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Green Roof Energy Performance Modelling

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BACKGROUND

Green roofs are systems that comprise a vegetation layer, a substrate layer and a drainage layer (Figure 1). An accurate green roof energy model is needed to quantify the potential thermal benefits and facilitate design process. However, the existing models only consider the vegetation and substrate layers while the other functional layers are neglected. In this study, the drainage layer is introduced into the green roof energy balance model and its impact on temperature simulations is investigated.

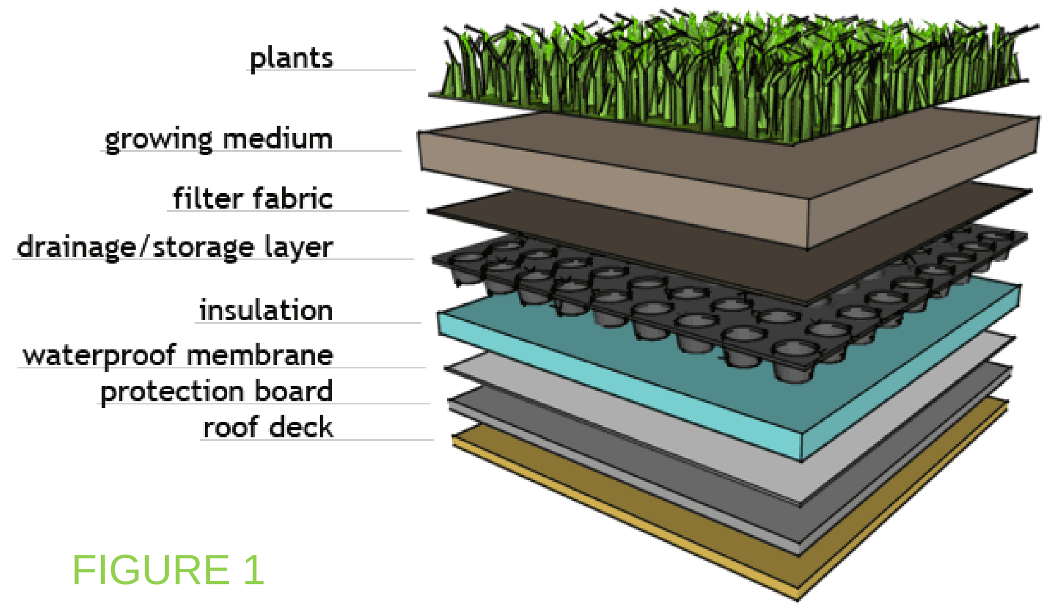

FIGURE 1

ENERGYPLUS ECOROOF IN MATLAB

A physically-based energy model of a green roof system is first developed on Matlab based on the EnergyPlus Ecoroof model. The model is divided into the foliage and ground surface layer. An energy balance equation is established for each layer and only radiative, convective, latent and conductive heat fluxes are considered. The model is validated by comparison with the observed substrate temperature data from the Eastside green roof experimental site (Figure 2) and it is the basis of the proposed green roof energy model.

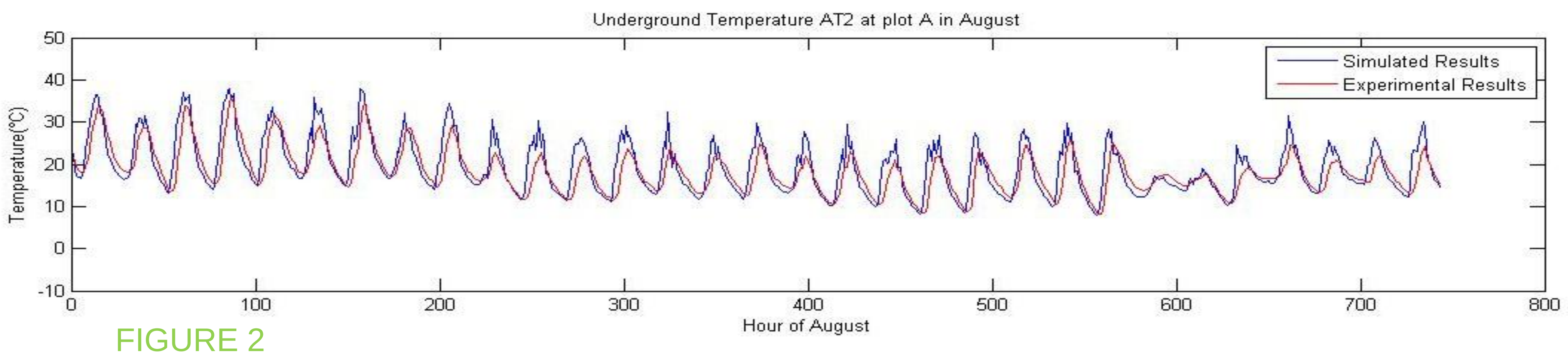

FIGURE 2

PROPOSED ENERGY MODEL WITH DRAINAGE LAYER

This model is an extension of the EnergyPlus Ecoroof model. Two additional energy balance equations are introduced: energy balance at the bottom of the substrate (T_{bs}) and the drainage layer (T_{dr}) respectively (Figure 3). The indoor temperature (T_{cr}), which is assumed to be correlated with the outdoor air temperature, was selected for the lower boundary condition. Only conductive heat flux is considered in these two equations. The two equations are reduced to a set of simultaneous equations with two unknowns - the temperatures at the bottom of the substrate and the drainage layer respectively.

$$C_{bs} = K_g \times \frac{\partial T_g}{\partial z} - K_d \times \frac{\partial T_{dr}}{\partial z} = 0 \rightarrow C_1^{bs} + C_2^{bs} T_{bs}^n + C_3^{bs} T_{dr}^n = 0$$

$$C_{dr} = K_d \times \frac{\partial T_{dr}}{\partial z} - K_c \times \frac{\partial T_{cr}}{\partial z} = 0 \rightarrow C_1^{dr} + C_2^{dr} T_{bs}^n + C_3^{dr} T_{dr}^n = 0$$

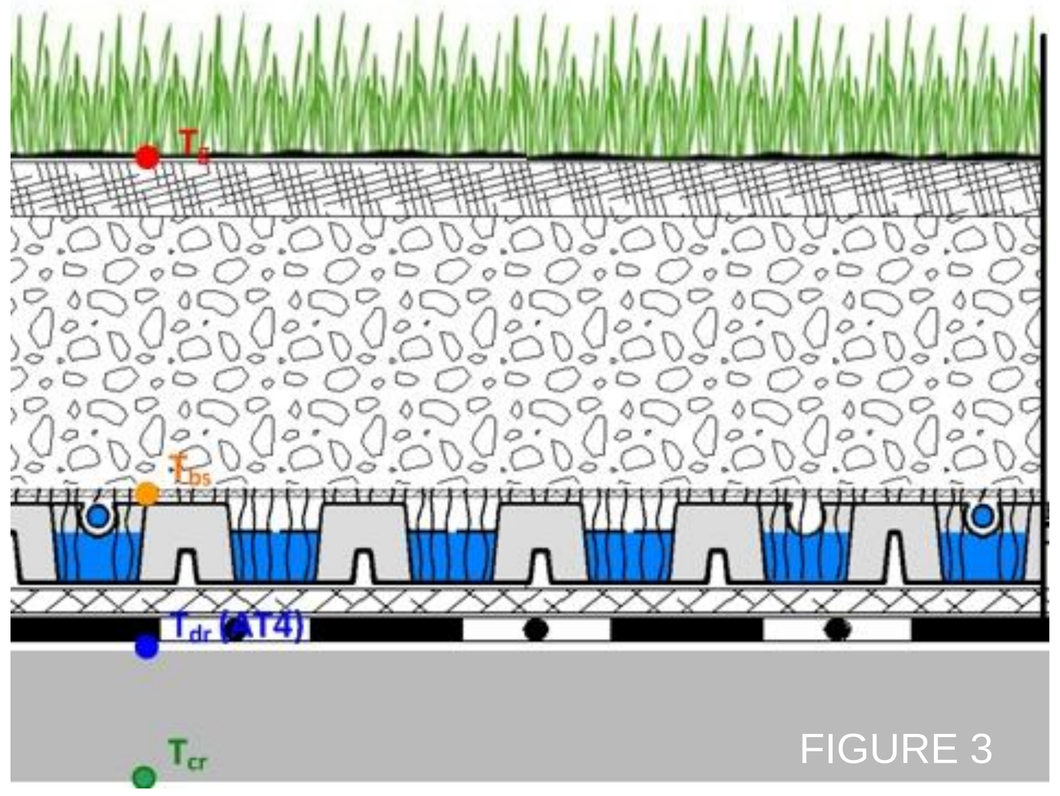

FIGURE 3

The thermal conductivity of the drainage layer (K_d) is estimated by Monte Carlo method (Figure 4). It fluctuates between 0.2 W/ m K and 0.14 W/ m K for extensive and intensive green roofs, respectively.

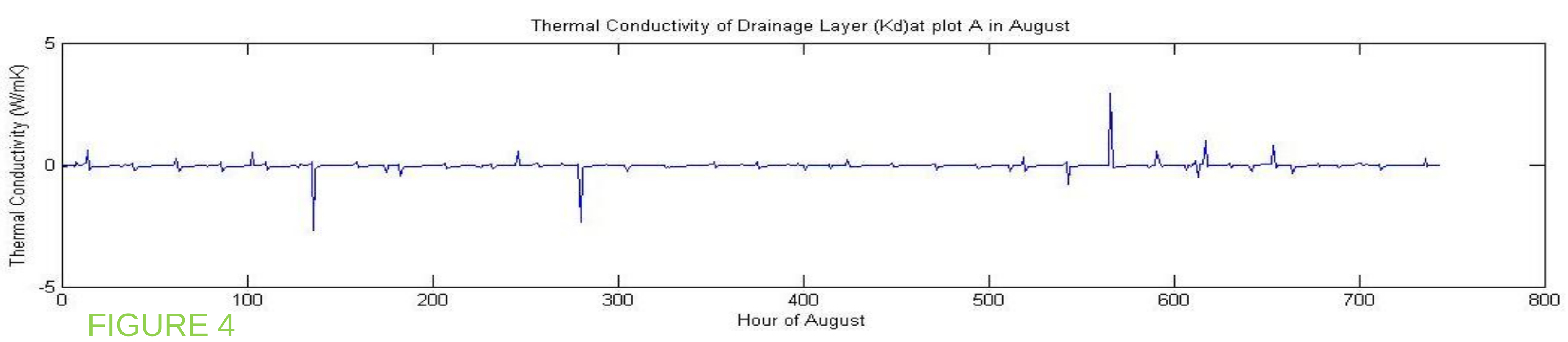

FIGURE 4

SIMULATION RESULTS

The proposed model can simulate the dynamics of the temperature variation in extensive green roofs (i.e. substrate depth: 70mm, plot A & B) with good accuracy (Figure 5 & 6). In general, it can achieve a positive correlation coefficient above 0.8 and the average bias is around 2.6°C. The model performance on intensive green roofs (i.e. substrate depth: 150mm, plot C) is relatively weak due to the more complicated drainage layer design (Figure 7).

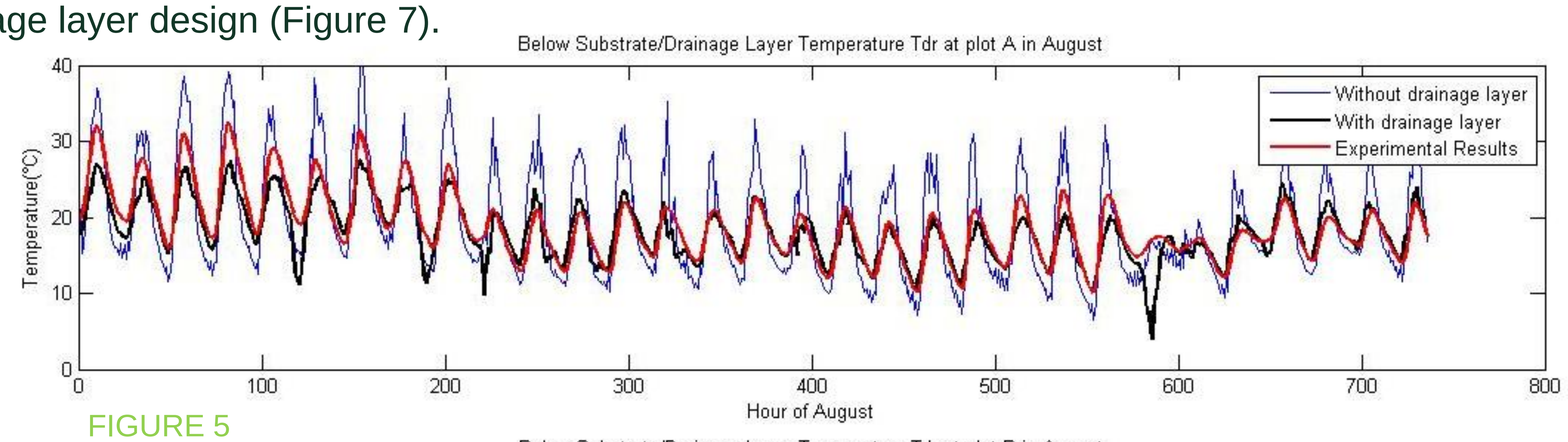

FIGURE 5

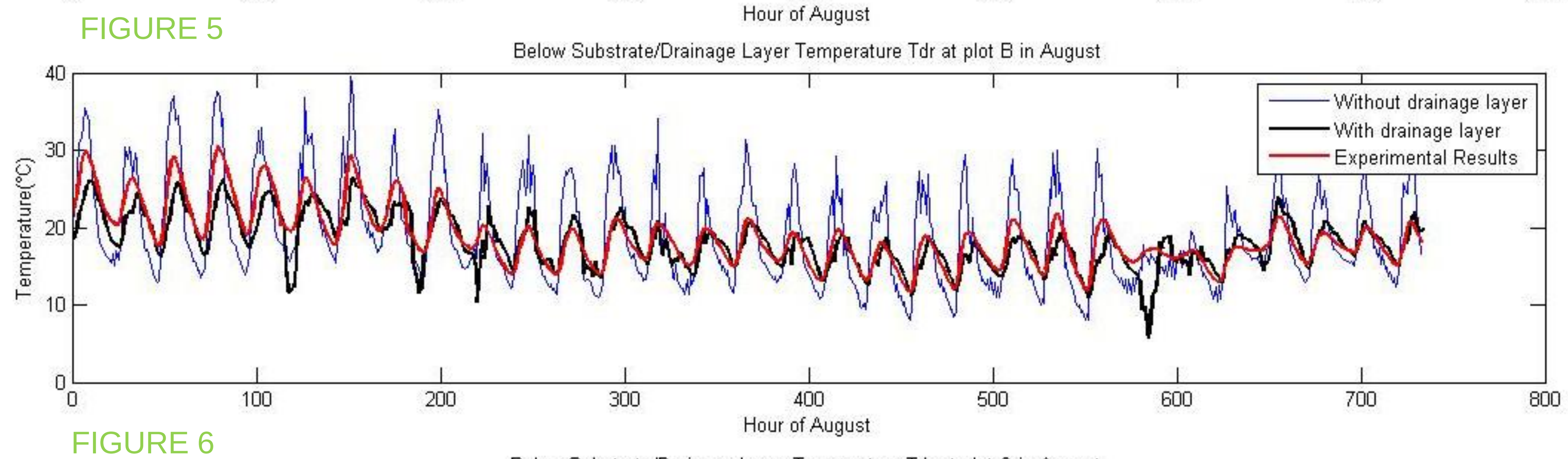

FIGURE 6

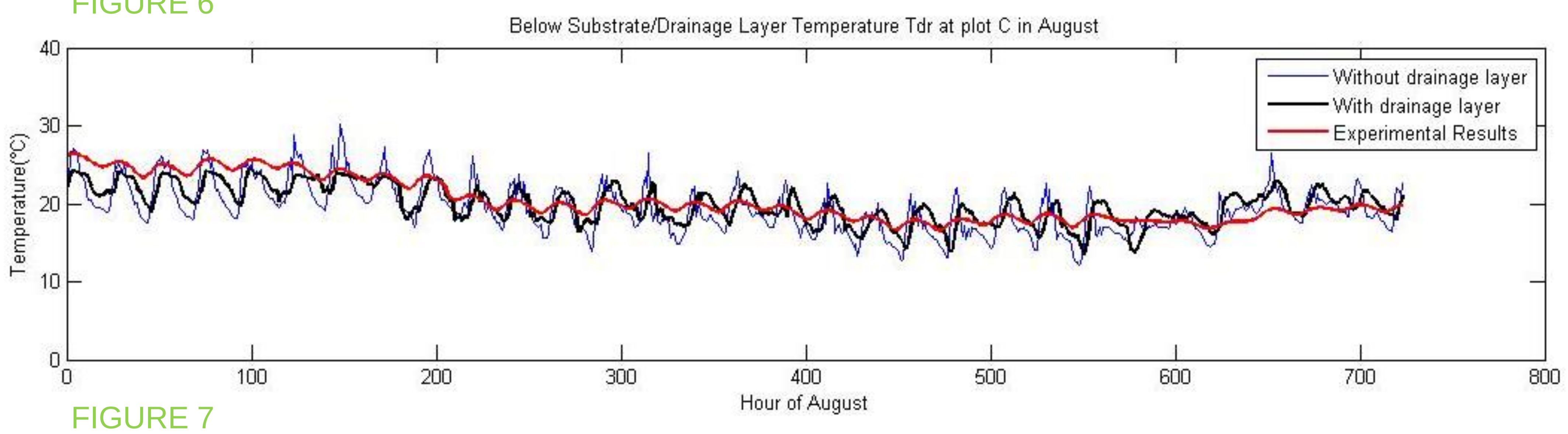

FIGURE 7

Compared to the initial model, the proposed model reduce the average bias by 25% in extensive green roofs. The improvement on intensive green roofs is much more significant as it can increase the correlation coefficient by nearly 50% and reduce the average bias by 1.31°C in average.

CONCLUSIONS

The significant improvement in the model performance reassures that the drainage layer should not be neglected in the energy balance simulations of a green roof system. The current model can be further refined by coupling with the water balance module so that the soil moisture content and the amount of water stored in the drainage layer can be calculated at each time step. The thermal properties of the substrate and drainage layer should be determined by prior lab experiments.

ACKNOWLEDGEMENTS

Special thanks to my supervisor, Dr. Ana Mijic and Xi Liu for their excellent guidance and support throughout the project.

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