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Establishment and validation of a sustainable evaluation model for heat metering technology in China

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ABSTRACT

Although China's heat metering technology has developed rapidly in recent years, the improvement demonstrates an unbalance in different provinces. It is of great significance to outlook application and sustainability of heat metering technology in various regions technically. Taking the sustainability of heat metering technology as research object, the author establishes a sustainable evaluation model in this paper. Factors in the evaluation model are assigned through a main questionnaire and actual application of typical projects. A pecking-order contrast method is adopted to determine weights of factors in the evaluation model, correspondingly sustainable development of heat metering in various locations is assessed. Sustainability scores in three regions (Northeast, Northwest and North China) are obtained via evaluation model. The model owns high accuracy compared with results of heat metering work assessment by the Ministry of Housing and Urban-Rural Development (MOHURD). The heat metering in the three regions score 60, 62 and 75, respectively, implying that the sustainability in the northeast and northwest is unsatisfactory but in north is somehow better. It is suggested that envelope heat insulation should be increased in the northeast region, while policy support and heat metering technology ought to be enhanced in the northwest.

1. Introduction

1.1. Unbalanced heat metering status in countries and regions

Reducing consumption on fossil fuels and improving energy efficiency have become significant issues in the field of heating for countries around the world. There have been tremendous researches and explorations conducted in many countries. Among all measures of slashing dependence on fossil fuels, heat metering has been considered important for energy efficiency; therefore actual energy saving of metering has drawn increasing attention worldwide [1–3]. According to EU directive 2012/27/EU, independent heat metering devices must be installed to measure heat consumption and domestic hot water consumption in multi-apartment buildings by December 31, 2016 [4]. Heat metering technology is already taken as an effective measure to improve energy efficiency of user behavior [1,5]. However, an investigation showed that individual consumption meters are slowly spread, resulting in strong limitation on metering and charging for heat and hot water in Sweden. Reasons lie in slight effect on energy saving and poor knowledge of individual metering and charging [6]. All these factors show that development of heat metering technology is not balanced across the world, i.e., energy savings of this technology varies by region.

1.2. Application effect of heat metering in China

In China, heat metering has achieved rapid development with implementation of the *Code for Acceptance of Energy Efficient Building Construction* since October 1, 2007. According to statistics of heat metering and charging annual summary by MOHURD, from 2008 to 2012, heat metering and charging area of 15 provinces has increased from 46,000,000 to 805,000,000 m^2 [7]. Four kinds of heat metering devices, which are heat meters, heat cost allocator, heat allocator by time and areas, and heat allocator by temperature, have been widely used with implementation of the *Code for Technical Specification for Heat Metering of District Heating System* since July 1, 2009. Many scholars have addressed application effect of heat metering in China. Zhao et al. studied the energy-saving benefits of heat metering in northern China based on a multi-index comprehensive evaluation method, indicating that a technology line should be established to discover suitable region for heat metering [8,9]. Ding et al. discussed achievements of heat metering for existing residential buildings in heating regions of northern China, such as environmental protection effects, improvement of indoor environments and heating systems, investment guidance effects as

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well as promotion of relevant industries. He qualitatively analyzed influential factors on the application effect of heat metering [10]. Liu confirmed that key issues of heat metering are to strengthen controls on system, prevent users from opening windows or setting the room temperature set point too high, as well as encourage developers to weatherize the buildings. He also pointed out that energy consumed by households at the top or corners of buildings is two to three times higher than those located elsewhere. Accordingly, a new "wireless on-off control" technique for adjusting and metering household heat has been proposed [11,12]. Bao et al. studies the development of heat metering and charging in China in "the 11th Five-Year Plan". Proposals were made regarding organization system, financing model and others [13]. Qiu, former vice minister of the Ministry of Housing and Urban-Rural Development (MOHURD) of the People's Republic of China, summarized obstacles to Chinese heat metering technology in the *Heat Metering Annual Assembly*, including lack of recognition, mechanism obstacles, as well as faults and capability defects in metering devices. From the research above, it has been demonstrated that the application effect of heat metering is usually analyzed qualitatively.

1.3. Influential factors on heat metering application effect and sustainability

Factors influenced application effect of heat metering includes many aspects, such as metering device quality, water quality of heating system, and users' behaviors. Quality of heating metering devices is one of the most important factors among all the influential factors. Of course, application effect of heating metering devices is related to water quality of heating system. Users' behaviors, such as concerning about heat charge, making windows opened, and regulating heat valves, also affect heat metering application effect and sustainability. Several factors restrict technological development, including an important one that some heating companies hold the opinion that their economic benefits will shrink in line with implementation of the technology. In Europe, there are three commonly used heat metering and charging methods which are all related to heat consumption of users and charge amount depends on heat consumption [14]. However, in China, the heat charging policy is "refund for any overpayment, but no supplemental payment for any deficiency". Following this policy, some heating companies have to refund up to 30–40% of heating fees to users, which certainly affects their profit margins. Routledge and Williams assessed the cost-effective rate of heat metering in UK by two methods and drew similar conclusion that heat metering in existing dwellings was not cost effective, except for older houses with greater savings [15].

The quality of heat metering devices has been analyzed in several studies, which imposes important influence on heat metering and charging. In 2010, the General Administration of Quality Supervision, Inspection and Quarantine spot-checked 35 types of heat meters. The result showed that 80% of meters did not meet codes and standards. Although the unqualified rate declined to 11% in 2013, the quality of heat meters still restricted heat metering technology to some extent [16,17]. Huang analyzed the heat meter qualifying rate and concluded that due to high water quality, appropriate environmental temperature and limited verification flow, the qualifying rate posted 90% in experimental conditions [18]. For heat meters operating over an entire heating season, the rate dropped to below 70%. Aside from heat meters, no national supervision or inspection has been conducted in other heat allocation devices such as heat allocators, indoor temperature sensors and query devices in China, resulting in unguaranteed quality. Victorian Auditor General also pointed out that there is a technical risk when adopting new measuring instruments for unproven or unknown technologies [19,20].

There have been achievements by scholars from various countries in the study of application and constraints of heat metering technology. It will be important for developing the technology in the future that quantitative studies are conducted on the whole application effect of heat metering, especially the sustainability of heat metering. Furthermore, through quantitative studies, reasons for unbalanced application effect in different regions can be analyzed and pertinence measures can be taken.

1.4. Research propose

A sustainable evaluation model is established in this paper through taking the sustainability of heat metering technology as research object. A principal questionnaire and actual measurement for the effects of typical projects are adopted to assign factors in evaluation model. To assess heat metering development sustainability in various regions of China, the author takes pecking-order contrast to determine the weight of factors in the evaluation model. With the adoption of the model, sustainability of heat metering technology in Northeast, Northwest and North China are explored. The model is validated to verify its accuracy.

With the establishment of sustainable evaluation model, the sustainability of heat metering development in various regions of China is assessed with obstacle factors to be discovered. Meanwhile, quantitative understanding on some problems which were only qualitatively studies is to achieve. Additionally, questionnaire result and calculated equation of energy efficiency can be referenced for other relevant researches.

2. Sustainable evaluation model of heat metering technology

2.1. Model establishment

The sustainable development of a technology is influenced by society, economy and other aspects [21]. Among these, the main influential factors are as follows.

(1) Urgency and importance of technology development
(2) Advancement and reliability of the technology
(3) Effects of the technology
(4) Development of the technology
(5) Recognition of the technology [22,23]

The main effects on the sustainable development of heat metering technology, based on the major influence factors of the technology above, are as follows.

Factor 1: Energy conservation potential and desire as indicated by the behavior of users
Factor 2: Reliability of heat metering devices
Factor 3: Energy savings of typical projects with the adoption of heat metering technology
Factor 4: Current development of heat metering
Factor 5: Confidence of relevant parties for future development of heat metering technology

As to quantitative analysis of heat metering sustainability and weight relationship among factors under combined effect, a sustainable evaluation model of heat metering was established, as shown by

$$Q = \sum_{i=1}^{5} \left(\sum_{j=1}^{n} q_{ij} \times p_i \right) \quad (1)$$