IMPROVED BUILDING ENERGY PERFORMANCE MODELLING THROUGH COMPARISON OF MEASURED DATA WITH SIMULATED RESULTS

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ABSTRACT

This work forms part of the ModBen project conducted by Fraunhofer ISE. This paper aims to compare actual detailed hourly building energy data from a non-residential, demonstration building located in Berlin, with results simulated using IDA-ICE for the same building. The dataset collected at the demonstration building consists of total energy consumption, weather data, indoor conditions and HVAC system parameters, measured in at least hourly time steps. This paper presents the first steps in modelling the building and comparing simulated results to the measured data.

The simulated building energy performance results achieved in the first stage of computer modelling show a reasonable correlation with measured data, however, further work is required to create a building model that describes reality to a level suitable for optimisation of controls and various studies on fault detection and diagnosis.

Keywords: Equation-based building simulation, energy modelling, building energy monitoring, Barnim, IDA-ICE.

INTRODUCTION

This work forms part of the ModBen (model based benchmarking, sponsored by BMWi) project which aims to improve the energy efficiency and thermal comfort of buildings through extensive monitoring of existing non-residential buildings in addition to comprehensive computer modelling, simulation and a thorough comparison with actual monitoring results (ModBen 2008a). This paper will focus on one of the ModBen demonstration buildings, the Barnim Dezernat 3 building (ModBen 2008b), and presents the first steps in modelling the building and comparing simulated results to the measured data.

The Barnim building is one of a group of government office buildings, located in Berlin. The building was commissioned in 2007 and is participating in the EnBau research program (ModBen 2008b). The Barnim building is a 4 storey office building with an atrium and a total floor area of 4,878m^2 (Voss 2007).

Features of the building include a well insulated façade with a lightweight wood construction and cellulose insulation, triple glazed windows, mechanical ventilation with high efficient heat recovery and a heat pump with a borehole heat exchanger which uses the ground as a heat source in winter and a heat sink in summer (Voss 2007).

The building simulation software IDA ICE (Indoor Climate and Energy) (Sahlin 2004) was used to model and simulate the Barnim building. This equation based program was selected for various reasons: it is easy to implement and change mathematical models; the variable time steps determined by the solver (essential for control studies); the compatibility with Modellica and the possibility to import Industrial Foundation Class (idf) building description. Further, the IDA ICE model library aims *"to provide the best possible resolution of key phenomena while enabling whole-building, full-year simulation within commercially acceptable execution times"* (Sahlin 2004).

A comprehensive measured dataset is collected from the Barnim building consisting of over 400 data points measured in sub-hourly time steps by the building automation system. The measured data of interest for this work includes the total energy consumption, weather data, indoor conditions and HVAC system parameters.

MODELLING AND SIMULATION OF THE BARNIM BUILDING

Construction of the building model

Detailed building plans of the plant and HVAC systems, architectural drawings, and energy performance reports including details on building materials and construction were the main sources used to obtain the information required to create the building model.

The Barnim building is a complex building. The complexity comes from the architectural design that features an unusual building shape and internal spaces that are also irregularly shaped. This required the specification of non-rectangular zones. The design and layout of the internal spaces and rooms also varied between each level. From the outset two different models were created - a detailed model and a simple model. The detailed model contained different zone shapes and layouts for each level. Each window was entered separately and each zone had water radiators and cooling units. This detailed model resulted in a total of 35 zones. External shading devices are included in the model and the control scheme implemented closes the external shading devices when the radiation on the surface is greater than 200W/m².

The simple model used the same zone shape for all levels which was approximated to be representative of the zone shape for each level (see Figure 1). This simple model was created using only 9 zones. The window area was summed for each level and input as a single window. The heating power for each zone was also added and a single radiator unit was input for each level. The heights of the zones in the simple model were defined to be the height of the building. This means that there are no visible internal floors in the model. However, the floors are entered as thermal masses. Internal walls within zones are also entered in this manner. This simple model required significantly less time to develop and requires much less time to execute building simulations.

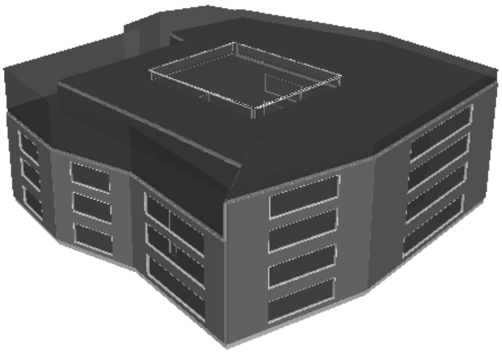

Figure 1: Three dimensional view of simple Barnim building model

The benefit of grouping all the windows and radiators together is the reduction in simulation time. For example the calculation and summation of the solar input, heat transmission … of windows identical windows of one zone is a process that the simulation program performs at every time step (IDA ICE 2008). If these windows are manually combined to one at the point of building modelling prior to simulation, the number of calculations performed each time a simulation is executed is reduced and the speed of simulation is significantly faster. It should be noted that the grouping of windows is not a suitable approach for all buildings. For building simulations where the view factors of the windows and natural ventilation through windows are important factors to be considered, it would be necessary to input each window separately into the building model. For the Barnim building additional natural ventilation is not modelled yet and the windows are reasonably evenly spaced making variations of the view factor negligible in this case. If only identical windows in the same height are grouped and the wind pressure coefficients are uniform over entire façade modelling of natural ventilation is still possible.

Heating and cooling system

The building heating and cooling system features a borehole heat exchanger coupled to two reversible heat pumps which supplement the heat gained from the earth. Boilers do not form part of the system. Water radiator heating units are located in the offices and rooms. Corridors are heated and cooled using an integrated floor system.

The building model, at this stage, does not include these non-standard HVAC system components. This work has concentrated on developing the building envelope and analysing the heating energy of the building corresponding to the available measurement data as the first step. Water radiator heating units and an AHU system were implemented in the model to provide the heating requirement. The heating systems were oversized so that the system has unlimited capacity to provide the required heating. The heating demand calculated by the simulation program represents the energy required to maintain the zone within the set temperature range.

Weather data

The weather data used initially for the simulations was the inbuilt ASHRAE 2001 weather file for Berlin. As the weather data used for simulation in this case was different from the actual weather, the simulated results and measured data could not be directly compared. In order to provide a relevant comparison between simulated results and measured values, an energy signature graph was generated (see Figure 4).

The weather data used for further simulations was real data measured on site at the Barnim building. A weather file was created from the actual global radiation, outdoor temperature and humidity data. The real weather data used for simulation of the Barnim building covers the period from January 2008 to May 2008. Collection of this weather data is ongoing and will be used for further work to continue the comparison between simulated results and measured data over the whole year.

Electricity consumption

Electricity consumption data of three minute resolution for the whole building is part of the measured data set and this data was used to create various input schedules for the modelled building.

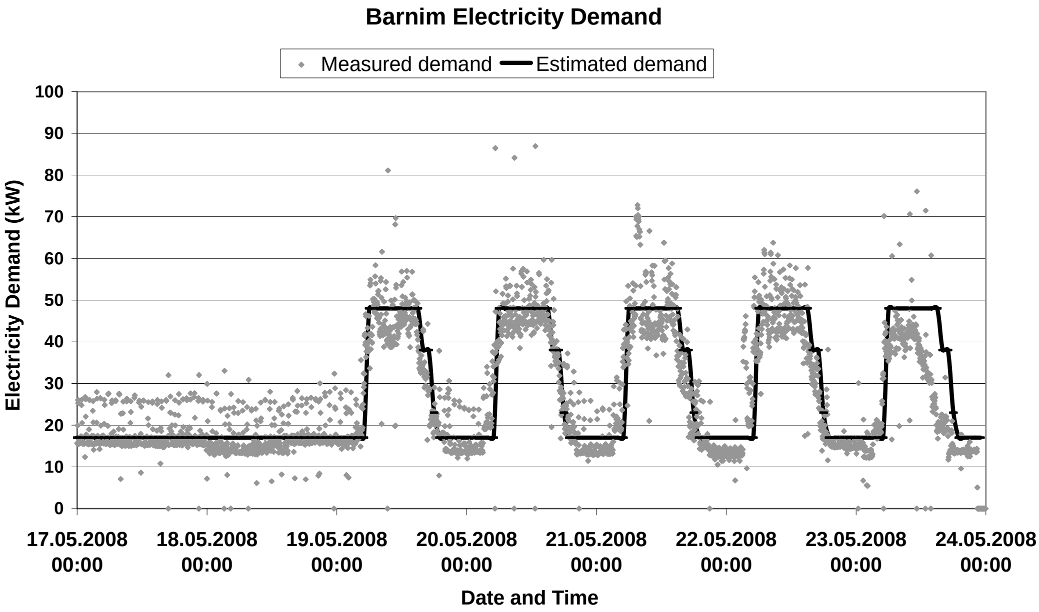

Figure 2: Measured overall energy consumption compared with the approximated energy consumption for Sunday17th – Friday 23rd May 2008

An approximate breakdown of the energy consumption between the broad categories of HVAC, artificial lighting, office equipment, and other equipment (lifts, server rooms etc.) was generated. This was used to assist with matching the modelled electricity consumption data to the measured values. The graph in Figure 2 above shows a comparison of the measured electricity values with the electricity schedule used to provide input values for the simulation program. Due to a malfunction in the monitoring device that was only recently fixed, electricity consumption data for the Barnim building is available only from 1st May 2008 onwards.

COMPARISON OF SIMULATED RESULTS WITH MEASURED DATA

The return air temperature from the HVAC system, the AHU heating coil power were the variables selected for comparison. An input source file was used for the simulations and this contained the actual AHU supply air temperatures that were recorded at the building. Air is delivered by the AHU to the office areas and is extracted from the corridors to facilitate air flow though the building. At this stage of the modelling process, before the plant equipment is specifically defined, this analysis was used to provide an indication of how closely the modelled building represents the actual building.

Comparison of AHU return air temperatures

The return air temperature is similar to the room air temperature for well mixed ventilation so return air temperatures are taken as a measurement of the mean zone air temperatures. Figure 3 shows the comparison between the simulated and measured values. It can be seen in the graph that the overnight measured values have been removed and only the measured values for the period of AHU operation are shown. This is because the measured values of the AHU return air temperature for the overnight period do not reflect the air temperature of the zones during this time but show the temperature of the AHU. However, in the simulation the return air temperature always reflects the mean zone temperature. The modelling of the real behaviour of the return air temperature at the AHU under no-flow conditions would be very complex and is not necessary for other parts of the simulation.

For the hours of AHU operation the modelled results correspond reasonably well to the measured values. The return air temperature of the AHU increases throughout the day due to internal gains from people, office equipment and lights and sunlight entering through the windows. It is obvious from the graph that further work is required to more accurately match the values for the modelled and the real building but it also shows the wide range of zone temperatures due to user and control influences. The next steps will involve modelling of the floor heating and cooling system used in the corridors, and development and input of the actual plant equipment installed in the building. It is also necessary to gain a better idea of the user influence on building operation and an improved understanding of the actual building control system.

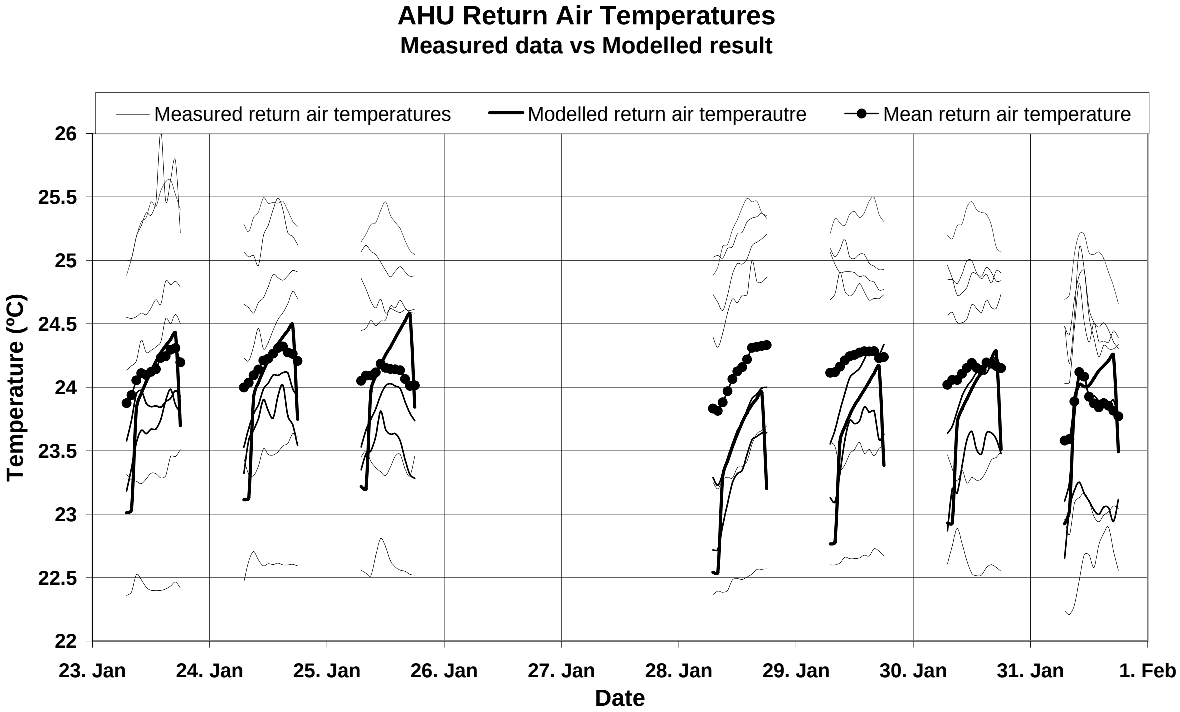

Figure 3: Comparison between measured and simulated return air temperatures for 23rd January– 1st February 2008 only recorded when fans are operating

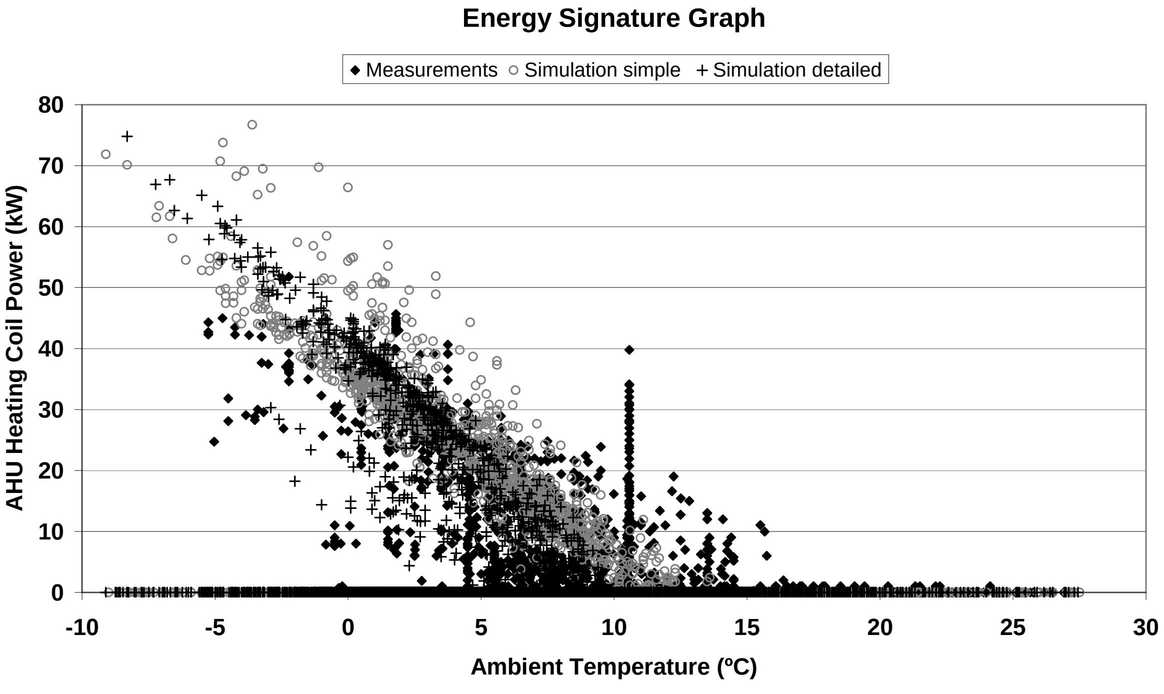

Figure 4: Energy signature graph of AHU heating coil power for 1st January – 25th May

Comparison of AHU heating coil power

Figure 4 shows an energy signature graph for the heating coil power. As explained previously, this graph was generated to examine how closely the initial simulations represented the actual building performance given that the modelled building was subjected to different weather conditions during simulation compared with the actual building. As the heating coil power required by the AHU is affected by the outdoor temperature, a useful comparison can be made by graphing this variable against the corresponding ambient temperature. The modelled value was plotted against the ambient temperature from the weather file used by the simulation program and the measured values for

AHU heating coil power were plotted against the actual ambient temperatures measured at the building site. The energy signature graph shows good correlation between the measured and simulated data with both sets of data points following a similar trend.

This graph also highlights one of the problems experienced with the measurement data with a series of data points stacked at 10.57 degrees Celsius ambient temperature. In this case, the data acquisition system received no new ambient temperature values over a period of 10 days and reported only the last measured value for the whole period.

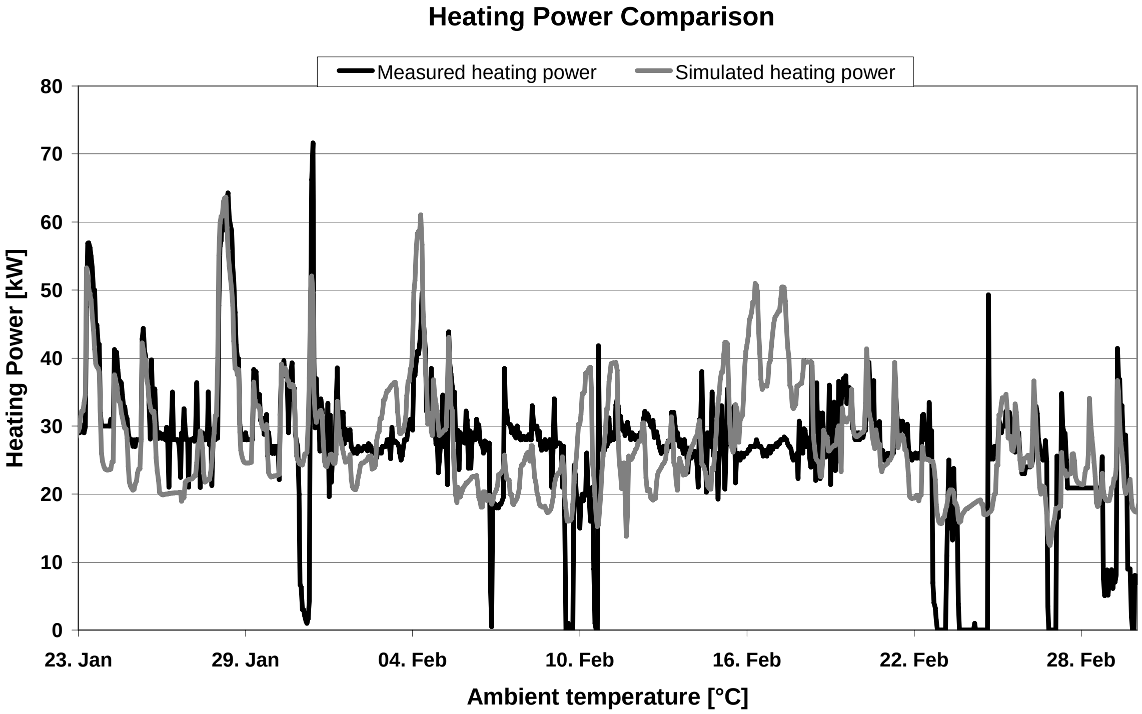

Figure 5: Energy signature graph of the total supplied building heating power for 23rd Jan – 29th Feb 2008

Comparison of heating power supplied to building

Further simulations were conducted using an input file of the real weather data measured at the Barnim Building. This allowed direct comparison between the measured and simulated values for the total heating power supplied to the building. Figure 5 presents a graph in which the combined heating power supplied to the radiators and the AHU heating coils in the simulated and measured cases are compared. The simulated heating power supply and the measured heating power supply are plotted over the period from 23rd January – 29th March.

The simulated values in Figure 5 show reasonable correlation to the measured values. The correlation coefficient on hourly values is 0.7 and on daily mean values 0.93. The deviation of the simulated heating demand over this period is +14%. This is likely to be due to user influences and control issues. It is known from observing the measured data, that there were several changes of the control strategies in this time period. Furthermore there seem to be some missing data values.

DEMONSTRATION OF HEATING ENERGY OPTIMISATION

To demonstrate the goals of these building simulations one first step of a manual optimisation was done. The supply temperature was limited to 23 °C instead of values up to 31.9 °C taken from the measurements. The heating energy was reduced by 4 % without a noticeable change to the thermal comfort. The operative temperature decreased by 0.2 K. For some of the zones with temperatures above 25 °C the thermal comfort improved considerably.

COMPARISON OF SIMULATION RUN TIME

The duration of the simulation run time for the detailed 35 zone model to complete a simulation for a 5 month time period was 22 minutes on a 2.4 GHz PC (AMD Athlon™ 64 Processor 4K+). The simple 9 zone model was approximately 5 times faster and required 4 minutes to complete the same simulation and provided very similar results. Figure 4 provides an example of the similarity between the simple and detailed simulation results for the AHU heating coil power. Due to the length of the simulation run time for the detailed model, the simple model was preferentially used to provide the simulation results presented in this paper.

The simulation run time is an important consideration in the energy performance modelling of buildings. In order for energy performance modelling to become a standard part of the building design phase, or in the case of existing buildings, part of the energy performance optimisation, the construction of the building model and the simulation run time should be simple and quick. It should be convenient for building designers and consultants to perform and thus use less of the available project funds while still providing valuable and accurate results.

Throughout the building modelling process it is necessary to run the model frequently, following even small changes to the model. This allows the causes of problems with the building model to be identified and rectified more easily. Reduced simulation run time is also important in this situation.

CONCLUSION

The ongoing aim of this work is to create a fast building model simulation that describes actual building energy performance to a level suitable for optimisation of controls and various studies on fault detection and diagnosis (FDD). This paper has shown that the first stage of building energy modelling has produced simulated results that show reasonable correlation to actual measured values.

Continuing work will focus on developing code for the non-standard plant equipment, and refining operation schedules and control issues for input into the simulation program. While modelling this complex building, an emphasis on maintaining the simplicity and minimising simulation run time of the building model will remain an important aspect of this work.

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