261: Implications of varying weather data sets for predictions of thermal performance of buildings

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Abstract

This paper explores the implications of different input assumptions pertaining to local weather conditions (as represented in weather files) for computational predictions of buildings' thermal performance. As a case in point, we used twenty two distinctive weather files (based on meteorological data from different weather stations, different years) for the city of Vienna to compute heating and cooling energy demands of three different buildings. The results demonstrate the significant fluctuations in the buildings' predicted heating and cooling energy demand due to differences in micro-climatic assumptions. We explored the possibility to assess the impact of projected changes in standard micro-climatic indicators such as heating degree days and cooling degree hours on the buildings' heating and cooling loads.

Keywords: heating and cooling energy demand, micro-climate, weather files, simulation

1. Introduction

Computational building performance simulation provides a potentially effective means to support the design of buildings that provide desirable indoor environmental conditions while operating in an energy-efficient manner [1]. The reliability of performance simulation is, however, dependent on the quality of simulation input assumptions. Simulation-based prediction of the primary indicators of a building's thermal performance (energy requirements, thermal comfort conditions) requires, amongst other things, the specification of the micro-climatic context of the building [2]. Toward this end, dynamic thermal simulation applications typically rely on standard weather files. Such files are based on long-term monitored data from weather stations. There are two main reasons why this process involves uncertainties:

- Firstly, monitored data on weather conditions is available, in the strict sense of the word, only for a limited number of locations. Conditions in the specific location of a building may deviate from those of the designated (e.g. closest) weather station's location [3]. Algorithms are available, of course, that generate weather file data for locations for which measured data is not available. But the generated results contain various levels of error depending on the circumstances (e.g. the distance of the building location from the weather station location, differences in topographic conditions).

- Secondly, weather files are typically based on past observations. The actual weather conditions in any specific year can be very different from the pattern indicated by such long-term data. This is of course to be expected and is, as such, not problematic: the main objective of performance simulation is usually design benchmarking and optimization and not derivation of absolutely accurate predictions for a specific point in time in future. A problem occurs, however, if – as highlighted by recent discussions – a change in climate is to be expected [4]. For example, according to recent studies, the winter temperatures in eastern Austria in the next thirty years will be about 1.3 K higher than in the last eighty years. The summer temperatures in the dense urban areas could be up to 2.5 K higher and the frequency of heat waves will significantly increase. This would imply that historic weather information, if uncritically used for the prediction of the future performance of a long-life product such as a building, may lead to systematic errors. Thus, the scope of uncertainties caused by variations in the assumptions regarding micro-climatic conditions must be studied and the respective results must be provided to the professionals (architects and building performance specialists) toward realistic appraisal and specification of thermal performance characteristics of designs.

In this context, the present contribution explores the implications of different assumptions regarding micro-climatic boundary conditions (in a specific location) for computational predictions of energy performance of buildings. Specifically, the effects of variance in micro-climatic input data due to spatial (position of the monitoring station) and temporal (date of weather file) origins of weather information on the outcome of thermal performance simulation studies are analyzed.

2. Approach

The research method involved the following steps:

i) Three reference objects were selected, representing buildings of different size, function, and construction. Table 1 provides some basic information on these objects.

ii) Local weather information was collected for a reference city (Vienna, Austria). Thereby, 22 annual climatic data documents were considered (seven files from three different weather stations, data from one weather station for eleven successive years, a file from a simulation application, and three files from a climate database). Table 2 provides a summary of the selected weather files. Figure 1 shows the considerable differences in mean outdoor temperature, heating degree days (HDD), and cooling degree hours (CDH) associated with these files. HDD is a single-number descriptor (in Kd) of the climatic conditions in a specific location in view of building heating requirements. It is computed as the sum of the differences between the design indoor temperature (in this case 20 °C) and the mean daily outdoor temperature over all days for which the average outdoor temperature is below a certain threshold value (in this case 12 °C). CDH is a single-number descriptor (in Kh) of the climatic conditions in a specific location in view of building cooling requirements. It is computed as the sum of the differences between the threshold indoor temperature (in this case 26 °C) and the hourly outdoor temperature over all hours for which the outdoor temperature is above the threshold value [5].

iii) Numeric simulation of heating and energy demand was conducted for the selected reference objects using the above mentioned 22 alternative micro-climatic input data assumptions (cp. Table 2). Table 3 summarizes the user profile assumptions used for the simulations, which were conducted using a numeric transient thermal simulation application [6].

iv) Simulation results were used to explore the uncertainty involved in the computational prediction of criteria pertaining to the thermal performance of buildings. Moreover, the results were discussed in the context of climate change projections and their implications for the simulation-based predictions of buildings' energy performance.

Table 1: General information concerning the three building models for simulation of heating and cooling demand

Building	B1	B2	B3
Type	Single family house	Unit in Apartment house	Office building
Gross floor area [m^2]	287	222	2887
Net floor area [m^2]	233	191	2656
Volume V [m^3]	976	687	10025
Envelope area A [m^2]	737	143	1594
Window area [m^2]	51	19.4	1409
Mean envelope U-Value [$W.m^{-2}.K^{-1}$]	0.72	0.63	1.37
V/A [m]	1.32	4.33	6.29

Table 2: Selected weather files (city of Vienna, Austria)

Weather file	Source	Year
W_1	WS "Hohe Warte"	1996
W_2	WS "Hohe Warte"	1997
W_3	WS "Hohe Warte"	1998
W_4	WS "Hohe Warte"	1999
W_5	WS "Hohe Warte"	2000
W_6	WS "Hohe Warte"	2001
W_7	WS "Hohe Warte"	2002
W_8	WS "Hohe Warte"	2003
W_9	WS "Hohe Warte"	2004
W_10	WS "Hohe Warte"	2005
W_11	WS "Hohe Warte"	2006
W_12	WS "Innere Stadt"	2004
W_13	WS "Innere Stadt"	2005
W_14	WS "Innere Stadt"	2006
W_15	WS "TU-Vienna"	2004
W_16	WS "TU-Vienna"	2005
W_17	WS "TU-Vienna"	2006
W_18	WS "Unterlaa"	2006
W_19	Standard weather file in TAS [6]	1993
W_20	Standard weather file Meteonorm [7]	1961 – 1990
W_21	Standard weather file Meteonorm	1996 – 2005
W_22	Standard weather file Meteonorm (extreme)	1996 - 2005

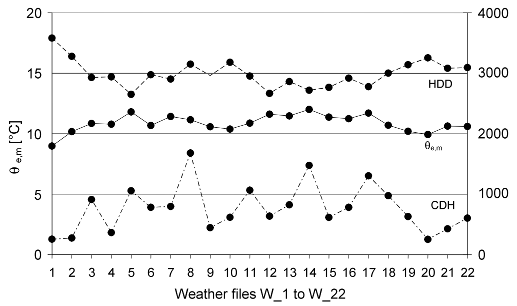

Fig 1. Mean outdoor temperature $\theta_{e,m}$ [°C], HDD [Kd], and cooling degree hours CDH [Kh] corresponding to weather files W_1 to W_22 (see Table 1)

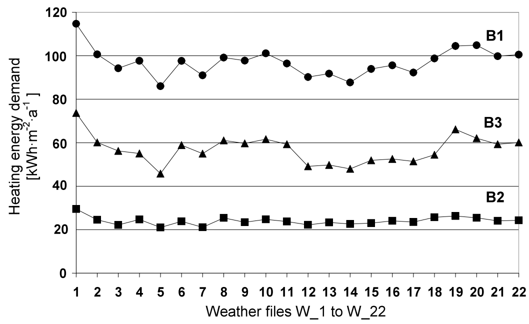

Fig 2. Simulated heating energy demands of buildings B1 to B3 for weather files W_1 to W_22

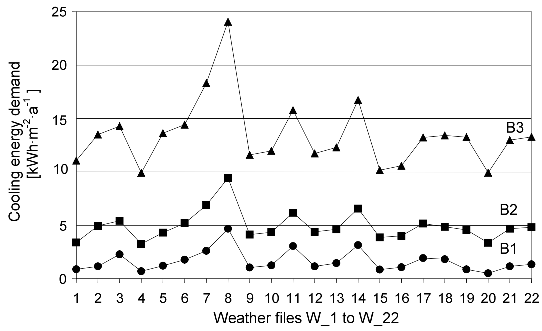

Fig 3. Simulated cooling energy demands of buildings B1 to B3 for weather files W_1 to W_22

Table 3: User profile assumption for simulations

Building type	Residential	Commercial
Heating set-point temperature [°C]	20	20
Cooling set-point temperature [°C]	27	26
Heating system operation (hours)	24	14
Cooling system operation (hours)	24	12
Air change rate [h^{-1}]	0.4	1.2
Internal gains (people, lights, equipment) [$W.m^{-2}$]	3.75	3.75
Operation days	365	269

3. Results

Figures 2 and 3 show the simulated heating and cooling energy demands of buildings B1 to B3 for weather files W_1 to W_22. As these figures demonstrate, computed heating and cooling energy requirements under the assumption of a standard reference year (such as W_19) can significantly deviate from those computed for weather station of any specific year. To further illustrate this point, Table 4 summarizes the deviation of simulated heating and cooling energy demand of buildings B1 to B3 for standard weather file W_19 from the corresponding mean values simulated for more recent weather station files W_1 to W_11.

Furthermore, Table 5 shows the relative deviations (in %) of the maximum heating and cooling energy demand of buildings B1 to B3 from corresponding minimum values as applied to simulation results from year W_1 to year W_11.

These results suggest that assumptions pertaining to past data on micro-climatic conditions lead – given a ongoing gradual increase in global temperatures – to overestimation of future heating energy demand and underestimation of future cooling energy demand of buildings.

Table 4: Relative deviations (in %) of heating and cooling energy demand of buildings B1 to B3 for standard simulated for weather file W_19 from the corresponding mean values simulated for weather station files W_1 to W_11

Building	B1	B2	B3
Heating energy demand deviation	+7	+10	+12
Cooling energy demand deviation	-111	-14	-8

Table 5: Relative deviations (in %) of the maximum heating and cooling energy demand of buildings B1 to B3 from corresponding minimum values as applied to simulation results from year W_1 to year W_11

Building	Energy demand for	Relative deviation [%] of maximum from minimum
B1	Heating	33
	Cooling	566
B2	Heating	40
	Cooling	66
B3	Heating	61
	Cooling	143

In addition to demonstrating the impact of different weather data assumptions on the magnitude of predicted pertinent energy performance indicators, we also explored the possibility that such impact could be expressed as a function of simple numeric descriptors of weather information such as heating degree days (HDD) or cooling degree hours (CDH). The results are shown in Figures 4 and 5.

Figure 4 shows the relative deviation of the simulated heating energy demands of the buildings B1 to B3 derived for weather files W_1 to W_11 from heating energy demand of a reference year W_5 (year 2000) as a function of the relative deviation of respective HDD values from that of the same reference year.

Figure 5 shows the relative deviations of the simulated cooling energy demands of the buildings B1 to B3 derived for weather files W_1 to W_11 from cooling energy demand of a reference year W_4 (year 1999) as a function of the relative deviation of the respective CDH values from that of the same reference year.

These results are significant: They imply that it is possible, in principle, to estimate the heating energy demand of a given building model for any year with a known (or assumed) HDD value, based on simulated results for a reference year. Likewise, a building's cooling energy demand for a year with and assumed CDH value could be estimated based on simulation results of a reference year.

The following two examples shall illustrate this possibility:

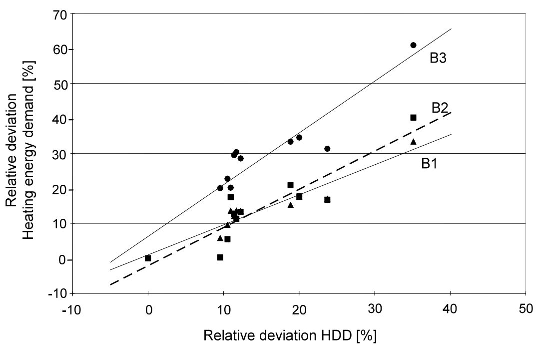

Fig 4. Relative deviation of the simulated heating energy demands of the buildings B1 to B3 derived for weather files W_1 to W_11 from heating energy demand of a reference year W_5 (year 2000) as a function of the relative deviation of respective HDD values from that of the same reference year

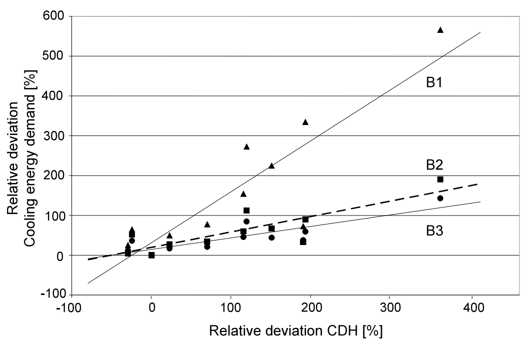

Fig 5. Relative deviations of the simulated cooling energy demands of the buildings B1 to B3 derived for weather files W_1 to W_11 from cooling energy demand of a reference year W_4 (year 1999) as a function of the relative deviation of the respective CDH values from that of the same reference year

- The heating energy demand of a single house in Vienna as simulated for the reference year 2000 (W_5, HDD = 2650 Kd) is found to be 86 $kWh.m^{-2}.a^{-1}$. To estimate the heating demand of this house in a future year with a projected HDD of 2385 Kd, the relative deviation is derived first (-10%). Given this information, the relative deviation of heating energy demand can be derived using the B1 function in Figure 4 (-7.6%). Based on this information, the projected future heating energy demand is found to be 79 $kWh.m^{-2}.a^{-1}$. An examination of the above procedure, as applied to buildings B1 to B3 for the weather files W_1 to W_11, did not involve errors more than ±10%.

- The cooling energy demand of a single house in Vienna as simulated for the reference year 1999 (W_4, CDH = 364 Kh) is found to be 0.7 $kWh.m^{-2}.a^{-1}$. To estimate the cooling demand of this house in a future year with a projected CDH of 1680 Kh, the relative deviation is derived first (+361%). Given this information, the relative deviation of heating energy demand can be derived using the B1 function in Figure 5 (+495%). Based on this information, the projected future cooling energy demand is found to be 4.2 $kWh.m^{-2}.a^{-1}$. It should be noted at this stage, that the estimation of cooling energy demand (for a year with a known CDH value) results, as compared to estimations of future heating demand, in considerably larger errors (±50% and more). This implies that CDH performs rather poorly as a single-number descriptor of weather information in relation to cooling energy demand.

Note that the B1 functions in Figure 4 and Figure 5 apply to a specific building model and are thus not representative of all single house buildings. Ongoing studies aim at the exploration of the possibility to derive a set of generalized (representative) functions for a number of building types.

Our data allows also to further explore the influence of the location of the weather station on fluctuations of simulated heating and cooling demand: As mentioned before, Vienna weather files were available for three different weather station locations ("Hohe Warte", "Innere Stadt", and "TU-Vienna") for three consecutive years (2004 to 2006). Table 6 summarizes the relative deviations of maximum from minimum simulated heating and cooling demand (in %) based on weather data from the three above mentioned weather stations and for the years 2004 to 2006. These results suggest that discrepancies in simulated heating and cooling energy demand due to the application of weather data from different locations can be significant. In our study, such deviations were especially high in case of heating energy demand calculations for office buildings and cooling energy demand for single houses.

Table 6: Relative deviations of maximum from minimum simulated heating and cooling demand (in %) based on weather data from three different weather stations in the city of Vienna for the years 2004 to 2006

	Heating energy demand			Cooling energy demand		
Year	B1	B2	B3	B1	B2	B3
2004	8	5	22	22	13	15
2005	10	6	23	36	15	16
2006	10	5	24	68	27	27

4. Conclusion

Computational building performance simulation is an important instrument to support the design of habitable and sustainable buildings. It provides a means to perform virtual experiments on building designs and to evaluate and optimize their expected performance before the actual construction and operation of buildings. However, building performance simulation is prone to errors and uncertainties beyond those associated with the reliability and robustness of the underlying algorithmic methods and procedures: one such source of uncertainty was addressed in the present paper, i.e., implications of micro-climatic assumptions for the simulation of the thermal performance of buildings.

Using the instance of alternative weather files for the city of Vienna, Austria, the significant range of fluctuations in the simulated values of buildings' heating and cooling energy demands was demonstrated. Specifically, simulation-based thermal performance predictions based on long-term past weather data are likely to considerably deviate from those that take climate change projections into account. The present study further demonstrated that it is possible, in principle, to compute the heating (or cooling) energy demand of a given building design for any year with a known (or assumed) value of heating degree day HDD (or cooling degree hour CDH), based on simulated results for a reference year.

5. References

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