Occupant Behavior of a Plus Energy Building Regarding Monitoring and Standard Values

Henryk Haufe, Mario Stelzmann, Ulrich Moeller and Stephan Schoenfelder

Leipzig University of Applied Science, Leipzig, Germany

Kurzfassung

In einer aktuellen Monitoringstudie des Bundesministeriums für Umwelt, Naturschutz, Bau und Reaktorsicherheit werden 35 Gebäude mit zukünftigen Energiestandards untersucht. Zwei dieser Gebäude (Plus-Energiehäuser) werden an der HTWK Leipzig betreut und untersucht. Das Energiekonzept eines nach Effizienz-Plus Standard gebauten Hauses beschreibt den Grundsatz, dass in der Jahresenergiebilanz mehr Energie erzeugt wird als Primär- und Endenergie benötigt. Schon zum heutigen Zeitpunkt zeigen sich zum Teil gravierende Differenzen zwischen Planungssimulation und Messung. Der wesentliche Grund dafür liegt an nicht passenden Simulationsmodellen. Die hochkomplexe technische Gebäudeausrüstung, verknüpft mit dem Einsatz von neuen Baustoffen, überschreitet die Einsatzmöglichkeit dieser einfach zu bedienenden genormten Programme und genormter Nutzerverhalten. Dieser Beitrag beschreibt mit Hilfe von Monitoringdaten und SimulationX den Einfluss von Hausbewohnern auf die Gebäudetechnik im Niedrigenergiehaus-Standard und verdeutlicht die zunehmende Einflussnahme der Nutzer auf den Energieverbrauch von zukünftigen Wohnhäusern im bewohnten Zustand.

Abstract

Durring a current monitoring study of the Federal Ministry for Environment, Nature Conservation, Building and Nuclear Safety 35 residential buildings with future building standards are analyzed. Two of these buildings (Plus Energy Buildings) are managed and analyzed by the Leipzig University of Applied Science. An energy-plus house produces more energy from renewable energy sources, over the course of a year, than it imports from external sources. Until now there are serious differences between planning simulation and measurement. The main reason has been identified as non-matching simulation models. Complex technical building services, associated with the use of new building materials, exceed the possibility of usage for standardized programs. By using monitoring data, this paper describes the influence of tenants in low energy houses by using the Green-Building library in SimulationX. The increasing influence of occupants on energy consumption will be illustrated.

1. Introduction

Until 2050, the legislature pursues the aim a climate-neutral building stock in Germany. The reduction of the heat demand in residential and non-residential buildings and the use of renewable energies are essential keys to achieve this goal.

For homeowners a high consumption of regenerative power is important. The close link between highly efficient building services and new construction techniques requires a high level of building planning. Even small mistakes in planning may have a major impact on energy balance and costs (VDI guideline 2078). The capabilities of dynamic simulations can change the process of planning, design, implementation and management phase of buildings. Taking a holistic view of the entire system can change standard building processes.

Though, occupant state monitoring can validate if the requirements can be fulfilled in practice. Therefore, it is necessary to detect continuously the used amounts of energy, such as electricity and heat as well as the fed in public power grid. Deeper analysis of consumption structure requires balancing the amounts of energy, climatic conditions and usage behavior of the residents. In this work monitoring data are analyzed in correlation with a dynamic building simulation model using SimulationX.

2. Reference Building and Simulation Model

2.1 Reference Building

Figure 1: „Plus-Energy-House" in Bischofswiesen

The reference efficiency plus house in Bischofswiesen (Figure 1) which was built in 2013 is located in an alpine region (Bavaria) 15 km south of Bad Reichenhall. The multi-family building includes six apartments. In two rented apartments there are living three people each. Four other tourist apartments strongly vary in usage.

The total heated floor space is 627.5 m². Underfloor heating is available on the ground floor and upper floor, the attic has wall mounted radiators. All electrical household devices are rated at least A + energy standard. A water/water heat pump is used for heating. Currently the heat pump operates in mono state and feds a heating storage tank and a domestic hot water storage tank. Generated solar energy from the photovoltaic system with a total capacity of 41.6 kWp, are either stored in lead acid batteries with a usable capacity of 25 kWh or are fed into the public grid. Ventilation systems with heat recovery are installed in all floors. The living space ventilation is carried out via six separate on demand ventilation systems. Moreover an electric car is provided. Every 10 minutes a full measurement is recorded by the existing monitoring technology [1], [2].

2.2. Simulation Model

In order to reduce the complexity of the entire system and perform complete calculations, it is necessary to reduce the detailing level of simulation. Nevertheless, it needs to be guaranteed that interactions between different modules and components can still be to illustrated appropriately. The first sub-module includes the electric vehicle with own charging station and the photovoltaic system. The second sub-module features the domestic water storage, the hot water extraction point and a heat pump. Compared to the original heating system, simulation model includes 2 heat pump devices. The first one supplies water heating and the second one feeds the heat storage tank connected to the

third sub-module. This one includes the reference house with the heat pump, heating system and building components. Individual apartments are divided into 3 residential floors and a basement. Each of them includes different building characteristics and the individual occupant behavior.
A one year period has been established for analysis of observation data. Within this period, two weeks were simulated in SimulationX. These two weeks correspond to the warmest and coldest week, as recorded by the local weather station. For assessment of technical systems, it is important to choose weather extremes for building and technical equipment. Thus, the two weeks with weather extremes were selected. The third simulation was defined as a stress situation for the installed heating system technology. It is assumed as a cold winter week with an initial outside air temperature of -10 °C, stormy weather and no solar gains. Every 24 hours, the air temperature is lowered by 1 Kelvin until -16 °C is reached.
Using electric devices cannot be adjusted based on a "standard user profile" for all occupants. Individual user profiles, for each residential floor based of monitoring data, have been developed. Based on people activities heat dissipation is determined in VDI 2078 and DIN 13779 [3]. On average 15 to 60 liter of hot water per person at a temperature of 45 °C are required in homes every day. This indicates that the user-related energy demand of domestic hot water assumes a wide range [4]. Therefore an individual analysis of user behavior for each residents is required. One example (power consumption profile) is shown in hourly values for the hottest week in Figure 2. The basic power load was set to 0.4 kWh. Based on this as well as balancing tourist tax, determine room temperatures, heating consumption and residents absent time, the house can be set for summer and winter simulation. Though, a lot of different other occupants behavior, e.g., window opening/closing is unknown.

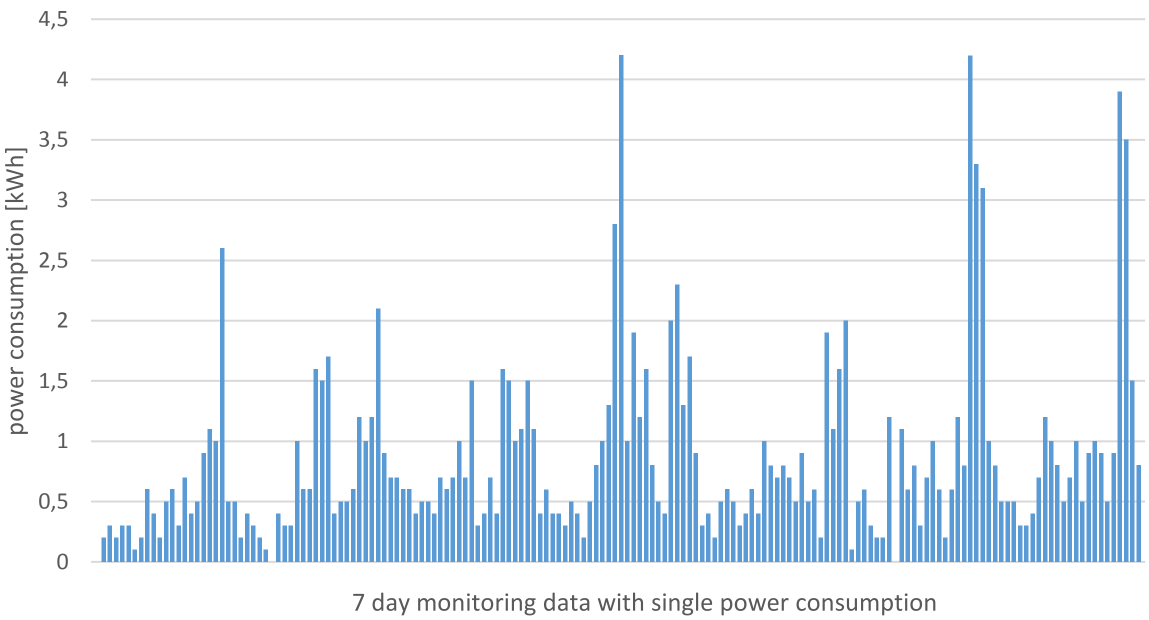

Figure 2: Residents power consumption profile in a winter week

3. Results

3.1 Summer Week

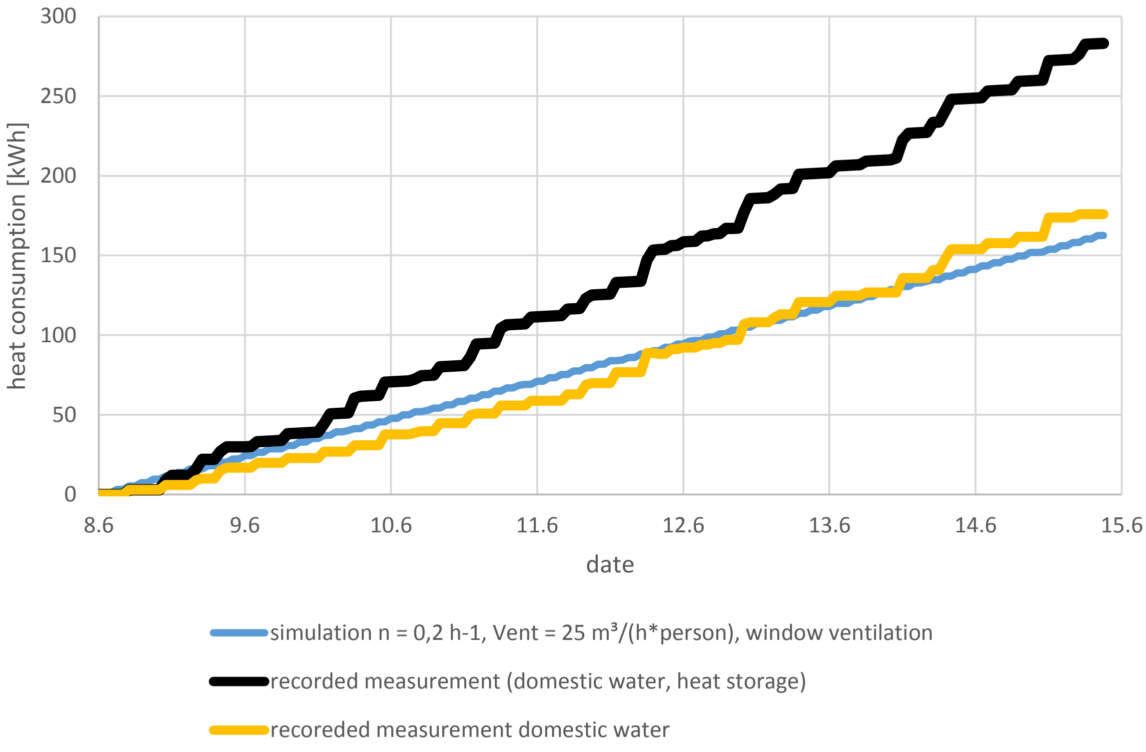

Figure 3: Heat consumption in summer week

In Figure 3 monitored and simulated heat consumptions are compared. Recorded heat consumption includes 2 curves. The first curve (measured value) represents the heat consumption for the domestic water heater. The second curve includes actual heat consumption of the heating system. Power uptake for water heating sums up to 55 kWh in the computer model. This corresponds to 50 percent electricity consumption for water and heating supplies. The recorded heat pump performance factor in the summer is 2.6 while the simulation predicts a performance factor of 3.0. Figure 4 illustrates the domestic water temperatures within the simulation and the actual recorded data. Maximum hot water temperatures are measured between 56.1 ° C and 55.5 ° C.

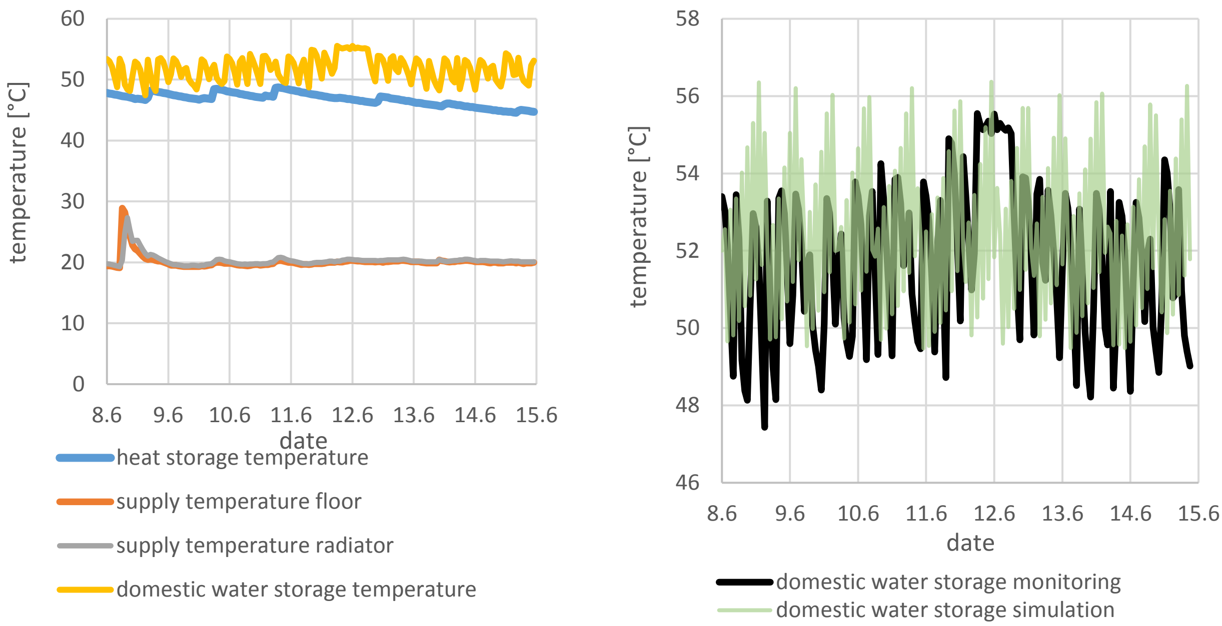

Figure 4: Domestic hot water temperature and storage tank temperature in summer

Figure 5 illustrates the living room temperatures at an increased window ventilation behavior at night depending on the outside temperature in summer. During the warmest day, the temperature differs from the real measured values, 1.2 to 1.6 K in relation to simulated values. The power consumption of the reference building including building services and electric car usage in summer simulation assets 171 kWh. Recorded power consumption in the reference house is 228 kWh.

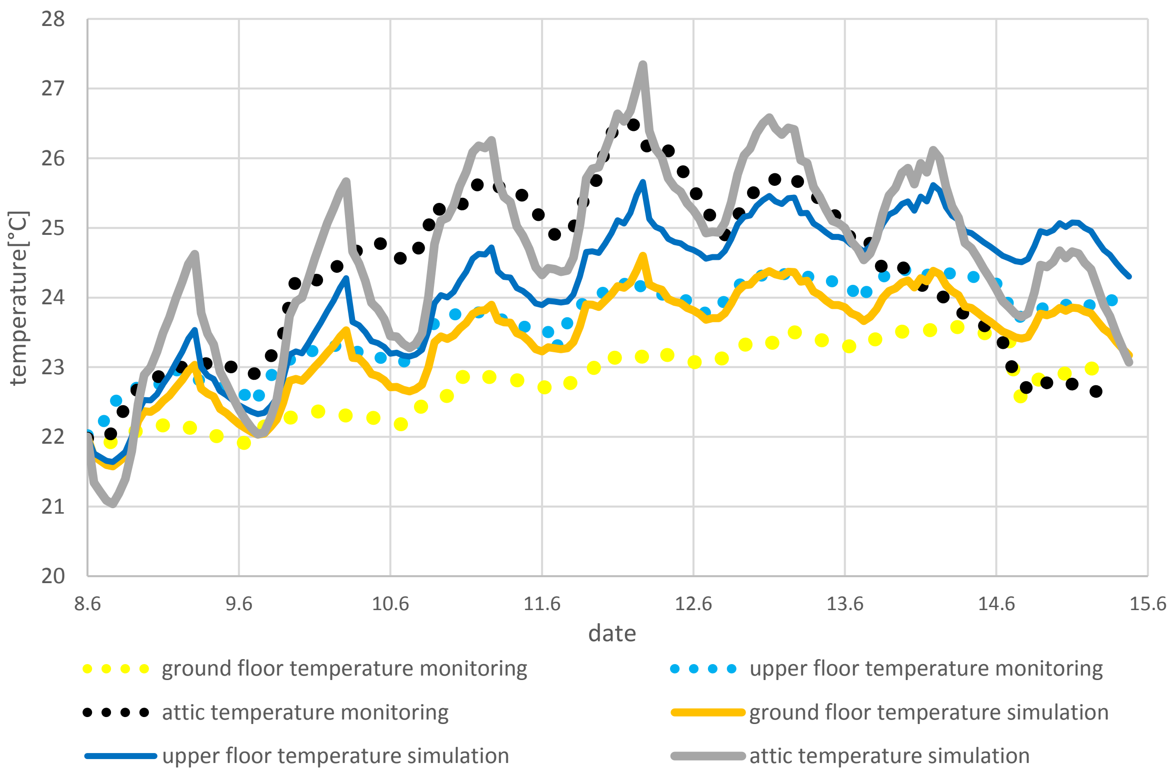

Figure 5: Interior temperatures with manual nightly airing

3.2 Winter Week

A large number of simulations were performed to evaluate the heat consumption in winter. These simulations revealed the influence of the air exchange rate. Heat consumption for heating and domestic water supply during winter is presented in Figure 6. It illustrates the increasing influence of air exchange rate to the heat consumption.

With power consumption and heat pump output, performance factors can be calculated. The actual performance factor in relation to the domestic hot water is 1.7 at a combined performance factor of 2.7. Combined performance factor in simulation is 4.0.

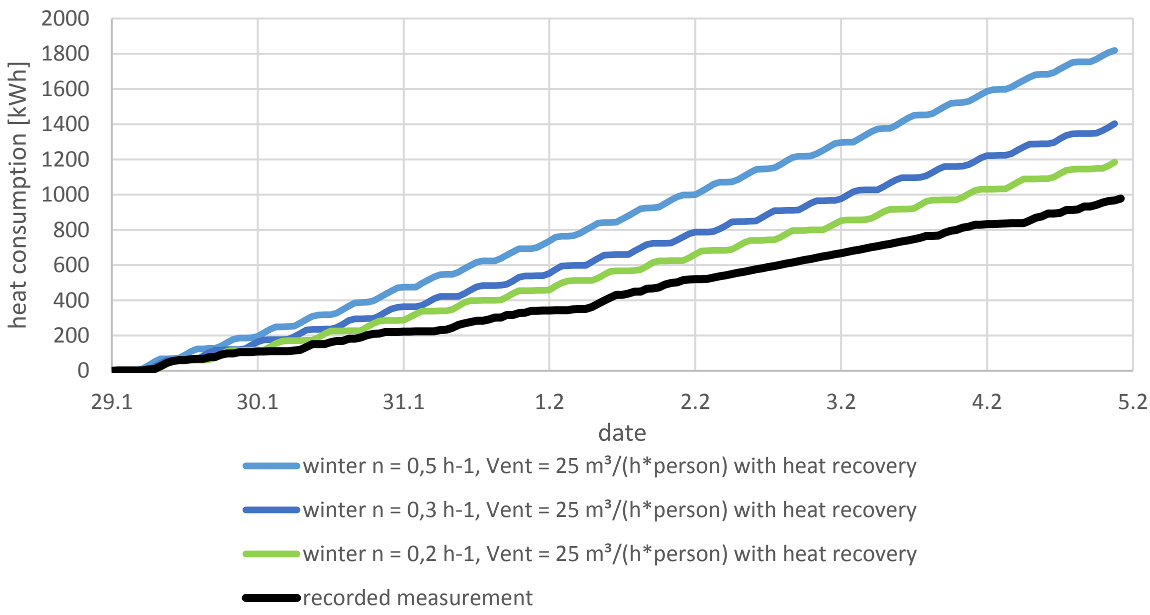

Figure 6: Heat consumption with differences in air exchange

3.3 Stress Simulation – Cold Winter

Simulation results have shown that the heat pump can exclusively be used to an air exchange rate of 0.5 h^{-1} with environmental conditions of window ventilation, stormy wind and external air temperature of -10 ° C. At an air exchange rate of 0.3 h^{-1} and window ventilation the heat pump is suitable to below -16 ° C outdoor air temperature.

4. Conclusion

4.1 Summer Week

The difference between recorded performance factor for DHW ranges from 2.6 to 3.0 within the simulation. This is mostly caused by thermal gradients of the groundwater to selected flow temperature of 55 ° C. Other influences on an improved performance factor are: assuming a constant groundwater temperature and the abstracted heating system with two heat pumps in simulation models. Analyzing recorded data, demonstrate that heat storage in summer is also supplied by the heat pump. Compared to simulation results an increased power and heat consumption is recorded. Supply flow temperatures confirm the first impression. While all thermostats in the apartments are switched off during summer, the heat storage is still involved in the hydraulic heating system. Reduced power consumption within simulation is caused by non-usage of the heat pump. Adjusting the control system and implementing the existing three way valve for hydraulic switching will reduce power consumption for heating. Inner temperature profiles shown in Figure 5 have differences up to 1.9 Kelvin between real system and abstracted system. The reason for this is related to the chosen simulation models and a model without window shading.

4.2 Winter Week

On basis of incoherent living room usage and level of abstraction a distribution of heat requirement is shown. The recorded heat demand by the air exchange rate of 0.2 h^{-1} in the winter approaches real consumption but data are not transferable. Influences of the occupants with specific lifestyle and prevailing climatic conditions in a building are too important. Individual ventilation behavior and lifestyle are the main factors for heat consumption in low energy houses. The recorded combined performance factor of the heat pump is 2.7. The reduction of performance factor for domestic water heating to 1.7 in the winter is conspicuous in direct comparison to the measured data in summer. The reason for a very low performance factor is caused by different elements. Some of them are higher fixed temperatures for domestic water or a possible mixture of melting water and groundwater in winter. Furthermore the building service configuration is of great importance.

4.3 Optimization

Current and previous results initiate several optimization suggestions for installed technical systems. For example the average temperature in the heating storage tank should be lowered from 46 ° C to 39.5 ° C to permanently increase the seasonal performance factor. Lowering the temperature improved the performance factor of 4.0 to 4.4 in the simulation. Rooms can be supplied with lower heating flow temperature (35/30 ° C) by using low-temperature radiant panel heating. It should be altered whether the given heating temperature and heating surface of the radiant panel heating element is sufficient to heat the attic in winter. Occupants should use active heat recovery of the ventilation system in each floor to reduce the power consumption of the heat pump.

5. Summary and Outlook

Using dynamic simulations, it is possible to analyze the “Plus Energy House” in Bischofswiesen with some limitations. The reasons for restriction are differences and unknowns in occupant behavior and the chosen level of abstraction in SimulationX. Nevertheless, with SimulationX and the chosen simulation model it is possible to analyze the behavior of residents in low-energy houses. However an exact analysis and evaluation of the monitoring data is important.

For further extensive research in low-energy house sector it is recommended to analyze the actual energy demand of house residents. This study shows that the actual energy demand is determined by the people. A wide range of variation is confirmed. The heat demand of a building can not be predicted by a purely technical statistical point of view. Psychological aspects of residents should be studied further and be included in simulation models.

6. References

[1] Henryk Haufe, *Analyse von Monitoringdaten bestehender Wohngebäude mit Hilfe der energetischen Gebäudesimulation,* Leipzig: HTWK Leipzig, 2015.

[2] Mario Stelzmann, *Endbericht der Modellvorhaben Effizienzhaus Plus Nr. 20, Wissenschaftliche Begleitung des Effizienzhaus Plus Angerer, H. in Bischofswiesen,* Leipzig: Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (BMUB), 2016.

[3] VDI-Richtlinie 2078, *VDI 2078.*

[4] Bruno Lüdemann, *Auslegung, Energiebedarf und Komfort von Anlagen zur Heizung und Warmwasserbereitung im Niedrigenergiehaus bei Berücksichtigung des Nutzerverhaltens,* Technische Universität Hamburg-Harburg, 2001.