Relationship between Mean Radiant Temperature and Building Type for Pedestrians in Rotterdam

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Abstract. Outdoor thermal comfort for pedestrians becomes important issues in urban planning affecting everyone's daily lives. Mean Radiant Temperature (T_{mrt}) is one of the most important parameters in micro climate. In this study, we built a computerised model with variable and typical building types. Then a radiation model SOLWEIG was used to simulate pavements' T_{mrt} spatial variations. We analysed and discussed the simulation results by comparing different building types. We used RayMan to find some relationship between thermal comfort index PET or PMV. Our finding can act as a reference for architects and planners to make design decisions on quantifying the thermal comfort in specific urban environment and their building types.

Keywords: Mean radiant temperature (T_{mrt}), pedestrians, thermal comfort index, spatial variations.

1 Introduction

Micro climate has become an important issue in urban planning and has a strong impact on human health. Some key meteorological parameters have a great influence on outdoor thermal comfort. The Mean Radiant Temperature (T_{mrt}) is one of these major important parameters.

Several researches showed that there is a strong relationship between T_{mrt} and thermal comfort index, such as *Physiological Equivalent Temperature* (PET), during weak wind summer days [1-3]. Wind speed is low in medium-sized western European cities especially during heat wave. T_{mrt} becomes an important thermo-physiological parameter in these regions, such as cities in the Netherlands or Germany.

T_{mrt} weighs all short-wave radiation flux in direct, diffuse and reflected and long-wave radiation flux emitted from sky, wall, floor [4], as well as the radiation flux considering the human surface area in each direction [5-6].

Currently there are four common micro-scale models to simulate T_{mrt}, such as the ENVI-met Model [7] developed by Ozkeresteci, the point simulation model called *RayMan* [8], *SkyHelios* for calculating sky view factor and sunshine duration

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J. Zhang and C. Sun (Eds.): CAAD Futures 2013, CCIS 369, pp. 306–314, 2013.

calculating [9] and the *Solar Long Wave Environmental Irradiance Geometry* (SOLWEIG) model developed by the Göteborg Urban Climate Group [10-12]. Thorsson et al [13] showed that SOLWEIG simulates reasonable T_{mrt} for typical urban forms in Goteborg, which has a similar climate with the Netherlands according to Köppen-Geiger climate classification [14]. We also choose SOLWEIG to simulate the spatial variations of T_{mrt} within a given typical urban form.

Several studies have also showed the relationships between urban form and thermal comfort. Emmanuel and Fernand examined T_{mrt} and urban geometry for Colombo and Phoenix [15]. Kakon et al [16], Chen and Ng [17] and Kruger et al [18] found Sky View Factor (SVF) is an important factor for urban micro climate. Ali-Toudert et al [19], Ali-Toudert and Mayer [20], Johansson [21] and Johansson and Emmanuel [22] focused on what role plays the geometry of urban canyons on the thermal comfort for people. Pearlmutter et al considered the pedestrian thermal comfort in micro urban street scale [23]. Kruger et al [24] focused on height to width ratio (H/W), time zone and orientation impact while Shashua-Bar et al [25] considered H/W, orientation, ground coverage, distance from sea for urban morphology. Bourbia and Awbi [26] focused on orientations and shading. Ali-Toudert and Mayer [27] considered street orientations by *ENVI-met.* Herrmann and Matzarakis [28] considered the center of an idealized urban canyons using RayMan. Thorsson et al [13] have showed the different spatial variations of T_{mrt} with four urban forms with different SVF in Goteborg using SOLWEIG. Our research takes into account the whole pavement areas of six typical building types in urban Rotterdam and focuses on the spatial-temporal T_{mrt} distributions by using the SOLWEIG model. The aim of this study is to quantify the effect of building type for thermal comfort in Rotterdam.

2 Method

Our methodology is described in this section. First we examine the suitability of SOLWEIG, and then choose appropriate representative simulation day. Second, we chose typical building types in Rotterdam and built the idealized buildings in ArcGIS. Third, we simulate these buildings in SOLWEIG and extract their T_{mrt} value of pavements around the buildings for analysis.

2.1 Suitability Test of SOLWEIG

We compare real survey data with the SOLWEIG simulation results to test the suitability for urban areas of Rotterdam with setting albedo value (0.15), surface emissivity (0.95) and buildings emissivity (0.90), the same setting as Thorsson et al did [13]. The Meteorology and Air Quality Research Group at Wageningen University surveyed T_{mrt} for urban Rotterdam on 6th August, 2009 by mobile equipment [29]. Meanwhile, *Digital Elevation Model* (DEM) data of Rotterdam was simulated T_{mrt} by employing SOLWEIG. We found that there is significant correlation (0.84) between the simulation and real survey data [30]. Subsequently SOLWEIG is suitable to simulate T_{mrt} in Rotterdam on that day.

2.2 Selection of Simulation Day

Urban Rotterdam's approximate Longitude is 4°28' and Latitude is 51°55'. The profile of global radiation on 6th August, 2009 (the same day as Heusinkveld et al chose) is a diurnal distribution (smoother diurnal distribution expresses less wind and a clear day). Then we synchronize Rotterdam's meteorological data of that day, which includes temperature, relative humidity and global radiation. The five step process of SOLWEG is shown in Figure 1.

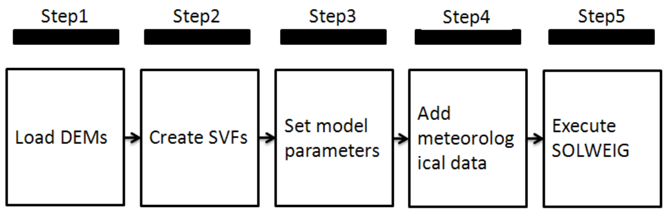

Fig. 1. Five steps to generate simulation results using SOLWEIG [32]

2.3 Idealized Urban Buildings and Simulated T_{mrt}

We set the height (h) to 15 meters, since this represents the typical height of buildings in Rotterdam. We chose six typical building types from *Google Earth* and built these building types in similar size in *ArcGIS*.

In SOLWEIG, we chose the location, loaded the building data from ArcGIS, calculated the sky view factor based on buildings data, adjusted the suitable model parameters, synchronized meteorological data (including relative humidity, temperature and global radiation) of a clear day and finally got the simulation results for day time hours from 6:00 to 18:00 (total of 13 hours).

3 Simulation Results and Discussion

Figure 2 shows the six building types in urban Rotterdam and the corresponding average T_{mrt} value over 13 hours. The black shaded areas represent buildings while the colorful ones symbolize pavements. Red represents a high T_{mrt}, yellow and orange middle-range, and green T_{mrt}. We can see that the building type has impact on T_{mrt}: the values are the highest in southeastern pavements. A low T_{mrt} appears in the eastern areas of building types 1, 2, 3 and 6. The highest T_{mrt} occurs in four corners and south pavements in building type 4 and 5.

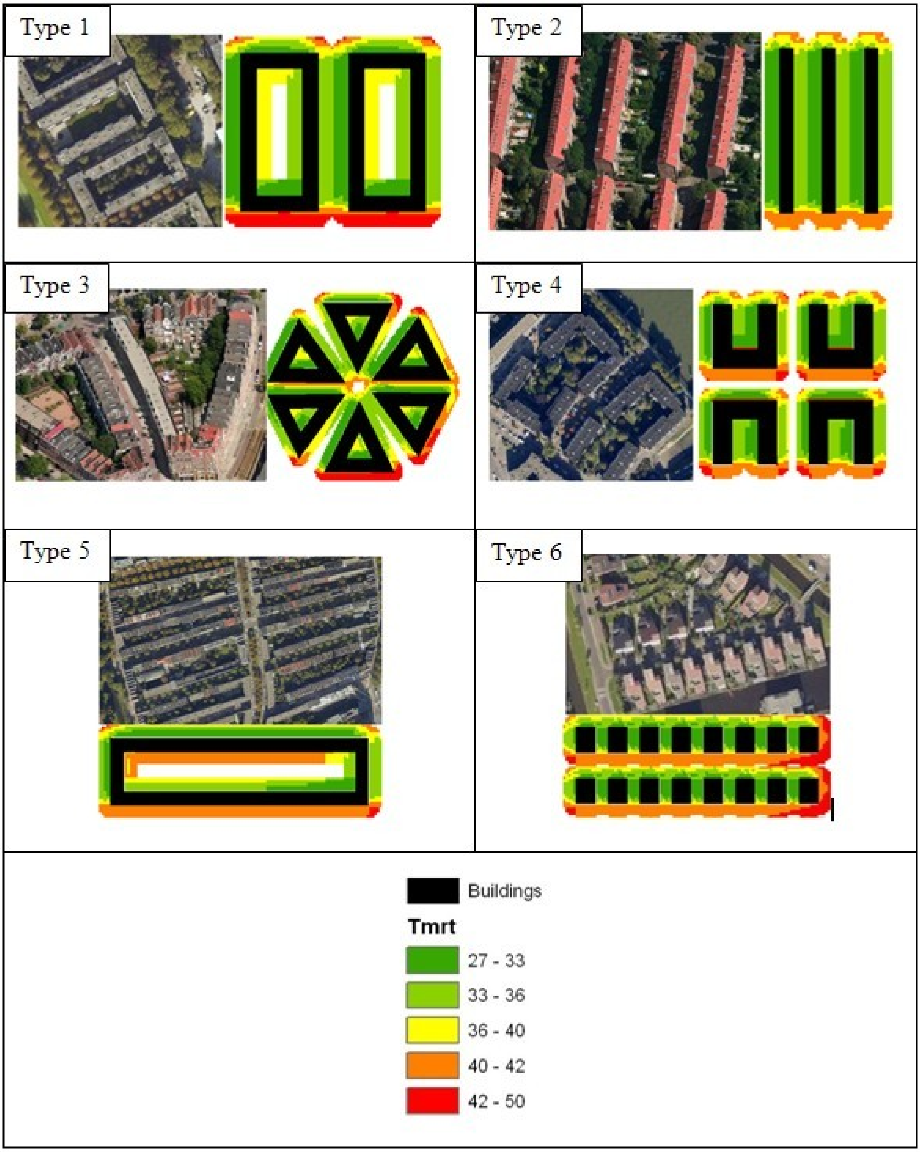

Fig. 2. Real area in urban Rotterdam and the average T_{mrt} of six building types

In general, the highest T_{mrt} is around noon time. Figure 3 shows the overview of T_{mrt} at noon.

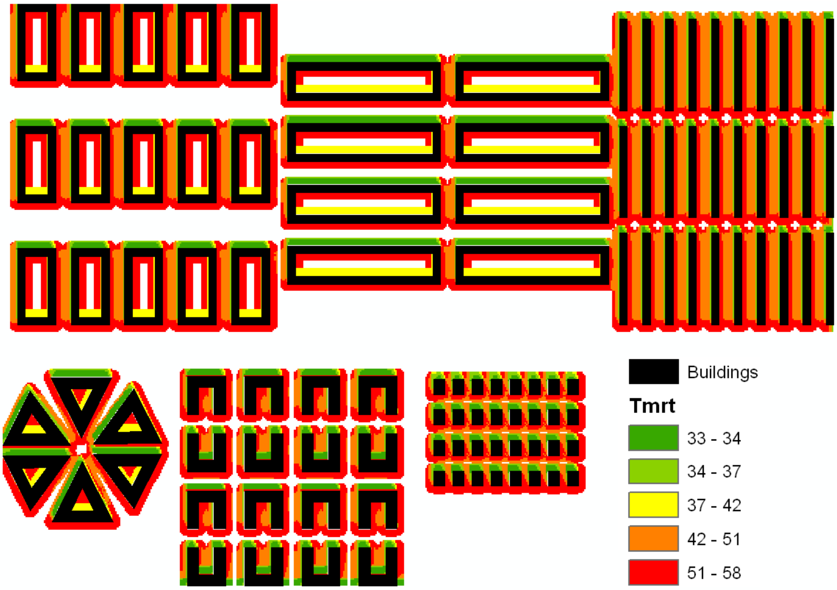

Fig. 3. The overview T_{mrt} at 12:00 noon

The thermal comfort index *Predicted Mean Votes* (PMV) or *Physiological Equivalent Temperature* (PET) is depending on T_{mrt}, wind speed, humidity and temperature. For our pedestrians zones sun/shade sides, the air temperature (T_a) and humidity will not be too different. We assume that wind speed is rather similar across the street so the main impact is T_{mrt} but not the only index. For example, an extreme case: we have T_{mrt} =50C in winter or in summer. This means that it is either cold or warm, depending on the T_a and wind speed. We therefore need to show the sensitivity of a heat stress parameter such as PMV or PET to T_{mrt}, wind speed, temperature and humidity. The SOLWEIG model mainly calculates T_{mrt} based on solar angles and albedo's and emissivity. It needs to estimate surface temperatures and uses a very crude approach to calculate this from temperature and wind speed. To find PET or PMV we need to run another programs such as RayMan to get these values.

The T_a in a way affects surface temperature and this affects thermal radiation which is part of T_{mrt}. Thus firstly, we need to check how much T_{mrt} is affected by Ta and make T_{mrt} as a function of T_a. T_{mrt} for building type 2 is lowest. We took building type 2 (H/W = 1) as an example and simulated them with RayMan: Ta = 30C, T_{mrt} = 56.8C in sun, 48.4 in shade. We found the simulation with RayMan matches well the SOLWEIG model. Then we can make a few surface graphs with sun/shade side of the street and impact on PET. A 3D graph (Fig.4.) shows PET in color, where x = T_a and y = Wind speed. Figure 4 is important since valuable information can be derived from it: sufficient ventilation can reduce PET significantly. For example, from the 30 degrees vertical line of our study and we can extract of how much the wind speed has to increase in order to have the same thermal sensation as in the shade at low winds (i.e. to arrive at the same PET in the shade).

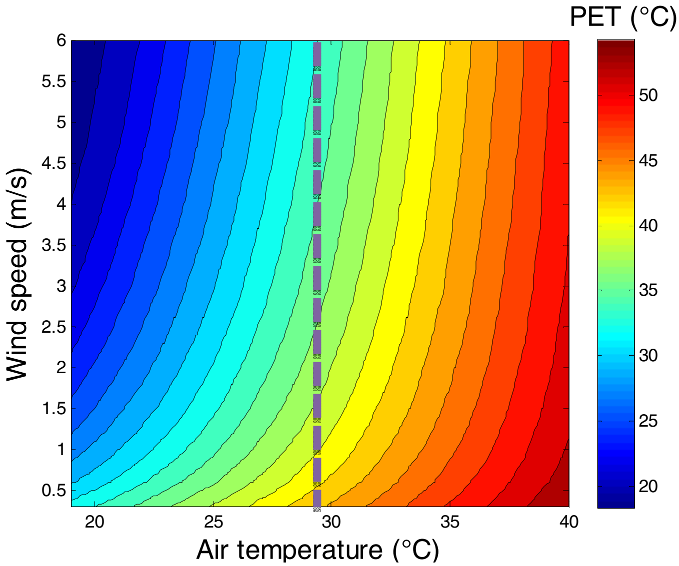

Fig. 4. The relationship between PET and wind speed, air temperature

Figure 5 shows the dependency of PMV on T_a and relative humidity for a given T_{mrt}=50C and u=0.3m/s. By generating a simple text file with three columns and process the data with Rayman we can plot the data using *Matlab*. This can be done for a few combinations of wind speeds and T_{mrt}. Then we can generate a heat stress table in further studies [32].

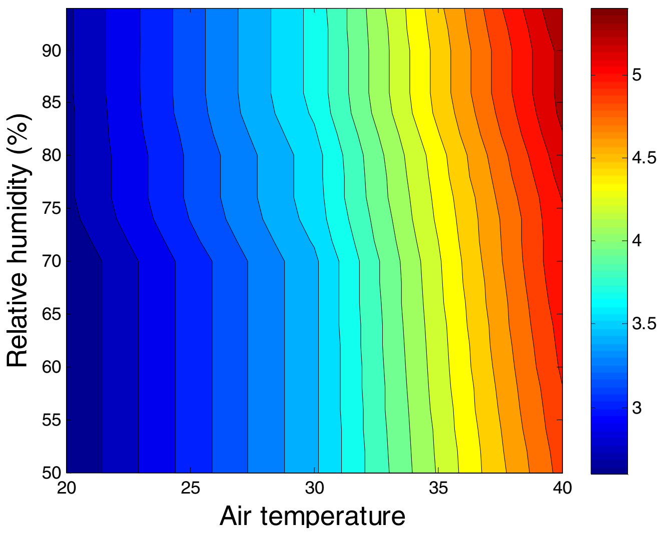

Fig. 5. The relationship between PMV and relative humidity, air temperature

4 Conclusion

We simulated six typical types of buildings in Rotterdam and considered the thermal comfort index. Thermal comfort of pavements around buildings plays an important role on people's livelihoods. Building types including their heights, widths, sizes, orientations, layouts, roughness and geometries play an important role on the micro T_{mrt} and are considered in this research. Our results show for example that there is higher T_{mrt} in south orientated pavement areas or generally lower T_{mrt} in building type 2. The micro climate simulation results can be used as a reference for building design and urban planning.

A heat stress table can be generated with more detailed combinations of parameters. As next steps we will conduct a long time study (over longer period of time and different days of the year), include more details in our simulation, and consider other factors (such as vegetation, sun angle). Additionally we will compare our results with other simulation software (e.g. ENVI-met, RayMan) to fine-tune the accuracy of our study. Our further research will analyze the relationship between the urban form and T_{mrt}, and transfer the model to other climate zones.

Acknowledgements. Special thanks are given to Dr. Bert G. Heusinkveld from the Meteorology and Air-quality Group of Wageningen University for his valuable support of this study.

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