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Air source heat pump for domestic hot water supply: Performance comparison between individual and building scale installations

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ABSTRACT

Air source heat pump (ASHP) for domestic hot water (DHW) preparation under cold climatic conditions is studied by TRNSYS simulation. Emphases are focused on comparing different strategies of installation using energy efficiency performance criteria. Studied strategies include individual (apartment-scale) and collective (building-scale, centralized) installations. Different daily hot water consumption profiles are considered in the annual simulation program. Simulation results show higher annual system efficiency from individual installations than centralized system. In the latter case, pump consumption during hot water recirculation makes the overall system less efficient. Due to lower over-sizing factor, the centralized installation is more favourable to the ASHP performance than individual ones. In both the two cases, GHG emissions can be significantly reduced by 7 thanks to ASHP. This paper provides decision-making information regarding energy efficiency incentive policies of heat pumps for a more sustainable energy supply.

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1. Introduction

Domestic Hot Water (DHW) is a behaviour-driven consumption [1] and addressing the energy consumption linked to its supply requires consideration both to the energy conversion system and the draw-off profile. Considering the whole urban water cycle, domestic hot water (DHW) preparation is by far the highest energy consumer, representing approximately 85% of total energy needs [2,3]. In the residential sector, contrary from energy demand in space heating that decreases distinctly thanks to strict energy regulations in building envelope insulation and energy system management, the energy need in DHW remains the same. As a result, on the one side, the energy consumption in DHW preparation should be reduced through using higher efficiency system or introducing other renewable sources; on the other side, basic DHW draw-off patterns should be considered that could have strong temporal variation [4] and thus influence to the system performance.

Air-Source Heat Pump (ASHP) water heater is considered as an efficiency way of preparing hot water in the building sector. Under European [5] and WHO guidelines [6], DHW is heated to 60–65 °C to combat bacterial hazards, particularly *Legionella spp.* Given that the water inlet is between 10° and 15 °C [7], the temperature must be raised by 45–55 °C on average throughout the year, not accounting for seasonal variations. DHW tank should be permanently maintained at 60 °C, especially during the standby mode (no flow). At the end-user side, flowing DHW is generally consumed at 45 °C. Since the COP (Coefficient of Performance) of ASHP depends highly on the temperature rise as well as the ambient climatic conditions, a rigorous dynamic study is critical to provide annual performance indicators.

Moreover, scaling-up individual DHW supply to centralized systems (building or district) may be a better solution while requires more complex regulations. On the one hand, high diversity factor in a centralized installation helps reduce the over-sizing factor (both to ASHP and to cumulus storage tank) compared with an individual scale application. On the other hand, the recirculation of DHW in a centralized system should be maintained for a better DHW availability while is not necessary in an individual installation. A comparative study between individual and collective solutions based on energy efficiency criteria has strategic societal interest [8].

This study aims at comparing the energy efficiency performance of the two strategies by all-year operating dynamic simulation

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approach. Main determinants such as local meteorological data, DHW temperature, Urban Heat Island (UHI) effect [9] as well as tank sizing criteria are considered. Our results provide decision-making support for public decision makers, HP fabricants, property holders and energy service companies.

The rest of the paper is organized as follows: first, the comparative dynamic simulation approach is described with special attention to the system configuration and component model. Then, annual simulation is conducted for 8 families in Paris both for individual and collective solutions. Annual Energy Factor of ASHP itself or the system as a whole, together with Greenhouse Gas (GHG) emission savings are used as evaluation criteria. We also investigate the sensibility of our results regarding the air temperature in high density urban centers due to UHI effect and possible lower DHW preparation temperatures.

2. Methodology

In this study, we construct an annual performance simulation program to compare individual and collective ASHP installations following the methodology shown in Fig. 1. We model the ASHP-DHW system by annual dynamic analysis through TRNSYS [10], considering key influencing factors such as tank sizing, draw-off profiles and their diversity factor, meteorological data as well as control strategy regarding auxiliary heater. The annual simulation program comprises of four main parts: energy production by heat pump, DHW storage, DHW consumption and system control. Simplified empirical ASHP model is employed with performance data retrieved from certificated product specifications provided by a fabricant. Meanwhile, the water storage tank is described by a detailed stratification model. For the comparison of the two installation scenarios, we use parameters such as energy losses, annual energy factor and annual HP production efficiency.

What else, meteorological data of the Paris region (cold climatic condition) are used as a reference for the determination of instantaneous COP of ASHP. Four draw-off profiles are considered in individual scale model. While at the building level, we summed up those draw-off profiles. Control strategies are based on cumulus heat preparation, i.e. DHW preparation out of draw-off hours. Electrical auxiliary heater is considered in case of DHW shortage during the day. For the total system performance evaluation, we calculate annual efficiency based on a year cycle production-consumption dynamics.

2.1. ASHP model

An ASHP water heater is mainly composed of a compressor, an evaporator, a condenser, and an expansion valve. The hot side of heat pump, i.e., the condenser, is connected to a DHW storage tank through an immersed coil heat exchanger.

A simplified empirical heat pump model is used in the simulation. Theoretically the COP (Coefficient of Performance) of an ASHP depends on different functional points of the reversed Carnot cycle and the instantaneous COP value is highly dynamic. Since an annual performance simulation should cover all 8760 h of a year, the real dynamic simulation considering the thermodynamic cycle would be too time-consuming. Thus in this study, the heat pump system is simplified by an empirical COP dataset which depends merely on cold side temperature (air, evaporator side), as well as the hot side temperature (water, condenser side).

The heat pump performance data used in this study is retrieved from the commercialized model from fabricant's catalogue [11]. Its empirical performance is integrated in TRNSYS 17 [10] through the Type 941. The performance data are given by standard field test, with the air-side inlet temperature ranging from −10 °C to 35 °C. For the condenser side, corresponding inlet temperatures are between 10 °C and 60 °C. The performance data shown in Fig. 2 are linear regression COP variation with respect to load (water tank) and source (ambient air) temperatures. Under nominal operating conditions (7 °C for air source and 35 °C for the condenser side), the value of COP is 4.3. The risk of freezing in low temperatures and corresponding defrosting operation are not considered in current study.

By using this model we not only avoid detailed dynamic calculations from a physical modelling of the heat pump, but also make the most of real performance data of a commercialized product. In this way, annual simulations with a short time step are realized.

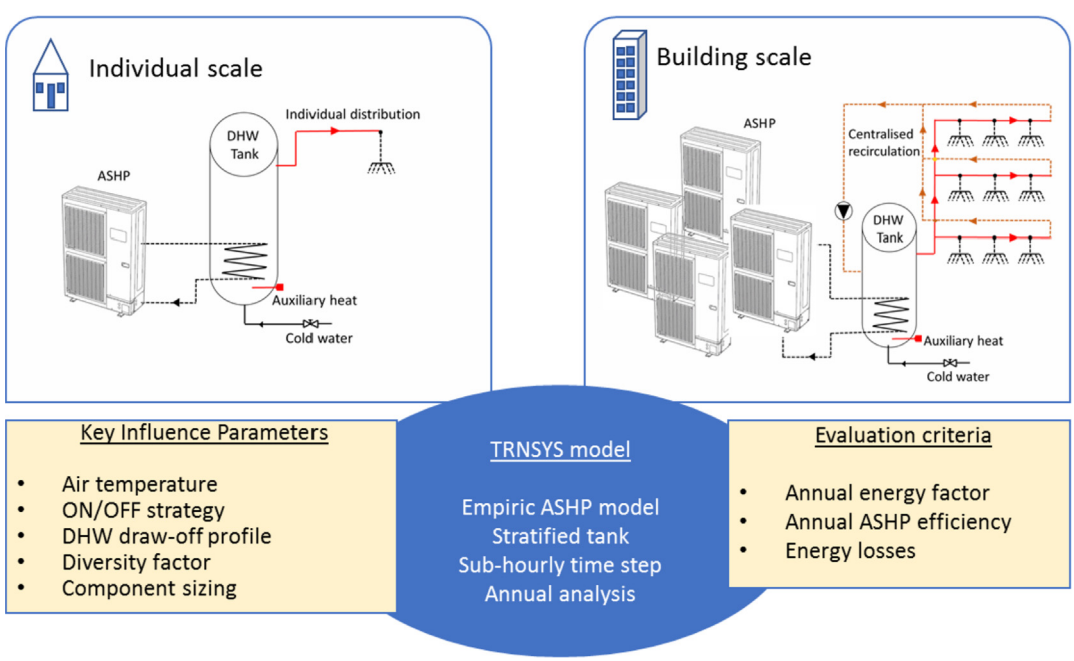

Fig. 1. Comparative simulation approach – what is the best heat pump integration scale for a residential need?.

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