Building Dynamic simulation uncertainty evaluation based on sensitivity analysis

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Abstract

Building dynamic simulation are used to estimate the energy performance of buildings and to size some of the equipment that will be used. It is a valuable tool to help designing sustainable buildings, by showing the impact of different solutions on the building's behavior in both new buildings and retrofit projects.

However, models are by definition approximate and represent a simplification of the real physical world. Sources of uncertainty abound in building simulation and must be taken into account into the results of the simulations. These sources have been identified and classified in three categories: the simplification of the model, the input parameters based on assumptions and standards values and the physical processes used by the software. This paper will study the impact of the input parameters in the results of the simulation. Considering the uncertainty factors aims at improving designer confidence in the simulations.

Sensitivity analysis plays an important role in the understanding of complex models. It helps to identify the influence of input parameters in relation to the outputs. For building energy models, combining sensitivity analysis and simulations tools helps to rank the input parameters (or family of parameters) and then to select the most appropriate to be considered.

This study aims to analyze and illustrate the potential usefulness of improving the accuracy of the input parameters in order to reduce the models uncertainty.

The analysis of the results showed that the impact on the simulation’s results depends on the type of inputs. It was found that some parameters that have a major influence on the outputs can be easily made more precise such as the wall’s characteristics. Moreover some parameters that are complex to estimate can also impact the

accuracy of the results, such as the air infiltration rate through the building's envelope.

Introduction

Developing building simulations at the project phase have usually little adherence to real energy consumption when the building is operating. Sources of uncertainty abound in building simulation due to simplification and assumptions made to draw the energy model. It is essential to take into consideration the accuracy of the model to know to what extent the results can be relied on, and to identify and reduce the sources of uncertainty.

The uncertainties come from 3 levels: the simplification of the model, the input parameters based on assumptions and standards values and the physical processes used by the software. It is very complicated for the user to have an impact on the software physical model, but a lot of work can be done on the input parameters. These parameters are taken from real data (material, design, measurement), assumptions (time of use of the equipment, occupancy) and from collected data measured on-site or nearby (weather files).

To partially solve this issue, standard values provided by the ASHRAE Guidelines are very often used. However, even if standard values can be a good approximation, it is hard to know to what extend they approach the reality of each buildings.

A great way to determine which parameters influence the most the precision of the model is to perform a sensitivity analysis which assess the relationship between variations in input parameters to variation in output (predicted) parameters. All the design parameters do not affect building energy performance on the same level. The impact on the model of these sensitive parameters will be measurable, therefore it will be possible to ascertain whether the extra effort is necessary and worth to achieve better predictions. The importance level of the parameters will guide the decision-making process and extract priority input parameters that must be particularly accurate to improve the accuracy of the results.

This thesis aims at evaluate the sources of uncertainty of these simulation models using a sensitivity analysis and to identify how these results can be used to improve the reliability further simulations.

Case Study

The building studied is the Kompas Multimedia Tower located in Jarkarta, Indonesia. The building has 25 stories above ground level and 3 stories below ground level forming the parking lots.

A simulation work based on the architect's drawings was carried out to assess the performance of the design specified by the Mechanical, electrical, and plumbing (MEP) consultant. Additionally, this simulation work also assessed the performance of the exterior façade.

The design input parameters implemented in the simulation are based on standard values from the ASHRAE Guidelines or are approximations given by the building's manager.

Methodology

Kompas Tower work plan of measurement

In order to compare the results of the simulation with the real behavior of the building, measures were taken on-site during 3 days. At this stage, the building was empty and not being utilized yet. No system were running. Therefore, the measures show the natural behavior of the building in its environment, without any heat or cool produced. The first simulation shows the difference between the simulation of the empty building and the data measured on-site.

The simulation was realized with EnergyPlus software and SketchUp OpenStudio plug-in.

To perform the sensitivity analysis on the normal use of the tower, several simulations had to be realized modifying the design parameters in order to see their impact on the simulation's results. The software JEPlus was used to perform this multiple design parameters analysis. The Latin Hypercube Samples (LHS) were generated using SimLab. The same software was used to analyze the outputs of the simulations. . In this study, 50 samples were generated knowing that the minimum number of executions recommended for the LHS corresponded to 12.

This process is summed up in the following figure:

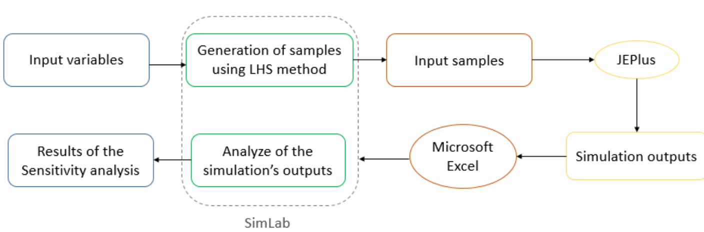


Figure 1: Process of the sensitivity analysis using JEPlus and SimLab

The sensitivity indices were calculated using the Pearson product moment correlation coefficient (PEAR) since it offers a good compromise between accuracy and computational cost in building energy models. (Nguyen and Reiter 2015)

Design parameters studied

The following table shows the design parameters involved in the sensitivity analysis:

N°	Parameter	Unit	Initial value	Interval
P1	Windows U value	W/m².K	3.5	1.75 – 5.25
P2	Windows SHGC	%	25.5	12.75 – 38.25
P3	Wall insulation thickness	m	0.2105	0.11 – 0.3158
P4	Concrete density	kg/m³	1280	640 - 1920
P5	Roof insulation thickness	m	0.2105	0.1053 – 0.3158
P6	Lights	%	70	35 - 100
P7	Equipment	%	70	35 - 100
P8	Air infiltration	1/hour	0.15	0.075 - 0225

Table 1: List of the parameters studied in the SA

The interval was made from the value used in the initial simulation: the minimum is half of the initial value and the maximum is equal to 3 times the minimum. As such, the initial value is the middle of this interval. The samples generated took random values in these intervals for each parameters, using a uniform distribution.

- The concrete is used in the structure of the building, in every exterior wall and in the roof. The parameter ''concrete density'' shows the impact of the density of the structure in the simulation.
- The lights and equipment correspond to the percentage used during the week days out of the capacity attributed to each zone.
- The windows U value corresponds to the windows overall heat transfer coefficient.

- The windows SHGC corresponds to the windows Solar Heat Gain Coefficient.
- The air infiltration corresponds to the air changes per hour due to the natural ventilation. 0.15 changes per hour means that the air inside a room is completely renewed every 4 hours.

Outputs

The impact of the variables on the different outputs were examined. The simulation had for goal to size the ventilation and cooling system (HVAC + Chiller) of the future building and to evaluate the impact of different glazing and shading options on the building's behavior and on its energy consumption. This is why the following outputs were chosen:

n°	Output	Unit
c1	Main Chiller: Chiller Electric Power	W
c2	Facility: Electricity consumption	J
c3	Whole Building: Facility total building electric demand power	W
c4	Whole Building: Facility total HVAC electric demand power	W
c5	Cooling: Electricity consumption	J
c6	Fans: Electricity consumption	J

Table 2: List of the SA outputs

- There is no output of temperature inside the building because the systems are set-up to be auto-sized to fit the set points of every room.
- The chillers are used to cool down the water coming from the Fan Coil Unit (FCU). Knowing about their nominal power gives an idea of the size of the HVAC system.

Results

Overview

This graph represent the factor of impact of the variables on each output.

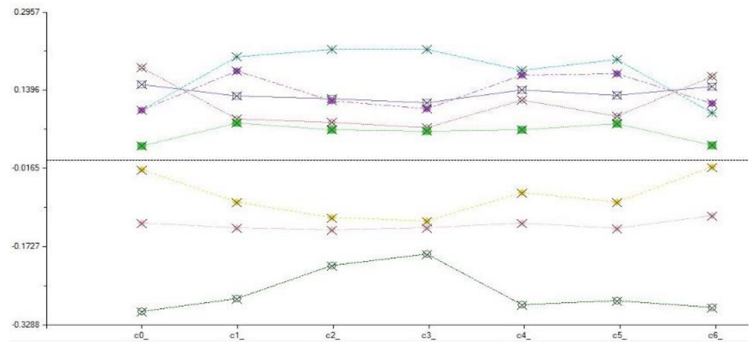


Figure 2: PEAR

The analysis include positive and negative values for the factors, corresponding to the impact of the parameters on the outputs: when the factor is positive, increasing the value of a parameter increases the value of the output, and vice versa.

The bigger the absolute value of the factor of impact is, the more the parameter impacts the results of the simulation. The parameters represented close to the central continue line barely impact the results.

Some points can be noticed:

- 2 parameters have a major impact on the simulation's results: the wall insulation thickness and the concrete density.
- The equipment have a similar impact on every output contrary to the windows U value that affects mostly the radiant chiller electric power, the fans' electricity consumption and the total HVAC electric demand power.

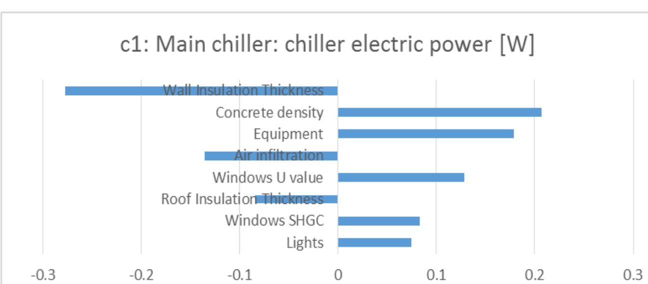
- The lights barely impact the simulation's outputs.

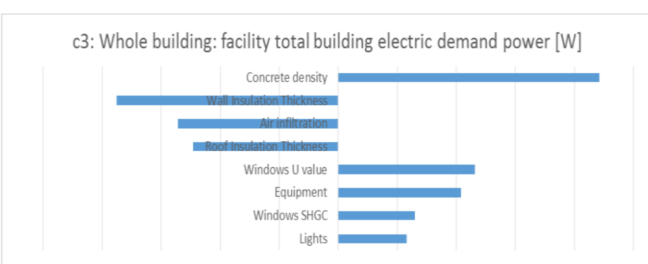
The sign of the sensitivity index for all the design parameters remains the same for every outputs, with just one exception noticed in the PCC method. It implies a correlation between the outputs showing that they will be affected in the same way by the parameters, but with different amplitudes. This result seems logical in this study, since using bigger HVAC systems will increase their capacity as well as the building power demand and the electricity consumptions of all the systems.

Detailed results

The Tornado diagram lists vertically the data categories, and order them so that the largest bar appears at the top of the chart, the second largest appears second from the top and so on. This type of diagram is great to represent the sensitivity indices of the parameters and to highlight the one that have the most impact on the simulation.

The following figures represent the sensitivity indices of the parameters on each outputs:





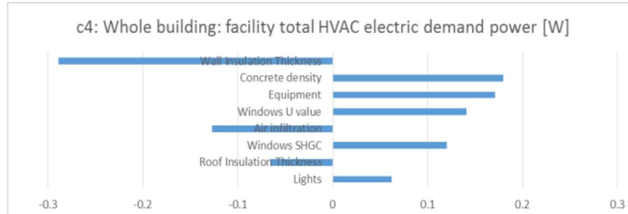


Figure 3: Results of the sensitivity indices of the parameters on each outputs using the PEAR method

It is clear that the wall insulation thickness has a major impact on the simulation's results. It is not very surprising since the exterior walls are the major link between the inside of the tower and its surrounding environment. The walls are exposed to the sun rays, to the wind and to the hot outside temperatures.

At the contrary, increasing the density of the concrete used in of the walls' and roof's layer increases the HVAC needs. This happens because it increases the thermal mass of the walls, therefore the quantity of heat that can be stored by the facade. The heat is then released in the building even when the outside temperature decreases below the building's average temperature.
The concrete density often appears also of major influence on the simulation.

Concerning the windows characteristics, their overall heat transfer coefficient (U value) seems to have slightly more impact on the simulation's results than their Solar Heat Gain Coefficient (SHGC). Besides, it is satisfying to see that the SHGC can have a significant impact on the simulation, meaning that the sun rays are really taken into account into the EnergyPlus calculation model. So studying the impact of the implementation of shading devices or solar films using dynamic simulations makes sense and has potential.

As supposed, the roof's insulation thickness impacts on the simulation is much lower than the walls' insulation thickness since the area covered is smaller.

The impact of air infiltration on the simulation seems contradictory with what could be expected: increasing it reduces the HVAC needs. It can be explained by the natural ventilation effect when the outside air penetrates the building. Knowing that in a day there are more hours when the outside temperature is lower that the temperature inside the building, it helps the HVAC systems cooling down in these hours. Reducing the air infiltration also increase the needs of mechanical ventilation required to guarantee a good air quality inside the building bringing ''new air'' from outside, and by consequence the electrical consumption.

The role of adding the equipment and the lightings to the simulation is to add their heating and electricity loads in the calculations. As expected, the more they are used and the more the building needs to be cooled down, and the bigger is the energy consumption. The energy consumption is affected in two points: the equipment and lightings consume directly electricity to run, and they release heat that need to be compensated by the cooling systems that also consume electricity to run.

The electricity consumption and the heat release associated to the lightings are in smaller proportion than the equipment, explaining the modest impact of the lightings on the simulation.

The following figures sums up the absolute values of the average of the sensitivity indices on all the output parameters:

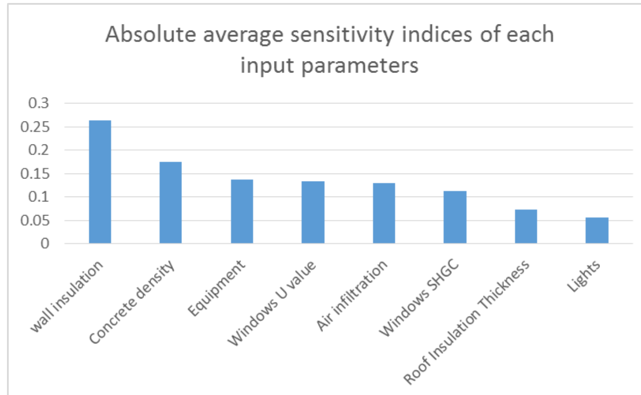


Figure 4: Absolute average sensitivity indices of each input parameters

- As seen previously, the wall's composition has the biggest impact on the simulation. Therefore its exactness should be considered in priority.
- The equipment arrived on the third position. This parameter is difficult to make accurate since the final equipment used are rarely known precisely in advance, the heat they will release is based on approximation and their use schedules are also complicated to determine. However, investing more time to make all these information as close to the reality as possible would be worth to improve the accuracy of the simulation's results.
- The windows characteristics are usually reachable using the supplier's technical information, and would also improve the accuracy of the results without being too complicated to add.
- The air infiltration is quite complicated to evaluate, using the standard values in

case of lack of better data would limit the uncertainty due to this parameter.

- The lights do not impact the model significantly, it does not worth to spend much time to make their schedules or consumption very precise. The standard values should be approximate enough.

To improve the inputs, the building's manager should provide the people in charge of the simulation with more detailed data. Unfortunately, these information remains hard to get if the technical details have not been discussed yet or because it is hard to reach the people that hold the information needed.

However, it remains very complex to measure the final accuracy of a simulation without having on-site measured data to draw a comparison.

Conclusion and discussion

The main target of this thesis was to ascertain whether improving the input parameters accuracy worth to achieve better predictions. The importance level of the parameters was measured through a sensitivity analysis made on a simulation of a tower building in Jakarta, Indonesia.

This work was very limited due to the computation cost of the simulation and the non-professional equipment used. It would have been more relevant to realize a sensitivity analysis comparing the impact of more input parameters.

The analysis of the results showed that the impact on the simulation's results depends on the type of inputs. It was found that some parameters that have a major influence on the outputs can be easily made more precise such as the wall's characteristics. Moreover some parameters that are complex to estimate can also impact the accuracy of the results, such as the air infiltration rate through the building's envelope.

The uncertainty in these inputs parameters can be due to a lack of technical information about the building and its systems and due to assumptions that are difficult to make in the context of the project.

To partially solve this issue, standard values provided by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Guidelines are very often used. However, even if standard values can be a good approximation, it is hard to know to what extend they approach the reality of each buildings.

This work shows that the envelope of the building (walls, widows and roof) have a significant impact on the outputs. However, there were implemented using standard values. Knowing about the exact composition of the envelope of the building would have increased significantly the accuracy of the simulation, and these information should be accessible.

Calibrating the model before performing the simulation is another great way to improve the simulations accuracy. The simplest way is to calibrate the weather file using data measured on-site to the weather file used for the simulation. A more complete calibration would be to compare the results of the simulations with data measured inside the building in the same conditions. Unfortunately this method requires the building to be already built and maybe some equipment to be running, so it could only be used for building's retrofit projects.

Acronyms

KMT: Kompas Multimedia Tower
PEAR: Pearson product moment correlation
SA: Sensitivity Analysis
SES: Synergy Efficiency Solutions
HVAC: Heating, Ventilation and Air Conditioning
FCU: Fan Coil Unit
LHS: Latin Hypercube Samplings

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