Sensitivity Analysis for Energy Performance Contracting in new buildings

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ABSTRACT

Since buildings are responsible for around 40% of total energy, many initiatives have been made to guarantee the savings to the purchaser. Before a building construction, an energy performance contracting (EPC) consists in predicting the energy required to maintain the user's comfort by using thermal dynamic simulation tools. Many building and HVAC system characteristics are uncertain due to lack of knowledge on uncommitted parameters at design stage or implementation defaults at construction stage.

To define a performance guarantee, not only a consumption threshold for the performance contracting taking into account uncertainties should be set, it also important to identify the key parameters to pay special attention to during the design phase in order to reduce the risks of non-compliance of the contract. The identification of the most influencing parameters is part of a quality procedure.

This article focuses on several sensitivity analysis methods all useful for an Energy Performance Contracting:

- Quick sensitivity analysis methods to identify the most influencing parameters and to reduce the uncertainty analysis
- Reliability methods to assess part of uncertainty due to the parameters in the failure probability factors for a given consumption threshold
- Global sensitivity methods studying all the input space.

The aim of this paper is to draw recommendations concerning the use of these different methods according to the time budget, the expected accuracy and the type of building parameters to be studied.

The selected methods are assessed on a real case study, a 4000 m² office and stock building of 2 levels located in Nantes (West of France) with 2 air handling units to ensure indoor air quality and 2 reversible Heat Pumps suppling underfloor heating systems, chilled beams and AHUs. The building is modeled under TRNSYS 17 environment. For this building, 49 uncertain parameters of the building and its systems have been identified: AHUs, heat pumps, water networks, building walls, building glazing, infiltration, ground exchanges, set points and occupancy. Three types of probability density are chosen to characterize the parameters, depending on the knowledge we have of the parameters: uniform, beta and truncated normal distributions.

We firstly study two local sensitivity methods: Morris method (screening) and differential sensitivity analysis. Our aim is to reduce the number of input parameters of the probabilistic study by identifying the most influential ones. The ranks obtained by Morris method or Quadratic Combination are very similar, except slight changes between groups, but quadratic combination requires 4 times less calculation than Morris method. The Morris method provides additional information such as the detection of non-linear effects of the parameters and the interactions between factors. If the physical model contains parameters with very non-smooth effects (for instance, threshold effects correlated with several input parameters), the quadratic combination is not appropriate anymore, so that Morris method is recommended in order to select the most influent input parameters. In the other cases, Quadratic Combination is advised. This first step permits to reduce the number of parameters from 49 to 24.

Then, we study FORM/SORM reliability methods. These methods permit to compute the probability of exceeding a threshold and to assess the contribution of each parameter on the failure probability for a given consumption threshold. These local sensitivity methods are very interesting for EPC. Indeed, the importance factors permit to identify which parameters are critical to maintain a building consumption and thus to adapt the measurement protocol. As the FORM method's cost is low, it can be applied to different consumption thresholds to study the evolution of the share of responsibility of the parameters in the probability of exceeding these thresholds.

Finally, global sensitivity methods are assessed. Since the sampling sensitivity analysis methods cannot be applied directly in our case, an approximation method is used. Indeed, given the computational time of one simulation with our physical model (11'), computing Sobol indices would require around 24000 simulations to study the selected parameters, that is to say, several weeks of computational time. Thus, as the computational time to apply global sensitivity methods are too high, one solution is to approach the physical model by a much faster model constructed by analysing the effect of the input random variables on the outputs.

The physical model is replaced by a sparse Polynomial Chaos expansion metamodel which runs a building simulation in less than one second. The advantage of the sparse polynomial chaos expansion is that is easily provides Sobol indices by analysing the coefficients. The first order Sobol indices identify the most influential model parameters. Sparse chaos polynomial expansion permits to approach a physical model in a very efficient way, with less than 500 simulations, depending on the number of parameters. The approximation of a model by a sparse polynomial chaos works if the model is smooth enough, for example, without threshold effects.