

Method and case study of quantitative uncertainty analysis in building energy consumption inventories

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ABSTRACT

Collections of building energy consumption data are often uncertain due to unavoidable measurement errors, random errors, non-representativeness of sample data, etc. On the basis of the quantitative uncertainty and Monte Carlo uncertainty propagation methods, the uncertainty of building energy consumption data is quantified. A real case study is conducted on the electricity and gas consumptions of buildings in Ma'anshan city in China in 2009. The results show that the electricity consumption distributions of four kinds of buildings fit Weibull distribution, gamma distribution, normal distribution and lognormal distribution respectively. The total energy consumption of buildings in the city at the cumulative probability of 97.5% is 16.6% higher than that obtained using the conventional method. The uncertainty of random sampling error in total energy consumption is about 14%. The sensitivity analysis results can provide information about the main sources that can help in reducing the uncertainty of the overall energy consumption inventory. This kind of quantification of uncertainty in energy consumption inventories could assist the decision-makers in determining the likelihood of complying with energy reduction objectives, and framing more scientific energy-saving strategies that may reduce building energy consumption.

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1. Introduction

The use of quantitative methods for characterizing uncertainty has been widely recognized and recommended for environmental modeling and assessment applications [1–6]. For instance, United States National Research Council (NRC) called for new efforts on mobile source emissions estimation and quantification of uncertainty in emission models [2]. Heijungs [3,4] reviewed several approaches to treat different types of uncertainty in LCA (life cycle assessment) and discussed the qualitative techniques that are available to address uncertainty. Macdonald and Strachan [5] demonstrated the partial application of uncertainty analysis by reviewing sources of uncertainties and incorporation of uncertainty analysis in Esp-r. Zhong [6] introduced the current methodological framework for quantifying uncertainty in emission inventories and conducted a case study on NOx emission inventory from power plants using uncertainty analysis.

In recent years, the use of uncertainty and sensitivity techniques is largely popularized in different branches of disciplines. There have been some researches focused on the investigation of

uncertainties and/or sensitivity in input parameters for building design support and in prediction of energy consumption. Hopfe and Hensen [7] conducted a case study of uncertainty analysis on design parameters in building simulation. Wang [8] investigates uncertainties in energy consumption due to actual weather and building operational practices using a simulation-based analysis of a medium-size office building. Macdonald [9] quantifies the effects of uncertainty in building simulation with respect to annual energy consumption, peak loads and the internal temperature. Brohus [10] presented a new approach for the prediction of building energy consumption. The approach quantifies the uncertainty of building energy consumption by means of stochastic differential equations to predict the performance of the systems and the level certainty for fulfilling design requirements under random conditions. Heiselberg et al. [11] applied sensitivity analysis to identify the important design parameters to change in order to reduce the primary energy consumption. Most of these researches almost concern the uncertainty analysis and sensitivity analysis of input parameters on energy consumption of whole-buildings, in which, the number of uncertain parameters is much larger. This study addresses the building energy consumption at city level. Nearly all analyses on energy and environmental control technologies at early phases of research involve uncertainties. Energy consumption inventories are a vital stage in energy-saving decision making. For example, energy consumption inventories are

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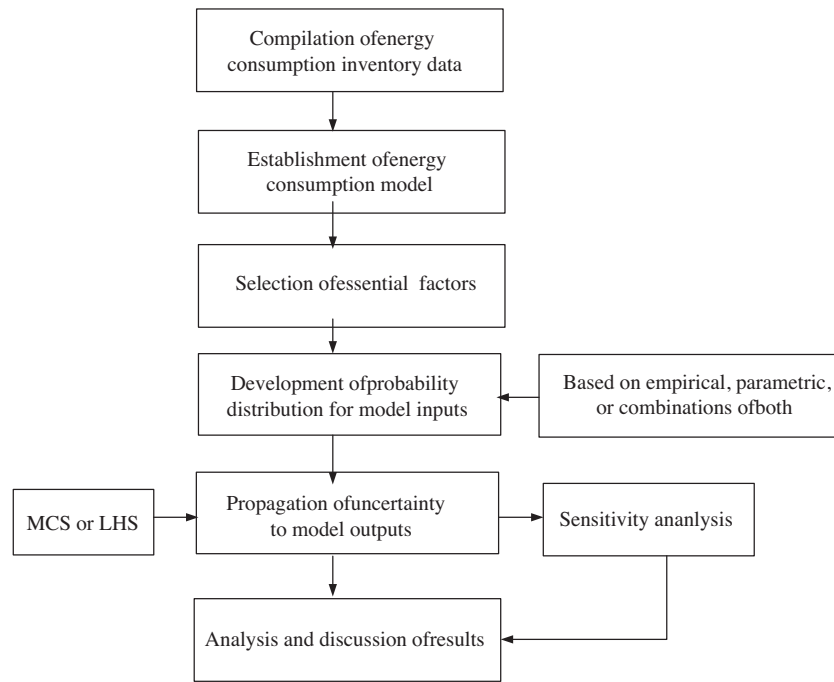


Fig. 1. Uncertainty analysis procedure.

used for: (a) characterization of temporal energy usage; (b) energy-saving budgeting for regulatory and compliance purposes; and (c) prediction of the trends of energy consumption. The energy consumption, such as electricity and gas, is increasing rapidly with the rapid development of economy in Ma'anshan city of Anhui province recently. Therefore, the inventories reflecting the energy consumptions of different buildings in the city could be very helpful in assisting building energy conservation programs at city level. However, there may be uncertainty in the resulting building energy consumption data because of random sampling errors, measurement errors, and/or possibly non-representative samples. If random errors and biases in energy consumption inventories are not quantified, they may lead to erroneous judgment on trends of total energy consumption, source apportionment, compliance, etc. Uncertainty analysis and sensitivity analysis can provide information about the reliability and influence of uncertain parameters on total energy consumption. The methods could enable the decision-makers to determine the likelihood of complying with energy reduction objectives, and to frame more scientific energy-saving strategies that may reduce building energy consumption.

The energy consumption intensities of different types of buildings are usually evaluated using sufficient number of samples to predict the total energy consumption of buildings at city level. The uncertainty and sensitivity of energy consumption intensities have significant impacts on the accuracy of the prediction. To make precise prediction, the uncertainty in the energy consumption intensities should be concerned. This paper therefore presents an inventory study on the distributions of energy consumption intensity in four types of buildings (office buildings, large public buildings, small public buildings and residential buildings) in Ma'anshan city. Bootstrap Simulation is used to quantify the uncertain parameters: the energy consumption intensities of four types of building. Monte Carlo simulation (MCS) method is used to predict total energy consumption of these buildings. Finally an effective way to reduce uncertainty in the overall energy consumption inventory is studied using the sensitivity analysis.

2. Quantitative uncertainty analysis procedure and methods

2.1. Uncertainty analysis procedure

Fig. 1 shows the procedure for uncertainty analysis on building energy consumption. The first step is the compilation of energy consumption inventory data, including identifying the parameters that might influence the final results. The second step is to establish the model. In most cases the model can be established using a formula that refers to some essential parameters. Hence, the most relevant parameters (factors) have been selected with some parameters assumed as fixed parameters, which have less uncertainty. The probability distribution models can be then developed using the selected relevant parameters as model inputs. The probability distributions may be empirical, parametric or combinations of both. Having the models, propagations of uncertainty from input parameters to model outputs can be quantified using Monte Carlo simulation (MCS) or Latin hypercube sampling (LHS). Finally, the quantitative or numerical estimates of the uncertainty associated with energy consumption estimates are determined.

2.2. The methods for simulating uncertainty propagation

In this study, a numerical simulation method, MCS, is used for simulating the propagation of probability distributions of all inputs using a model based on simulated random sampling. MCS and LHS are the most commonly used numerical simulation methods nowadays. In MCS, a model is running repeatedly, using different values for each of the uncertain input parameters each time. The values of each of the uncertain input parameters are randomly generated based on the probability distributions for the parameters. The advantage of using MCS is that it can provide an excellent approximation of the output distribution with a sufficient sample size. The disadvantage is that it may be necessary to use large sample sizes to obtain a smooth approximation of the cumulative distribution function (CDF). In LHS, the values of each uncertain input are not randomly generated. Instead, the probability distribution

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