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Modelling of the daytime and night-time urban thermal environment

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ABSTRACT

The world's urban population is expected to increase over the coming decades. To maintain and improve the health and well-being of urban citizens, it is important to increase our knowledge and develop methods for evaluating the urban thermal environment to support urban planning. The aim of this thesis is to develop and improve the modelling of the urban thermal environment, particularly enabling modelling to be done using readily available data and hardware. The thesis has four parts. The first and second parts describe the development of simplified models for computing day- and night-time urban site-specific air temperatures (T_a) at street level. The third part presents an analysis of nocturnal cooling in the near-surface atmosphere and discusses its implications for modelling the night-time T_a. The final part presents improvements of the SOLWEIG model that allow it to account for different ground cover types when computing the mean radiant temperature (T_{mrt}). T_{mrt} is one of important variables governing outdoor human thermal comfort.

The daytime model was developed by coupling a convective boundary layer slab model and an urban land surface model. It is used to perturb routinely observed T_a values from a reference site (e.g. rural, airport) to obtain urban site-specific T_a data. The night-time model was developed empirically based on the concept of nocturnal cooling progressing in two distinct phases. It simulates cooling rates at a height of 2 m in urban canyons depending on building density. The modelled cooling rates are then used to estimate the night-time T_a. The models were designed to run on commodity computers and to require only standard meteorological input data and land surface information, all of which are widely available. Both models perform well in terms of temporal development and accuracy.

Nocturnal cooling in the lower layer of the near-surface atmosphere (between the ground and a height of 60-70 m) was shown to be more intense and to evolve differently over time compared to cooling in the upper layer (up to 105 m). In addition, two distinct cooling phases were detected in both layers. Around sunset, the rates of cooling diverge decreasing with increasing height in both layers. However, within a few hours after sunset, the cooling rates converge in the lower layer, while the height-dependent cooling rate differences in the upper layer remain largely unchanged over night. The persistent differences in the upper layer are linked to the formation of a stabilized atmospheric layer. The pattern and intensity of cooling depend on the synoptic weather situation (defined in terms of the Lamb weather type) and the season. These results imply that the night-time model can be applied to other heights with a few modifications.

A ground cover scheme in the SOLWEIG model was developed based on field observations conducted in Gothenburg. The effects of different ground materials (grass and asphalt) on T_{mrt} were a few degrees, i.e. about one tenth of the shadowing effect of buildings. This suggests that changing the ground cover type may not be as effective as shadowing at mitigating radiant heat loads during hot days. Nevertheless, it could contribute to a reduction in T_{mrt} when shadowing is not an option. An evaluation study showed that the model also predicted T_{mrt} reasonably well over different ground surfaces in London, UK.

The models presented in this thesis will be implemented in a climate service tool, which can be used for various scientific and practical applications.

Key words: urban thermal environment, microclimate modelling, air temperature, mean radiant temperature, nocturnal cooling rates, synoptic weather types