DERIVATION OF LOCALLY ADJUSTED HIGH-RESOLUTION WEATHER INFORMATION FOR BUILDING PERFORMANCE SIMULATION

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ABSTRACT

Building performance calculations are usually done with regional weather files. Studies have proven that the microclimatic conditions vary widely within the urban area. This is due to the influence of the surrounding urban fabric (e.g. the materials used, the building structure and orientation, vegetation, etc.) and the anthropogenic heat emission on the aerodynamics, thermodynamics and the radiation, and therefore on the surrounding climatic conditions. In order to get more accurate results for the buildings performance, detailed information on the surrounding climatic conditions are needed. This paper compares and evaluates the possibility of generating microclimatic information using the example of a courtyard in Vienna. The results can later be used as input information for more detailed building performance calculations.

INTRODUCTION

To properly predict a building's thermal performance with respect to energy demand and indoor conditions, reliable input information is necessary. Specifically, simulation requires detailed and dependable data on external micro-climatic conditions at the building's specific location. For this purpose, typically standardized weather files are used. Such files are based on long-term weather records as derived from weather stations. However, the density of weather station locations is limited. Frequently, data from airport weather stations are used to generate weather files for simulation. As a result, available weather files do not necessarily represent the microclimatic conditions at the exact location of projected buildings: Micro-climatic conditions can vary significantly depending on the site features such as surrounding surfaces, prevailing wind situation, degree of vegetation, and sources of anthropogenic heat emissions. A number of studies have been performed which try to investigate these micro-climatic differences via simulations (Georgakis and Santamouris 2007, Gobakis et al. 2011, Yao et al. 2011, Ali-Toudert and Mayer 2007).

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The present paper explores the possibility of methods and models for enhanced microclimate representation in building simulation studies. Toward this end, we consider two possibilities to model weather conditions in the immediate proximity of a building. The first possibility uses the existing capabilities of building simulation models. Thereby, "semi-outdoor" spaces, buffer spaces, and transitional spaces around buildings are treated in terms of thermal zones and included in the general balance computations, which are conducted in the course of simulation. The second possibility is the application of CFD-based microclimatic models that use forcing data from available weather stations to estimate the microstructure of climatic conditions around projected buildings. The resulting thermal information can then be applied, in a second pass, as the boundary condition for the actual building simulation study. The use of such detailed weatherfiles can have important impact on building performance simulation results. The proper building and systems design depends thus on the proper representations of micro-climatic conditions around buildings.

METHOD

General

In the present contribution, we specifically compare measured data on weather conditions close to a building with corresponding calculated values derived based on two options. The first option uses the existing capabilities of building simulation models. The second option is the application of CFD-based microclimatic models that use forcing data from available weather stations to estimate the microstructure of climatic conditions around projected buildings. Toward this end, microclimatic conditions in a courtyard within a campus building of our university was considered as a case in point. Measured and simulated data was compared for a number of days in May 2012. The results provide a basis to evaluate the reliability of both building simulation applications and microclimatic modeling tools toward the derivation of higher resolution and locally adjusted boundary conditions for building performance simulation studies.

Investigated area

The investigated area pertains to a courtyard of a university building which is located in the city of Vienna. In this courtyard microclimatic parameters such as temperature, humidity, global horizontal radiation, and wind speed were measured with a stationary weather station which was mounted 2 meters above ground. At the same time a reference weather station, which is mounted on a tower at the university campus, monitored temperature, humidity, global horizontal radiation, diffuse horizontal radiation, wind speed, and wind direction. This reference weather station was used to generate the boundary conditions for the two simulation options.

Figure 1. Map of area showing the positions of the weather stations, whereby WS refers to the reference weather station and M to the courtyard weather station

Simulation models

We considered two possibilities to model weather conditions in the immediate proximity of a building. The first option explores the possibility of the building simulation model Energy Plus. The second possibility is the application of the microclimatic model Envi-met. Note that, we refer to simulated temperatures using option 1 (Energy Plus) as "S1" and option 2 (Envi-met) as "S2".

Energy simulation tool

For the first option the existing building simulation tool Energy Plus is used. Energy Plus is a detailed dynamic energy analysis and thermal load simulation tool (EnergyPlus 2012). It has an integrated heat balance based solution technique that allows for simultaneous calculation of radiant and convective effects at surfaces (interior and exterior) for each time step. The radiation heat flux is calculated from the surface absorptivity, surface temperature, sky and ground temperatures, and sky and ground view factors. EnergyPlus is equipped with a combined heat and mass transfer model that accounts for moisture adsorption/desorption effects (either layer-by-layer integration or as an effective moisture penetration depth model) into the conduction transfer functions. Energy Plus deploys an anisotropic sky model for calculation of diffuse solar on tilted surfaces (EnergyPlus 2009, Perez et al. 1990). A model of the aforementioned university building was generated. Thereby, the courtyard was modeled as a thermal zone, which is surrounded by internal office zones. The roof of the courtyard was modeled as a highly transparent and conductive glazing layer. Simulation input assumptions regarding U-value and surface properties of building components and internal gains are summarized in Table 1. Naturally, an important input information relates to air change rates. In the present case, an air change rate of 0.5 h^{-1} was assigned to office spaces. The assumed air change rate in the courtyard was varied in terms of a sensitivity analysis. An air change rate of approximately 13 h^{-1} displayed good results.

Table 1. Simulation assumptions pertaining to U-values, surface characteristics, internal gains, and occupancy density.

Parameter	**Value**	**Unit**
External wall U-value	1.14	$W.m^{-2}.K^{-1}$
Roof U-value	2.0	$W.m^{-2}.K^{-1}$
Thermal absorptance walls	0.9	-
Solar absorptance walls	0.6	-
Visible absorptance walls	0.6	-
Thermal absorptance of ground in courtyard	0.9	-
Solar absorptance of ground in courtyard	0.7	-
Visible absorptance of ground in courtyard	0.7	-
Internal gains office space	16	$W.m^{-2}$
Occupancy density office space	0.11	$people.m^{-2}$

Micro-climate modeling tool

The second set of simulations was performed using ENVI-met V4.0. ENVI-met is a three-dimensional numerical microclimate model that simulates aerodynamics, thermodynamics, and the radiation balance in complex urban structures taking into account the position of the sun, vegetation, urban geometry, surfaces, and construction materials. It was designed to simulate complex urban environments and works with a typical resolution of 0.5 to 10 m in space and 10 sec in time (ENVI-met 2012). One limitation of this application is that it can only accept one value for surface properties albedo and construction properties U-value. Recently ENVI-met has been used in a number of studies to simulate urban microclimate, the influence of vegetation on the urban climate and different mitigation measures for urban heat islands (Ali-Toudert and Mayer 2007, Spangenberg et al.2008, Fahmy et al. 2009, Chen and Wong 2006, Fahmy and Sharples 2009). Figure 2 shows the geometry of the area as created for ENVI-met simulation. The size of the modeled area was 90 by 80 units corresponding to 450 by 400 m (i.e. the grid size is 5 by 5 m). The height of the calculated model was 30 units and the telescoping option was used. Simulation was performed for May 15th 2012 for 24 hours, starting at 3 am. Simulation assumptions pertaining to climatic boundary conditions as well as building and surface properties are summarized in Table 2.

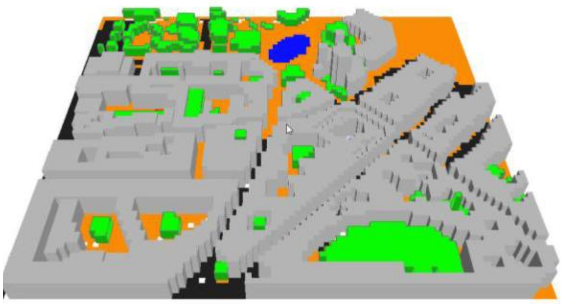

Figure 2. 3D Model in ENVI-met

Table 2. Input assumptions for ENVI-met simulations

Parameter	Value	Unit
Wind Speed	5	$m.s^{-1}$
Wind Direction	315	°
Initial Temperature	283.15	K
Solar Adjustment	0.82	-
Relative Humidity	56	%
Absolute Humidity	8	g $Water.kg\ air^{-1}$
Heat Transmission Walls	0.6	$W.m^{-2}.K^{-1}$
Heat Transmission Roofs	0.6	$W.m^{-2}.K^{-1}$
Albedo Walls	0.4	-
Albedo Roofs	0.4	-
Internal (Room)Temperature	295	K

RESULTS

Figure 3 shows simulated temperatures S1 (simulation option 1; assumed courtyard air change rate = 13 h^{-1}) over 6 days in the courtyard together with measured temperatures in the courtyard (M) and at the reference weather station (WS).

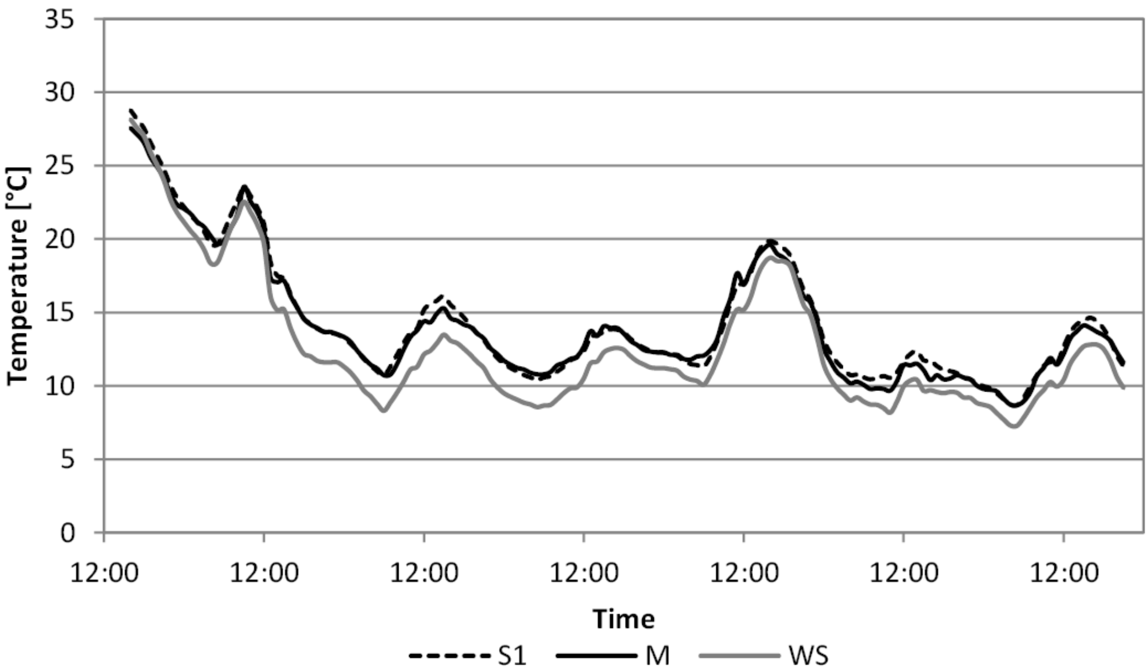

Figure 3. Simulated courtyard temperatures (S1) for a period of 6 days (in May 2012) together with measured temperatures in the courtyard (M) and the reference weather station (WS).

Figure 4 shows simulated courtyard temperatures over 24 hours conducted with the simulation program ENVI-met (S2) together with measured values from of the courtyard (M). Note that the graph includes also simulated temperatures of option 1 (S1). Figure 5 shows the correlation of simulated and measured temperatures in the courtyard for option 1. Likewise, Figure 6 shows the correlation of simulated and measured temperatures for simulation option 2.

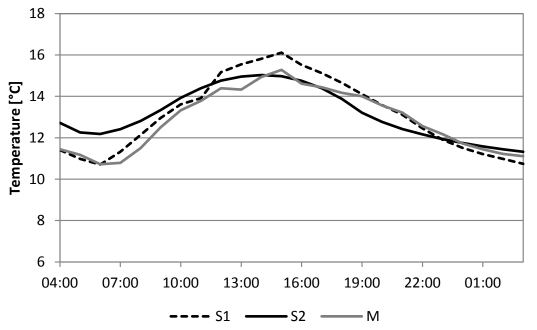

Figure 4. Simulated temperatures of simulation option 1 (S1) and simulation option (S2) over 24 hours in the courtyard together with the measured temperatures (M).

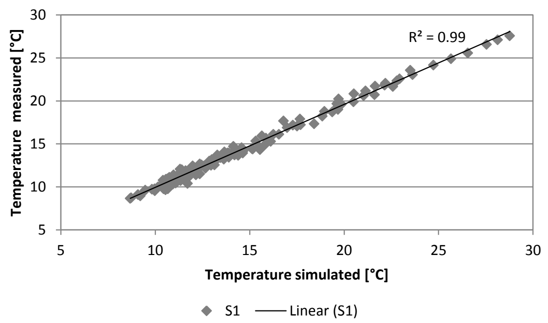

Figure 5. Correlation of simulated and measured temperatures in the courtyard over 6 days using option 1.

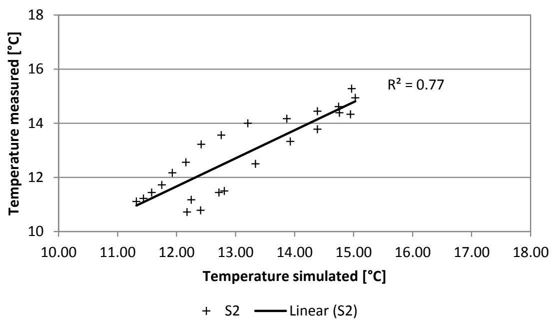

Figure 6. Correlation of simulated and measured temperatures in the courtyard over 1 day using option 2.

DISCUSSION AND CONCLUSION

We presented an approach to derive locally adjusted weather information for outdoor spaces adjacent to buildings from available weather station data. This weather information can be used to improve the accuracy of output results from building performance simulation models.

The option involving the energy simulation tool could be evaluated against data from a 6-day measurement period. The results were fairly satisfactory ($r^2 = 0.99$), despite simplifications involved (particularly the assumption of constant air change rates for indoor and outdoor spaces). Figure 7 illustrates the ramifications of different courtyard air change rates assumptions (from approximately 13 h^{-1} to 80 h^{-1}) for the predicted air temperatures. The micro-climatic model results could be generated for a shorter time span (1 day) since CFD driven methods such as Envi-met are typically time consuming. Nonetheless, the prediction results displaced a fairly good agreement with the measurements ($r^2=0.77$).

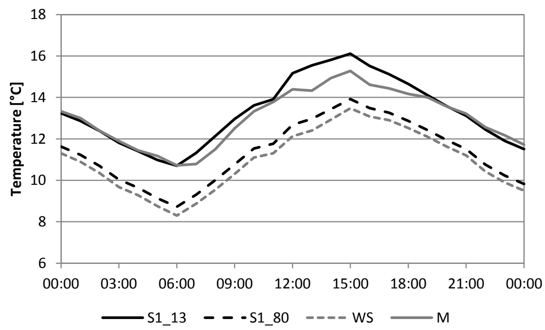

Figure 7. Simulated temperatures of option 1 with air change rate 13 (S1_13) and with air change rate 80 (S1_80), together with measured courtyard and weather station temperatures for 1 day.

OUTLOOK

Many more comparisons of measurements and simulation results of microclimatic conditions in outdoor spaces are needed before we can conclusively evaluate the reliability of the options proposed in this paper. Nonetheless, the results so far seem to point to an attractive potential of buildings and microclimate simulation tools toward more detailed input information regarding boundary conditions for thermal performance simulation tools.

ACKNOWLEDGEMENT

This project was funded in part by the EU-Project "Development and application of mitigation and adaptation strategies and measures for counteracting the global Urban Heat Island phenomenon (Central Europe Program, No 3CE292P3). Additional resources were made available within the framework of Wirtschaftskammer Wien – Wirtschaftskammer-preis 2011- "Monitoring and modeling of the urban micro-climate". The authors would also like to acknowledge the contributions by Aida Maleki, Matthias Schuss, Salahaldin Shoshtari, and Farhang Tahmasebi toward the generation and processing of the data used in this paper.

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