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Ontology of ground source heat pump

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ABSTRACT

Ground source heap pump (GSHP) systems constitute one of the most prevalent technologies for reducing energy consumption and fostering sustainable development. Owing to the urgent need for GSHP dissemination, the Chinese government has introduced various policies in the form of subsidies, regulations, codes, etc. Nonetheless, the lack of a generic understanding of GSHP systems has led to an improper interpretation of their development and dissemination; thus, financial subsidies for GSHP dissemination have not been optimized. This paper proposes an ontology that delineates GSHP technology. The proposed ontology is developed using keywords extracted from existing studies, as well as their relationships, which are defined on the basis of a literature review and semi-structural interviews. Co-occurrence analysis is conducted to evaluate the relationships among the keywords. The proposed ontology, which consists of 34 components within five levels, systematically highlights the critical components and delineates the GSHP system, thereby serving as a rigorous foundation for underpinning changes in government policies and industrial R&D.

Contents

1. Introduction

In 2009, the Chinese government pledged to reduce China's carbon emissions per unit GDP by 40–45%. Nonetheless, China

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already is the world's leading consumer of energy, and its energy consumption (EC) is expected to increase by 40–50% per capita by 2035 [1,2]. In spite of setting energy reduction targets as part of its 12th five-year plan (2010), China's total EC in 2011 (3.478 billion TCE) was 7% greater than that in 2010, and it increased further in 2012 (3.617 billion TCE) [3,4].

According to the National Energy Conservation Center of the Ministry of Housing and Urban-Rural Development, the building sector accounts for 27.8% of the total EC in China. Moreover, heating, ventilation, and air conditioning (HVAC) contributes 65% of the building sector, thereby accounting for a major part of the total EC [5,6]. Therefore, it can be argued that HVAC should be highly prioritized when considering energy savings with various technologies, e.g., ground source heat pump (GSHP) systems, which are considered highly effective [7,8].

Many regions that require heating in the winter and cooling in the summer have abundant shallow geothermal energy [9]; thus, theoretically, GSHP is economically feasible for wide dissemination in China. By the end of 2012, more than 5000 GSHP systems were installed countrywide, 80% of which were located in Northern and Northeastern China, where hot summers and cold winters are predominant. Further, the building area where GSHP systems were installed exceeded 0.14 billion m^2, and it has been increasing annually [10], as shown in Fig. 1.

Owing to the urgent need for EC reduction, the use of GSHP systems has increased significantly since 2007. However, according to the general feedback collected thus far, these systems have not met expectations because of drawbacks such as poor quality and high initial investment [7,9,10,12]. In order to overcome these problems and thus increase GSHP dissemination, the Chinese central and local governments introduced more than 100 policies/legislations at various levels [11]. However, these policies did not produce the desired impact. For instance, Xu and Zhang [9] argued that financial subsidies were insufficient to address the high initial investment. They also suggested that the technological feasibility, operation strategies, and construction techniques required further investigation, and that the official codes should be especially emphasized. Similar conclusions have been drawn by other studies. [7,10–12]

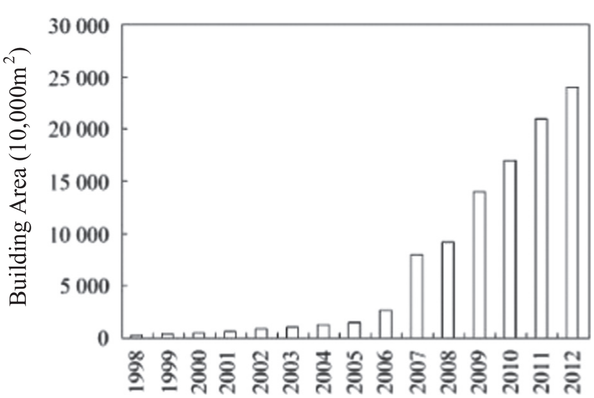

Fig. 1. Increase in total GSHP usage area [10].

Another issue that was more or less overlooked by previous studies but surfaced during onsite interviews is that GSHP is a set of sub-technologies, each of which has its advantages and drawbacks related to both R&D and practical application, which should be well reflected by promotional policies. In fact, the preference for specific GSHP sub-technologies could be found in some local policies, indicating that governments are trying to provide different incentives for different technologies. For instance, in order to encourage greater usage of soil heat pumps and hybrid heat pumps, Beijing, Shenyang, and Chongqing subsidized GSHP projects according to the heat source. However, the heat source is not the only consideration for GSHP system selection and design. Different combinations of various technologies involve different coefficients of performance (COP) and costs. In other words, current policies fail to distinguish high-potential sub-technologies with appropriate incentives.

A closer examination of the nature of these problems reveals a lack of overall knowledge of GSHP, which has also been reported in previous studies. Zhang [7] demonstrated that although current legislation and codes are macroscopic, economic incentives remain focused on single technologies or products, indicating that a comprehensive understanding of GSHP, as a rigorous foundation for policies and R&D, is lacking. Further Yang [12] asserted that miscommunication among stakeholders during the construction process continued to occur owing to an inadequate understanding of GSHP systems, and a lack of knowledge among bodies in the GSHP market was also reported.

According to the theory of technological innovation, diffusion, and management, legislations and policies should be based on a thorough understanding of the relevant issues [13]. In other words, a clear and generic understanding of GSHP systems is required to underpin further research on their development and dissemination. Therefore, to provide a solid foundation for future studies, this paper builds a knowledge structure, specifically, an ontology of GSHP technology.

2. Literature review

2.1. General classification of GSHP and limitations

In general, GSHP can be regarded as a combination of three sub-systems: the primary circular (ground loop system), the heat pump, and the secondary circular (heat distribution system).

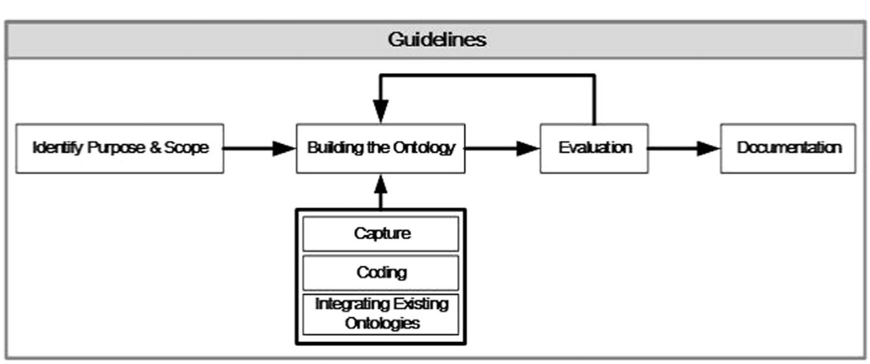

Fig. 2. Skeletal methodology [23].