building energy consumption as described by Schoetter et al. (2017). For a simulation for any city in the world, default parameters are included in the ECOCLIMAP database, however, these will not be very precise. We consider that the explanation of these details seems not very relevant to Section 2.3 since nothing new has been done with respect to the TEB input parameters. Only the

outdoor radiative transfer routine has been changed. However, the main urban morphology paramters of the districts that are actually simulated in the present study are now given in Table 1.
(2) Radiative interactions between trees and buildings are taken into account by all models used in the present study. This is now stated at the beginning of Section 3.
(3) Figure 1a has been added to show how the module for the calculation of outdoor radiative exchanges (radiosity method for TEB-Classical or SPARTACUS-Urban for TEB-SPARTACUS) is embedded in TEB.

6. Equations 12 and 14: Where do those coefficients (e.g., 0.88, 0.06, 0.06, 0.308, 14.774) come from? Please also provide the references for these equations.
The coefficients 0.88, 0.06, and 0.06 are from Thorsson et al. (2007), which we already cited in the original manuscript. The coefficients 0.308 and 14.774 characterise the projection of direct solar radiation on an upright standing human body. They can be found for example in Di Napoli et al. (2020), which we now also cite at the appropriate place.
7. Equation 17: I would suggest providing the value of Nr used for different solar elevation angles in this study.
Thanks, this information has been added to Section 3.3. By checking the number of iterations in the HTRDR-Urban output files, it has also been noticed that, to avoid excessive computational cost, the number of realisations N in Equation 17 is limited to 10E+7 (10 times N_{zen}, the value for the solar zenith), which leads to deviations from the original Equation 17 for the very low solar elevation angles 1° and 5°. This missing information has been added to Equation 17.
8. Section 3.4: I would suggest explicitly stating that for each test, the HTRDR-Urban, TEB-Classical, and TEB-SPARTACUS used exactly the same urban geometries configuration (is my understanding correctly?). If the configurations are different in three models, then this would not be an apple-to-apple evaluation/comparison. Please clarify.
HTRDR-Urban, SPARTACUS-Urban, TEB-Classical, and TEB-SPARTACUS use the same geometries for the flat roof geometries, the pitched roofs are indeed not represented in SPARTACUS-Urban, TEB-Classical, and TEB-SPARTACUS. Furthermore, we have to point out that HTRDR-Urban deals with the real 3D geometry, whereas TEB-Classical and TEB-SPARTACUS deal with the representative geometry at district scale. The urban canopy models cannot directly simulate the real 3D geometry, but they use the morphology which is representative of the real 3D morphology. We now explain this better at the beginning of Section 3, and in Section 3.2.
9. Figure 2 caption: Please also include a description of Q_D.
Thanks, this has been added to the captions of Figures 2, 5, B1, B2, B3, and C1.
10. Section 4.1.2: Are the mutual SW impacts of tree shading on building and building shading on tree considered in TEB-SPARTACUS (I assume they are included in HTRDR-Urban?)? If this is the case, then it may contribute to the discrepancies between TEB-SPARTACUS (or TEB-Classic) and HTRDR-Urban. This needs to be clarified. Similarly, some clarifications are needed for Section 4.3.2 in terms of the LW radiative interaction between trees and buildings.
All radiation models used in this study consider the mutual shading of buildings on trees and trees on buildings for solar radiation and the mutual interactions of terrestrial radiation between trees and buildings. The differences between the radiation models do not come from whether they take the interaction into account, but how the building and tree geometry

is simplified. In the case of HTRDR-Urban, the geometry is not simplified, so the HTRDR-Urban results serve as a reference. This is now stated more clearly at the beginning of Section 3.

11. Following my #1 comment above, it would be useful if there is an uncertainty section that quantifies the sensitivity of TEB-SPARTACUS simulations results to several key TEB-SPARTACUS input parameters (e.g., albedo, emissivity). This can be just idealized TEB-SPARTACUS simulations without the need to comparing with HTRDR-Urban, which can give users an idea of what the relative importance of those uncertain input parameters and shed lights on future model and/or input data improvement.

    We have added the results obtained when applying SPARTACUS-Urban in Offline mode with a 1~m vertical discretisation of building density and building perimeter (Section 3.4) in the Figures 2, 5, B1, B2, B3, C1. We did not add additional sensitivity studies on urban facet albedo or morphology, since this is rather straightforward and such idealised investigations have been made in the community since decades. The fact that the 3D morphology and potentially different urban facet albedo alter the urban surface energy budget compared to a rural environment has been the motivation for the introduction of the urban canopy models with for example an idealised street canyon representing the complex 3D morphology in a simplified manner.