

1. INTRODUCTION

Increased absorption of shortwave radiation, decreased wind speeds and low evaporation in urban environments often produce climate conditions that can induce thermal heat stress for human walking or standing inside the structures. Several biometeorological models have been developed to assess thermal comfort with respect to given climate conditions: e.g. the outdoor version of Fangers PMV-Model ("Klima-Michel", Jendritzky 1993), the OUT-SET* for urban environments (Pickup and de Dear, 1999) or the Perceived Temperature (PT) (Jendritzky et al., 2000). Unfortunately nearly all models assume homogeneous climate conditions which normally cannot be found in urban areas. Moreover, the models assume steady state conditions at the interface between the human body and the climate environment. In daily life, people normally walk through the urban areas and they are not exposed long enough to the same climate environment to reach steady state conditions which can take one hour or more. In order to achieve a more realistic simulation of human thermal stress in urban environments, a coupled model system has been created that overcomes the drawbacks of "classical" biometeorological models.

2. THE MODEL SYSTEM

The model system consists of two different numerical models that will be described briefly in the following sections. The first model (ENVI-met) is a microscale climate model that provides the basic climate information for each point inside the urban environment for each time of the day. The second model (dPET) is a complex dynamic biometeorological model that simulates the responses of the body of a "virtual walker" to the conditions found at the recent position inside the city.

2.1 The Atmospheric Model ENVI-met

ENVI-met is a three-dimensional non-hydrostatic numerical model which calculates exchange processes in, at and between urban elements with a high spatial (1 to 10 m) and temporal (10 s) resolution (Bruse and Fleer, 1998). ENVI-met provides detailed climate information including speed, air temperature and radiative fluxes for each point inside the model domain. ENVI-met calculates dynamically over at least one diurnal cycle to simulate different surface heating and cooling processes and their effects on microclimate.

2.2 The Biometeorological Model dPET

The dPET (dynamic Physiological Equivalent Temperature) model is based on the two-node model of the human thermal system introduced by Gagge (1971) and the *Munich Energy-Balance Model for Individuals* (MEMI) by Höpfe (1999). Several extensions have been made to the basic models in order to include non-steady state effects and motion. The dPET temperature is analogous to Höpfe's (1999) Physiological Equivalent Temperature (dPET), which is defined "as the air temperature at which in a typical indoor setting the heat budget of the human body is balanced with the same core and skin temperature as under the complex outdoor conditions to be assessed". The dPET model allows a "virtual person" to walk through the model environment on a user defined path. The walkers are defined in terms of their sex, age and body mass. The thermal resistance of the clothing (*clo*-value) can be chosen as well as the walking speed and the internal energy production (metabolic rate).

2.3 Linking the Two Models into a System

The basic climate data provided by ENVI-met are: Air temperature (T_a), Radiative Temperature (T_{mrt}), Wind speed (v , giving the convection coefficient hc) and Vapour pressure (ea) at the 1.1 m level above ground. Depending on the selected route of the virtual walk and the walking speed, the dPET model is provided with new climate information with respect to the walkers position. The main parameters on which the dPET value depends are Skin Temperature (T_{sk}) and Core Temperature (T_{core}).

3. CASE STUDY: GREEN STREET CANYON

The test case study analyses the effects of urban vegetation on human thermal comfort. The test scenario is a simple N-S orientated street canyon (width 16 m, length 46 m) with homogenous buildings (height 16 m) on both sides. The vegetation is represented by 20 m high deciduous trees with a dense crown layer. The simulation was carried out for Bochum, Germany at 53° N 7.5° E. In the first simulation ("bare"), a bare street canyon without any vegetation was used, the second run ("green") then assumed a closed tree cover along the canyon.

One walker (male, 35 years old, clothing insulation 0.5 clo) was defined in the dPET model, starting his walk at 14:00 LST. The layout of the selected route can be seen in Figure 1. The left side of the street is always shaded by the buildings, whereas the right pavement is only shaded if trees are available. After leaving the canyon, the walker changes between the shaded and the sunlit areas behind the right building to show the effects of additional shortwave radiation on thermal comfort after passing the street canyon. Fig. 1 and 2 show the

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calculated dPET temperature for the grid points along the way.

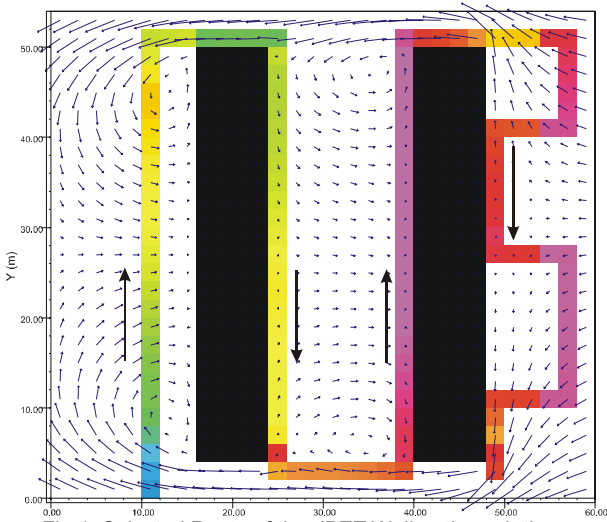


Fig 1. Selected Route of the dPET Walker through the environment. (light to dark gray= low to high dPET value)

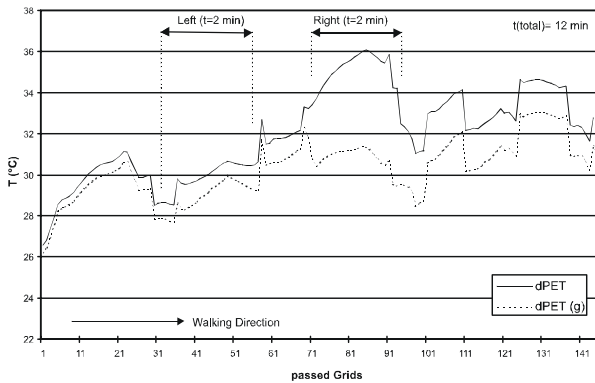


Fig 2. dPET values experienced during the walk at 14:00 LST (Solid line: bare case, dotted line: green canyon).

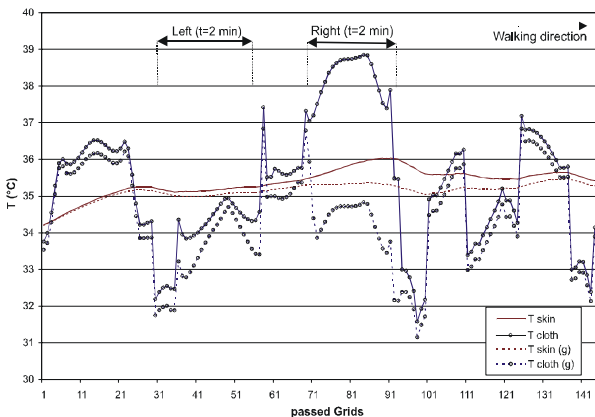


Fig 3. Temperature of skin and cloths while walking through the model environment at 14:00 LST. (Solid line: bare case, dotted line: green canyon)

Calculated values for skin and cloth temperature during the walk are shown in Fig. 3 for both cases. The arrows indicate the sections where the walker walks along the left or the right side of the road.

4. RESULTS AND CONCLUSIONS

Neglecting the first meters of the walk, the dPET temperature has a local minimum at the northern end of the street canyon due to high wind speed and missing shortwave radiation. On the right side of the street, the exposure to the sun combined with relative low winds cause an increase of dPET up to 36 °C in the bare street canyon whereas in the street canyon with tree cover the dPET value is around 31 °C at the end of the street.

Behind the right building the big advantage of transient models turns out: Although the meteorological situation upstream of the street is fairly the same for both scenarios, the dPET values differ, because the model takes in account the heating of the body experienced in the unshaded street. The additional input of sun radiation leads to a different thermal sensation for a person who have walked through a shaded street before than for a person who walked the unshaded passage.

It can be seen (Fig. 3), that the skin temperature in the treeless case remains higher even at the end of the walk. This effect cannot be reproduced with traditional steady state biometeorological models, as they would calculate the same thermal comfort for areas upstream the street canyon regardless to the situation inside the street because the meteorological situations are alike in both cases. Models running without a combined atmospheric model lack detailed climate information and will therefore also not be able to simulate the system in whole.

The case study showed, that the effects of greening a street canyon are not restricted to the street canyon itself although meteorological data might suggest that. Taking in account that people move through urban structures, occasional street with tree cover could keep the energy stored inside the body below a critical mark, so that the complete urban structure could benefit from the change.

5. REFERENCES

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ASSESSING THERMAL COMFORT IN URBAN ENVIRONMENTS USING AN INTEGRATED DYNAMIC MICROSCALE BIOMETEOROLOGICAL MODEL SYSTEM

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