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Coupling of whole-building energy simulation and multi-dimensional numerical optimization for minimizing the life cycle costs of office buildings

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Abstract

The minimization of life cycle costs for building materials and operational energy consumption of a reference commercial office building model is achieved through the optimization of envelope design parameters by the use of integrated energy simulation and multi-dimensional numerical optimization techniques. The whole-building energy simulation program EnergyPlus v6.0 is coupled with GenOpt v3.0 generic optimization tool to automatically compute the optimal values of thermal insulation thicknesses for external walls and roofs in addition to glazing unit types for vertical fenestration. A life cycle cost (LCC) model is implemented within the GenOpt program for the objective function evaluation using simulation outputs pertaining to energy consumption and associated utility costs. A stochastic population-based and multi-dimensional optimization technique of Particle Swarm Optimization (PSO) is utilized for searching the parameter space. This algorithm can result in a 36.2% reduction in the computational effort to converge to the global minimum point with a very high degree of accuracy compared to the full enumeration technique. The results indicate that the annual total site energy consumption of the optimized building model is reduced by 33.3% with respect to the initial baseline case. The optimized envelope parameters can yield 28.7% life cycle cost reduction over a 25 years life span with a simple pay-back period of 4.2 years.

Keywords

whole-building energy simulation,
multi-dimensional numerical optimization,
coupling framework,
life cycle cost,
office building envelopes

Article History

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1 Introduction

The building industry is the largest energy consuming sector in many countries and has a substantial impact on the environment. According to the statistics from the U.S. Department of Energy, buildings are currently responsible for approximately 41% of the total primary energy use in the U.S., including 19% for commercial buildings and 22% for residential buildings. Buildings are also responsible for 40% of carbon dioxide emissions in the U.S. (DOE 2011). It is therefore critical and essential for the building industry to improve the energy efficiency levels and provide means for sustainable developments in the built environment. The building delivery process typically involves several complex actions with different characteristics and generally spans a long time period in the magnitude of decades (Braun 2002). In such a lifespan, the building envelope plays a critical role due to its lasting influence on the building's energy and environmental performance throughout the whole life cycle. The selection of construction materials for the building envelopes not only changes the building's primary cost at the construction phase but also impacts the HVAC (heating, ventilating, and air conditioning) systems' energy consumption and costs during the building operation phase.

In conventional building design, the specifications of building envelopes are determined based on either the requirements given in building energy efficiency standards or the rule-of-thumb guidelines gained through the experience of architects (Bichiou and Krarti 2011). Such design approaches which lack parametric and analytical feedbacks tend to ignore the influence of the optimized building envelope features on building's life cycle energy performance. Furthermore, the simulation-based parametric analysis for the determination of optimum design choices for the building

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