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Geoscientific
Model Development
Discussions

Interactive comment on "Development and evaluation of a building energy model integrated in the TEB scheme" *by* B. Bueno et al.

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REVIEWER #1

Comment 1.1. The scientific significance of the paper is rated "good". There are definitely substantial contributions to urban and possibly global climate models as well as models such as EnergyPlus. EnergyPlus' sophistication could be improved through the adoption of some of the methods used in Bueno et al.'s work, especially those methods relating to "real' air conditioning systems. The "excellent" rating is withheld on the suspicion that urban waste heat from HVAC systems are a relatively minor contribution to climate systems and even to the urban heat island (UHI) effect. It is strongly recommended that this paper include a sentence (or lengthier discussion as appropriate) on the relative magnitude of the impact of waste HVAC heat to these phenomena (global

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climate, local climate, and UHI effects) to that these suspicions can be confirmed or refuted. There is also a technical issue related to the discussion of the importance of waste HVAC heat to the UHI effect, which will be discussed below.

Two new references will be included to support the argument that the waste heat emissions from air-conditioning systems can have a significant effect on the urban climate.

De Munck et al. (2012) carried out a series of simulations coupling the mesoscale model Meso-NH with TEB and using inventories of installed cooling systems in Paris. They show that the baseline UHI effect in Paris without air-conditioning systems is 4.5°C; it is 5.3°C, taking into account the current equipment level of air-conditioning systems; and it is 6.4°C, simulating a projection for 2020 in which the installed equipment is doubled.

Bueno et al. (2012) show that, for building densities lower than 0.6, the increase in outdoor air temperature is approximately proportional to the waste heat emissions per unit of urban area released into the urban canyon with a relation of 1 K per 100 for low wind speeds and 0.5 K per 100 for high wind speeds.

To specify the contribution of waste heat emissions to the UHI effect in a percentage is not possible because it is case-specific. For example, a very cold city may not have a significant amount of air-conditioning systems; weather in a very hot and populated city, waste heat fluxes might be of the same order of magnitude as other urban heat fluxes.

Comment 1.2. The scientific quality is also rated as "good". The methods used are valid (pending discussion of a potential technical issue with the "f" terms in equation 2, discussed below) and the statistics used to present results, such as MBE and RMSE are valid statistics for discussing the model's ability to make predictions. Again, with some context missing, however, it is difficult to say whether the results of the BEM-TEB model can lead to significant results. For example, a RMSE of 13.31 W/m2 seems like a great deal of error given an average value of 50.16 W/m2. Is it or is it a mundane, ac-

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ceptable error given the context? A comment in the text on the answer to this question would be appreciated. It may be a simple answer, for this and other statistics presented, but without comment it seems as though the authors are dodging the question. Without context, an “excellent” rating cannot be given. There are several assumptions made by BEM-TEB, as there are with any model, and most assumptions given in this paper are reasonable, intelligent, practical, and well-described.

Table 2 will include a reference value to which compare errors. In the case of heat fluxes, the reference value will be the average of the heat fluxes calculated by the model during the simulation period.

In the last manuscript, the error obtained in the waste heat comparison was affected by the fact that, in BEM, the heat flux associated with the air leaving the building through exfiltration was added to the waste heat flux, whether in the CS this effect is not considered (the description of the exfiltration heat flux calculation in BEM will be included in the next manuscript). By comparing just the waste heat emissions from air-conditioning systems obtained by BEM and the CS, the RMSE is 9.9 W/m2, which is of the same order of magnitude as the reported errors of building energy demand and energy consumption. This is around 20 % of the average heat flux calculated for the simulation period.

A new reference will be added (Grimmond et al. 2011) to show that the error we obtain is acceptable given the state-of-the-art of urban canopy models. The Fig. 11 of this reference shows that the surface heat flux error of urban canopy models is usually greater than 20 %.

Comment 1.3. p. 2978: Equation 2. But the terms frd and flat are defined as fractions of Qig. Presumably, there’s some fraction remaining, fr, after radiant and latent heat are accounted for. If the formula is correct as written in the manuscript, the terms should be more clearly defined in the text.

The definition of these terms will be clearer explained. Qig = Qlatent + Qsensible, then

Qlatent = f_latent*Qig, and Qsensible = (1-f_latent)*Qig. At the same time, Qsensible = Qconvective + Qradiant, then Qradiant = f_radiant*Qsensible, and Qconvective = (1-f_radiant)*Qsensible. Therefore, Qradiant = f_radiant*(1-f_latent)*Qig, and Qconvective = (1-f_radiant)*(1-f_latent)*Qig.

Comment 1.4. p. 2980: The claim regarding a value of 0.77*SHGC requires a reference or data to make it credible.

The analysis we made to obtain this relationship will be included in the Appendix.

A series of simulations were carried out with EnergyPlus for eight different orientations of a window in intervals of 45°; for three characteristic days in Toulouse, the two solstices and an equinox; and for different values of the SHGC. The solar transmittance factor is defined as the ratio between the average of the solar transmittances for different window orientations and the SHGC. The analysis shows that a constant solar transmittance factor of 0.75 ± 0.03 can be considered for an average-oriented window with a SHGC between 0.6 and 0.9.

Comment 1.5. p. 2984: The assumption that supply air humidity is equal to mixing humidity needs qualification. Is this a reasonable assumption? Is it one frequently made by others? If it is wrong, how is that likely to affect results?

This is a very common assumption in the design and analysis of HVAC systems. A heating system without humidifier just adds sensible heat to the supply air (mix between outdoor and recirculated air) without affecting its humidity content.

Comment 1.6. p. 2984: The term “Qexch,cool” is not clear.

This term will be clarified. Qexch represents the absolute value of the heat supplied by the HVAC system to the building. For example, consider a centralized HVAC system in which air passes through a refrigerant-air coil in the machine room and then is supplied to the conditioned spaces. In a cooling situation, Qexch would be the heat absorbed by the refrigerant from the air while passing through the coil. On the contrary, QHVAC

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is the energy consumption of the HVAC system; in the example above, it would be electricity consumption.

Comment 1.7. p. 2987: Again, some context of qualifying comment is required. The sentence, "Positive values of MBE indicate an over-prediction of the cooling and heating energy demand calculated by the SM with respect to the energy demand calculated by the DM." leaves the reader wondering, "so what?" Is the magnitude of the over-prediction acceptable?

As stated before, Table 2 will include a reference value to which compare errors. In the case of building energy demand, the reference value will be the average of the energy demand calculated by the model during the simulation period.

In order to analyze the tendency of the SM to over-predict the cooling energy demand, simulations of the same building with other levels of details have been carried out. It seems from these analyzes (data not shown) that one improvement that could reduce this overestimation would be to simulate the last floor in SM. A perspective will be added on this point in the discussion.

Comment 1.8. p. 2989: How does the reader know that the first building performs more regularly than building 2? Why is that the case? Some qualification there would be useful, even if it is just a reference to a table or figure.

Fig. 10 will include the outdoor air temperature measured during the same period, and the sentence will be reformulated.

By "more regularly", we meant that the building has fewer fluctuations of internal heat gains, and that the indoor air temperature is in phase with the outdoor air temperature.

Comment 1.9. p. 2993: Where do the coefficients A1, B1, etc. in Appendix A2 come from? How were they arrive at and why are they valid?

A reference to EnergyPlus will be included.

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These coefficients are the ones used by EnergyPlus when a single-speed direct-expansion cooling system is defined, which is the system currently included in BEM. The performance curves are published by HVAC manufacturers and are based on experiments on the equipment. For HVAC simulation, EnergyPlus selects typical performance curves of each type of equipment.

Comment 1.10. p. 2974: The term “real” as applied to real air conditioning systems seems inappropriate. BEM-TEB cannot model “real” air conditioners under true operating conditions, but rather makes fewer assumptions than does EnergyPlus. The air conditioner models still assume that air conditioners follow theoretical equations, which they may do fairly well in test conditions, but will not do in real applications. It is suggested that this term be re-thought and this part of the discussion merely mention that BEM-TEB allows for previously unavailable sophistication in the modeling of air conditioners.

I more careful use of the term “real” will be considered.

The “realistic definition of an HVAC” is used in contrast to the “ideal definition of an HVAC” and is explained in section 2.6.1.

Comment 1.11. p. 2975. Rather than saying “This phenomenon” the paper should effectively say, “This increased temperature, to which waste heat from HVAC systems contributes X%, is known as the UHI.” This change would clear up the ambiguity in the writing, as well as provide the context recommended above.

This sentence will be reformulated to avoid confusion. See also response to comment 1.1.

Comment 1.12. p. 2795: In “Masson et al., 2002”, TEB stands for Town Energy Balance. In this paper it is given as Town Energy Budget. This difference may be an intentional change and not an error at all, but may deserve the attention of the authors.

The name Town Energy Balance will be used. This is the term used in most of the

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publications about the model (Masson et al., 2002, Lemonsu et al. 2004 and Pigeon et al. 2008).

Comment 1.13. p. 2976: The first paragraph in section 2.1 should have an additional sentence or sentences briefly reiterating the value of BEM's objective. The objective is clear, but it would be worth quickly restating the motivation.

BEM's objective will be clearer stated.

BEM constitutes a new version of the TEB scheme, in which the energy effects of buildings in urban climate are better represented. The previous version of TEB could not calculate cooling energy consumption of buildings and the waste heat emissions associate with HVAC systems.

Comment 1.14. p. 2984: In the last sentences of section 2.6.4, the word "supply" (and conjugations) is used in two senses (a figure provided to the model and "supply" air). Perhaps "provided" would be better in uses such as "supplied by the user" to avoid confusion between the different senses of the word.

"Provided" will be changed by "supplied" in the referred uses.

Comment 1.15. p. 2988: "averaged on" looks like it should be "averaged over".

This change will be included.

Comment 1.16. p. 2992: Is Uref in the final sentence of appendix A1 meant to read Uurb?

- Yes.

Comment 1.17. p. 3005: Figure 4's caption should tell the reader what the meaning of the figure is. Why is the figure of interest to the reader? What should the reader be looking for in the figure? The same is true for Figures 2, 5, 6, 7, 8, 9 and 10.

The caption of the figures will be extended.

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REVIEWER #2

Comment 2.1. Page 2975 Line 3: The formation of the urban heat island phenomenon is not only due to the waste heat emission. I think it is better to reformulate this sentence in order to avoid any confusion for the reader.

This sentence will be reformulated.

Comment 2.2. Page 2975 Line 10: The authors should specify which version of TEB is used: either the single-layer version or the multi-layer version coupled to the surface boundary layer scheme (CANOPY). In Figure 1, the authors present also the different CANOPY levels but without any explanation in the text.

The simulations were carried out with the single-layer version of TEB.

Comment 2.3. Page 2975 Line 14: If you are using the multi-layer version of TEB, you should add also a reference for its evaluation. Hamdi R., V. Masson. Inclusion of a drag approach in the Town Energy Balance (TEB) Scheme: Offline 1-D validation in a street canyon. Journal of Applied Meteorology and Climatology, 47, 2627-2644, 2008.

A reference to the multi-layer version of Hamdi and Masson (2008) will be included in the text.

Comment 2.4. Page 2975 Line 20: The authors present the strategy to improve the simple representation of building energy processes as described in Pigeon et al. (2008) but they did not show any comparison in the evaluation section between this simple method and the new method using BEM-TEB.

A comparison between the version of Pigeon et al. (2008) and the coupled scheme (CS) between EnergyPlus and TEB was presented in Bueno et al. (2011), Fig. 5. There, we stated that the previous building energy model did not calculate cooling energy consumption and missed some important aspects of the building physics, such as internal heat gains. In this new paper, we compare BEM directly with the CS.

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Comment 2.5. Page 2975 Line 25: The authors claim that the coupled scheme (CS) did not allow for coupling with atmospheric model and therefore they develop a new version of TEB integrating a new building energy model. However, they did not show in the evaluation section the effect of this strategy on the surface turbulent flux calculated by TEB which are passed to the lowest atmospheric level for the next time step.

A comparison of surface heat fluxes will be included.

We will compare the sensible heat fluxes observed during the experiment CAPITOUL with those calculated by BEM-TEB (see attached figures). Two scenarios will be considered. In the first one, we assume no waste heat emissions associated with cooling systems. This represents a situation in which air-conditioning systems are not widely used. In the second scenario, all buildings of the urban area under study are assumed to have conditioned spaces and waste heat emissions from cooling equipment are released into the environment. The comparison shows a good agreement with an RMSE = 26.7 W m-2 between the daily-average sensible heat fluxes calculated by BEM_TEB and from observations for a whole-year simulation. The average difference in sensible heat flux with and without waste heat emissions is 27 W m-2 in summer.

The argument used to state that the CS is not appropriate for atmospheric simulations is that it requires a number of iterations between EnergyPlus and TEB to reach convergence. These iterations are not made in a timestep-basis but after simulating the models for the whole simulation period as explained in Bueno et al. (2011), section 3.3.

Comment 2.6. Page 2976 Line 5: The authors did not show in the evaluation section the effect of taking into account passive building system and therefore confirm the benefit of adding this new feature.

The benefits of adding passive systems such as shading devices are presented in Bueno et al (2011), Table 4. A reference to this paper will be added.

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Comment 2.7. Page 2976 Line 10: I think that the authors should add in the evaluation section: (1) a comparison between the old version of TEB and the new BEM-TEB, (2) evaluation of the effect of BEM on the surface fluxes calculated by TEB, (3) since BEM-TEB needs new parameters to be initialised, a sensitivity study of BEM-TEB to the specification of these parameters will be very important since many input parameters are subject to uncertainties.

(1) See response to comment 2.4. (2) See response to comment 2.5. (3) Most of the new parameters introduced in the model (glazing ratio, glazing definition, heating/cooling system) are traditional parameters of building energy models and for this reason, they are described in a large set of references and do not present too much uncertainty. The authors recognize that a complete sensitivity study of the TEB-BEM model would be interesting, but it is not the main objective of this paper which is to describe the model and present its evaluation.

Comment 2.8. Page 2977 Line 2: The authors need to provide a comparison of the computer timing and resources needed for BEM-TEB as compared to TEB only.

The computer timing has been evaluated and will be presented in the manuscript. The original version of the TEB model had a computing time of 0.95 ms per time step for 1 processor (2.4Ghz). The new version runs in 1.15 ms per time step for the same processor, which gives an increase of almost 21%. However, this increase is acceptable given that one-year simulation for one location with a 300 s time step is about 100 s for the original version of TEB.

Comment 2.9. Page 2980 Line 5: A reference is needed for this input.

See response to comment 1.4.

Comment 2.10. Page 2987 Line 6: The authors should give the reader an explanation about the tendency of the SM to over-predict the cooling.

See response to comment 1.7.

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Comment 2.11. Page 2987 Line 6: In general and from a reader point of view figures and tables should be described and interpreted in more detail.

This point will be improved.

Comment 2.12. Technical corrections: 1. Page 2975 Line 7: Replace Town Energy Budget by Town Energy Balance.

The name Town Energy Balance will be used.

Comment 2.13. Page 3002 Fig. 1: The SBL levels are not explained in the text. Are you using the single or multi-layer version of TEB ?

See response to comments 2.2 and 2.3.

References

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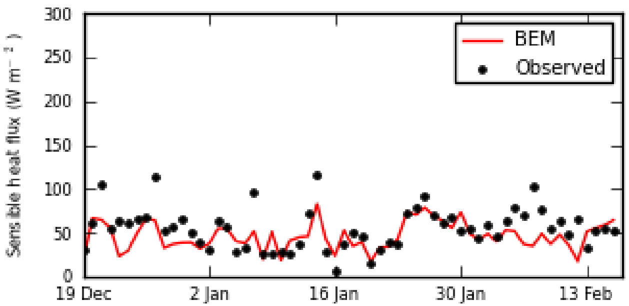

Fig. 1.

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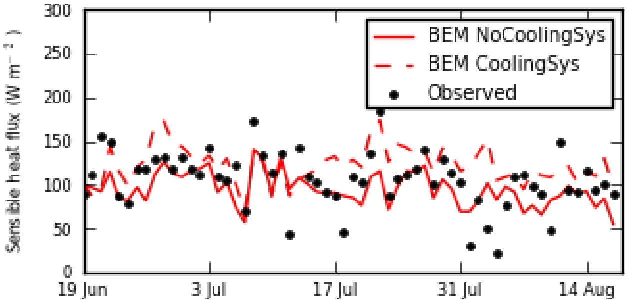

Fig. 2.

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