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A Meta Model Based Bayesian Approach for Building Energy Models Calibration

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Abstract

Buildings contribute a large proportion of energy-related emissions. In order to characterize the buildings' energy performance, building energy models have been widely used due to their flexibility and convenience. When building energy models are developed to represent the existing buildings, there always exist some unknown or unmeasurable parameters which need to be specified in the simulation models. It is important to calibrate these parameters before applying the building energy models for intended use. In addition, there are various uncertainties in the using of the building energy models. To provide more reliable and confident results for decision making, it is necessary to account for these uncertainties in the calibration procedure. In this paper, a metamodel based Bayesian approach is proposed to calibrate the building energy models. This method is efficient by using the metamodel and can also take into account various uncertainties. To further improve the computational efficiency of the proposed method, a posterior approximation method is proposed to analytically evaluate the posterior distributions in the Bayesian approach. The proposed method is applied to calibrate an EnergyPlus model which is developed to simulate an office building located in Singapore. The numerical results indicate that it is accurate and efficient to use the proposed method for building energy models calibration.

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Keywords: Building energy model; Bayesian calibration; Gaussian process; Posterior approximation.

1. Introduction

Building is one of the major contributors to the global energy consumption and energy-related carbon emissions [1]. With the increasing concern about the climate change, it is important to improve the building energy performance so as to reduce the building energy consumption and emissions. Due to the complexity of the physical process of real building, building energy simulation models are often used to assist in analysing the real building energy performance. For instance, they can be used to support building design and retrofit [2]. Currently, there are many different types of building energy models, including DOE-2, EnergyPlus, TRNSYS and ESP-r. The comparison among these simulation tools can be found in [3].

When the building energy model is used to represent the existing building, there always exist some unknown parameters in the existing building but their values have to be specified in the building energy model, such as thermal properties, occupancy schedules

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and receptacle power. In order to improve the fit of the building energy model to the existing building, it is important to calibrate these parameters. Various calibration methods have been proposed for building energy model calibration. One type of methods is to calibrate manually. Manual calibration can be applied using the characterisation of building physical properties [4], graphical representation [5], parameter reductions [6], and data disaggregation [7]. The disadvantage of the manual calibration methods is that they usually depend on expert knowledge, which can be biased. Another commonly used way for building energy model calibration is to define an objective function and then apply some optimization methods to find the optimal parameters [8, 9]. This way can be easily automated. However, it is usually not easy to account for various uncertainties in this type of method. For a better quantification of uncertainties in the analysis, Bayesian calibration method is often used [10]. Recently, metamodel based methods become popular where the simpler and cheaper metamodels are used instead of the original complex building energy simulation models. One of the commonly used metamodel is Gaussian process (GP) model. For instance, a Gaussian process (one type of metamodel) based methods have been applied to calibrate building energy models [11, 12]. This type of method is more efficient for the time consuming simulation models by using faster metamodels. However, the process to develop the metamodel (e.g. GP) itself can be complex and the computation for metamodel based method can be expensive.

In this paper, a GP based Bayesian method is proposed to calibrate the building energy model. For the Bayesian method, it is required to evaluate the posterior distributions of the unknown parameters. However, the analytical forms of the posterior distributions are usually not available due to the complex structure of the metamodel. In this situation, the numerical methods are often used to evaluate the posterior distributions, such as the commonly used Markov chain Monte Carlo (MCMC) method [13]. These numerical methods usually require a large number of evaluations or replications to obtain an accurate posterior distribution. Therefore, the numerical method can also be time consuming if the posterior evaluation is time consuming. To ease the computational burden, analytical approximations to the posteriors are often used. There are several posterior approximation methods, such as the radial basis function based approximation method [14], variational inference method [15] and weighted normal approximation method [16]. Among these methods, the weighted normal approximation method can provide convenient analytical forms to approximate the posterior distributions. Based on [16], a weighted normal approximation method is further proposed to improve the GP based Bayesian calibration method. This method is much more efficient not only by using the GP model, but also by directly evaluating analytical posterior approximations. In addition, this method can also take into account various uncertainties. This paper is organized as follows: a GP based Bayesian calibration method is provided in Section 2. A posterior approximation method is proposed in Section 3 to extend the GP based Bayesian method. A case study is given in Section 4 to illustrate the accuracy and efficiency of the proposed approximation method. The conclusion is given in Section 5.

2. Bayesian calibration based on Gaussian process

Building energy model is often developed to represent the existing building. The relationship between the real observed output from existing building and the simulated output from building energy model can be denoted as Equation (1) according to [17].

$$z = y(x,\theta) + \delta(x) + e \tag{1}$$

where z denote the observed output from existing building and $y(x,\theta)$ denote the simulated output from building energy model at variable input x and unknown optimal calibration parameter θ. The interest it to adjust the calibration parameter θ. $\delta(x)$ denote the discrepancy between the existing building and the building energy model which is assumed to be independent of θ. The discrepancy exists as the building energy model usually cannot perfectly represent the existing building. e denote the observation error of the observed output from existing building, which is usually assumed to be a normal random variable [17].

Building energy model is usually easier to evaluate than existing building. However, building energy model itself can be time consuming to evaluate. In this situation, metamodel (e.g. GP model) can be further used to represent the building energy model, which is simpler and faster to evaluate. Here, simulation output $y(x,\theta)$ and discrepancy term $\delta(x)$ are both assumed to be a constant mean Gaussian process. A GP with constant mean is widely applicable in practice [18]. To be more specific, a function $h(\cdot)$ (e.g. $y(x,\theta)$ or $\delta(x)$) can be assumed to be a GP with constant mean μ and covariance function $\sigma^2 R(\cdot,\cdot)$, where the correlation $R(\cdot,\cdot)$ between any two input sets (e.g. x_i and x_j) is assumed to a commonly used Gaussian correlation [18] with the following exponential form.

$$R(x_i, x_j) = \exp\left\{-\phi \left\| x_i - x_j \right\|^2\right\} \tag{2}$$

With these assumptions, it can be found that the unknown parameters contain μ, σ^2 and ϕ besides calibration parameter θ. Then the issue becomes how to estimate these parameters. Bayesian method has been widely used to estimate the parameters by obtaining their posterior distributions [19]. The advantage of the Bayesian method is that it can reflect the prior knowledge and take into account various uncertainties [20]. Here, the Bayesian method is used to estimate these parameters based on the developed GP model.