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INFLUENCE OF NUMBER OF WARM-UP DAYS ON ENERGYPLUS PREDICTION OF NET ZERO ENERGY BUILDING BEHAVIOUR

Abstract: *This paper analyzes the use of EnergyPlus software in analysis of energy consumption of the net zero energy building in a specific period. The problem can be represented as a difference in the amount of energy needed for the zero-energy building. The observed time interval can be a full year or, more precisely, the impact of climate on the territory of the Republic of Serbia – the seasons on the need for energy. The program analyses the influence of the number of warm-up days on the prediction results. Discrepancy of the results in the observed time interval can have both positive and negative values.*
Keywords: *Zero Energy Building, EnergyPlus, Warm-up, Simulation*

1. INTRODUCTION

Current condition in energy worldwide shows need for further investigation of energy efficiency and energy savings. Therefore, new types of houses are being built and the final idea is to build a house that produces the same amount of energy as it is consuming. These houses produce more energy during the summer by using renewable energy sources like PV panels and the house gives the additional energy to the network, and, during the winter days, it takes energy from network. If the house produces more energy than it consumes, then it is Zero-Net Energy Building (ZNEB) [1].

Bojic et al. investigated positive-net-energy residential buildings application in Serbian conditions [1]. Marszal et al. presented definitions and methodology for calculations for zero energy buildings in their paper [2]. Hernandez and Kenny defined the life cycle for the zero energy building (LC-ZEB) [3]. Marszal et al. have defined the life cycle cost analysis for zero net energy building in Denmark and they have discussed if it is better to have on-site or off-site renewable energy supply options [4]. Leckner and Zmeureanu analysed the life cycle cost and energy in zero net energy buildings with solar combisystem [5]. Elkinton et al. discussed usage of wind and solar systems in zero-net energy housing system in USA [6]. Praene et al. investigated usage of renewable energy sources in zero net energy systems on Reunion Island [7]. Kolokotsa et al. gave different thermal models and monitoring systems in automating systems used in zero net and positive energy buildings to make them intelligent [8].

Current investigations use different software to decrease time needed for calculations. EnergyPlus is one of the best software for modeling of energy use in buildings [9]. It can simulate heating, cooling, lighting, ventilation, water network and other energy flows in a built environment. One of factors that can influence energy flow and all other energy

aspects of building is the type of used solar distribution model.

Warm-up period can influence entire simulations. During this warm-up period, subject is prepared to "working level". The question of how long to run a discrete event simulation before data collection starts is an important issue when estimating steady-state performance measures such as average queue lengths [10]. In his paper [10], Winfried Grassmann checked influence in many experiments to see how long the warm-up period should be. He concluded that only if the starting state is highly unlikely the warm-up period should be introduced. Stewart Robinson used a variety of methods to warm-up his discrete-events simulations [11]. Crawford and Gallwey discussed influence of warm-up period on reducing bias and increase in confidence interval width and coverage probability [12].

2. SCOPE OF RESEARCH

Aim of the paper is to research the influence of number of warm-up days on simulation results and after what number of days the convergence in results between different numbers of warm-up days is reached. Difference between simulations will occur because of preheating of walls and the heat that is stored in them during heating or during hot days.

2.1. Investigated house

The residential house has two-storeys and four rooms. On the first storey, it has one large living room and one toilet, while on the second storey, it has two bedrooms (Fig. 1).

Living room has the area of 31.46 m^2, toilet 2.95 m^2, and bedrooms 8.6 m^2 each. External walls have the total area of 73.32 m^2 and the roof has the area of 43.37 m^2. There is no south wall because of the sloped roof, which is under an optimal angle for a PV power generation.

Regarding fenestration, the house has

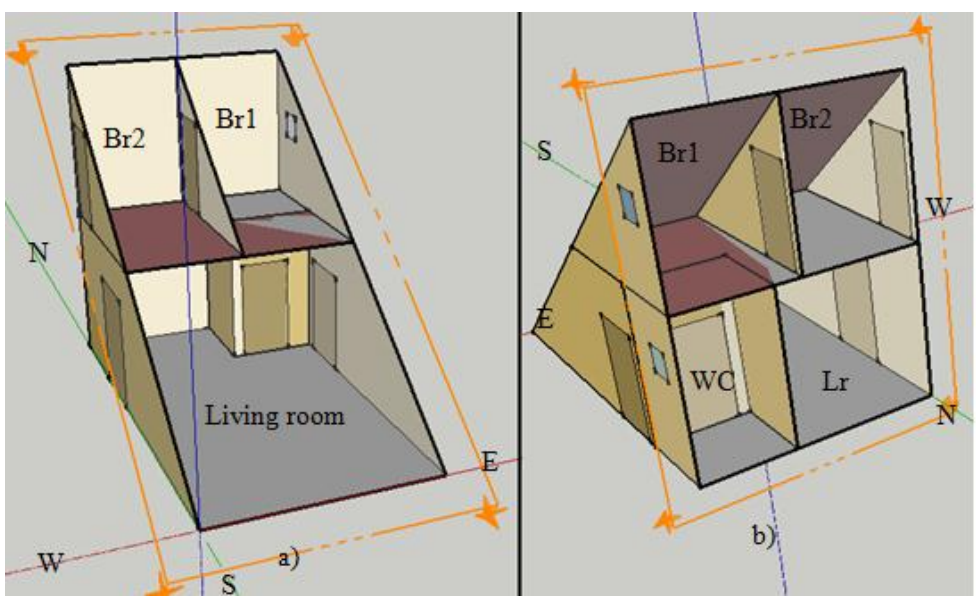

Figure 1. *Geometrical definition of the residential house (Br-bedroom, Lr-Living room, WC-Bathroom) (a) South side; (b) North side.*

two windows, one in the bathroom and one in the bedroom 1, and it has seven doors, three of them external. The bedroom 1 is oriented toward the east and the bedroom 2 toward the west.

2.2. Space heating of the house

According to the Serbian heating codes [13], the desired air temperatures in the living room and the bedrooms are set to 20°C, and in the bathroom to 22°C. Electrical heaters heat the entire house. Rooms are heated from 7:00 a.m. until 10:00 p.m. The heating system is designed according to the standard procedures defined in [13]. In most cases, the desired air temperatures are met in the first half an hour after the heating started, with installed thermostatic valves. The thermostatic valves thus save energy by turning off the heaters when the air temperature is above the desired value and then by turning on the heaters when the air temperature falls below the desired value. Values for radiator power are given in table 1.

Table 1. Radiator power

Room	Radiator power, W
Living room	1000
WC	190
Bedroom 1	300
Bedroom 2	350

3. ENERGYPLUS

EnergyPlus is a simulation program for energy in buildings that engineers, architects and researchers use to model energy and water use in buildings. Modeling the performance of a building with EnergyPlus enables building professionals to optimize the building design to use less energy and water. Each version of EnergyPlus is tested extensively before release [14]. EnergyPlus models heating, cooling, lighting, ventilation, other energy flows and water use. EnergyPlus includes many innovative simulation capabilities: time-steps less than an hour, modular systems and plant integrated with heat balance-based zone simulation, multi-zone airflow, thermal comfort, water use, natural ventilation and photovoltaic systems.

Number of days used for warm-up is 1, 2, 3, 4, 5, 6 and 7. Default value for this input is 25. Input dialog for EnergyPlus and position to input number of days are given in figure 2.

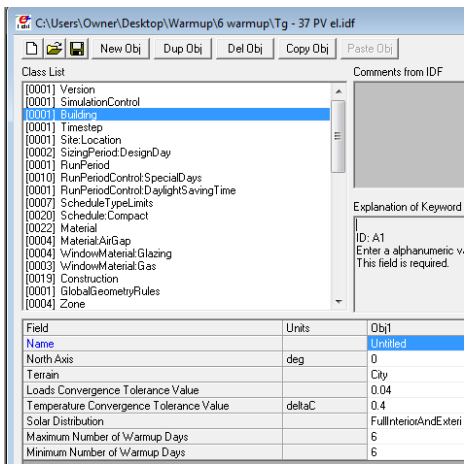

Figure 2. *Input dialog for maximum and minimum number of warm-up days*

4. RESULTS AND DISCUSSION

4.1. Houses without heating

The first thing that occurs is that program doesn't think it is good to work with less than 6 warm-up days as it says that convergence surely is not good and, therefore, it may have the adverse effects on the simulation results:

"** Warning ** GetProjectControlData: Building: Loads Convergence Tolerance Value invalid. Experience has shown that most files will converge within 6 warm-up days.

** ~~~ ** ...Choosing less than 6 warm-up days may have adverse effects on

the simulation results, particularly design day simulations.

** ~~~ ** ...Users should only alter this parameter if they are certain that less than 6 warm-up days is appropriate for a particular file."

In addition, when number of minimum warm-up days is satisfied then software can ask to increase number of maximum warm-up days to achieve convergence:

"** Warning ** CheckWarmupConvergence: User supplied maximum warm-up days=6 is insufficient; setting to 25."

4.1. Heating without thermostatic valves

The house is heated without thermostatic valves, so temperatures can rise above desired temperatures and, therefore, heat stored in walls will be different until convergence is reached.

To make sure that selected number of days is used, the maximum and minimum numbers of warm-up days are set to the same value, the value used in simulations and results. It can be seen in figure 3. That, for all warm-up days used after about 6 days of heating without thermostatic valves, average temperature in living room is same. Therefore, basically, after few days of simulation and actually after few days of "warming" the walls convergence is reached.

Problem with convergence is shown in figure 4., where starting days of simulation are shown. It can be seen that convergence is "missed" by 1.3 °C when there is only one day of warm-up. Then after 6 or 7 days, average temperature in the living room is the same for all possible conditions of number of days for warm-up. That gives conclusion that, probably, the best number of days for warm-up is 6, as lines for 6 and 7 days of warm-up are the same and, for all warm-up conditions, convergence is reached in 6 or 7 days. This may vary depending on the complexity of the model.

4.2. Heating with thermostatic valves

If thermostatic valves are used, then convergence is reached faster because they keep temperature during the day at the same level as explained.

As for the temperature in the rooms when thermostatic valves are installed, it can be seen in figure 5, that the temperature is almost the same and there is slight difference in time needed to reach the desired temperature. After that, the radiators condition temperature and keep

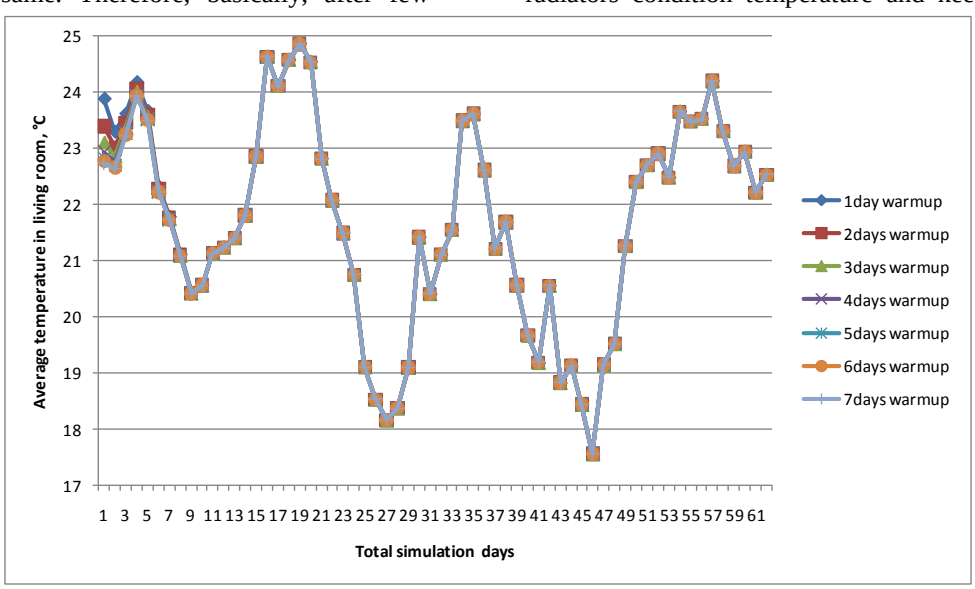

Figure 3. *Average temperatures in living room during 3 coldest months*

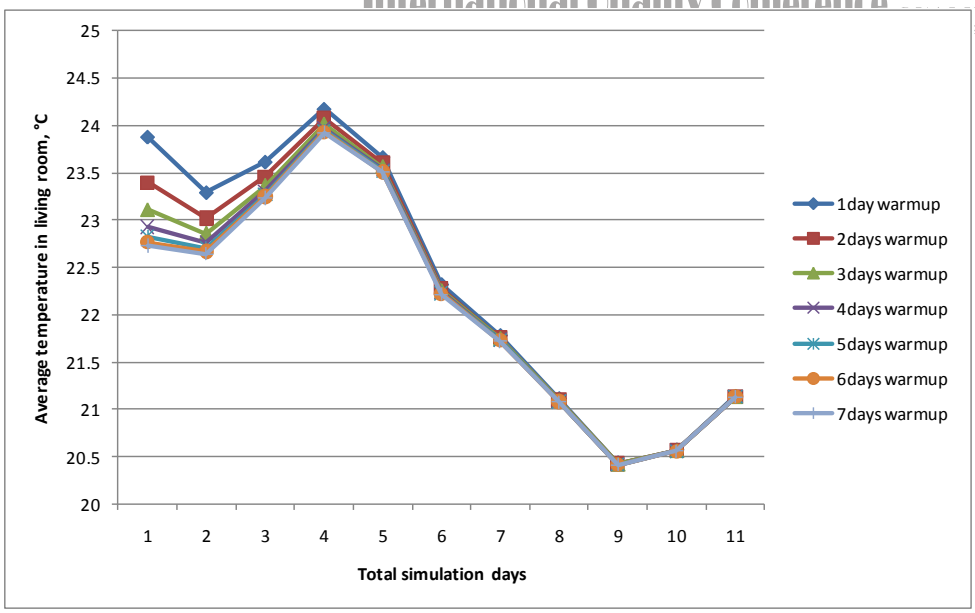

Figure 4. *Average temperatures in first 11 days of simulation depending on number of warmup days*

the temperature above 15 °C during the night.

By looking at figures 2-5 conclusion can be make that software takes higher temperatures in room and walls if the number of days for warm-up is smaller. In addition, this means that heat stored in walls is higher and that they passively heat the room. This is why temperature jumps until sufficient number of days for warm-up is used.

Energy consumption for heating is shown in figure 6. and this also shows that radiators use more energy as convergence is not reached for smaller number of days. After 5 or 6 days of warm-up, they use the same amount of energy.

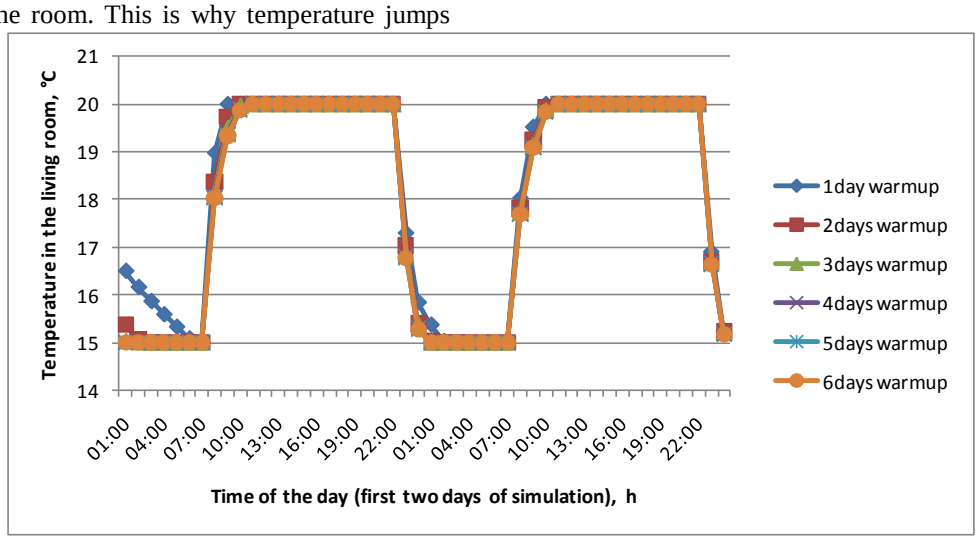

Figure 5. *Temperature in the living room during first two days of simulation when thermostatic valves are installed*

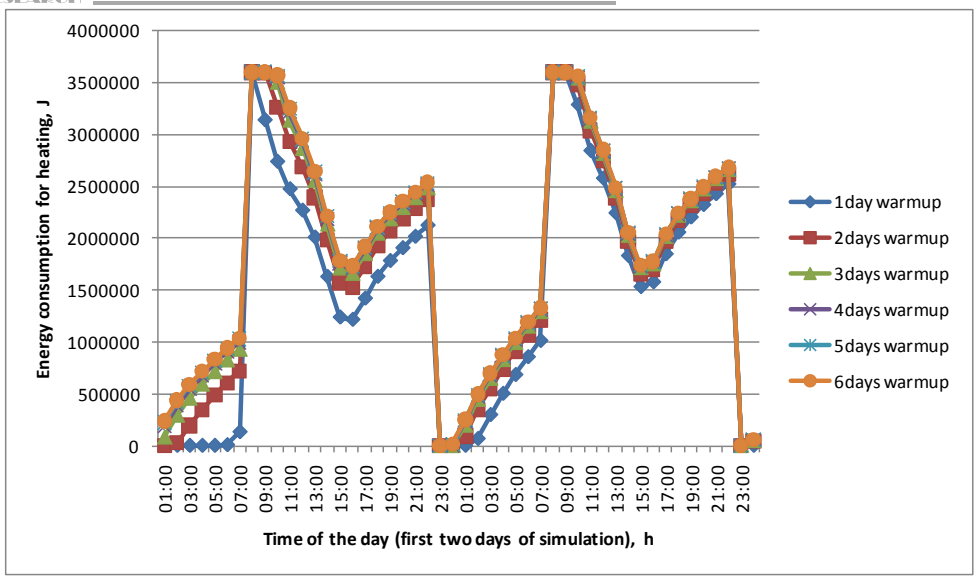

Figure 5. *Temperature in the living room during first two days of simulation when thermostatic valves are installed*

5. CONCLUSIONS

Number of days for warm-up can change a simulation a lot in the first days of simulation, but convergence is reached in a few days. Because of that, the recommended number of days for warm-up is more than 6. In most cases, convergence is reached during this period. On big scale simulation that lasts more than 4 or six months, this can change consumption for less than 0.5%. Increase in 6 days for warm-up cannot take more than 1 second. During the warm-up, the simulation is prepared to have the correct results from the first day of simulation. In this research, it is possible to see that, if thermostatic valves are introduced, the influence of number of warm-up days is reduced, which leads to conclusion that, depending on simulation type, warm-up can have different influence on convergence, but convergence is reached in 6 days for middle scale model.

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