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INFLUENCE OF SOLAR DISTRIBUTION MODELS TO ENERGYPLUS PREDICTION

Abstract: *This paper analyzes use of EnergyPlus software to analyze 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 to the need for energy. The program analyses the influence of the solar distribution models such as that of full exterior, full exterior and interior, minimal shading, full interior and exterior with reflections and full exterior with reflections 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, Solar model, Simulation*

1. INTRODUCTION

One of the most discussed problems nowadays in science community worldwide is energy and its usage and generation. Ways of renewable energy production are now promoted and sponsored by governments and therefore this type of energy production enters the residential buildings and properties, like PV panels on the top of the house for example. If there are smart grids installed householder can even sell his “clean” energy to network.

Investments in increased energy efficiency are growing and all mentioned leads to creation of new smart and efficient houses, which uses less energy for heating, cooling, lighting and appliances than it is producing.

When house needs more energy than it is producing, it is taking energy from the grid, and when it is producing more than it needs house gives energy to the grid. If house produces more energy than it consumes on annual level 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. gave definitions and methodology of calculations for zero energy buildings in their paper [2]. Marszal et al. defined life cycle cost analysis of zero net energy building in Denmark. They also discussed is it better to have on-site or off-site renewable energy supply options [3]. Leckner and Zmeureanu analysed life cycle cost and energy in zero net energy buildings with solar combisystem [4]. Lifecycle for zero energy building is defined by Hernandez and Kenny as LC-ZEB in their paper [5]. Elkinton et al. discussed usage of wind and solar systems in zero-net energy housing system in USA [6]. 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]. Praene et al. investigated usage of renewable energy sources in zero net energy systems on Reunion Island [7].

Current investigations uses different software for investigation to decrease time needed for calculations. One of the best software for modeling energy use in building is EnergyPlus [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 type of solar distribution model which is used.

Gueymard investigated solar irradiance in many of his works. He researched direct solar transmittance and irradiance with broadband models [10], developed REST solar radiation method [11] and defined clear sky irradiance by comparing 18 different broadband radiative models [12]. Gueymard later improved his method and called it REST-2 [13].

2. SCOPE OF RESEARCH

Aim of the paper is to analyse influence of the solar distribution models. There are five different solar distribution model given in this paper which would be discussed later. Two models of zero energy houses will be used. First one is heated throughout the heating season and the second is not heated to see real influence of different type of solar distribution model.

2.1 EnergyPlus results

When using EnergyPlus for building modeling and simulation there are 5 choices of how EnergyPlus will treat beam solar radiation and reflectances from exterior surfaces that strikes and ultimately, enter the building. They are: **MinimalShadowing**, **FullExterior** and **FullInteriorAndExterior**, **FullExterior WithReflections**, **FullInteriorAnd ExteriorWithReflections** [14].

2.1.1. Minimal Shadowing

In this case, there is no exterior shadowing except from window and door reveals. All beam solar radiation entering the zone is assumed to fall on the floor, where it is absorbed according to the floor's solar absorptance. Any reflected by the floor is added to the transmitted diffuse radiation, which is assumed to be uniformly distributed on all interior surfaces. If no floor is present in the zone, the incident beam solar radiation is absorbed on all interior surfaces according to their absorptances. The zone heat balance is then applied at each surface and on the zone's air with the absorbed radiation being treated as a flux on the surface.

2.1.2. FullExterior, FullExterior WithReflections

In this case, shadow patterns on exterior surfaces caused by detached shading, wings, overhangs, and exterior surfaces of all zones are computed. As for MinimalShadowing, shadowing by window and door reveals is also calculated. Beam solar radiation entering the zone is treated as for MinimalShadowing - All beam solar radiation entering the zone is assumed to fall on the floor, where it is absorbed according to the floor's solar absorptance. Any reflected by the floor is added to the transmitted diffuse radiation, which is assumed to be uniformly distributed on all interior surfaces. If no floor is present in the zone, the incident beam solar radiation is absorbed on all interior surfaces according to their absorptances. The zone heat balance is then applied at each surface and on the zone's air with the absorbed radiation being treated as a flux on the surface.

2.1.3. FullInteriorAndExterior, FullInteriorAndExteriorWithReflections

This is the same as FullExterior except that instead of assuming all transmitted beam solar falls on the floor the program calculates the amount of beam radiation falling on each surface in the zone, including floor, walls and windows, by projecting the sun's rays through the exterior windows, taking into account the effect of exterior shadowing surfaces and window shading devices. If this option is used, user should be sure that the surfaces of the zone totally enclose a space.

User should also be sure that the zone is convex. Examples of convex and non-convex zones are shown in Figure 1. The most common non-convex zone is an L-shaped zone. (A formal definition of convex is that any straight line passing through the zone intercepts at most two surfaces.) If the zone surfaces do not enclose a space, or if the zone is not convex user should use FullExterior instead of FullInteriorAndExterior.

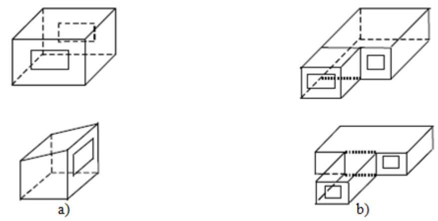

Figure 1. Illustration of: a) convex and b) non-convex zones

2.2. Solar gains

The total solar gain on any exterior surface is a combination of the absorption of direct and diffuse solar radiation given by:

$$Q_{so} = \alpha \cdot \left(I_b \cdot \cos\theta \cdot \frac{S_s}{S} + I_s \cdot F_{ss} + I_g \cdot F_{sg} \right) \quad (1)$$

where: α presents solar absorptance of the surface, θ is angle of incidence of the sun's rays, S is area of the surface, S_s stands for sunlit area, I_b stands for intensity of beam (direct) radiation, I_s stands for intensity of sky diffuse radiation, I_g is intensity of ground reflected diffuse radiation, F_{ss} presents angle factor between the surface and the sky and F_{sg} presents angle factor between the surface and the ground.

If the surface is shaded the program modifies F_{ss} by a correction factor that takes into account the radiance distribution of the sky. Shading of ground diffuse solar radiation is not calculated by the program. It is up to the user to estimate the effect of this shading and modify the input value of F_{sg} accordingly.

2.3. Building thermal and geometrical description

Inspected residential house is created to show influence of solar radiation to temperature inside zones (Fig. 2). House has four rooms oriented to each side of world and they are of the same size with windows of the same size on exterior wall. Size of rooms are 12.5m^2 (5x2.5m) and the size of windows are 2m^2 (2x1m).

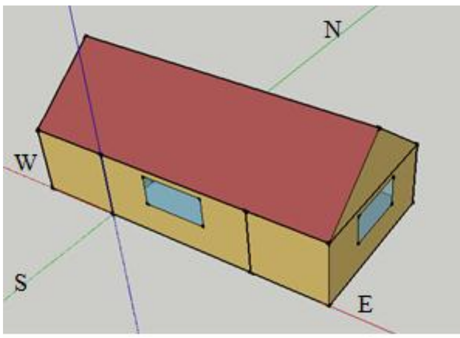

Figure 2. *Inspected house*

Windows are oriented so the rooms have same conditions of gaining heat through solar radiation according to the side of the world they are oriented. The geometrical definition of the house and rooms is shown on figure 3.

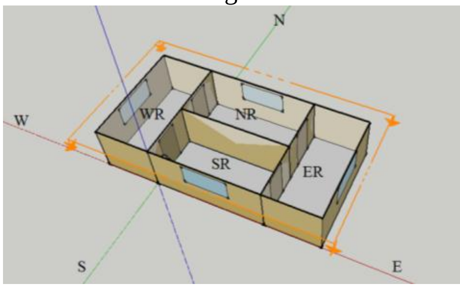

Figure 3. *Geometrical description of the house (NR-north room, SR-south room, ER-east room, WR-west room)*

There are 2 cases: in first case rooms are not heated and they gain heat only by conduction through walls and by solar radiation through windows; in second case house is heated by electrical equipment (heaters).

In case when the house is heated by electric heaters desired temperatures are 20 °C in each room. Also there are thermostatic valves to keep the temperatures at a desired level.

3. RESEARCH METHOD

3.1. EnergyPlus software

To simulate heating, cooling, lighting, ventilation, water network, and other energy flows in a built environment, EnergyPlus software can be used [9]. This software can model energy use in a residential building. EnergyPlus takes into account all factors that influence thermal loads in the building, such as electricity devices, lighting, pipes in the building, solar radiation, wind, infiltration, and shading of open rooms [15]. This software enables us to simulate energy behaviour of the residential buildings for defined period. EnergyPlus software enables modelling of space heating of residential buildings taking into account all heat losses and gains. This software enables modelling of different scenarios of the building heating.

For the purpose of the simulations house models are created in Google SketchUp and then implemented in EnergyPlus by using OpenStudio plugin [16, 17].

3.2. Mathematics used

An average temperature for whole year in each room is calculated during a year for each hour by following equation:

$$t_{r,h,ave} = \frac{\sum_{d=1}^{365} t_{h,r,d}}{365}, \tag{2}$$

where $T_{r,h,ave}$ presents average temperature in each room type – *r*, for selected hour – *h*. Average temperature is calculated for all days – *d* in year during simulation.

The annual heat consumption of the house presents an annual heat consumption of the heaters in the house to sustain the desired air temperature, as shown in the following equation:

$$E_u = \sum_{d=1}^{365} \sum_{h=1}^{24} E_{uhd}, \tag{3}$$

where E_{uhd} for heat consumption in hour – *h* on day – *d*.

4. RESULTS AND DISCUSSION

4.1. Houses without heating

First results from house which is not heated shows that temperatures in rooms follow the path of the sun. In early morning average temperature is highest in the east room – up to 22 °C, after that it is highest in the south room as the Kragujevac is on northern hemisphere – up to 23.3 °C, and in the evening the highest temperature is in the west room – up to

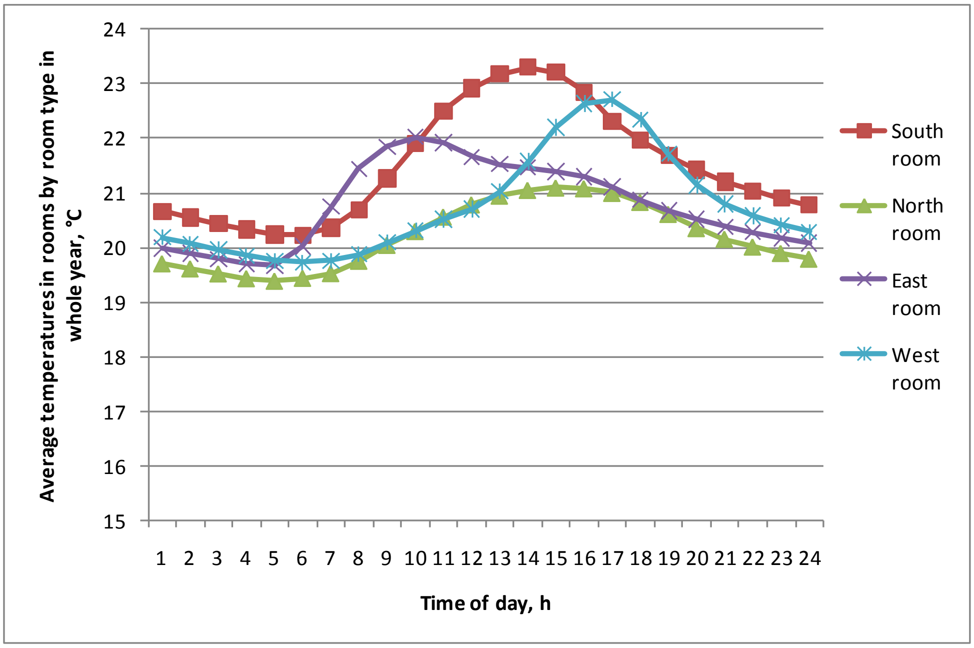

Figure 4. *Average temperature in rooms during whole year when FullInteriorExterior solar radiation model is used*

22.8 °C. Highest temperature in the north room is at 21.1 °C.

As one can see the most complex models for solar radiation are FullInteriorExteriorReflections and FullInteriorExterior. After those are FullExteriorReflections, FullExterior and MinimalShadowing by the order of mentioning. Comparison between those models is given by difference in average temperature during a year in the north room on figure 5.

It can be seen from figure 5 that there is no difference between

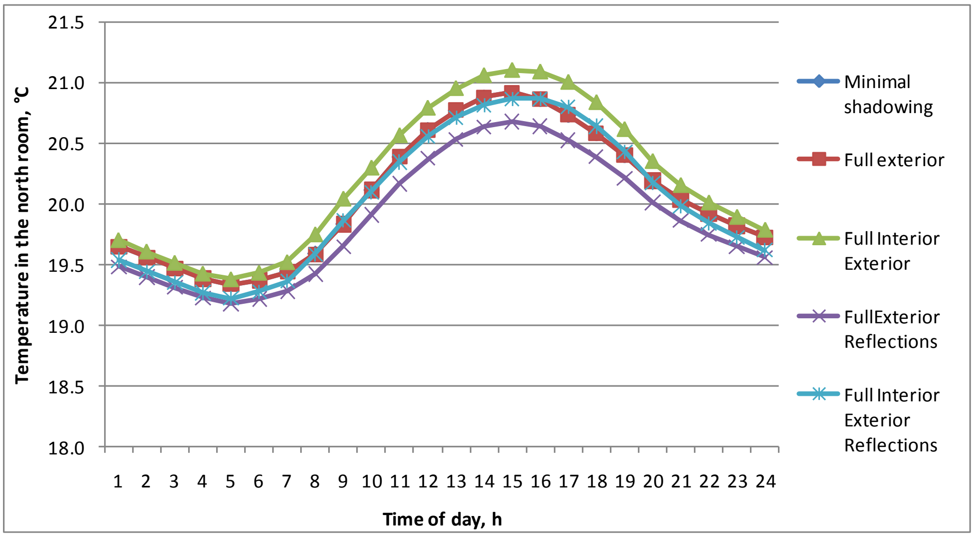

Figure 5. *Average temperature in the north room during a year by different solar radiation model*

MinimalShadowing and FullExterior model. Temperatures in model with reflections are lower due to the fact that some of heat reflects from interior and goes out through windows again. Highest average temperature by solar radiation model and room type is given in Table 1.

Table 1. Highest average temperature by room type and model

	South room	North room	East room	West room
Minimal Shadowing	23.11	20.92	21.83	22.35
Full Exterior	23.11	20.92	21.83	22.35
FullExterior Reflections	22.94	20.68	21.68	22.16
FullInterior Exterior	23.30	21.10	22.03	22.71
FullInterior Exterior Reflections	23.13	20.86	21.87	22.53

Time needed for simulation is proportional to complexity of solar distribution model (Table 2). Difference in simulation time is at most 9.9% bigger which is not lot in case that user wants correct results.

Table 2. Simulation time of different solar radiation models used

	Simulation time (s)	**Difference in simulation time (%)**
Minimal Shadowing	55.73	0
Full Exterior	58.11	4.27
FullExterior Reflections	61.25	9.9
FullInterior Exterior	59.48	6.73
FullInterior Exterior Reflections	61.14	9.71

4.2 Houses with heating

When heating of rooms with the thermostatic valves is introduced, a change in consumption can be seen as the heat gain from solar radiation is different and there is less energy needed for achieving design temperature. Energy consumed for heating by solar radiation model used is given in table 3.

Table 3. Energy consumption for heating by solar radiation model used

	Consumption, GJ
Minimal Shadowing	7.96
Full Exterior	7.96
FullExterior Reflections	8.08
FullInterior Exterior	7.89
FullInterior Exterior Reflections	8.01

5. CONCLUSIONS

It can be seen that solar model works well and that temperatures during day in rooms on different sides of world are rising or falling according to the sun position. Also according to the simulation time models with reflections are more complex then other models, and it takes about 10% more time to do the simulation. On smaller scale models this is not a problem and results are more accurate. Due to the difference in solar radiation models, average temperatures in same room between models can vary up to 1° C. Difference in consumption are much smaller and they can vary up to 1,5%.

On smaller scale models like one used here by looking on results, it is recommended to use one of the two models with reflection. This investigation shows that time used is not big increase as the convergence in temperature can vary a lot.

NOMENCLATURE:

α – solar absorptance of the surface
θ – angle of incidence of the sun's rays
d – number of days
E_{uhd} – heat consumption in hour – h on day – d.
E_u – annual heat consumption
I_b – for intensity of beam (direct) radiation
I_s – for intensity of sky diffuse radiation
I_g – intensity of ground reflected diffuse radiation
F_{ss} – angle factor between the surface and the sky
F_{sg} – angle factor between the surface and the ground.
$t_{r,h,ave}$ – average temperature in each room type – r, for selected hour – h.
$t_{r,h,d}$ – temperature in each room type on selected hour on day d.
S – area of the surface
S_s – for sunlit area

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Acknowledgment: This paper is a result of two investigations: (1) project TR33015 of Technological Development of Republic of Serbia, and (2) project III 42006 of Integral and Interdisciplinary investigations of Republic of Serbia. The first project is titled “Investigation and development of Serbian zero-net energy house”, and the second project is titled “Investigation and development of energy and ecological highly effective systems of poly-generation based on renewable energy sources. We would like to thank to the Ministry of Education and Science of Republic of Serbia for their financial support during these investigations.