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Life cycle assessment of residential heating systems: a comparison of distributed and centralized systems

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Abstract

With increasing awareness of the importance of thermal comfort, occupants, even those living in a mild climate, show rising demand for space heating. The question remains which heating system has a better environmental performance when it is utilized to meet moderate heating need. This paper presents a comparison of distributed and centralized heating systems with respect to the life-cycle greenhouse gas emissions. The heating systems are sized for a typical apartment in Hangzhou, China, where daily average low temperature is above 0 °C. Results show that air-source heat pump renders lower greenhouse gas emissions compared to centralized heating.

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Keywords: Distributed heating; Centralized heating; Life cycle assessment; Greenhouse gas emissions; Air-source heat pump

1. Introduction

Thermal comfort has been shown to be a key aspect of successful building design as it can strongly influence an occupant's productivity [1] and health [2]. With increasing awareness of the importance of thermal comfort, a number of research resources have been devoted to issues relating it. For example, several studies have focused on the fundamental basis of thermal comfort standards [3, 4], and emphasized that adjustments to the basic standards should be made to incorporate the influences of

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building structures and climates [3]. Although the standards have continuously improved, little attention has been paid to the influence of climate change and the emerging need for a change in the heating, ventilating, and air conditioning (HVAC) designs [5]. Because of the impacts of the El Niño–Southern Oscillation climate pattern, extreme weather conditions have been observed with higher frequencies across the world [6], making it essential to revise the current heating or cooling systems [7]. Well-designed heating systems are becoming increasingly important and essential parts of homes located in the regions where heating issues were not previously considered critical.

This paper focuses on regions with moderately cold winters, e.g., the hot summer/cold winter climate zone in China [8, 9]. In contrast to the regions with lasting-cold winters, where centrally generated heat (provided mainly by boilers or combined heating and power assets) is distributed to occupants, the regions addressed in this paper typically have an insufficient heat distribution network, poor building insulation envelope [10] (especially if maintaining good ventilation is a critical issue), and short heating seasons. These features cause heating system designs to differ from traditional ones.

A range of heating systems have been studied and designed for varying climates [5]. Centralized heating systems are typically provided through steam/hot water radiators. Coal/natural-gas based boilers and combined heat and power plants are typically utilized to generate steam and hot water. Distributed heating systems have more options [11, 12], such as a geothermal heat pump, air-source heat pump, electric resistance heating, active solar heating, natural gas furnace, and steam/hot water radiator. Different heating systems have been compared in terms of energy usage (including both embodied energy and operating energy usage) [9], environmental impacts [13, 14], and system efficiency (including both generation and distribution efficiencies) [15]. Regarding the environmental impacts, life-cycle assessment (LCA) is considered as an effective method to evaluate the greenhouse gas (GHG) emissions of a particular heating system throughout its life cycle.

Although the emerging need for space heating and the characteristics of heat loads in regions with moderately cold winters have been addressed in a number of previous studies, few paper addressed the environmental impacts of heating systems in these regions. This paper aims to compare the life-cycle GHG emissions of different heating systems in regions with moderately cold winters, which is of significance for the future development of heating systems in these regions. This paper compares two distinct heating systems, i.e., air-source heat pump for distributed heating, and steam/hot water radiator heating systems for centralized heating. Detailed heating system designs for a typical two-bedroom apartment located in Hangzhou, China, and LCA-related data and methods, including functional units, boundaries, emission factors, and impact assessment method, are discussed in Section 2. Preliminary GHG emission evaluation results are then presented in Section 3, followed by the uncertainties and future work being discussed in Section 4.

2. Data and methods

This section is organized as follows. First, the characteristics of a typical two-bedroom apartment in Hangzhou are described in Section 2.1; then, the two heating systems, i.e., a distributed heat pump system (including three air conditioning units) and a centralized hot water radiator system, are designed for the apartment, according to the specific heating load satisfying the basic thermal comfort criteria (minimum room temperature being 18 °C) in Section 2.2; lastly, detailed LCA methods and data sources are presented in Section 2.3.