ANALYSING HUMAN OUTDOOR THERMAL COMFORT AND OPEN SPACE USAGE WITH THE MULTI-AGENT SYSTEM BOTWORLD

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Abstract

Attractive public open spaces can serve as key design elements for enhancing life quality in urban areas and to diminish the negative effects of urbanisation. In order to fulfil this task, open spaces must meet the expectation of potential users and offer the right mix of environmental, economic and social conditions. It is well known that the local microclimate belongs to the main factors driving the individual perception and assessment of an outdoor environment. In order to simulate the thermal comfort of pedestrians in urban open spaces, the method of Multi-Agent Systems (MAS) is used. Each agent in the MAS represents a virtual pedestrian with individual physiological properties and different routes through the model environment.
While walking through the domain, these agents are virtually exposed to different microclimate conditions. The impact of these climate environments on the individual thermal comfort are simulated using a dynamic model of the human thermoregulatory system. To assess the local microclimate conditions, a Fuzzy-Logic based rule system is used, which takes into account not only the local microclimate itself, but also the actual thermal state of the agent. Depending on their individual thermal comfort level, the agents can adjust their routing decisions and also consider using optional facilities such as benches or restaurant chairs.

This paper presents the present state of the Multi-Agent System ENVI-met BOTworld and it application to thermal comfort analysis

Key words: BOTworld, ENVI-met, Multi-Agent simulation, outdoor thermal comfort

1 INTRODUCTION

Attractive public open spaces can serve as key design elements for enhancing life quality in urban areas and to diminish the negative effects of urbanization. In order to fulfill this task, these open spaces must meet the expectations and requirements of the potential users by offering the right mix of environmental, economic and social conditions. It is well known that the local microclimate offered by an area is one of the main factors that drive the individual perception and assessment of an outdoor environment. The right mix of sun and shade or the shelter from wind- Pleasant conditions will attract people who, in return, will make these areas more attractive for shops, restaurants or other facilities depending on pedestrian frequentation. In short, the success of a public space can be based on the number of people who use that space (Carmona et al., 2003).
Urban planners and architects are faced with the problem of assessing the interactions between the local design, he resulting microclimate and the response of the potential users. Complex and iterative systems like this can only be solved using numerical simulation tools.

2 METHODS

Traditionally, static thermal indices like PMV or PET are used to express the impact of local climate onto the thermal comfort of humans exposed to these conditions. These indices relate the average thermal comfort more or less directly to the local meteorological conditions. However, taking the fact that most people are moving through the urban environment and that there is a big magnitude of different microclimate conditions found on close space in urban areas, the response of the human thermoregulatory system is normally far from reaching such static conditions. Hence the assessment found by static indexes often overrate the local conditions, especially in the case of hot discomfort.

Dynamic models of the human thermoregulatory system are a better approach to simulate the reaction of the human body on varying climate exposures. As these models are individual based, they are also able to simulate different human characters such as age, weight or climate adaptation which is not possible with community based indexes like PMV. In order to be practically applicable, individual based models require a computational framework which simulates movement patterns of the users though the urban environment and provides the biometeorological models with the required microclimate data as input. One elegant way to construct such a system is to link the individual based thermal comfort model to a Multi-Agent Simulation system (MAS). In such a system, software agents take the role of the virtual humans moving through the model environment and different microclimate conditions while their thermal comfort is monitored constantly.

2.1 The MAS BOTworld

The method of Multi-Agent simulations (MAS) allows the simulation of complex systems by focussing on the single actor, the so-called *agent*. Each agent represents – in this case – a virtual pedestrian with given physiological properties such as gender or body mass and certain routing targets generating the movement through the model environment. While following their plans, these agents are virtually exposed to different climate conditions, just like real pedestrians would be. The impact of these climate environments on the individual thermal comfort, are continuously monitored using a simple transient 2-node model of the human thermoregulatory system.
The MAS BOTworld was especially developed to simulate and analyse pedestrian movement and thermal comfort in complex urban environments (see www.botworld.info). The simulation system integrates the biometeorological thermal comfort model ITCM, the pedestrian traffic simulation model PedWalk. The required microscale meteorological data are taken from ENVI-met simulations. During the MAS simulation, the climate data are provided as boundary conditions for the ITC model. Figure 1 shows the basic concept of the Multi-Agent simulation system BOTworld focussing on the thermal comfort simulation.

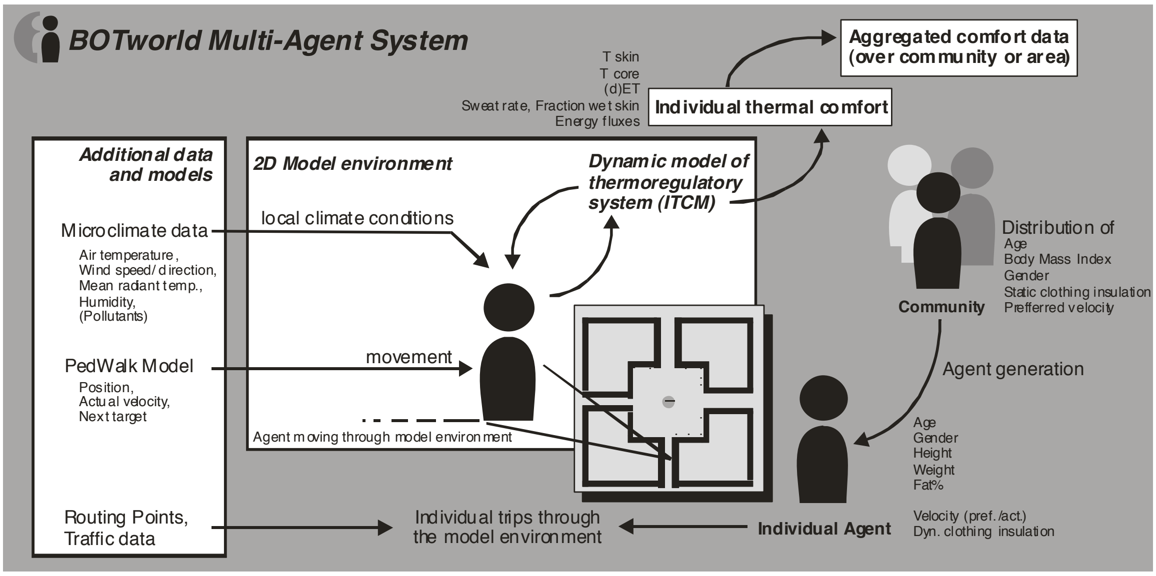

Figure 1:Schematic overview over the BOTworld simulation system

After simulating a sufficient number of virtual pedestrian walks (2300 agents in the example shown in Figure 3), the data generated by the comfort model are gathered and aggregated with respect to the objective of the analysis. Typical aggregation methods are for example spatial aggregation, summarizing the state of all agents visiting selected locations of the area, or individual aggregation which reports about the state of all agents at a given time. As the agents are aware of their thermal state, they are also able to adjust their routes through the urban environment with respect to their thermal state: If an agent feels hot, he will favour the shady side of the street rather than the sunlit one. This aspect also steers the usage of optional targets such as benches or restaurant tables as shown later on.

2.1. Assessment of environmental conditions by Fuzzy-Logic

The pedestrians individual assessment of the microclimate conditions is a crucial factor when analysing the environmental quality offered by a location. The question whether a certain location is regarded as pleasant or not depends not only on the location itself but on two factors: the thermal state of the individual pedestrian and the microclimate conditions at the respective location. For example, a sunny location with calm winds might be assessed as comfortable and pleasant by a person coming out of a shady street but the same spot may be considered as too hot by someone entering from another sunny and hot open space.
As both, thermal state of the pedestrian and microclimate conditions, cannot be clearly classified by using sharp class ranges (at what temperature does the microclimate change from "warm" to "hot"?) a Fuzzy-Logic based assessment system is used in BOTworld.
The assessment system used in BOTworld is called **"F-A-ST model"** in which the **F** stands for the environmental factor to be assessed (e.g. solar radiation, "external parameter" in Fig. 1) while **ST** ("internal state" in Fig. 1) represents the associated thermal state of the agent which has an impact on the assessment of F.
Finally, **A** is the resulting assessment value which ranges from -1 to +1, where -1 is the worst possible assessment and +1 the best one. An A value around 0 indicates a neutral assessment of the analysed situation.

3. A CASE STUDY: REDESIGNING AN URBAN OPEN SPACE

3.1 Overview

In order to demonstrate some typical model results, we will analyse a simple urban open space with the size 200 m x 200 m including four 150 m long connecting streets. As the BOTworld system is a grid based system, the model domain is horizontally resolved into 2 m x 2m grid cells. This resolution is relatively coarse for analysing pedestrian traffic flows but sufficient for microclimate analysis. In this example, we will compare two different design scenarios: The “bare” scenario represents an open space without any greening but with a small water pond in the center of the place (see Figure 2 left). The “green” re-design scenario (Figure 2 right) represents a new layout of the open space with a number of newly plated trees plus a structure of hedges in the centre of the place.

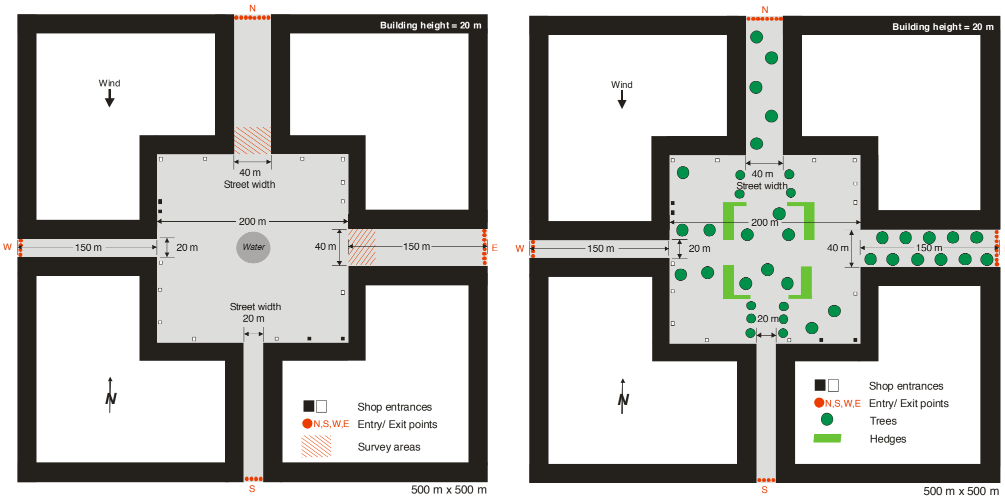

Figure 2: Layout of the case study seen from the top. Left: Old design without greening (“bare” scenario), Right: New design with additional trees and hedges (“green” scenario)

3.2 The thermal comfort situation in the “bare” case

From the number of different parameters and indices that can be used to describe the human thermal state, we have chosen the average skin temperature (Tsk) to demonstrate the model results. Figure 3 illustrates the spatial distribution of the skin temperature averaged over all agents entering the respective grid cell (between 20 and 50 agents for most cells of the area). Different to the spatial distribution of the microclimate (compare Tmrt shown in Fig. 4), the Multi-Agent simulation generates a structured pattern of thermal conditions over the complete open space with hotter areas in the eastern parts of the open space and in the eastern street. This is mainly due to the fact, that the northern and eastern connection streets are wider than their western and southern counterparts. Hence, more parts of these streets are in the sun and, as a consequence, people using these streets are more exposed to the sun. When those people enter the open space, their thermal load is higher compared to people coming from the narrower and more shaded streets. This results in a higher skin temperature level observable in those areas of the open space directly connected with the wider streets.

3.3 Impact of microclimate on open space usage

If we think of an urban open space as a location that offers more options than just traffic distribution, the impact of microclimate can become much larger and visible. For example, the selection and usage of benches or the frequentation of restaurant tables is much more sensitive to the local climate than the routing choice.
To investigate this phenomenon, BOTworld offers the possibility to define “Optional Targets” inside the model domain.
Figure 4 shows the distribution of the Mean Radiant Temperature and the relative occupation time of the optional targets for the center place. The relative occupation time is defined as the occupation time of a target relatively to the total time of simulation. In the “bare” scenario (Fig. 4 left) the benches in the center of the place are completely unused during the simulation time (empty circles) as they are exposed to the bare sun and therefore do not offer an adequate microclimate environment. Only the restaurant tables in the upper left which are in the shade are well used with frequentation rate approaching 100% (filled circles). In case of the “green” scenario (Fig. 4 right) the frequentation of benches and restaurant chairs has increased significantly. It also has to be notified

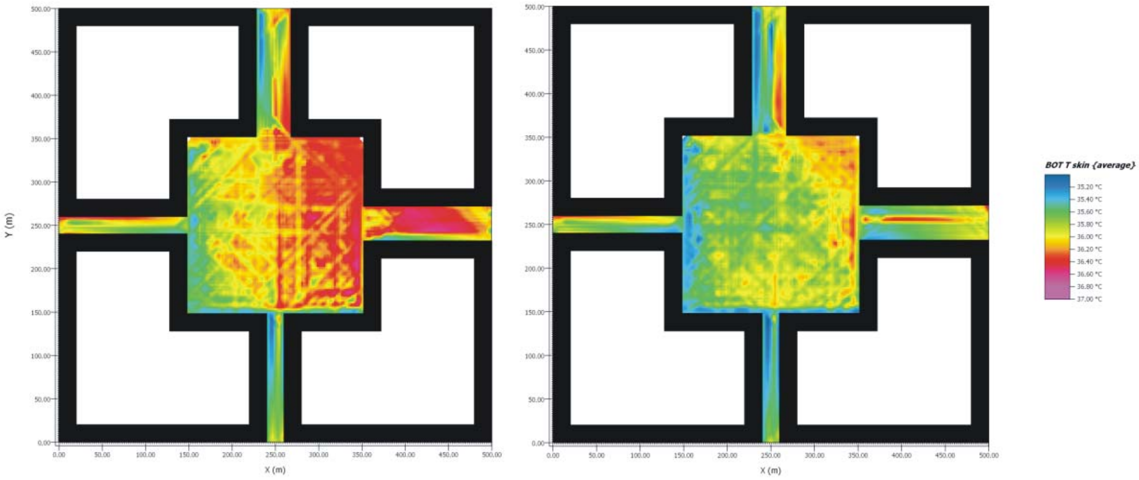

Figure 3: Distribution of average skin temperature calculated over 2300 (“bare” scenario, left) and 2000 (“green” scenario, right) different agents

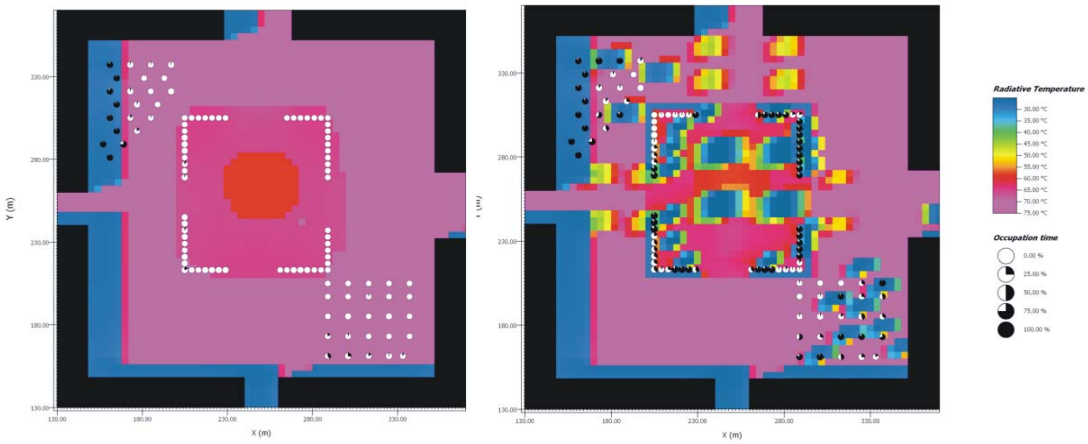

Figure 4: Distribution of Mean Radiant Temperature and relative occupation time of optional targets for the main center place (left: “bare” scenario, right: “green” scenario), Simulation for 14:00 local solar time

that although the assessment of the open space has improved all over the area (compare Fig. 4 right), the usage of benches and tables is still basically limited to the shaded or half-shaded locations.

3. CONCLUSION

The microclimate offered by an urban open space has a strong impact on the thermal comfort of visiting pedestrians and consequently on the perception and the usage of the open space. The technique of Multi-Agent simulations (MAS) allows investigating the impact of the microclimate conditions on human thermal comfort on the level of the individual pedestrian. As pedestrians move through the urban environment, they are exposed to different microclimate conditions over a short time. With MAS it is possible to analyse the impact of such dynamically changing conditions on the thermal state of the simulated pedestrian and to make assumption on the resulting usage patterns of urban open spaces.

References

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