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Research Paper

Heat exchanger design aspects related to noise in heat pump applications

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HIGHLIGHTS

- In indirect heat pumps the outdoor unit noise level can be reduced.
- Flat tube heat exchangers can reduce the noise from the outdoor unit of a heat pump.
- Flat tube heat exchangers seem more preferable than round tube heat exchangers.
- The design of the heat exchanger highly influences the noise from an outdoor unit.

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ABSTRACT

An increased use of heat pumps is one of the measures that can be taken to reduce energy consumption on a large scale. For a wider acceptance, and major heat pump market expansion, it is crucial to develop heat pumps that cause minimal disturbance.

Results from field measurements made by SP Technical Research Institute of Sweden indicate that the use of indirect heat pumps has potential to significantly reduce the outdoor noise level of ambient air heat pumps. The noise level caused by such heat pumps has been shown to be highly influenced by the design of the air-to-fluid heat exchanger.

The overall purpose of this study is to propose a design of an air-to-fluid heat exchanger that allows for a well performing system as well as a low level of noise and cost. Two different types of heat exchangers, with flat tubes and round tubes, are compared theoretically.

According to the modelling results, a heat exchanger with flat tubes and plain fins is the most suitable out of the studied designs due to its low heat transfer resistance on the tube side. The round tube heat exchangers showed to be significantly less suitable, displacing more than twice the volume.

1. Introduction

Results from field measurements made by SP Technical Research Institute of Sweden (research to be published) indicate that the use of a so-called indirect heat pump system has potential to significantly reduce the outdoor noise level in comparison with a conventional heat pump system. The main reason is that in an indirect system the outdoor unit comprise only an air-to-fluid heat exchanger and one of the main noise sources in a heat pump, the fan [1]. The compressor, which is the other main noise source, can be placed on the inside of the building. Also, the noise from the compressor can quite easily be reduced with classical sound attenuation techniques [2]. Moreover, the transient noise from the heat pump is reduced since other defrost methods than reversing technology are favorable.

The noise level caused by the outdoor unit in an indirect heat pump system has been shown to be highly influenced by the design of the air-to-fluid heat exchanger even though the noise radiated from the heat exchanger itself is negligible [3]. In this study the authors identified that it is mainly the flow of air delivered by the fan and the resulting pressure drop in the air flow across the heat exchanger that together influence the level of noise from the fan. Hence, in order to minimize the noise level from the fan, the heat exchanger needs to be of such a design that the necessary air flow and resulting pressure drop can be limited to a certain level. Also, the authors found that finned flat tube heat exchangers, which are not often used in heat pumps, seem to have suitable properties for a low noise heat pump design. In a study by Ayers et al. a low noise design strategy was applied for a heat exchanger and a fan in a cooling unit [4]. Their conclusion was that an optimization of the fan and the heat exchanger results in a very significant reduction

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in source noise generation. A similar methodology as in their research but for an indirect heat pump application was applied in a report by Cinadr and Löved as well as in this present paper which is a continuation of the study performed by Gustafsson et al. [3,5].

The overall purpose of this investigation is to propose a design of an air-to-fluid heat exchanger for an indirect heat pump system that allows for a well performing system as well as a low level of noise and cost. Specific objectives of this study were to:

- Decide what type of air-to-fluid heat exchanger that is mostly favorable in order to achieve a low level of noise and a heat pump energy performance at least as high as that of a comparable conventional heat pump given a certain outdoor temperature and heat demand.
- Investigate the correlation between the design of an air-to-fluid heat exchanger and the noise generation of the outdoor unit.

In this study, it is only the noise level of when the heat pump runs at normal steady-state conditions that is considered. That is, it is the so-called continuous noise level that is regarded during the design process. Also, only one temperature condition is included in the investigation and the research is solely based on theoretical modeling.

2. Methodology

In this study four different heat exchangers are compared theoretically on a noise generating basis. Initially the criteria that need to be met by the proposed heat exchanger were decided. Afterwards, using relevant measurement data and literature on heat transfer and heat exchangers, the necessary size (height, width and depth) and the corresponding air flow to fulfill these criteria were calculated.

The heat exchangers were compared to each other from a simplified economic standpoint. It was assumed that it is the volume of the heat exchanger that is the only indicator of which heat exchanger is the least expensive. Hence, other parameters such as manufacturing costs and material costs were not regarded.

After the most promising heat exchanger type was found an evaluation was performed on the design parameters that have shown to be of great importance of the noise level.

2.1. Operation conditions and constraints

According to heat pump test results issued by the Swedish Energy Agency [6], the level of noise of 14 different air to water heat pumps, tested between 2010 and 2013, varies between 71 and 56 dBA. Since the purpose of this study was to find a design of a heat exchanger that allows for a low level of noise, the value of the noise level is aimed to be 56 dBA or lower.

The standard rating point of 7(6)/35 °C (EN 14511) was chosen to be the rating point of the heat exchangers in this study. At this rating point, the outdoor unit is subject to a dry bulb temperature of 7 °C and a wet bulb temperature of 6 °C. The heating system supply temperature is 35 °C. At this point, the unit with the lowest noise level according to the tests issued by the Swedish Energy Agency has at a heat output of 9.4 kW and a COP of 3.9. This corresponds to a heat output of 7.0 kW of the evaporator which is set as the desired output value of the heat exchanger.

Some assumptions were made to declare the temperatures of the flows in and out of the heat exchanger in the indirect system subjected to the standard rating point of 7(6)/35 °C. The temperatures are shown in Fig. 1.

- The minimal temperature difference of the refrigerant to brine heat exchanger was 2 K.

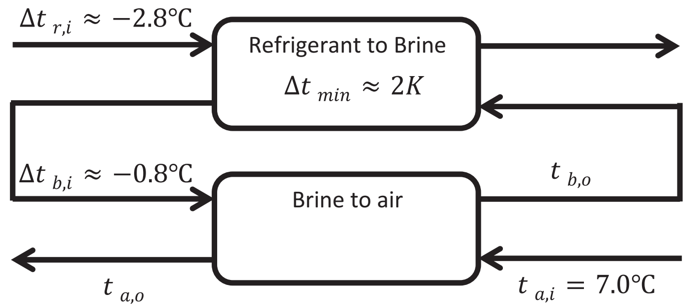

Fig. 1. Heat exchanger flow temperatures.

- The inlet temperature of the refrigerant was estimated to be –2.8 °C. This value was achieved by comparison with a direct expansion system with a refrigerant to air heat exchanger with a minimum temperature difference of 5 K.

An indirect system consists of an additional fluid pump that feed the brine to the refrigerant heat exchanger. A high efficiency system requires the work of the pump and the outdoor unit fan work to be kept as low as possible. Hence, in this study the pump/fan work was limited to 100 W. In accordance with the best performing pump in the test carried out by the Swedish Energy Agency the efficiency of the circulation pump was set to 25%. The efficiency of the fan was assumed to be 75%.

The brine solution was assumed to be 50:50% (by volume) water ethylene glycol mix and a fluid mass flow rate of 1 kg/s was tested and evaluated.

2.2. Heat exchanger types to be analyzed

The most common exchanger type for modern residential heat pumps is the round tube with continuous fins. All of the heat pumps in the tests carried out by the Swedish Energy Agency were configured in this way. Gustafsson et al. showed that heat exchangers with flat tubes have certain benefits seen from a noise point of view in comparison with round tube heat exchangers [3]. Therefore two types of compact heat exchangers with continuous fins were evaluated, one type with round tubes, and one type with flat tubes. For each type two heat exchangers with different geometrical measures were investigated. The differences between the two round tube heat exchangers are the size and spacing of the round tubes (FCTP1 and FCTP2). The flat tube heat exchanges are almost identical; however one of them has plain fins (FFTP) while the other has wavy fins (FFTW). The geometrical data for each of the four heat exchangers are shown in Table 1 and a schematic of the geometry is presented in Fig. 2.

2.3. Fan noise generation

The noise generation of a fan is dependent on the type of fan, its design and the operating conditions. It is a complex task to predict the noise from a fan and the uncertainties are usually very large. A general rule is that a fan is quietest when it is operating most efficiently and that the sound power level is proportional to the air flow rate and the square of the pressure. The blade pass frequency also contributes to the noise level. Thus, the sound power level of a fan (when it is operating with maximal efficiency) can be described by [7]:

$$L_W = K_W + 10 \log \dot{V}_a + 20 \log \Delta p + BFI \quad (2.1)$$

where L_W is the sound power level, K_W is the specific sound power level for a certain type of fan and BFI is the Blade passing Frequency