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Risk Model Sensitivity

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In my earlier columns, I tried to explain the concept of uncertainty analysis and also draw attention of the industry to the advantages of performing probabilistic energy modeling. One of the most valuable complementary tools to uncertainty analysis is sensitivity analysis. Terje Aven in his book, *Foundation of Risk Analysis,*[1] gives the following definition for sensitivity analysis: "A sensitivity analysis is a study of how sensitive the risk is with respect to changes in input parameter of risk model."

The main advantage that a sensitivity analysis brings to energy modeling process is that it can help the energy modeler (engineer) to evaluate and to compare the effects of uncertainty in different inputs to the model on the overall output of the model.

In other words, sensitivity analysis allows the energy modeler to know which of the model inputs have the largest impact on the model output. Such information opens a valuable window for the modeler to understand the relationship between the input and output variables and to prioritize which input variables should be more fully characterized, researched and finally improved.

Assume we have developed and use a commercial software program that is capable of performing a risk-base (probabilistic) energy modeling procedure. This requires us to include the uncertainty that resides in each input element of the building model, such as uncertainty in building exterior walls heating characteristics (Z_1), building glazing shading coefficient (Z_2), chiller testing agency allowable test tolerances (Z_3), allowable lighting power consumption tolerances (Z_4), and coil leaving air temperature sensor accuracy (Z_5), etc. (for more description of the possible sources of uncertainty in energy modeling input see my January 2014 energy modeling column "Performing Probabilistic Energy Modeling").

After completing this task and running the building energy model simulation, we will get a model output (building energy consumption) in the form of a probability distribution curve. Performing a sensitivity analysis based on the probabilistic model inputs then can help to estimate the respective percentage effect of each of the uncertain inputs in forming the final output probability distribution.

For example, let's assume the energy modeling output distribution that is a function of uncertain inputs Z_1, Z_2, Z_3, Z_4, Z_5, etc., can be represented by $Y(Z_1, Z_2, Z_3, Z_4, Z_5, \ldots)$. Then, the sensitivity analysis results can show that each variable (Z_1, Z_2, Z_3, Z_4, Z_5, etc.) has an impact equal to X_1%, X_2%, X_3%, X_4%, X_5%, etc., (In most sensitivity analysis methods sum of all these percentages will be 100%) on the overall uncertainty of the modeling output Y.

It is obvious that the higher percentages represent the more critical factors and, therefore, the greatest impact on the overall model output, while the lower percentages represent lesser effect on overall model output. Consequently any small improvement at level of input uncertainty of high impact factors will more significantly change overall simulation outcome. Conversely, even large improvements for those input parameters with little impact on the overall output of the simulation will only change the overall simulation outcome minimally.

The benefit is that the energy modeler can discover that for improving the overall energy consumption of each building it would pay off substantially to invest in improving the first group of inputs, but it would not pay off significantly to invest in improving the second group of the inputs. Availability of this knowledge in advance can have major energy savings and, therefore, financial benefits, because it not only helps the modeler to make better design decisions, but also would enhance the level of communication and understanding between the modeler, other design team members and the building owner as well.

An example of research in this field includes Heiselberg and Brohus,[2] who performed an energy consumption sensitivity analysis for a seven-story

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office building in cold climate considering 21 uncertain parameters with selected uncertainty (specific range and distribution) for each one of these inputs. The results showed mechanical ventilation rate in winter and lighting control were the top two sensitive factors in that specific building primary energy use.

Eisenhower, et al.,[3] studied two models (Nominal & High Performance) of a new construction medium size (three story office building) in hot and dry summer and cool winter climate zone. Other than a few parameters that were constrained, close to 1,000 uncertain inputs were varied by ±25% of their nominal values. The result of the simulations were divided into 10 parameter types, and by using the sensitivity analysis, the most influential factors in each category for this specific building were discovered.

For example, the most influential parameter in "heating source" group for the nominal building model was found to be the boiler efficiency and the most significant parameter for "air-handling unit" type for both nominal and high performance buildings was found to be the seasonal reset supply air temperature setpoint.

Such research and results not only show the importance and value of a risk-based analysis (uncertainty and sensitivity analyses), but also in the same time and, as I suggested in my January column, emphasizes the fact that one of the most important and immediate needs for performing these valuable risk-based analyses is gathering a reliable database for the variances assigned to the building material and equipment. This will not be possible without contributions from the manufacturers and material builders.

Saltelli, A., et al., in their book, *Global Sensitivity Analysis—The Primer,*[4] discuss many different purposes that a sensitivity analysis can be useful for. Some of these are surprising the analyst, uncovering technical errors in the model, identifying critical regions in the space of the inputs, establishing priorities for research, and simplifying models.

References

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