

ITCM- A SIMPLE DYNAMIC 2-NODE MODEL OF THE HUMAN THERMOREGULATORY SYSTEM AND ITS APPLICATION IN A MULTI-AGENT SYSTEM

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1 INTRODUCTION

Multi-Agents (MA) systems are a relatively new approach for simulating complex dynamical systems by focussing on the activities and opinions of the single actor (=agent) rather than describing the system dynamic globally through parameterized and abstract functions. In the context of the assessment of thermal comfort in urban open spaces, the method of MA simulation opens new analytical doors as it is possible to simulate the impact of the environmental conditions at the scale of a single individual and aggregate the data afterwards to obtain more general results. This allows not only the simulation of non-standardized communities e.g. elderly or less climate adapted people, but also to consider the effects of short-termed thermal effects on the human energy balance and the resulting impact on the assessment of local metrological conditions. In addition, behaviour feedback (e.g. avoidance of the sunny street if a shady alternative is available) can be considered in the model simulation.

To simulate the dynamic effects of varying microclimate environments on the energy balance on the agents, a simple transient two-node model of the human thermoregulatory system ("*Individual Thermal Comfort model*" ITCM) was compiled from different recent studies. This model is then used to provide the agents in the Multi-Agent system BOTworld with an individual thermodynamic response (see also Paper "Assessing urban microclimate from the user's perspective" in these proceedings)

2 METHODS

The primary design target for the model presented in this paper has been to produce an up-to-date but still simple and applicable model of the human thermoregulatory system. The model presented in this paper is a two-node model based on the approach from Gagge *et al.* (1971) updated with several extensions such as the suggestions from the BIOMED-II research project (e.g. Parsons *et al.*, 1999) or the approaches for model individualization presented by Havenith (2001). Furthermore, some extensions are added to the model to take into account the different dynamic information resulting from the embedment into the Multi-Agent system BOTworld (see www.botworld.info).

The basic properties of the ITCM agent and the main prognostic variables are summarized in Table 1. One of the big advantages of an agent based simulation of the thermoregulatory system is that for each time and each location, detailed information about the walking velocity, the exposure to wind or the solar load are available. Hence, the model can correct important physiological parameters such as the clothing insulation with respect to the actual conditions (e.g. relative wind speed) and enhance the realism of the simulation. Figure 1 gives a schematic overview over the main variables and thermal processes considered in the ITC model.

<i>Basic Properties</i>	
Gender (male, female)	<i>sex</i>
Age	<i>ag</i>
Height	<i>ht</i>
Weight (from BMI)	<i>wg</i>
Clothing Insulation	<i>clo</i>
<i>Dynamical/ Routing Properties (from PedWalk)</i>	
Preferred and actual velocity	v_{pref}, v_{act}
Relative wind speed	v_{wrel}
Actual position in model	(i, j)
Walking direction (angle)	ϕ
<i>Main Physiological Properties</i>	
Percentage fat (from BMI)	$\%fat$
Mean skinfold thickness	<i>SF</i>
<i>Body surface areas:</i>	
DuBois area	A_{du}
Clothed surface area	A_{cl}
Skin surface area	A_{sk}
<i>Main ITCM Biometeorological Variables</i>	
Core temperature	T_{core}
Skin temperature	T_{sk}
Cloth temperature	T_{cl}
Metabolism	<i>M</i>
Energy flux core – skin	Q_{co-sk}
Conduction skin – cloths	G_{sk-cl}
Radiative budget skin	R_{sk}
Convection skin	C_{sk}
Radiative budget cloths	R_{cl}
Convection cloths	C_{cl}
Latent heat flux	<i>LE</i>
Sweat on skin	<i>SW</i>
Fraction wet skin	Γ

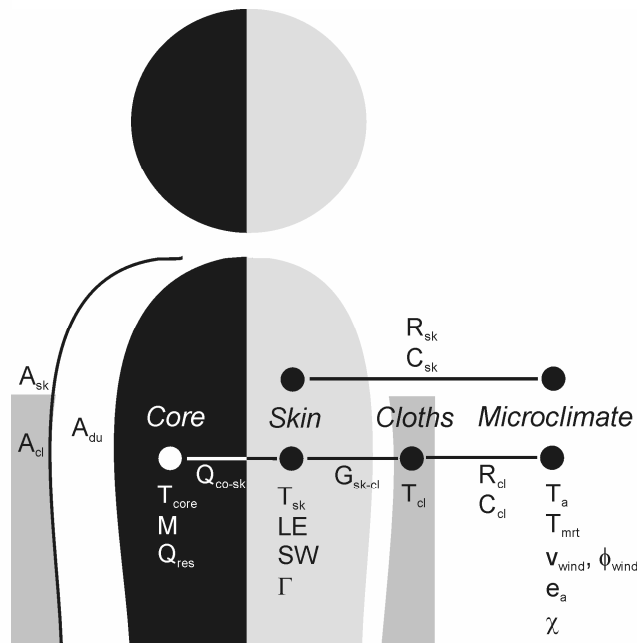


Table 1 (left): Main properties of the ITCM agent
 Figure 1 (right): Schematic overview over the ITCM model

3 RESULTS

There are many possible ways to look at the multitude of data generated by the BOTworld system. In the accompanying paper "Assessing urban microclimate from the user's perspective" the focus is set on the spatial aggregation of the individual thermal comfort data. Hence, for this paper we will focus on the thermal processes taking place at the scale of a single agent.

The case study area and the meteorological data framework are the same as in paper mentioned above: A simple square urban place 200 m x 200 m large with no trees and 4 connecting streets (150 m) at each side studied for the 14:00 CET situation. In order to show the dynamics of the thermal comfort model from the perspective of the virtual pedestrian, two agents "Marvin" and "Claire" have been picked randomly out of the pool of generated agents. "Marvin" is male, 48 y and weighs 75 kg whereas "Claire" is female, 17 y and weighs 56 kg. The other main difference between the two agents is that "Marvin" walks from the west to the east in the model area using the shady street side whereas "Claire" walks from east to west on the sunny street side.

Figure 2 shows the development of selected parameters of the thermoregulatory system while the selected agents move through the model environment. On the abscissas, the life time of the agent relative to the time of release into the model area is plotted. Also, the period while the agents cross the open space is marked. As the virtual pedestrians move with different walking velocities, the time required to cross the model area is of course different.

The diagrams labeled "(a)" show the radiative microclimate conditions in terms of mean radiant temperature T_{mrt} plus the resulting skin, core and clothing temperature (T_{sk} , T_{core} and T_{cl}). The "(b)" diagrams allow a closer look at the actual energy state of the agents. Here, the absolute energy gain or loss of the body (Q_{EB}) and the energy fluxes at the bare skin (R_{sk} , C_{sk} and LE_{sk}) are shown. Finally, the plots marked with "(c)" take a look at the actual fraction of wet skin in relation to the local absolute and relative wind speed (v_{wind} and v_{wrel} respectively).

Starting the analysis with agent "Marvin" moving West to East in the shade, the effect of the local microclimate on the skin temperature can be well observed (Fig. 2 a): When entering the shady street

section, the skin temperature drops from the initial 36.61 °C down to 35.54 °C. After 200 seconds total time, the end of the street is reached and the agent enters the open space where he is exposed to a high mean radiant temperature of 72 °C. Immediately, the skin temperature rises again until the opposite shady street canyon is reached. The core temperature shows only little reaction on the different microclimates. Here, a general drop from the initial 37.72 °C down to 37.54 °C at the end of the complete walk can be observed. This small decrease is only slowed down while the agent walks through the sunny open space.

The energy balance of the body and the energy fluxes plotted in Figure 2 (b) allow a detailed analysis of the thermal processes taking place at the different locations of the model area. In principle, a positive energy balance Q_{EB} indicates that the body is heating up and has not reached a stable thermal state (yet). The more positive the actual energy balance is, the more intensive is the perception of heating up when entering a different tempered environment. In case of a negative energy balance, the same principle applies accordingly. Inside the shady street canyons a negative energy balance of around -250 W can be observed, hence this location will give the impression of a cool environment. While "Marvin" crosses the open space, the energy balance changes to positive values and the body heats up.

For agent "Claire" the situation is different. As this agent walks constantly through the sun, there is only a small variation in skin temperature and almost no change in the core temperature. For this agent, the initially assumed sunny and warm conditions continue all through the walk through the model area and only small variations exist due to changing wind conditions. For this agent, the energy balance while walking through the street canyons shows a small positive value around 50 W. So, this section will get the impression of being slightly warmer than the initial conditions due to the reduced wind speed inside the street canyon. Contrary, the open space is appearing a little bit cooler than average due to the higher wind speed which becomes especially effective immediately after entering the open space with a relative high amount of sweat on the skin.

This aspect leads to the last two diagrams (c) of Figure 2 presenting the aspect of skin wetness while walking through the model environment. As it can be seen from Figure 2 (b), the transpiration of sweat contributes to a significant amount to the energy balance of the agents. For "Claire" who walks always in the sun, this contribution is at maximum with about -250 W/m², but even for "Marvin" who walks mostly in the shade it stays around -200 W/m² during the walk. As the amount of produced sweat depends to 90% on the core temperature of the body which is relatively constant for all agents, the fraction of wet skin shows its main variation with the relative wind speed (v_{wrel}). For "Marvin", relative high percentages of wet skin can be observed inside the street canyons which can be explained mainly through the low relative wind speed as a consequence of the local wind speed and the walking velocity and direction. With amounts up to 80% wet skin, the street canyons will not appear comfortable to this agent, even if he walks in the shade. When crossing the open space, the fraction of wet skin stabilizes around 24% for "Marvin" and around 30% for "Claire" due to the high local wind speeds.

4 CONCLUSION

This paper presented some basic dynamics of the Individual Thermal Comfort Model ITCM linked to the Multi-Agent Simulation system BOTworld. By the example of two agents using only slightly different routes through the test area the differences in the dynamics of the thermoregulatory system have been shown. The model results demonstrate that the human energy balance is in a non-stationary state most of the time when moving through complex urban microclimate conditions.

References

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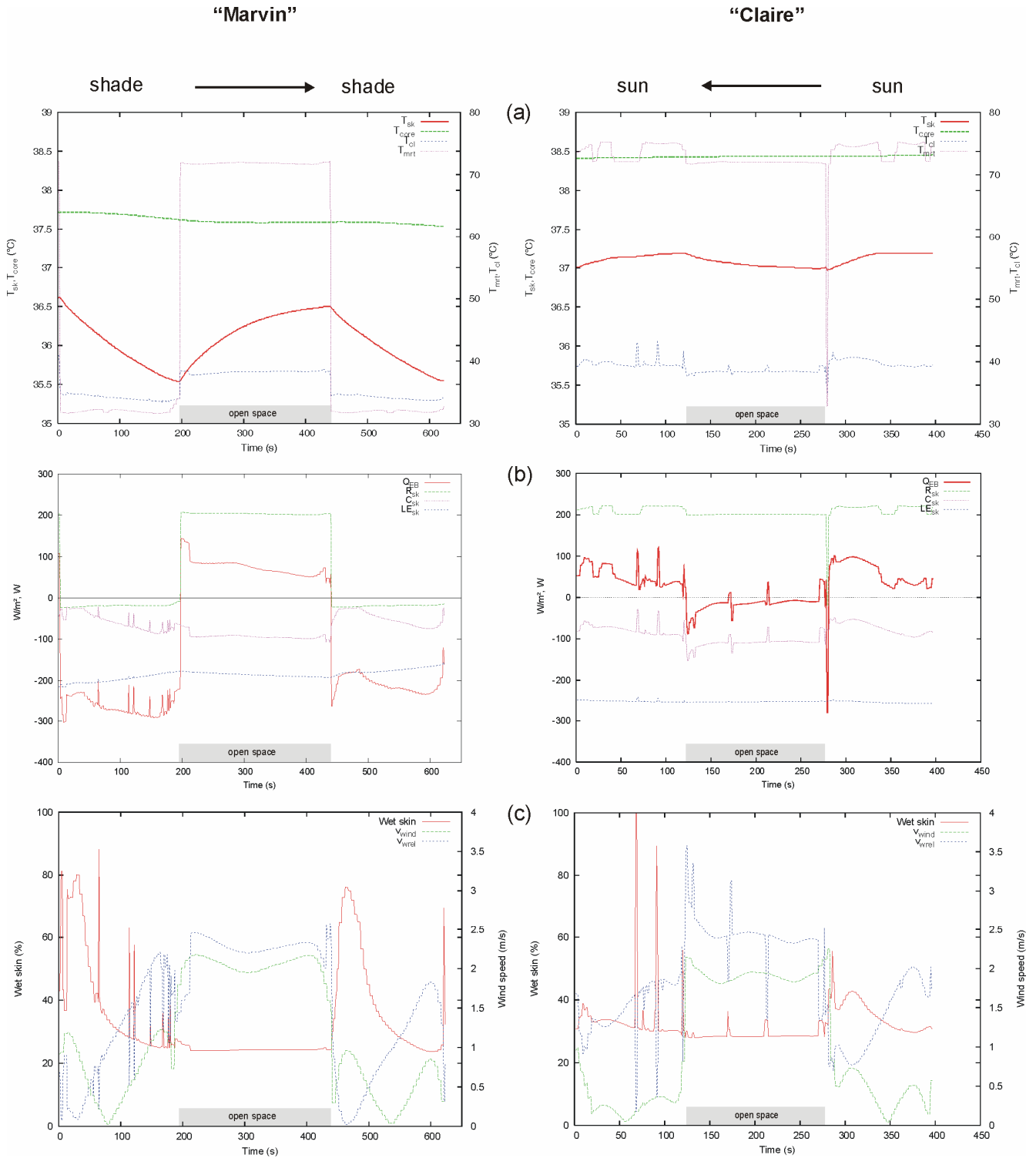


Figure 2: Evolution of selected parameters of the ITC model for the agents "Marvin" and "Claire" walking on the W--E axis of the study domain: (a) temperatures of skin, core and clothing and the local mean radiant temperature, (b) total energy balance and radiative, convective and latent energy fluxes per skin surface area, (c) fraction of wet skin and associated absolute and relative wind speed