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A multi-objective optimization design method in zero energy building study: A case study concerning small mass buildings in cold district of China

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ABSTRACT

This study aims to develop a new global multi-objective optimization design for zero energy buildings (ZEBs), integrating the multi-objective optimization technique with the comprehensive evaluation method technique. The study is conducted by adopting two design optimization methods for renewable energy systems in the building, including the multi-objective optimization using NSGA-II(Non-dominated Sorting Genetic Algorithm II)on the original design in terms of both costs and energy optimal designs, and then the mixture of grey correlation multi-level comprehensive evaluation method is applied to optimal design including the solar energy utilization efficiency, economy, energy conservation and social aspects. According to the selected determination based on global optimal design, the "best" solution, which can be guiding the scheme of practical engineering construction, is presented. In the end, a multi-objective design about a case study located in Tianjin of China is presented. Practice is proved that this method is beneficial to making effective scientific decisions.

1. Introduction

1.1. Background

Last century, A. K in Club of Rome advanced that it was energy (or exergy) that was the evaluation standard of the economy in future instead of money, because money is temporary while energy (or exergy) is eternal, which is a prejudgment of the universal laws in future. Now, this point was proved to be accurate. Some studies indicate that cities and energy will play a defining role in addressing the global environmental crisis [1]. How to improve the efficiency in using new energy has played a pivotal role in resolving problems of energy and environment. The growing concern about energy consumption in buildings, especially in residential buildings, has impelled the development of zero energy buildings and regulations aiming to increase building energy efficiency [2]. International Energy Agency(IEA) has also paid much attention to the development of the energy market. They proposed international standard limits of grid connected ZEBs in a paper Towards Net Zero Energy Solar Buildings, which was an amendment based on The International Building Code and Standards at that time [3]. As an official research field, studies related to ZEBs began to heat up around the world. In 2010, Europe has set a clear path to guide the member States accomplishing the zero energy buildings (ZEBs) target till the end of 2018 in public places and newly built buildings with the renewable energy production system nearby can balance power demand at the same time under the guidance. Then, by the end of 2020, all new buildings would be zero energy buildings [4,5].According to the statistics released by EU, German, America, Austria, Czech and some other countries have defined nZEBs [6]. The American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) have maken project for a target of net zero energy buildings fulfillment by 2030 [7].

1.2. Optimization method

The optimization of ZEBs aroused many questions regarding,(1) the LCC optimization method, (2) mathematical model & software

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optimization, and (3) the other special model optimization methods.

Some studies have been conducted by using the LCC optimization method, which can be summarized into three respective and efficient energy demands and energy supply systems: (1) the photovoltaic installation with photovoltaic/solar thermal collectors and an ambient air/solar source heat pump; (2) the photovoltaic installation with a ground-source heat pump; (3) the photovoltaic installation with the district heating grid. They believed that LCC analysis had its limitations due to some restrictions; that is to say, with the uncertain cost, obtained data would affect the accuracy of results [8–10]. Some researchers studied the cost-optimal energy performance renovation measures concerning nearly zero-energy building (nZEB) requirements [11]. Ayman Mohamed et al. [12] extended minimum life-cycle costs and took optimal measures by yielding the net zero-energy office building via a photovoltaic panel system.

Hamdy M et al. [13] investigated cost-optimal solutions towards nearly-zero-energy buildings. Different options of building-envelope parameters, heat-recovery units, and heating/cooling systems as well as various sizes of thermal and photovoltaic solar systems are explored as design options via three-stage optimization. The resulted economic and environmental trade-offs reveal that primary energy consumption ≥93 and ≤103 kWh/m2a is a cost-optimal energy performance level. Kurnitski J et al. [14] studied cost-optimal solutions of the residential and office buildings, and at the same time, the office building is selected as a case to analyze cost optimization of the building envelope, which suggested that the design of nZEBs could be directed by cost-optimal solutions since advanced technology leads to the uncertainty of costs and different construction parameter standards. E.Pikas et al. [15] released a paper which presents possible office building fenestration design solutions. In the solutions, both energy efficiency and cost optimality are taken into account. It was observed that for the cold Estonian climate, triple glazed argon-filled windows with a small window to wall ratio and walls with 200 mm thick insulation are energy-efficient and cost-optimal within 20 years. To achieving nZEBs, it is necessary to use photovoltaic panels for generating electricity.

Some other studies involve optimizing building orientations and shapes, and using insulated materials for the building envelope [16]. Some studies have started to research how to make a multi-objective optimization algorithm in the ZEBs [17,18]. They held that this software would play a more important role in realizing nZEBs or nZCEBs in future [19]. Baglivo Cristina et al. [20] studied several types of external walls for ZEBs in the area with the Mediterranean climate by adopting multi-objective analysis, to design efficiency external walls featured with high energy under this circumstance.

The research conducted by Lu Yuehong et al. demonstrated that the effects of climate and the site should be considered in design optimization methods of nZEBs [21]. Then, Zheng Keke et al. [22] studied the hybrid energy system of nZEBs, setting up an optimal procedure based on the cost, seeking a perfect match of the grid-connected system and renewable energy systems, which suggested that the optimization in future should focuses on ensuring the size of harvesting systems. Maria Ferrara et al. [23] made a case study for an independent nZEB in the French climate by using TRNSYS software stimulation, GenOpt optimal software and optimal-cost analysis to evaluate the configuration. Fabio Favoino et al. [24] studied optimal thermo-optical properties and energy-saving potential of adaptive glazing technologies and adopted the inverse methodology to devise optimal adaptive glazing properties and to evaluate the resulting reduction in the energy demand of buildings.

Francesco Guarino et al. [25] studied the Cross-entropy method based on electricity storage sizing algorithm concerning loading match optimization of a residential building case study [25].

In conclusion, it is clear that the international community has always paid much attention to the optimal issues of nZEBs and spent a lot of time on it. Many scholars are pursing suitable optimal methods for some certain environment, individual cases and partial energy-saving systems. While, a general and unified optimal analyzing system and the evaluation system still needed be room for improved. Optimal methods stretch from the single-objective to the multi-objective, and from the analytic hierarchy process to the intelligence algorithm. A large number of objects and subjects are involved into the ZEB study while the traditional optimal method has its limitations. Therefore, multi-objective optimal methods are introduced to this area to carry out related researches and then to obtain an ideal design effect. The international community could further the study on it.

1.3. *The novelty of study*

The current study of energy is at the exploration and argumentation period, and therefore, there are still some problems that need to be solved. The physic boundary and energy balance boundary of ZEBs in different areas featured with different architectural attributions need to be further studied and ensured. According to the statistics, it requires more integration materials and installation costs in ZEBs. How to optimize and match the relationship among technology-economy-ecology is still a problem. Besides, the key technique of regional statistics and evaluation has not been established yet. The connection and operation of zero energy buildings and the current energy system have not been formed. Classifying stages and types, and the coupling work with the existing conditions of the building energy consumption mode have not been realized. A large number of specific quantitative work will be carried out.

This study presents the global optimum solutions of zero energy residential buildings, including three spaces of discussion to energy, economy and ecology in addition to life cycle energy (LCE) analysis and LCC base on relativity principle to energy saving of buildings, for the first time. The research method used in the study, the simulation-based multi-objective optimization analysis regarding NSGA-II(Non-dominated Sorting Genetic Algorithm II) and comprehensive evaluation method, has not been previously used in any studies to determine the global optimal designing decision. The global optimum solutions cannot be determined by conventional methods, which a few individual energy efficiency measures are simulated and compared, as the comprehensive optimum solutions of buildings, which includes not only the objectivity factors such as construction interface and energy system etc. but also the subjective factor such as sociality and sustainability etc., typically include a great diversity of potential solution combinations. A novelty way of multi-objective optimal technological approaches for ZEBs is established as "EEE-ZEB-MOP" (Energy – Economy – Ecology ZEB multi-objective optimization technology)technical framework. Furthermore, this paper focuses on how to implement zero energy consumption optimization design in residential buildings of Tianjin in the cold district of China, which can be considered as the research object. The system of ASHP(Air Source Heat Pump) and GSHPS(Ground-Source Heat Pump System) were researched in the case of global optimum solutions. In addition, the above problems are systematically discussed in the research, the multi-disciplinary theory and the methods of multi-objective optimization study are adopted to find the way to solve these problems. It is innovating and incentive to establish a scientific and effective system of the optimization design and to construct the optimal design theory and the technology base for the future ZEBs promotion and practice.