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Suitability assessment of building energy saving technologies for office buildings in cold areas of China based on an assessment framework

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ABSTRACT

Blind application and extensive copy of building energy saving technologies have been found very common through investigation in China. Emphases should be put on the suitability assessment when selecting and optimizing building energy saving technologies. This paper created an assessment method, namely an assessment framework to assess the suitability level of building energy saving technologies from a holistic point of view. Fuzzy analytic hierarchy process was adopted. 3 factors and 8 sub-factors were included in the framework. The office buildings were classified into 3 types to calculate weights of factors and sub-factors. The assessment framework was established for each type of office buildings. 20 energy saving technologies from surveyed cases was selected as case study. Ranks of suitability level of the assessment objects were obtained for each type of office buildings. The assessment results could be referred when selecting building energy saving technologies in the design stage.

1. Introduction

Building energy consumption, which accounts for nearly 27.5% of total terminal energy consumption in China, is increasing with the improvement of living quality improvement [1]. Building energy saving technologies (BESTs), as effective energy saving measures, have been widely applied. A rigorous problem, which the BESTs are adopted in buildings without comprehensive analysis, was found through investigation. Blind copy is very common. However, the practical effects of BESTs depend on many factors such as the environment, operation and management. Thus, the prospective energy saving target would not been reached and the optimization collocation of resources would not be realized, though a great amount of money has been invested. Based on this phenomenon, it is necessary and urgent to put emphasis on the suitability assessment of BESTs.

The development of comprehensive suitability assessment and analysis of BESTs has been run a long course. Climate analysis, sociological theory, management and economic theory have been adopted. Picco et al. analyzed the barriers that prevented the integration of energy saving technologies in the early-stage building design and proposed a simplification methodology to optimize building energy efficiency [2]. Pisello et al. conducted calibration and uncertainty analyses to develop a reliable predictive model to examine primary energy for lighting [3]. Kurnitski et al. studied energy and investment intensity of integrated building specific renovation variants to determine cost optimal energy saving technologies [4]. Misra et al. presented the theoretical investigation of the CO_2 reduction of solar water heater, energy efficient lighting, energy efficient air conditioners, and energy efficient submersible water pumps [5]. Researches mainly focused on one or two aspects of application benefits. However, the suitability of BESTs is a comprehensive problem involving economic, environmental and technological factors. One or two aspect could not decide the comprehensive problem [6]. Suitability of BESTs should be assessed from a holistic point of view.

In that order, an assessment methodology which combines all the influence factors is essential. On one hand, these influence factors should be put proper attention according to the importance level. For example, certain BEST performs great environmental benefits while the economic benefits are poor. Whether a certain BEST is proper to be adopted should be decided after comprehensive consideration and comparison. On the other hand, the situation of BESTs for each influence factor should be judged based on reality. This paper created an assessment method according to the characteristics of BESTs. The assessment method, namely an assessment framework, could be applied in the suitability assessment of any BEST. Fuzzy analytic hierarchy process (FAHP) was adopted as the comprehensive assessment method. The gray relational analysis (GRA) was adopted to verify the assessment results. The assessment framework consisted of 3 factors and 8 sub-factors.

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Nomenclature

a_{ij}	scale of quantified importance level
A	comparison matrix of FAHP
A^*	consistent comparison matrix
A_d	comparison matrix of low energy consumption demonstration projects
A_g	comparison matrix of general used office buildings
A_r	comparison matrix of existing buildings needed to be retrofitted
E	comparison matrix of GRA
i_c	benchmark yield rate
R	final assessment vector
R_1	FAHP assessment vector
R_2	GRA assessment vector
s_{ij}	score of object i under sub-factor j
T	dynamic payback period (year)
TE	payback efficiency
$\bar{w}_i$	the largest eigenvalue of the consistent comparison matrix
$\overline{W}$	weight vector
W_d	weight vector of low energy consumption demonstration projects
W_g	weight vector of general used office buildings
W_r	weight vector of existing buildings needed to be retrofitted

Abbreviations

ALI	average level of the industry
BESTs	building energy saving technologies
BIPV	building integrated photovoltaic system
CCHP	combined cooling, heating and power system
DS	development stage
ER	equipment reliability
ESP	energy saving potential
EWR	efficient work rate
FAHP	fuzzy analytic hierarchy process
GRA	gray relational analysis
GSHP	ground source heat-pump system
IPR	investment profit ratio
ITCDR	dissatisfactory rate of indoor thermal comfort
MCDM	multiple criteria decision making
NEI	negative environmental impact
PC	production compatibility
POS	perfection of standards
SGSHP	solar-ground source heat-pump system
SP	safety performance
SWH	solar water heating system
THIC	temperature–humidity independent control system
TRL	technology readiness levels
VAV	variable air volume system
VRV	variable refrigerant volume system

Greek letters

λ_{max}	the largest eigenvalue of the consistent comparison matrix
$\varsigma_i(k)$	gray relational degree
ΔD	saving operation cost (Yuan)
ΔI	increasing investment (Yuan)

The office buildings were classified into 3 types according to the practical energy consumption to calculate weights of factors and sub-factors. The assessment framework was established for each type of buildings respectively. This method could be adopted by not only building designers but also energy saving policy makers to promote and adopt BESTs in a certain building or a certain kind of buildings. It could make the decision procedure easy and scientific at the same time by referencing studies and practical experiences. To show the assessment procedure, 20 BESTs from surveyed cases in cold areas were selected as assessment objects. The scores of these BESTs were decided by questionnaires, application statistics and existing study results. The final form of suitability was scores. Ranks of suitability level were obtained after data collection and necessary analysis. The assessment results also could be referred when selecting and optimizing BESTs in cold areas in the design stage.

2. Methodology

2.1. Analytical methodology

The suitability assessment of BESTs could be considered as a multiple criteria decision making (MCDM) problem. Comprehensive assessment is necessary. The reliability of assessment results is influenced by not only the relative data but also the assessment method. Fuzzy analytic hierarchy process (FAHP) has been proved to be one of the best assessment methods [7]. It simplified the complicated problem by dividing it into a hierarchy system of factors. Advantages were shown as follows. Firstly, many other MCDM methods had difficulty in dealing with the uncertain and imprecise information. FAHP overcome this by quantifying data to handle the fuzziness in an acceptable extent. Secondly, measuring qualitative factors by fuzzy values instead of crisp values helped both decision making and practical results obtaining. Based on the above analysis, FAHP was adopted to establish the assessment framework.

Because uncertain multiple variables were involved in FAHP, the results might be unreliable. Additionally, the factors and sub-factors were interacted and the relationship was incompletely clear. The gray relational analysis (GRA) was an effective approach to solve such kind of problems. In the control theory, the depth of color was adopted to show the completeness of system information. Black meant unknown while white meant known. A system contained known and unknown information was a gray system. The BESTs suitability was a typical gray problem because it was difficult to decide the clear relationship of economy, energy saving requirement and environment at present. GRA could process variables with different value types. The advantages of GRA were exactly in solving problems with complicated interrelationships between multiple factors and variables [8]. Based on the above reasons, GRA was adopted to verify the results of FAHP. The results would be recognized reliable with the consistent trends of results based on the two methods.

2.2. Assessment procedure

The assessment procedure consists of the following steps.

(1) Establish the assessment framework. The assessment framework consisted of assessment objects, assessment factor/sub-factors and weights of these factor/sub-factors. The assessment objects in this paper were BESTs adopted in office buildings in cold areas. The assessment factor and sub-factors could be proposed by analyzing the characteristics of assessment objects. Assume m assessment objects and n terminal assessment factors.