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A review on building energy efficient design optimization rom the perspective of architects

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ABSTRACT

Energy efficiency is a mandatory requirement and integral part of green and sustainable buildings. Energy efficient design optimization is both a design philosophy and a practical technique that has been proposed and used by architects and other professionals for several decades, especially in the past few years. In this review, a set of selection criteria are proposed and 116 works are identified as the core literature. Taking the perspective of architects, analysis is conducted to the core literature to reveal the state of the art of building energy efficient design optimization. The analyzed subjects include the general procedure, the origin and development, the classification, the design objectives and variables, the energy simulation engines, the optimization algorithms, and the applications. The review findings confirm that building energy efficient design optimization is a promising technique to design buildings with higher energy efficiency and better overall performance. However, obstacles still exist and future research is needed.

Contents

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1. Introduction

1.1. Background

After the two oil crisis in the 1970's [1], the energy cost sharply rose, which led to a paradigm shift to a more energy efficient society. Building energy efficient design started becoming mainstream among government, developers, architects, engineers, and other stake holders around the same time. This trend has been ongoing for more than three decades and only recently strengthened by a more profound awareness of climate change and other environmental challenges. One evidence among many is that a variety of green building standards, adopted by many countries, all have energy efficient design as an integral part with a heavy weight, examples being LEED of the US [2], BREEAM of the UK [3], and Green Building Label of China [4].

The emphasis on building energy efficiency would be merely a design philosophy and thus could not be materialized if designers, i.e., architects, mechanical engineers, lighting engineers, plumbing engineers, and others have no suitable technique at their disposal. Building energy simulation and its tools are developed to serve the purpose of providing such technique to designers. It is a broad and active research field. According to the Department of Energy of the United States, there are more than 400 building energy simulation models and/or programs available [5]. Some of them are powerful programs that are widely recognized and used all over the world and across disciplines such as EnergyPlus [6], TRNSYS [7], and DOE-2 [8]. The building energy simulation technique has greatly helped architects and engineers to achieve building energy efficient design by offering capability to accurately and rapidly calculate the loads and actual energy consumption of buildings.

Starting from the 1990 s and really gaining momentum since 2000, a new technique that combines building energy simulation with optimization has emerged. New terms are given to this technique such as “computational optimization” [9], “simulation-based optimization” [10], “building performance optimization” [11], “performance driven design” [12], etc. It should be pointed out that the term “performance” covers a broader range than just energy efficiency. Nevertheless, energy efficient design optimization for buildings is clearly an emerging technique that is being actively studied. The technique relies on optimization algorithms to generate new designs based on simulation results and user-defined design objectives. Compared with the conventional “trial-and-error” design methodology guided by designers’ knowledge and experience, this new technique is more efficient, more powerful, and more likely to find the optimal or near-optimal design solution. Post-processing methods such as Pareto frontier is often called for to locate the optimal or near-optimal design solution [13]. The building energy efficient design optimization technique seems promising and yet is not free of limitations. Hence, it has been becoming a very active research field as shown by several important review works published lately [9,10,14].

Building energy efficient design requires a multi-disciplinary design team. Architects and mechanical engineers are probably the two professionals who take the most responsibility in achieving an energy efficient building design. It can be reasonably argued that between the two the architect carries more weight in determining the final quality of the design in terms of the energy performance for several reasons. First, the architect designs the shape, space, and functions of a building, which are the most fundamental aspects of a building design and the most important features to the client. Furthermore, these aspects also greatly influence the energy performance of the design. Secondly, the architect is responsible of making decisions on building envelope, fenestration, and materials, which largely determine the heating and cooling loads of the building. Therefore, as the leading profession in a design team, the architect should be familiar with the latest development in the field of energy efficient building design. However, the reality is far from being ideal. Many architects, purposefully or not, tackles the energy efficient design with traditional, outdated, and inefficient techniques. They are not capable of using energy simulation programs to assist their design, let alone the design optimization technique that incorporates energy simulation and optimization algorithms. Therefore, the role of architects in building energy efficient design and their perspective on the design optimization technique have been studied [14,15].

1.2. Objectives of this review

The primary objective of this paper is to conduct a comprehensive and in-depth review of the building energy efficient design optimization technique. The emphasis is placed on reviewing and analyzing the state-of-the-art from the perspective of architects. The reasons why a review of such kind is both valuable and timely are multi-folds. First and foremost, as the leading profession in a design team, architects often find themselves in an awkward position when it comes to using the building energy efficient design optimization technique. It is clear to them that the conventional architectural design methodology, which in essence is an approach involving design principles mainly based on functions, forms, and spaces, would not suffice since building energy efficient design requires scientifically rigorous energy simulation, which most architects are not familiar with. The problem is further exacerbated when optimization is added. After all, how would you expect a traditionally trained architect to be familiar with optimization algorithms and complex programs, let alone computer coding which is required in many instances. This dilemma has been realized by many such as Flager et al. [16]. Secondly, the existing works in the field of building energy efficient design optimization cannot adequately address the needs of architects. Many of the research works focus on developing the technique and applying it to buildings. Few articles published discuss how the existing technique fits into the overall workflow of an architectural design project and how architects view it. Building service engineers and other professionals also play an important role in designing and optimizing energy efficient buildings. They can benefit from this review as well.

The objective of this review is to collect relevant literature in accordance with a set of clearly defined criteria and then analyze them to understand the evolution and current status of the building energy efficient design optimization technique. An emphasis is placed on how the technique, while achieving the goal of energy efficient design optimization, addresses particular needs of architects. The analysis of the literature is performed to focus on: (1) general procedure, (2) origin and development, (3) classification, (4) optimization objectives and optimized design variable, (5) energy simulation engineers, (6) optimization algorithms, and (7) application. Note that some of these subjects are of interests to