ENERGY PERFORMANCE COMPARISONS FOR A GIVEN BUILDING ACQUIRED USING MEASUREMENTS AND SIMULATIONS OBTAINED DURING ANNUAL OPERATION IN SLOVAK CLIMATIC CONDITIONS

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ABSTRACT

The paper presents a comparison of the simulation results and measured operating parameters of building in Slovakia. Attention is paid to the overall energy performance of the building during annual operations. Paper contains basic information on the building, technical equipment, design, material solutions as well as information from in-situ measurements. Paper presents simulation results of the building under the boundary conditions obtained from measuring in-situ. Energy performance of buildings during the actual operation and simulation are generally identical. Comparisons of simulations and measurements showed that a major factor influencing the end result is the human factor.

INTRODUCTION

When designing a building, we assume a certain state of the internal environment. For design solutions it's possible to use different calculation methods. As shown by various studies, the results correlated (Kokogiannakis et al., 2007). Based on the expected state of the internal environment we perform calculations with a focus on different areas of a buildings' design (Zhou et al., 2007). Nevertheless operations of the real building are influenced by many factors (Brohus et al., 2009). The most important but least predictable is the human factor

(Kabir et al., 2007). The inhabitants of a building control the state of the internal environment based on their physiological senses. To anticipate and predict these feelings is near impossible. (Mahdavi et al., 2009). Thus, design calculation results may differ from real data. When measured data is available, it's possible to verify the correctness of the design solutions (Johansson et al., 2009). At the same time it is also possible to verify the accuracy of computational methods (Stazi et al., 2007). Finally, with measured data, it's possible to detect inappropriate usage of the building or to give a recommendation for the more effective use of the building (Kalousek et al., 2006) . Therefore, attention is focused on assessing the energy balance of a real building based on real knowledge of in-situ measurement. The results of the calculations also focus on the comparison with the original design calculations.

BUILDING

Architectural solution

The building is a cubic body, which is complemented by wooden shading elements on the outside terraces (Fig. 1). Wooden elements serve as protection against summer overheating (Lopušniak, 2010). Architectural design is determined by the energy concept of building – two liter house. Large transparent surfaces serve to ensure sufficient heat gain from solar radiation and to achieve adequate levels of daylight.

Figure 1 Building model with shading, 15/09; 12:00

Floor plan layout

It is a single-storey, detached family house with a flat roof. The main entrance is oriented toward the north. The family house is suitable for housing a single family (2-3 persons). The space arrangement is shown in the figure 2. Built up area is 110 m^2. Usage area of the house is 82.8 m^2. Building volume for HVAC systems calculations is 211 m^3.

Figure 2 Floor plan of building

Opaque structures

Selected properties of structures are listed in Table 1 Thermal characteristics of materials are shown in Table 2.

External walls are made of porous concrete blocks 250 mm thick. The insulation system consists of thermal insulation with a thickness of 240 mm.

Table 1
Overview of the basic thermal properties of selected structures

STRUCTURE	U (W/m².K)	Solar factor g (-)
Envelope	0.125	-
Roof	0.098	-
Floor	0.120	-
Frame systems	0.85	-
Glazing - north	0.44	0.368
Glazing - south	0.51	0.604

Insulation of the foundations and parts of the outer wall at ground level is proposed by XPS with a width of 120 mm. The roof structure is designed as a single-layer flat roof. Roof insulation is designed with a thickness of 320 mm. Groundfloor insulation of 200 mm thickness is placed above the concrete slab. The connection between slab and wall (an important thermal bridge) is designed with 50 mm foamglass insulation.

Table 2
Thermal properties of used materials

Material	λ W/(m.K)	C J/(kg.K)	ρ kg/m³
Insulation facade	0.041	840	145
Insulation roof	0.038	840	145
Concrete	2.1	1000	2300
Autoclave blocks	0.124	1000	520
Ground Slab	0.18	1000	1000
EPS	0.038	1450	50

Transparent structures

For transparent constructions (windows, glass walls) frames are made of composite profiles with $U_f = 0.85$ W/(m^{2}K). Glazing parts for windows and glazed walls are proposed with triple glazing (4-12-4-12-4) filled with krypton. Due to the orientation of each façade, differing types of glazing are proposed for north and south oriented transparent structures. Heat transfer coefficient for the whole window is $U_{w,max}$ = 0.7 (W/(m^{2}K).

HVAC systems

The whole building is ventilated and heated by a hot air system with a 3kW output (Figure 3). The unit is designed for heating and circulating hot air simultaneously with ventilation and heat recovery. The unit works according to season or momentary needs in five basic modes:

- Equal-pressure heated mode: full year - n = 0.15 to 0.5 1/h
- Circulating heating mode: heating season - n = 0.15 to 0.5 1/h
- Circulating heating mode: the heating period without ventilation - n = 0 1/h
- Ventilation mode – depressurized: summer and the ventilation period – n = 0.15 to 0.5 1/h
- Ventilation mode - pressurized: summer period - n = 1.0 to 1.8 1/h

Recovery unit works with mean efficiency of 85%. The source of heat for the whole building is fuelled by warm water. Water is kept in a storage tank with a capacity of 615 liters. A tank is fitted with electric pads and is connected to solar heating panels.

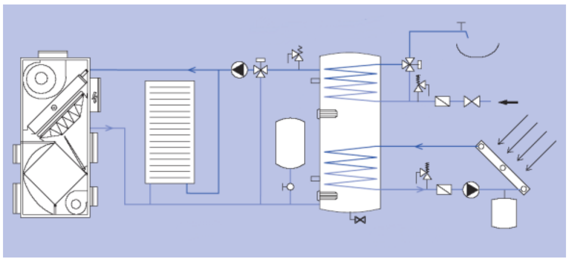

Figure 3 HVAC Scheme

DESIGN CALCULATIONS

The calculation was performed for design conditions for internal air temperature θ_{ai} = 20°C. Figure 4 presents the results of the design calculation of the heat demand. The heat demand for cooling in familly houses for slovak climates is ignored.

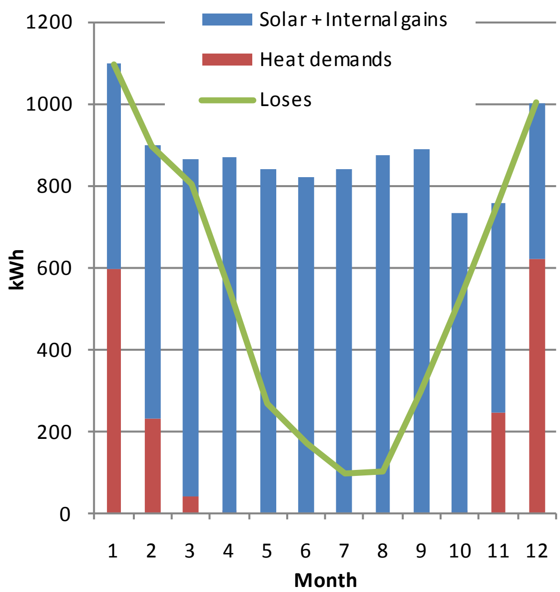

Figure 4 Heat demand of the building from design phase

Protection against summer overheating was solved solely with the use of external shading for which a proposal was prepared in relation to a critical summer day 21st July (Lopušniak, 2010).

MEASUREMENT

Methodology and basic results

Measurements commenced 09/2009. The first full annual set of measurements was obtained in 2010. Measurements will continue for two more years. The results are focused on two main objectives. The first objective is to optimize building operations and the efficient use of HVAC systems in terms of energy requirements. The second objective is to ensure optimal states of the internal environment in close conjunction with energy use. In the frame of the measurements (Bagoňa et al., 2010) the following was monitored:

- Internal environment state.
- External environment state.
- Operation of energy systems.
- Properties of building structures.
- Repeated blower door tests.
- Behavior and user satisfaction by questionnaire form.

The results of measurements produced take a comprehensive view on the buildings operation. Further analysis of energy requirements are in confrontation with the design solution making it necessary to understand the actual operation of the building. In this case the user of the building together with local climatic conditions play a very important role.

According to measurements, results of the building operation may be divided into three periods over the course of a year. The first period is called the heating period and lasts from November to February The second period is called the period of ventilation and occurs in the months of March and October. The third period, the cooling period lasts from April to September. This division is primarily copied by the use of the HVAC systems. During the heating period, both heating and ventilation systems of the building are active. During the ventilation period, the heating and ventilation are active. However, the results of measurements (Figure 5) showed that the requirements for heating are very low. Heat losses are covered by a sufficient amount of solar and internal gains. During the cooling period of the year ventilation system and heating (cooling) are switched off (user choice). Measurement results of operations of all energy systems are shown in figure 5. The definition of operational modes according to real use is critical for setting operational modes into a simulation.

From point of view of the internal environment the required indoor air temperature (user choice) is monitored during the year-long regime as basic information. Setpoint indoor air is a key input factor for the simulation of the heat (energy) for heating. Other measured data are used mainly to refine the building model in the simulation.

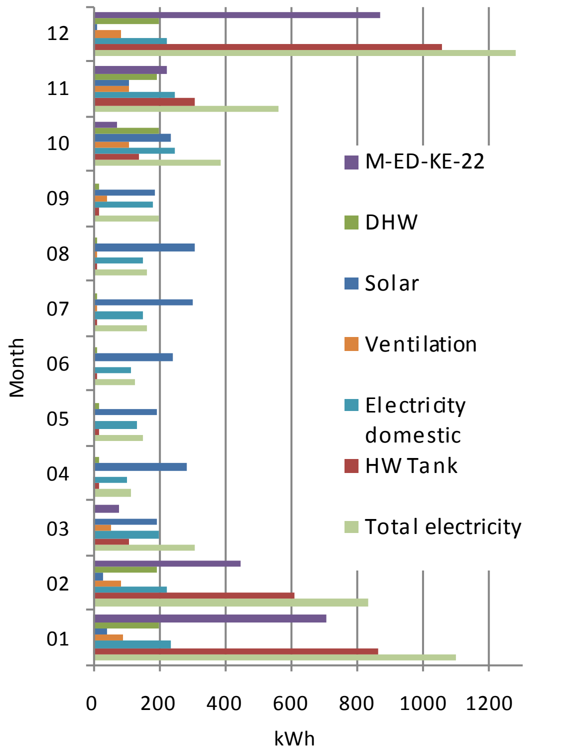

Figure 5 Monthly energy balance of HVAC systems

For the purposes of the contribution the following is stated:

- The building has been used by one person only for the prevailing time.
- The general mode of use is 7:00 to 8:30 and 17:30 to 23:00 on weekdays.
- The general mode of use is 7:30 to 23:00 for other days.
- Setpoint temperature of the indoor air is θ_{ai} = 22°C in the heating period which is higher than expected and exceeds the design value. This fact is due to higher requirements from the user.
- Indoor air temperature θ_{ai} in summer is in the range of 26-28°C This confirms that ventilation system for ventilation (cooling buildings) is not used.
- Relative humidity of the indoor air φi in heating period ranges from 55% to 65%. This range corresponds to the air change rate in the range of 0.1 to 0.2 1/h.
- The concentration of CO_2 is satisfactory (Lopušniak, 2011) in the cooling as well as

in the heating period. From this perspective we can accept an air change rate at this level.

- Energy balance of the building operation is higher than the building design calculation. This fact is a consequence of the above indicators of the internal environment state caused by the user.
- Air tightness of the building was determined by the experimental measuring to the value of n50 = 0.52 1/h (Lopušniak, 2009).

SIMULATION

Boundary conditions

To compare measurements and simulations boundary conditions obtained by measuring the external climate on site were used in the simulation. Course of the external air temperature and solar radiation intensity for 2010 are shown in the figures (Figure 8, 9).

Calculation

DesignBuilder software was used for computer simulation. The building was designed as a single-zone model. This concept is also consistent with control ventilation, heating and cooling, which envisaged the building as one zone. All constructions were defined in accordance with the description of the building. The specified operating condition of the building corresponds with the description given in section measurement. In the simulation we assumed three operating periods according to required states of the internal environment:

- The heating period: θ_{ai} = 22°C, n = 0.15 1/ h.
- The ventilation period: θ_{ai} = 21°C, n = 0.15 1/h; natural ventilation n = 3.5 1/h, set point temperature 27°C.
- The cooling period: θai = no requirements, n = 3.5 1/h.

A compact HVAC definition model was used for the HVAC system. All other parameters were defined in accordance with knowledge about the operation of the building available from measurements or from the buildings' users.

Attention was focused on the simulation of the heat and energy demand for heating. The calculation was also verified with design calculations. For all calculations the following tags are used:

- PHP - calculation using PHPP (ISO 13790).
- DB - simulation with DesignBuilder.
- HD - Heat demand.
- ED - Energy demand.
- IWEC – calculations with the boundary conditions from IWEC for Kosice.
- RR - calculations with the boundary conditions defined in PHPP.
- KE - calculations with the boundary conditions from the measurements obtained in 2010.
- 20, 22 - set point temperature for heating.

RESULTS

Comparison of the measured energy needs and energy needs of computer simulation

Comparison of measured (M-ED-KE-22) and calculated (DB-ED-KE-22) values are presented in the figure 6.

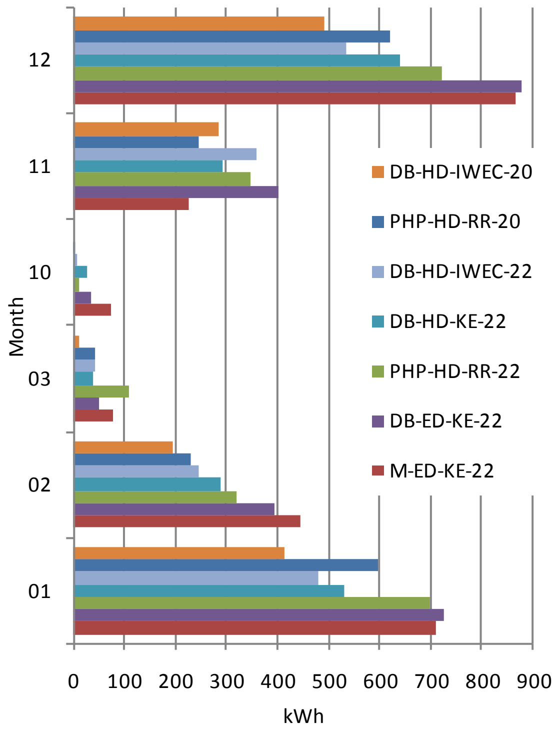

Figure 6 Monthly energy balance from measurement and calculations

The difference between measured and calculated values in the annual mode is 88.2 kWh. Overall consistency in the results is 96.45%. From the perspective of each month are the least consistencies ocurred in February (89%) and November (56%). The main reason for this difference is that November of 2010 was sunny and warm. This led to intermittent operation of HVAC systems, which was confirmed by users in the questionnaire. In the existing range of measurements we were unable to define the different periods of interruption. Because the measurements will be carried out for an additional two years, more attention will be devoted to this issue.

Comparison of heat and the design of computer simulation of heat

Comparison of heat was carried out for two design temperatures. The first was the design of the internal air temperature θ_{ai} = 20°C and the second θ_{ai} = 22°C. The results of calculations are given for each month in figure 6 and for the entire period in figure 7. Consistency ratings in the results for the entire period range from 80% to 90%. In all cases lower values are obtained from computer simulation.

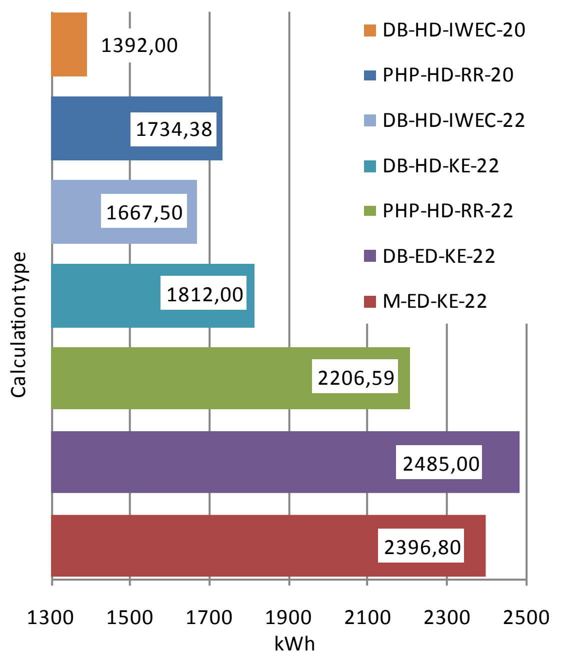

Figure 7 Annual energy balance from measurement and calculations

The differences in results are due to the variety of the input boundary conditions. For the PHPP calculation there are standard boundary conditions. However computer simulations lack a reference year for Košice. The only available data is garnered from IWEC for 2002. This results in non-conformity with the boundary conditions when calculating with PHPP. Since the boundary conditions are different, attention is no longer paid to the mutual comparison of results of specific calculations. From the perspective of the use of simulation for building designs, solutions can accept the existing boundary conditions. Results of the calculations provide usefull conclusions for the assessment of building design in terms of energy balance of buildings and systems.

CONCLUSION

The test building is being analyzed for a second year. From the point of presented results and for further use the following conclusions can be stated:

- The measurement results showed that the proposed scenario of the building for the design phase does not correspond to reality.
- The biggest difference is in user demand for indoor air temperature and intensity of air exchange.
- From the perspective of subjective assessment, the user expresses a high safisfaction with the internal environment.
- Measurement results and simulation results of the energy demand for heating using boundary conditions from measurements provide consistency at the level of 96%.
- Since there are the same boundary conditions for the calculation it is not possible to compare simulation results and design calculation according to PHPP.
- Simulations provide reliable conclusions for the energy balance of buildings and systems for building design using existing boundary conditions for the Kosice site.
- In order to reduce energy demand for heating it is necessary to lower the required indoor air temperature.
- The results of simulations and measurements have resulted in a recommendation to increase the air exchange rate to range from 0.2 to 0.25 1/h.
- The results of simulations and measurements resulted in a recommendation for the implementation of active ventilation during the cooling period to reduce indoor air temperatures.

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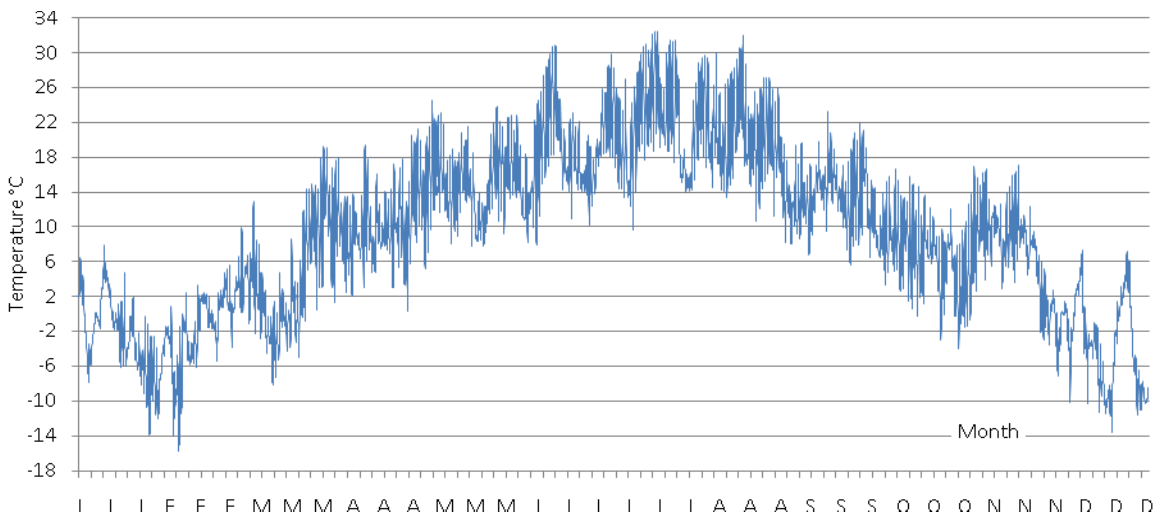

Figure 8 Course of the external temperature (°C), 2010

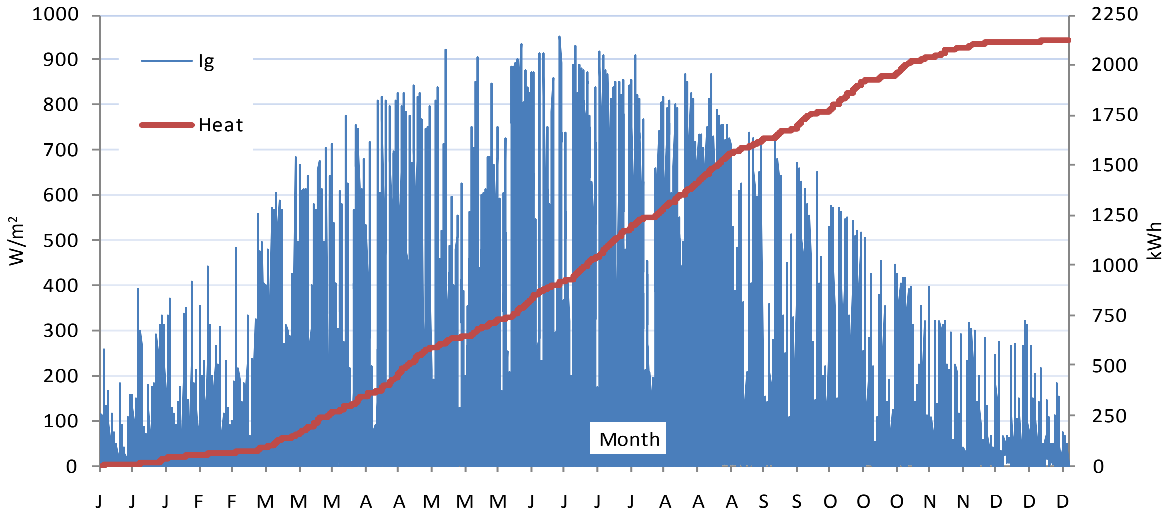

Figure 9 Global radiation (Ig, W/m^2) and Heat gains from solar panels (Heat, kWh), 2010

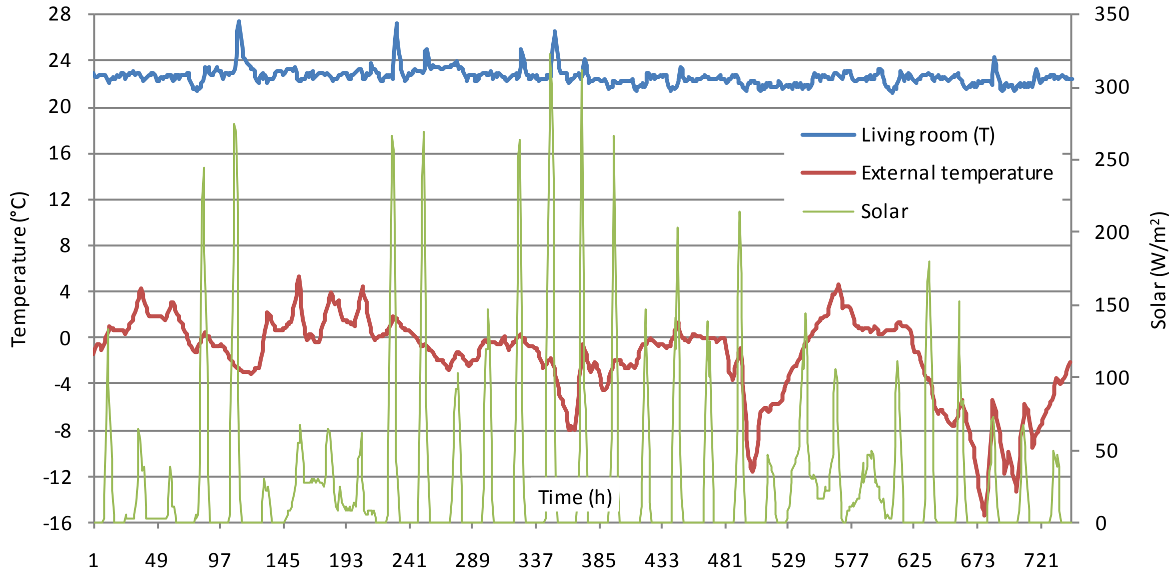

Figure 10 Living room θ_{ai} External temperature and Global radiation for December, values from measurement

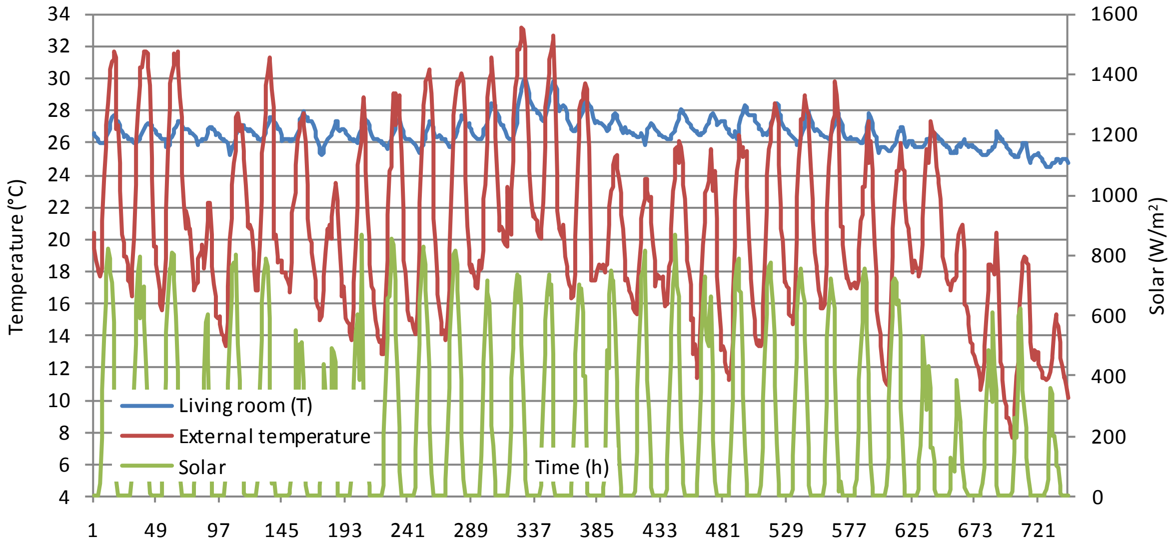

Figure 11 Living room θ_{ai} (°C), External temperature (°C), Global radiation (W/m^2) for August, values from measurement

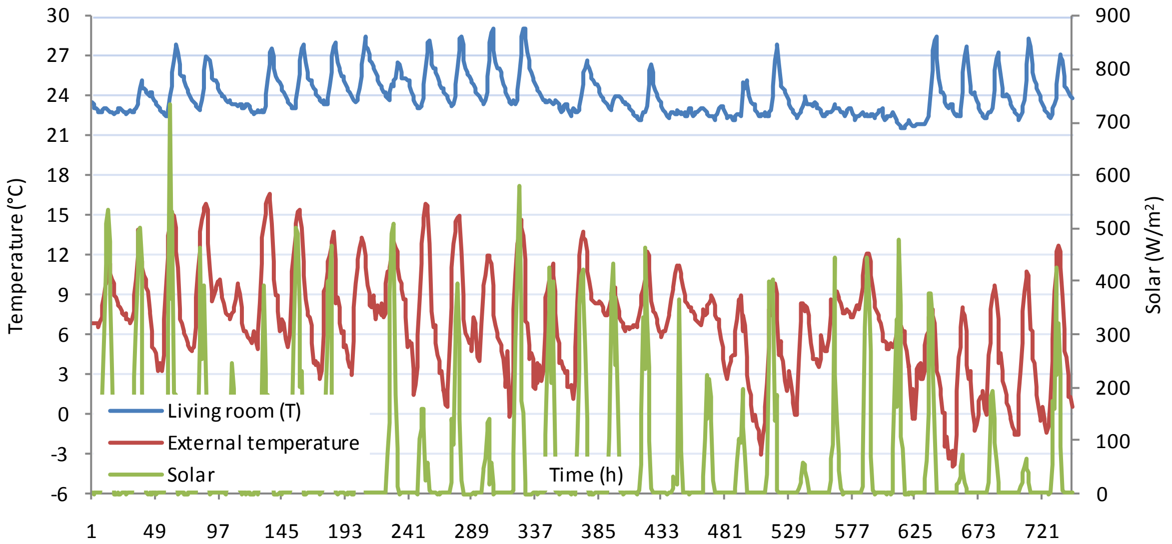

Figure 12 Living room θ_{ai} (°C), External temperature (°C), Global radiation (W/m^2) for October, values from measurement