SENSITIVITY ANALYSIS FOR DAILY BUILDING OPERATION FROM THE ENERGY AND THERMAL COMFORT STANDPOINT

Marko G. IGNJATOVIĆ*[*a], Bratislav D. BLAGOJEVIĆ[a], Mirko M. STOJILJKOVIĆ[a], Dejan M. MITROVIĆ[a], Aleksandar S. ANDJELKOVIĆ[b], and Milica B. LJUBENOVIĆ[c]

[a] Faculty of Mechanical Engineering, University of Nis, Nis, Serbia
[b] Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia
[c] Faculty of Civil Engineering and Architecture, University of Nis, Nis, Serbia

Original scientific paper
DOI: 10.2298/TSCI16S5485I

Improving energy performance of buildings is one of the most important tasks for reaching sustainability. Assessing building energy consumption is performed more often with specialized simulation tools. Sensitivity analysis proved to be a valuable tool for creating more reliable and realistic building energy models and better buildings. This paper briefly describes the methodology for running global sensitivity analysis and tools that can be used, and presents the results of such an analysis conducted for winter period, daily, on input variables covering a real building's operation, control and occupant related parameters that affect both thermal comfort and heating energy consumption. Two sets of inputs were created. The only difference between these sets is an addition of clothing insulation and occupant heat gain as input variables. The reference building was simulated for three distinctive winter weeks. Two additional input variables have an effect especially on thermal comfort, but they do not disturb the relative order of other influential input variables. The common influential variables for both energy consumption and thermal comfort were identified and are: air handling unit supply temperature and airflow rate and control system related parameters. This can help in future research into implementing the simulation-assisted optimized operation in real buildings.

Key words: *sensitivity analysis, daily building operation, simulation, EnergyPlus*

Introduction

Energy conservation in buildings is one of the top priorities in official energy policies of many countries. The main reason for this is the significant increase of energy consumption in building sector [1-3]. Bojić [4] stated that in Serbia the building sector participates with more than 50% of consumed energy.

Building energy performance simulation (BEPS) has become a generally accepted method for assessing building energy consumption during all stages of the building life cycle. However, practice has shown that there is a huge discrepancy between simulated and actually measured building energy consumption [5]. The reasons for this are numerous: specific building location weather deviations from generally used typical weather conditions in simulations; false assumptions during the design stage; simplifications in building modeling and misuse of simulation tools; differences in building operation from the designed one due to occupant be-

* Corresponding author; e-mail: marko.ignjatovic@masfak.ni.ac.rs

havior *etc.* Bridging the *gap* between the predicted and measured building energy performance is a concern for building energy performance calibration problems [6-8]. Numerous research studies concerned with the use of BEPS tools in the design and operation phase of building life-cycle, have proved that sensitivity analysis is a valuable tool [9]. Sensitivity analysis (SA), in general, allows finding the most influential input parameters in the model on the desired output. In the case of using SA with BEPS, this means modifying the model inputs in order to see how these modifications effect the model output(s) of interest. The SA is widely used [10-13] in building design and refurbishment projects and research, impact of climate change on buildings, building regulation *etc.* In these applications, the output parameter of choice is either heating/cooling load or building energy consumption. The SA was scarcely applied for finding the impact of input variations on occupant thermal comfort besides building energy performance [14]. It must be stressed that all these applications of SA are directed towards general recommendations for building design.

In recent years, there has been a strong research interest in improving building energy performance only by improving building systems operation through simulation-assisted approach [15]. These research efforts focus on finding optimal, operation related parameters in order to minimize energy consumption and maintain occupant thermal comfort. Since high thermal comfort and low energy consumption are two conflicting goals, these problems are solved by applying various optimization methods. It seems that SA could point out which input parameters in the model have the greatest impact on both thermal comfort and energy consumption (which variables in the model should be optimized). General definition of thermal comfort is *that condition of mind which expresses satisfaction with the thermal environment* [16]. It is proved that thermal comfort is influenced by physical, physiological and even psychological processes. Also, different studies show that despite different climate, living conditions and culture, the temperature that people choose as comfortable under similar conditions of clothing, activity, relative humidity and air velocity is very similar. Numerous research studies have been conducted on calculation of thermal comfort conditions. The most widely used thermal comfort index is predicted mean vote (PMV) index developed by Fanger, and it is used in this research as well. PMV index encompasses four environmental parameters (ambient air temperature, mean radiant temperature, relative air velocity and relative humidity) and two personal parameters (clothing insulation and metabolic rate).

This paper illustrates a performance workflow, and the results of sensitivity analysis applied to an EnergyPlus [17] model of real building which can be further used as the initial step for simulation-assisted building system operation optimization [18] intended to minimize daily energy consumption while preserving the occupant thermal comfort.

Methodology

Sensitivity analysis and tools

Three types of sensitivity analysis methods are distinguished: the screening methods, local methods and global methods. All these methods could be performed with a BEPS tool of choice. The screening method is necessary in situations with large number of input parameters. The main goal of applying it is to create a short-list of important factors for further analysis. It is usually run before global sensitivity analysis in order to save time. Local sensitivity analysis evaluates the output variability by changing one input variable at time while all others inputs are kept constant. Global sensitivity analysis investigates the effects of all the input variables at once. In other words, it can be used to quantify the influence of variability of all input parameters simultaneously on the variability of outputs. Usually, Monte Carlo analysis (MCA), as one of the global sensitivity analysis techniques is used. It requires input variables to be sampled with respective probability distribution functions. The accuracy of the analysis strongly depends on the sampling technique that must ensure a good coverage of the input space. The Latin hypercube sampling technique covers the input space better [9] than random or stratified sampling. The methodology for sensitivity analysis could be described by the following steps [9]:

– determine variations (probability distributions) of input variables with ranges or statistical parameters (mean value, standard deviation or range),
– create building energy models based on input variations,
– collect simulation results,
– run sensitivity analysis, and
– present sensitivity analysis results.

Many sensitivity indicators can be used after Monte Carlo is performed, such as standardized regression coefficients (SRC), partial correlation coefficients (PCC), or their rank transformations like standardized rank regression coefficient (SRRC), and partial rank correlation coefficient (PRCC).

The first step in SA is to determine the range of inputs. For global SA, probability distributions and ranges need to be defined in order to create an input parameter sample. The distribution function of inputs depends on the research purpose. For example, in the design stage every input could be presented with a uniform distribution function in a given range since all values are equally probable, but in model calibration or for operation optimization it could be presented with normal distribution since values are known and are likely to be around initial value. Other types of probability distribution functions (triangular, log normal, discrete, *etc.*) can be used. Also a combination of several different functions is possible. The second step is the most time consuming because large number of simulations must be performed. The minimum number of simulations must be at least 50% higher than the number of input variables. For this step any BEPS tool can be used. The third step includes both collecting simulation results and pre-processing them for sensitivity analysis. The fourth step is sensitivity analysis. Based on selected method appropriate software's for running sensitivity analysis could be used. Numerous software packages are available for this purpose like: Simlab 2.2 [19], R [20], SPSS [21], *etc.* The final step is post-processing and visualization of results. Results could be presented both graphically and in tables. The selection of the chart type depends on a number of inputs and outputs, and can be fairly simple like bar graphs (for few outputs) or very complex (tornado plot, cobweb plots *etc.*).

Reference building and modeling approach

The selected reference building is the Feniks BB company building located on the periphery of Nis (fig. 1). This building represents the combination of the office and manufacturing type of buildings which have become very common in Serbia in the past several years.

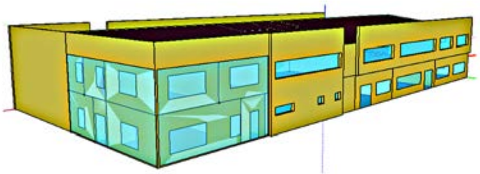

Figure 1. Isometric view of the reference building

The building has approximately 1630 m^2 of useful floor area. One part of the building is a manufacturing hall while the other part is divided into two stories where light manufacturing, servicing facilities and offices are located. Most of the outside windows and doors are double glazed with low emission glass with the average U-value of 2.5 W/m^2K, and solar heat gain coefficient in the range 0.2-0.4. Windows and doors account for 35% of the building façade. In one part, the north-east and south-east façade of the building are realized with semi-structural glass façade. All glass fields are double glazed 6-15-4 with green stop-sol outside glass layer. Outside walls are masonry with insulation and aluminum panels (except the north-west wall).

On the zone level, the heating system consists of baseboard heaters (radiators) equipped with thermostatic valves which heat most of the building premises and air heaters for manufacturing hall. For the office part of the building, besides radiators, heating can be provided with central constant air volume system (central air handling unit – AHU used as the only space cooling system for offices) as well (intended to be used as an alternative heating system in transitional periods). The AHU operates only on weekdays during the working hours (from 8 a. m. to 5 p. m.). Heat is provided by gas-fired boiler which supplies heat to main building and to several other premises on the location. Boiler operates in the low-temperature regime 65/45 °C. On the building level, heating energy consumption is measured with an ultrasonic heat-flow meter.

The systems are controlled by programmable logic controller (PLC). The boiler is available on weekdays from 6 a. m. until 10 p. m., if outside temperature is less than 17 °C, and supply water temperature is controlled with a PLC with several important features for this research: it has a four-point water supply temperature, fig. 2(a), and it has correction factors for water supply temperature within different periods of day and week, fig. 2(b). Correction factors F1, F2, F3, and F4 cover the following periods of day respectively: from 10:15 p. m. previous day until 6 a. m., from 6 a. m. until 8 a. m., from 8 a. m. until 4 p. m., and from 4 p. m. until 10:15PM.

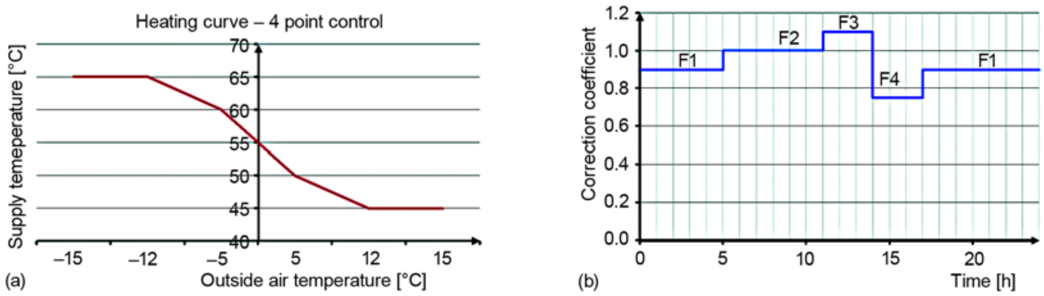

Figure 2. The PLC features for supply water temperature; (a) four-point outside temperature reset, (b) correction for supply water temperature depending of time of day

Since the selected building has two distinctive parts: manufacturing and administrative/office part, this research focuses on the office area presented in fig. 3, *i. e.* finding input variables that have the most influence on PMV in the considered zones and heating energy consumption of the whole building.

All parts of the building were modeled as separate thermal zones. Systems serving the building were modeled with their respective capacities while system operation and control were modeled based on the detailed site survey and copying the PLC logic into the built-in EnergyPlus energy management system with proper routines and subroutines [22].

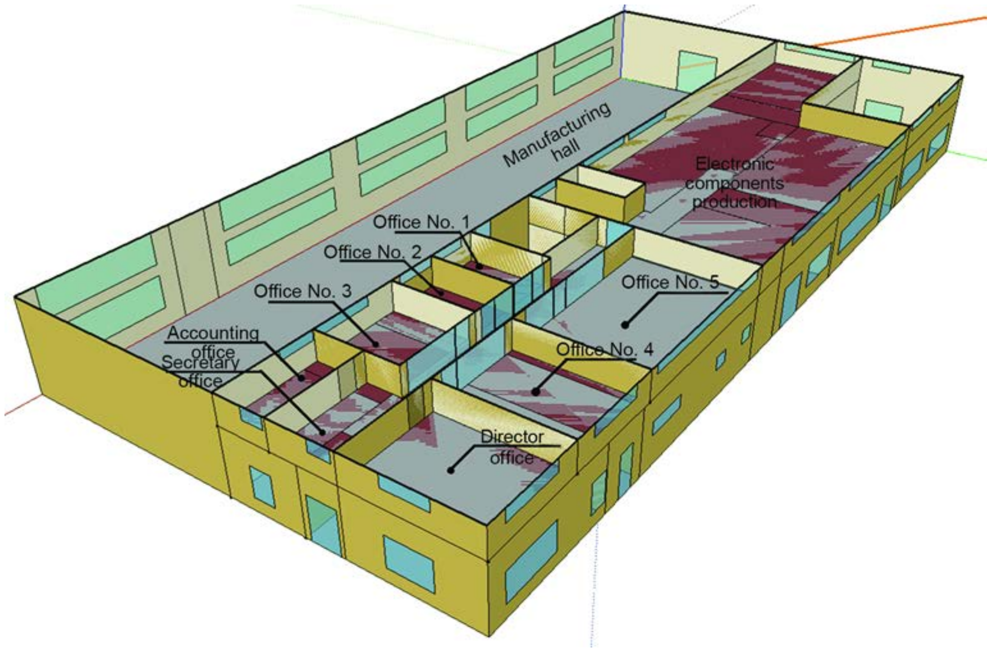

Figure 3. Office part of the building with neighboring zones

The fans of the AHU are equipped with frequency drives, so the airflow entering specific zone is assumed to be proportional to the design conditions (meaning that if airflow in particular zone is 20% of the design airflow, it will remain 20% for all other airflows) and is given in tab. 1. Since PMV is influenced by relative air velocity in the zone, air velocity within each zone served by AHU is calculated from airflow entering that particular zone. This was achieved by linear fit of calculated air velocities from different airflows for known size and type of installed air distribution equipment as in tab. 1.

Offices are occupied on weekdays from 8 a. m. until 5 p. m. and have a constant number of people as specified in tab. 1.

Table 1. Airflow percentage entering the zone, relative air velocity calculation and typical number of occupants in offices during weekdays

Thermal zone	Percentage of design airflow entering the zone	Relative air velocity linear fit	Number of occupants
Office No. 1	9.4	2.52 × ZoneAirFlow + 0.02	2
Office No. 2	8.4	2.52 × ZoneAirFlow + 0.02	2
Office No. 3	11.3	2.52 × ZoneAirFlow + 0.02	3
Accounting office	8	2.52 × ZoneAirFlow + 0.02	2
Secretary office	13.6	2.52 × ZoneAirFlow + 0.02	2
Director office	13	2.367 × ZoneAirFlow – 0.0234	1
Office No. 4	18	2.0238 × ZoneAirFlow – 0.0351	4
Office No. 5	18.3	2.0238 × ZoneAirFlow – 0.0351	6

Input and output variables

For this research, sensitivity analysis is applied on two output variables: daily heating energy consumption of building and hourly PMV in offices, both available as outputs [23] from simulations and related to specifics of the systems described in the previous subsection. These variables are crucial for building operation optimization. Daily heating energy consumption includes, besides consumption in office part, also the consumption in other parts of the building, thus not neglecting energy consumption in other zones of the building (which are not considered important from the thermal comfort standpoint). Unlike heating energy consumption, summed PMV value over time and different zones does not make any sense and it cannot be used to draw valid conclusions from the analysis. This is the reason why the hourly PMV value was selected. Furthermore, the hourly PMV from several zones would lead to having as much output variables as number of zones making analysis unclear. The weighted PMV, as a custom output variable, allows keeping PMV as a single output on one side and having the possibility to internally rank zones PMV importance on the other. Weighting PMV can be done in numerous ways: according to zone floor area, zone volume, number of people in zone, *etc.* Weighting PMV according to number of people was selected for this study:

$$\mathrm{PMV} = \sum_{i=1}^{i=8} \left| \mathrm{PMV}_i \right| \times \frac{N_i}{N_{\mathrm{tot}}} \tag{1}$$

where i represents the zone identifier, $|\mathrm{PMV}_i|$ – the absolute value of PMV in i-th zone, N_i – the number of occupants in the i-th zone (as given in tab. 1), and N_{tot} – the total number of occupants. By calculating PMV as an always non-negative number offset errors are avoided.

Input variables were chosen having in mind building and systems use and operation, features of the installed PLC and other control equipment (thermostatic valves, on/off switches for system components, *etc.*) as well as occupant behavior (position of thermostatic valves collected during several site surveys). Knowing PMV is more than a combination of thermal parameters and includes personal variables (clothing, metabolic activity, *etc.*), two sets of input parameters have been created: the first one contains only thermal parameters and the second containing two additional personal parameters (clothing insulation and occupant heat gain). These two sets of input parameters with probability distribution function types and relevant statistical indexes are given in tabs. 2 and 3, respectively. It is common [9] to choose the probability distribution function type according to the intention of sensitivity analysis. During the design stage values of input parameters are equally probable to happen and uniform or discrete distribution can be chosen. Similarly, for existing buildings, values of input parameters are likely to be around the design values and normal distribution function can be selected. It is usual to select standard deviation ±10% of the mean value for normal distributions. In this research, both uniform and normal distributions have been chosen, despite the fact that the research deals with the existing building. Normal distributions have been applied to the input variables which are not affected by occupant behavior (except clothing insulation and occupant heat gain – these two variables were added with generally accepted common values). Uniform distributions have been applied to input variables directly affected by occupant behavior, namely set-point and set-back temperatures in different zones, and the range for each was created after the several site surveys by just checking the position of thermostatic valves in each zone.

Latin hypercube sampling was performed for both sets of input parameters with the sample size set to 500.

Table 2. Input variables with respective probability distribution functions and statistical indexes for case 1

Input variable, unit, abbreviation	Probability distribution function	Mean, μ, and standard deviation or range, σ,
AHU supply temperature, IF1, [°C]	N	μ = 25, σ = 3
AHU airflow rate, IF2, [kgs^{-1}]	N	μ = 0.5, σ = 0.05
F1 correction factor, IF3, [–]	N	μ = 1, σ = 0.1
F2 correction factor, IF4, [–]	N	μ = 1, σ = 0.1
F3 correction factor, IF5, [–]	N	μ = 1, σ = 0.1
F4 correction factor, IF6, [–]	N	μ = 1, σ = 0.1
Manufacturing hall set-point temperature, IF7, [°C]	U	17-20
Manufacturing hall set-back temperature, IF8, [°C]	U	13-15
Director office set-point temperature, IF9, [°C]	U	21-24
Director office set-back temperature, IF10, [°C]	U	14-17
Accounting office set-point temperature, IF11, [°C]	U	23-25
Accounting office set-back temperature, IF12, [°C]	U	14-17
Secretary office set-point temperature, IF13, [°C]	U	23-25
Secretary office set-back temperature, IF14, [°C]	U	14-17
Office No. 4 set-point temperature, IF15, [°C]	U	20-22
Office No. 4 set-back temperature, IF16, [°C]	U	14-17
Office No. 5 set-point temperature, IF17, [°C]	U	20-22
Office No. 5 set-back temperature, IF18, [°C]	U	14-17
Electronic components production set-point temperature, IF19, [°C]	U	20-22
Electronic components production set-back temperature, IF20, [°C]	U	14-17
Other premises set-point temperature, IF21, [°C]	U	19-21
Other premises set-back temperature, IF22, [°C]	U	14-16

N – normal, U – uniform

Selected time periods

A custom weather file in required format, necessary to run the simulations, was made from the data provided by the Hydro-meteorological station Nis. The data contains values of, amongst the others, outside air dry-bulb temperature, outside air relative humidity, wind direction and wind speed, barometric pressure and global radiation in one minute resolution, for January 2016 and February 2016.

Table 3. Input variables with respective probability distribution functions and statistical indexes for case 2

Input variable, unit, abbreviation	Probability distribution function	Mean, μ, and standard deviation or range, σ,
AHU supply temperature, IF1, [°C]	N	μ = 25, σ = 3
AHU airflow rate, IF2, [kgs^{-1}]	N	μ = 0.5, σ = 0.05
F1 correction factor, IF3, [–]	N	μ = 1, σ = 0.1
F2 correction factor, IF4, [–]	N	μ = 1, σ = 0.1
F3 correction factor, IF5, [–]	N	μ = 1, σ = 0.1
F4 correction factor, IF6, [–]	N	μ = 1, σ = 0.1
Manufacturing hall set-point temperature, IF7, [°C]	U	17-20
Manufacturing hall set-back temperature, IF8, [°C]	U	13-15
Director office set-point temperature, IF9, [°C]	U	21-24
Director office set-back temperature, IF10, [°C]	U	14-17
Accounting office set-point temperature, IF11, [°C]	U	23-25
Accounting office set-back temperature, IF12, [°C]	U	14-17
Secretary office set-point temperature, IF13, [°C]	U	23-25
Secretary office set-back temperature, IF14, [°C]	U	14-17
Office No. 4 set-point temperature, IF15, [°C]	U	20-22
Office No. 4 set-back temperature, IF16, [°C]	U	14-17
Office No. 5 set-point temperature, IF17, [°C]	U	20-22
Office No. 5 set-back temperature, IF18, [°C]	U	14-17
Electronic components production set-point temperature, IF19, [°C]	U	20-22
Electronic components production set-back temperature, IF20, [°C]	U	14-17
Other premises set-point temperature, IF21, [°C]	U	19-21
Other premises set-back temperature, IF22, [°C]	U	14-16
Clothing insulation, IF23, [clo]	N	μ = 1, σ = 0.1
Occupant heat gain, IF24, [W per person]	N	μ = 120, σ = 12

N – normal, U – uniform

For finding most influential inputs on the heating energy consumption and thermal comfort, three different winter weeks were selected (change of outdoor temperature shown in fig. 4 is used to distinguish these time periods):

– *cold* winter week starting on January 18th 2016 and ending on January 22nd with average outside temperature of –5.5 °C,

– *moderate* winter week starting on January 25th 2016 and ending on January 29th with average outside temperature of 2.1 °C,
– *warm* winter week starting on February 15th 2016 and ending on February 19th with average outside temperature of 11.9 °C.

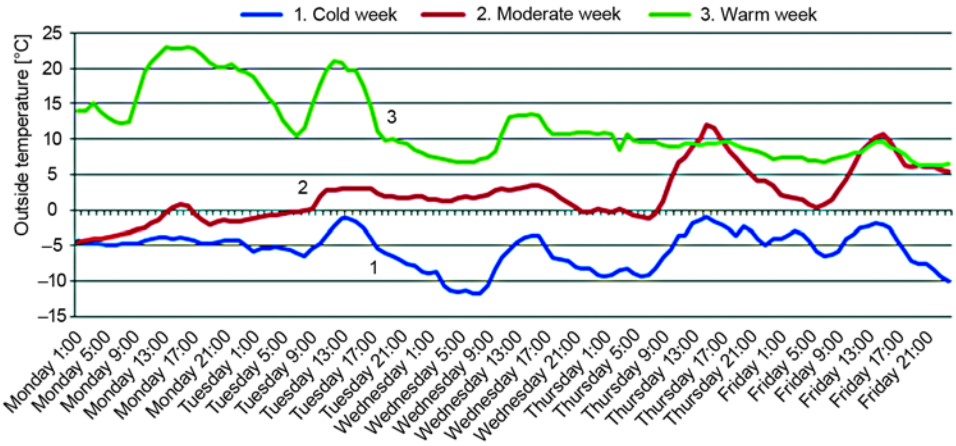

Figure 4. Outside temperature variations for the selected weeks

Overview of tools for this study

To briefly summarize the tools used in this study for performing sensitivity analysis as described in this section of paper. The BEPS tool used is EnergyPlus v8.4.0. The sampling technique selected was Latin hypercube with a sample size set to 500. Sampling was done, for two sets of input variables (22 and 24 input variables, respectively), with Simlab v2.2. Monte Carlo analysis was performed with Simlab v2.2. As a sensitivity indicator, SRRC was selected and was also calculated with Simlab v2.2. SRRC was calculated for two output variables: daily building heating energy consumption and weighted hourly PMV in the office part of the building. For all the pre-processing and post-processing, text editors and spreadsheet software were used.

Results and discussion

Since two different input sets were created for three different weeks, the results will be presented per output variable on weekly/daily basis.

Energy consumption sensitivity analysis

The sensitivity analysis results on heating energy consumption (figs. 5-7) show that both occupant heat gain and clothing insulation have very small influence, as expected. Threshold value for parameter to be sensitive is SRRC = ±0.1.

Considering *cold* winter week, in both cases the most sensitive input variables on a daily basis are: correction factor F3, AHU supply temperature, set-point temperature in other premises of the building, set-back temperature in electronic components production area and AHU airflow rate. This means that the energy consumption during the *cold* week is not sensitive to clothing insulation and occupant heat gain.

For *moderate* winter week, in both cases the most sensitive input variables on a daily basis are: correction factor F3, AHU supply temperature, AHU airflow rate, set-point and set-back temperatures in other premises of the building and set-back temperature in electronic components production area. Like for the *cold* winter week the energy consumption during the *moderate* week is not sensitive to clothing insulation and occupant heat gain.

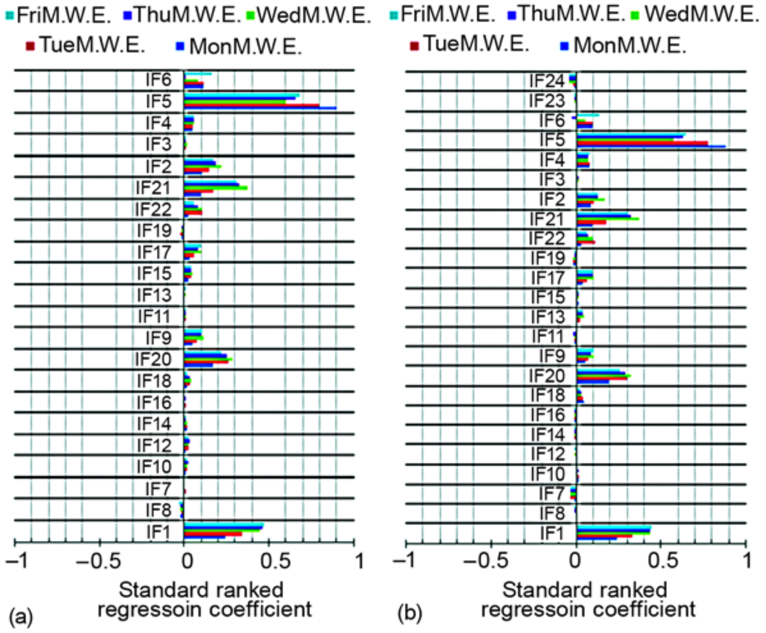

Figure 5. The SRRC for daily energy consumption for cold week; (a) first set of input variables, (b) second set of input variables
(for color image see journal web-site)

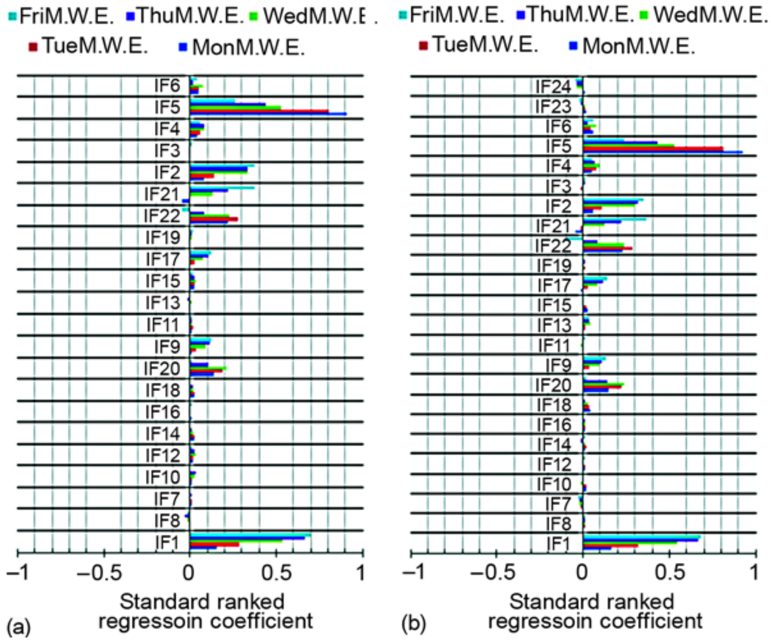

Figure 6. The SRRC for daily energy consumption for moderate week; (a) first set of input variables, (b) second set of input variables
(for color image see journal web-site)

For the *warm* winter week the situation considering sensitivity of two additional variables (clothing insulation and occupant heat gain) remains the same as for *cold* and *moderate*

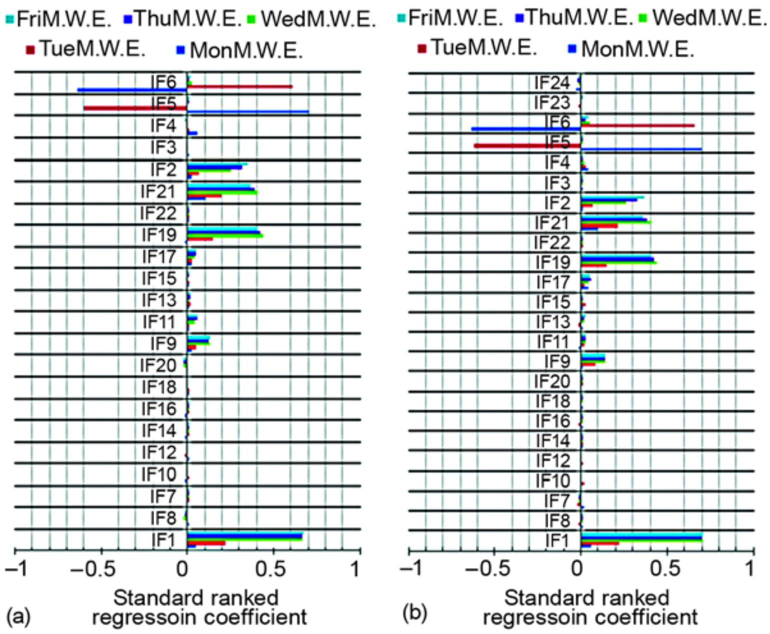

Figure 7. The SRRC for daily energy consumption for warm week; (a) first set of input variables, (b) second set of input variables
(for color image see journal web-site)

week, meaning the energy consumption is not sensitive to these variables. However, the order of the most sensitive parameters changes more often on a daily basis than for the other periods, and more input variables should be considered for operation optimization. For the *warm* week the following input variables are sensitive (not always in this order): AHU supply temperature, correction factors F3 and F4, AHU airflow rate, set-point temperatures in other premises of the building, electronic components production area and interestingly director's office.

To summarize, considering heating energy consumption, the most sensitive input variables are: AHU supply temperature and airflow rate, correction factor F3, set-point, and set-back temperatures in electronic component production area and other premises of the building. Interestingly, heating energy consumption is not sensitive to indoor temperatures in manufacturing hall, although having the largest area and volume in the building.

The PMV sensitivity analysis

The sensitivity analysis results on PMV index (figs. 8-10) show the importance of both occupant heat gain and clothing insulation, as expected. Since these two variables have much higher SRRC than the others, threshold value for SRRC in this case is ±0.05.

During the *cold* week the following variables can be considered sensitive for PMV: AHU supply temperature, correction factor F3, office No. 5 set-point temperature and to some extent: correction factor F2, set-point temperature in office No. 4 and other premises, AHU airflow rate. Impact of the AHU supply temperature increases during the whole occupied period, as well as the impact of office No. 5 set-point temperature.

During the *moderate* week the following variables can be considered sensitive for PMV: AHU supply temperature, correction factor F3, office No. 5 set-point temperature and to some extent: correction factor F2, set-point temperature in office No. 4, set-point temperature in director office, set-point in other premises, AHU airflow rate. The most sensitive variables follow the same trend as during the *cold* week.

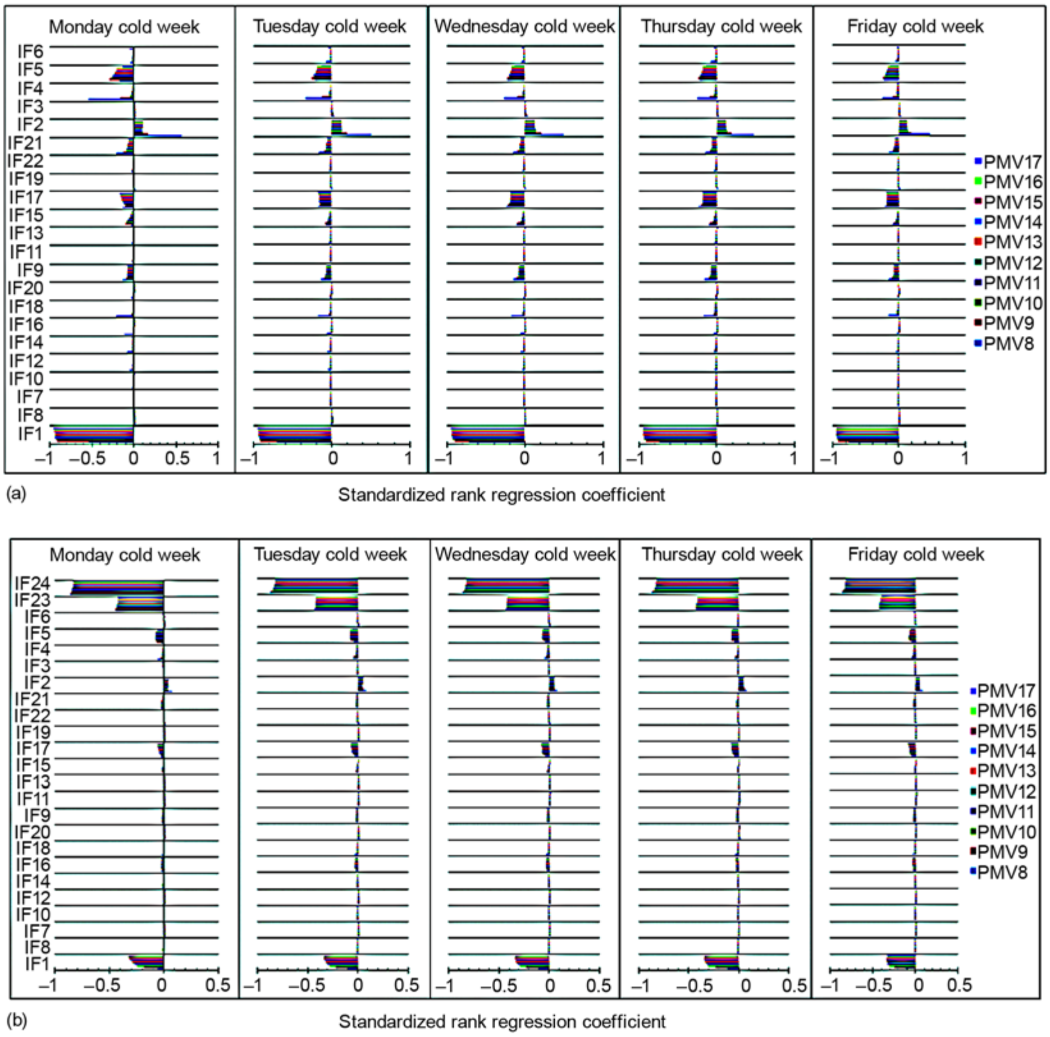

Figure 8. The SRRC for PMV index during cold week; (a) first set of input variables, (b) second set of input variables

Sensitivity analysis results on PMV index during the *warm* week have very similar trends as sensitivity analysis results on heating energy consumption. More often sensitivity of various inputs changes during one day, but the general conclusion is that the most sensitive are: AHU supply temperature and AHU airflow rate. The other sensitive inputs are to some extent correction factors F3 and F2 as well as set-point temperatures in offices with more occupants (offices No. 4 and No. 5). Both AHU supply temperature's and airflow rate's SRRC change sign, which implies that during the day inputs and outputs go in the opposite directions (negative SRRC) for one part of the day (between 10:00 a. m. and 11:00 a. m.), and in the same directions (positive SRRC) for the remaining time of occupied period (from 10:00 a. m., approximately). This means that when SRRC is negative, the increase in inputs leads to decrease of output, and vice versa, when SRRC is positive, the increase in inputs leads to increase of output.

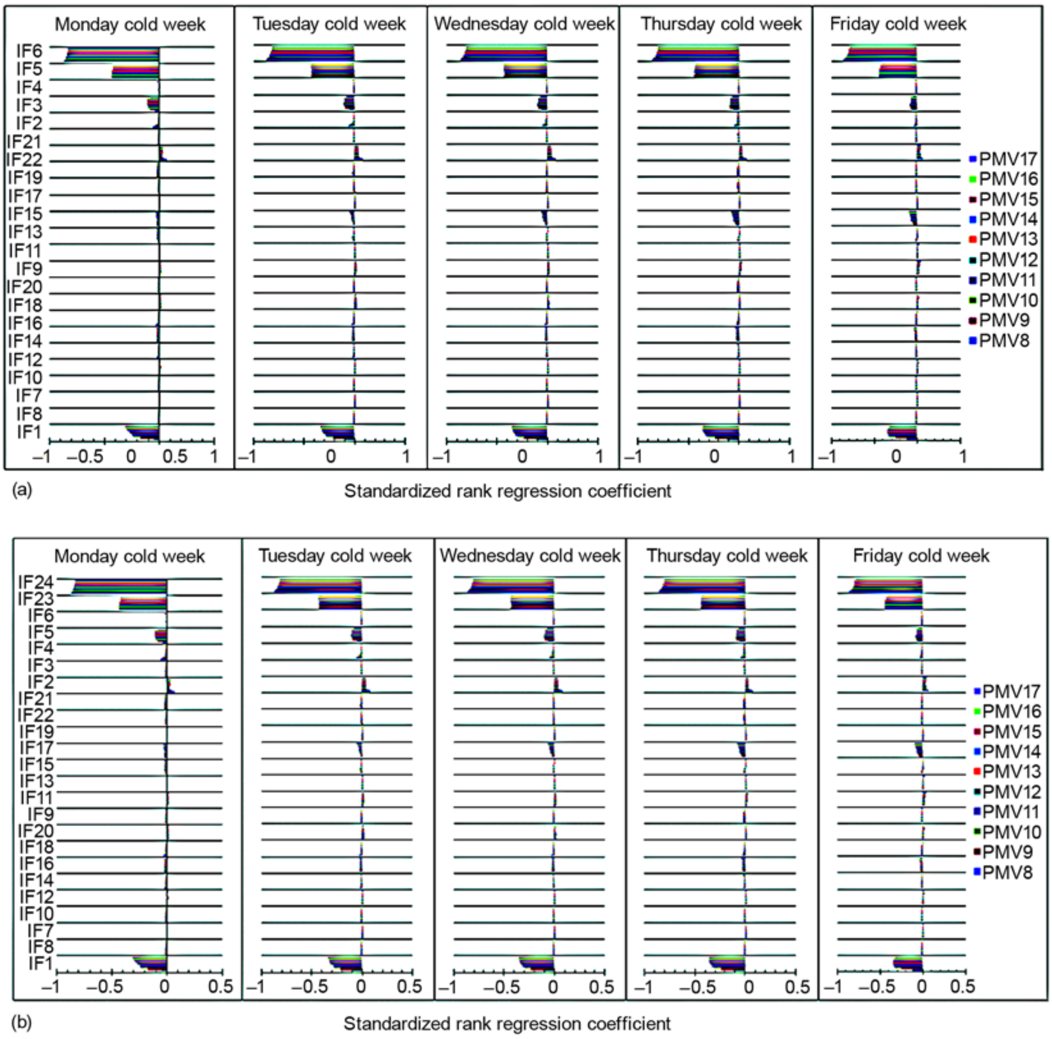

Figure 9. The SRRC for PMV index during moderate week; (a) first set of input variables, (b) second set of input variables

Common for all three weeks is a very small influence of neighboring zones on PMV which is expected.

Conclusion

From the presented results it is clear that sensitivity analysis can reveal the most important (sensitive) inputs to the conflicting model outputs, such as heating energy consumption and PMV index, on daily basis. This means than sensitivity analysis could be run on a daily basis, as a first step for simulation-assisted optimized building operation.

For the selected reference building, the common (most sensitive inputs) are: AHU supply temperature, AHU airflow rate, correction factor F3 and, to some extent, set-point and set-back temperatures in premises neighboring zones where PMV is of interest. The relative

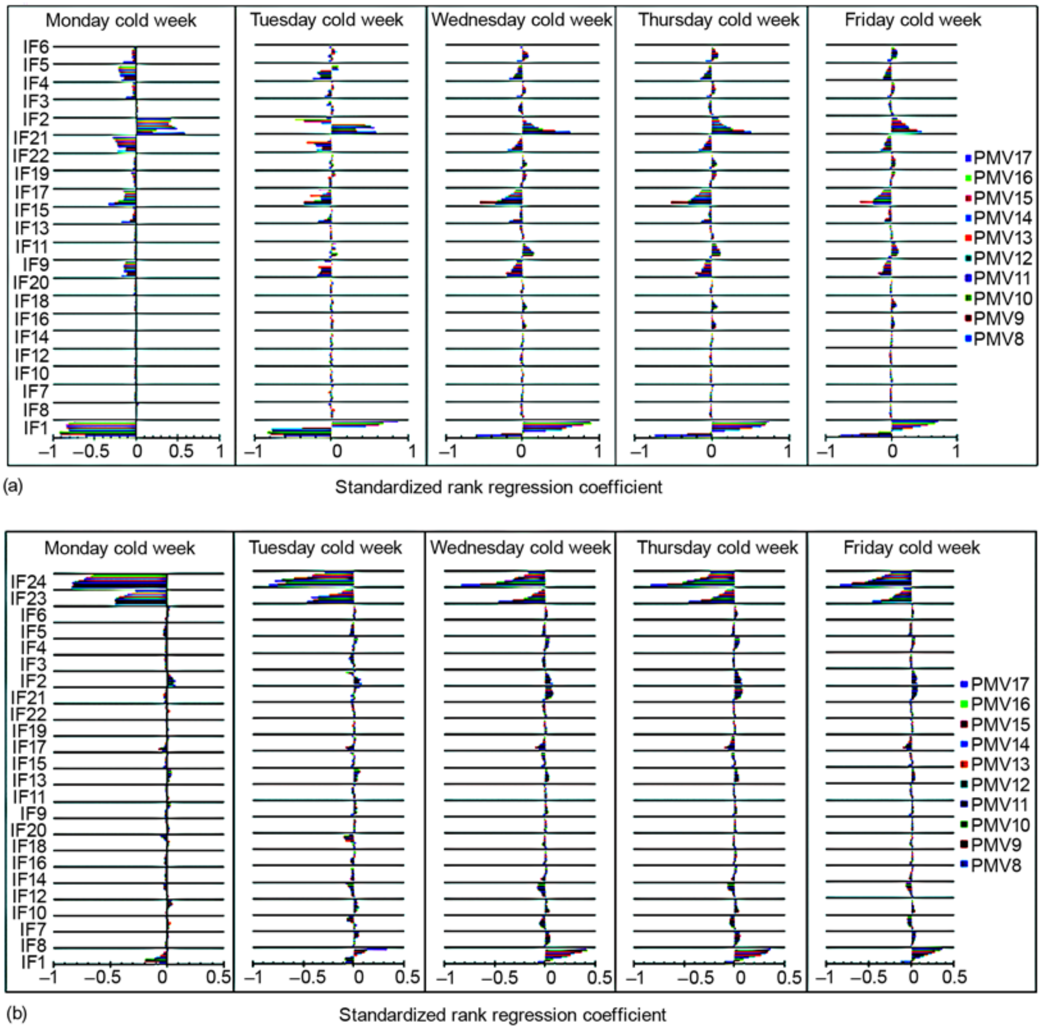

Figure 10. The SRRC for PMV index during warm week; (a) first set of input variables, (b) second set of input variables

order of the most sensitive inputs remains practically the same even when two additional personal parameters (clothing insulation and occupants' heat gain) are included. This is important for using sensitivity analysis for simulation-assisted optimization of building operation, since number of optimization variables can be reduced. Furthermore, omitting inputs which cannot be easily recorded on regular basis (clothing insulation and occupant heat gain) will simplify practical application of proposed methodology for improving real buildings operation.

In recent years in Serbia, there has been an ascending trend of constructing these kinds of buildings with similar layouts, heating and air conditioning system types, control systems and building operation, to the analyzed building. This means that there is a possibility, not only to enable the simulation-assisted operation of building systems, but also to give general recommendations for designing this type of buildings. This will require performing sensitivity analysis on a much larger scale with higher number of inputs, checking different probability distribution functions and more simulation runs.

Acknowledgment

This research is performed within the project TR-33051 *The concept of sustainable energy supply of settlements with energy efficient buildings*, funded by the Ministry of Education, Science and Technology of the Republic of Serbia under the program Technology Development. The authors are particularly grateful to the Republic Hydrometeorological Service of Serbia, Observatory in Nis for providing the weather data in order to conduct this research, and to the company Feniks BB d.o.o., Nis, for their support in helping record building operation and install additional measuring equipment.

References

[1] Perez-Lombard, L., *et al.*, A Review on Buildings Energy Consumption Information, *Energy and Buildings*, *40* (2008), 3, pp. 394-398
[2] ***, 2010 Buildings Energy Data Book, Office of Energy Efficiency and Renewable Energy, US Department of Energy, 2011, http://buildingsdatabook.eren.doe.gov/
[3] Gruber, M., *et al.*, Model-Based Controllers for Indoor Climate Control in Office Buildings – Complexity and Performance Evaluation, *Energy and Buildings, 68 Part A* (2014), Jan., pp. 213-222
[4] Bojić, M., *et al.*, A Simulation Appraisal of Performance of Different HVAC Systems in an Office Building, *Energy and Buildings*, *43* (2011), 6, pp. 1207-1215
[5] De Wilde, P., The Gap between Predicted and Measured Energy Performance of Buildings: A Framework for Investigation, *Automation in Construction, 41* (2014), May, pp. 40-49
[6] Maile, T., *et al*, A Method to Compare Simulated and Measured Data to Assess Building Energy Performance, *Building and Environment*, *56* (2012), Oct., pp. 241-251
[7] Raftery, P., *et al.*, Calibrating Whole Building Energy Models: An Evidence-Based Methodology, *Energy and Buildings, 43* (2011), 9, pp. 2356-2364
[8] Dong, B., *et al.*, Development and Calibration of an Online Energy Model for Campus Buildings, *Energy and Buildings, 76* (2014), June, pp. 316-327
[9] Tian, W., A Review of Sensitivity Analysis Methods in Building Energy Analysis, *Renewable and Sustainable Energy Reviews*, *20* (2013), Apr., pp. 411-419
[10] Rodriguez, G. C. *et al.*, Uncertainties and Sensitivity Analysis in Building Energy Simulation Using Macroparameters, *Energy and Buildings*, *67* (2013), Dec., pp. 79-87
[11] Yildiz, Y., Arsan, Z. D., Identification of the Building Parameters that Influence Heating and Cooling Energy Loads for Apartment Buildings in Hot-Humid Climates, *Energy*, *36* (2011), 7, pp. 4287-4296
[12] Lam, J. C., *et al.*, Sensitivity Analysis and Energy Conservation Measures Implications, *Energy Conversion and Management*, *49* (2008), 11, pp. 3170-3177
[13] Hopfe, C. J., Uncertainty and Sensitivity Analysis in Building Performance Simulation for Decision Support and Design Optimization, PhD thesis, Eindhoven University of Technology, Eindhoven, Netherlands, 2009
[14] Ioannou, A., Itard, L. C. M., Energy Performance and Comfort in Residential Buildings: Sensitivity for Building Parameters and Occupancy, *Energy and Buildings*, *92* (2015), Apr., pp. 216-233
[15] Afram, A., Janabi-Sharifi, F., Theory and Applications of HVAC Control Systems: A Review of Model Predictive Control (MPC), *Building and Environment*, *72* (2014), Feb., pp. 343-355
[16] ****, ASHRAE Handbook – Fundamentals, Chapter 9: Thermal Comfort, American Society of Heating, Ventilation and Air conditioning Engineers, Atlanta (Georgia), USA, 2013
[17] ***, EnergyPlus 8.4, US Department of Energy, https://energyplus.net/downloads
[18] Ignjatović, M., *et al.*, HVAC System Optimization Based on Dynamic Simulation Tool (in Serbian), *KGH*, *45* (2016), 1, pp. 53-57, in Serbian
[19] ***, SIMLAB. V2.2, Simulation Environment for Uncertainty and Sensitivity Analysis, Developed by the Joint Research Center of the European Commission, https://ec.europa.eu/jrc/en/samo/simlab
[20] ***, R Development Core Team. R: a language and environment for statistical computing. R foundation for statistical computing, http://www.R-project.org/S

[21] ***, SPSS Inc. Released 2007. SPSS for Windows, Version 16.0. Chicago, SPSS Inc, http://www.ibm.com/analytics/us/en/technology/spss/
[22] ***, EnergyPlus EMS Application guide, US Department of Energy, https://energyplus.net/documentation
[23] ***, EnergyPlus Engineering reference, US Department of Energy, https://energyplus.net/documentation

Paper submitted: May 6, 2016
Paper revised: July 12, 2016
Paper accepted: July 19, 2016