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OPTIMAL DESIGN OF BUILDING ENVELOPES FOR AN OFFICE BUILDING USING BAYESIAN OPTIMIZATION

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ABSTRACT

Design of energy parameters of building envelopes is one of the key processes to reduce Energy Use Intensity (EUI, kwh/m^2.yr). For the process, 2 approaches exist: prescriptive and performance based. The former is easy to use, but doesn't allow design flexibility. The latter could be more effective than the former but is difficult to find optimal combination of design variables in an infinite option space. In addition, design parameters are interrelated. This study aims to use Bayesian Optimization (BO) to find optimal parameters minimizing EUI for a given office building. It was found that BO can be beneficially used to an optimum.

1 INTRODUCTION

For simulating energy use of the office building, a dynamic building simulation tool, EnergyPlus(EP) was employed in this study. EP can predict EUI depending on design parameters. The target building is a medium office building by US DOE. The following design variables (thickness of wall insulation, window to wall ratio, and solar heat gain coefficient (SHGC) and U value of windows) are parameterized as inputs and bounded by upper and lower values. The design problem in this study requires designating an optimal choice per orientation (E, S, W, N) except insulation thickness. With regard to optimization algorithm, gradient based methods are fast, but can't be applied to non-differentiable problems. Meta-heuristic methods demand significant computation. For this study, Bayesian Optimization (BO) is introduced because it doesn't demand high computational resource and is good at multimodal optimization problems.

2 METHODOLOGY

BO is a global optimization algorithm and mimic Bayesian statistic. It is commonly used when the objective function is nonlinear and multi-modal. BO first takes as a random function as a prior distribution. With initial observations(x, y), prior distribution is updated to posterior distribution. And then, the acquisition function, $\alpha(x)$ chooses next x' which could be an optimum. The new observation(x', y') is appended to the initial observations to update the prior distribution in the next iteration. The process is repeated until a terminal condition, e.g. maximum iteration or converging criterion (Figure 1).

To implement BO, Gaussian Process(GP) is often used. The performance of GP model largely depends on hyperparameters and thus, Maximum Likelihood Estimation is applied. When the hyperparameters of MLE are converged, BO starts to find optimal variables. The acquisition function needs to be decided for selecting a next point to be simulated, considering both exploitation and exploration. Expected Improvement(EI) is chosen because it balances the two terms automatically. EI is the function of $\mu_{\hat{f}}(x)$ and $\sigma_{\hat{f}}(x)$ which are the mean and the standard deviation of posterior distribution at x. The former concentrates on minimum values and the latter considers their uncertainties.

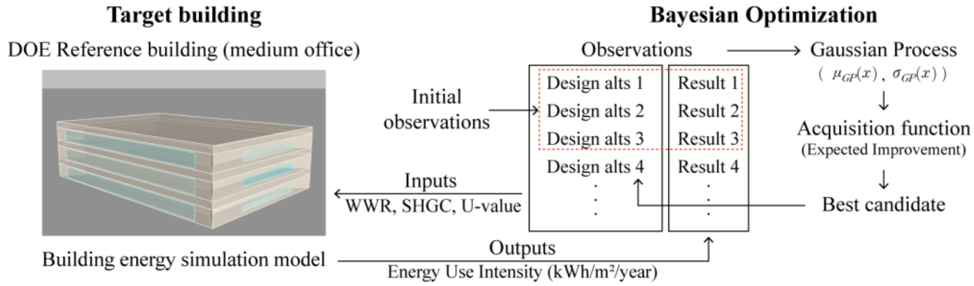

Figure 1: Proposed process of this study.

3 RESULTS AND CONCLUSION

Only after 64 iterations, BO has converged to the EUI of 91.5 (kwh/m^2.yr) (Figure 2). Table 1 compares a heuristic design with BO results. WWRs for North, East, and West are lower than 0.2, while South WWR is up to 0.96. In addition, high SHGC and low U-value are selected for South windows. This is due to the fact that it induces more heat gain and decrease conductive heat loss, leading to lowering energy use in winter season. It was found that BO can efficiently search design parameters that is highly nonlinear, multi-modal, and computationally exhaustive. The approach could be used for a variety of optimal design and control for building systems. Comparison with other optimization method will be conducted in future works.

Table 1: Design parameters and Energy Use Intensity (EUI).

best alts	wall	north windows			east windows			south windows			west windows			EUI
of.	a	b	c	d	b	c	d	b	c	d	b	c	d	
heuristics	0.18	1.5	0.6	0.4	1.5	0.6	0.4	1.5	0.6	0.4	1.5	0.6	0.4	103.4
BO	0.19	1.40	0.13	0.81	1.00	0.13	0.84	0.90	0.96	0.72	0.82	0.18	0.86	91.5

a: Insulation thickness(m), **b**: U value(W/m^2.K), **c**: WWR, **d**: SHGC

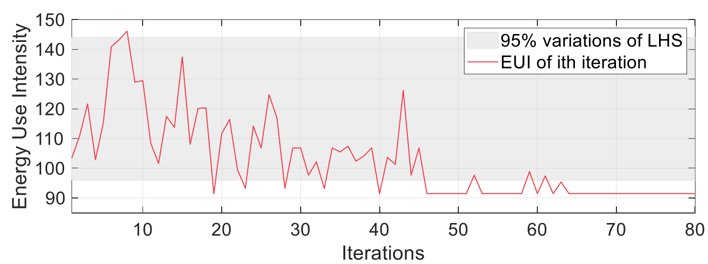

Figure 2: Convergence history of Bayesian Optimization(BO) algorithm.

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