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In situ measurement methods of air to air heat pump performance

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ABSTRACT

There is no in situ reliable measurement method of air-to-air heat pump heating performances. This paper tests and validates two methods in laboratory and in steady-state conditions. The first method based on refrigerant fluid measurements determines the refrigerant flow rate by using the compressor thermal balance. In particular, the evaporation pressure is measured by a saturation temperature measurement and the compressor ambient heat losses are evaluated from the heat exchanges. The method uses only non-intrusive sensors, except for the condensation pressure sensor installed at the refrigerant charging plug. The second method based on air measurements determines the air flow rate via a multi-point velocity measurement. According to the experimental results, these methods are fully applicable on field with deviations of 4% and 10%, for the refrigerant method and the air method respectively, when compared to the "etalon" measurement.

Méthodes de mesures in situ pour évaluer la performance des pompes à chaleur air-air

Mots clés : pompe à chaleur ; performance ; mesures in situ ; expérience ; frigorigène ; air humide

1. Introduction

The heat pump is one of the solutions promoted in order to reduce energy consumption of heating systems in buildings. In this context, the use of residential heat pumps (HPs) for heating has been rapidly spreading out in Europe because of their high efficiency measured on laboratory conditions. But the situation may differ in the field due to several factors including the installation quality, the design of the heating system and the climatic conditions. Moreover, people will be increasingly concerned by the seasonal in situ performance of their equipment as it directly impacts the final energy consumption.

For water-to-water or air-to-water HPs, the heating energy delivered is easily measured in the field by measuring the

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Nomenclature

a	heat loss coefficient, W K^{-1}
A	area, m^2
b	heat loss coefficient, W K^{-4}
c	heat loss coefficient, W
Cg	oil mass concentration
c_p	specific heat capacity, J kg^{-1} K^{-1}
D	tube diameter, mm
h	specific enthalpy, J kg^{-1}
$\dot{m}$	mass flow rate, kg s^{-1}
P	electric power, W
p	pressure, bar
$\dot{Q}$	energy rate, W
S	sensitivity index
T	(dry) temperature, °C
Td	dew-point temperature, °C
v	velocity, m s^{-1}
$\dot{V}$	volume flow rate, m^3 h^{-1}
x	refrigerant vapor quality
α	void fraction
ε	relative uncertainty
η	compressor heat loss factor
υ	specific volume, m^3 kg^{-1}
ρ	density, kg m^{-3}
σ	absolute uncertainty
W	humidity ratio

Subscripts

a	(moist) air
amb	ambient
atm	atmosphere
com	compressor
con	condenser (condensation)
da	dry air
eva	evaporator (evaporation)
ex	exhaust side
liq	saturated liquid
loss	heat loss
m	refrigerant–oil mixture
oil	oil
r	(pure) refrigerant
ref	reference
sat	saturation state
su	suction side
vap	saturated vapor

Abbreviations

HP	heat pump
IE	indoor heat exchanger
OE	outdoor heat exchanger

energy supplied to the water circuit (water temperature and water flow rate measures), but it is not the case for air-to-air HPs due to the difficulty of measuring the air flow rate and the air enthalpy in the field over a long time period.

McWilliams (2002) gives a review of airflow measurement techniques. The most commonly current technique on field is as follow: the air flow is led into a duct and then measured directly by an anemometer. The latter may be either a helix type, a Pilot-tube type or a calibrated capillary type as in the works of Howell and Sauer (1990), Francisco and Palmiter (2003) and Rivière et al. (2012). However, this technique is cumbersome so that it cannot be used at customer's dwelling for a long time. In addition, the measurement installation interferes more or less with the HP operation because it causes pressure losses which change significantly the air flow rate. A fan can be used to compensate the pressure losses but there is no way, on field, to check if it is correctly done.

In the work of Ichikawa et al. (2007), a multi point measurement of air temperature, humidity and velocity was performed to determine air enthalpies. In particular, the air velocity field was identified, and then corrected to fit the value of air flow rate given by the manufacturer. The main issue with this method is the likely evolution of HP performances over time, which cannot be evaluated.

Fahlén (2004) provides another approach based on refrigerant fluid measurement. In particular, the refrigerant flow rate is determined using the compressor thermal balance. This method was tested in water-to-water and air-to-water HPs and yielded accuracy better than 15%. The method is however problematic due to the fact that the compressor heat losses are not measured. In addition, it requires intrusive pressure measurements, which are always difficult to do on field if the HP doesn't already have the necessary pressure plugs.

In this context, the objective of the authors is to test and possibly validate two in situ methods allowing to overcome the different obstacles mentioned. One method is based on the measurements of the refrigerant fluid side, and is named here "in situ refrigerant method"; the other one uses measurements of the air side, and is named "in situ air method". This paper presents the first step to attain the objective, which is to check, in laboratory, the two in situ methods and to determine their accuracies in steady-state conditions for the heating mode. Further necessary steps required to reach a fully applicable method for in situ dynamic conditions are discussed in the conclusions and perspectives.

The existence of such methods would eventually allow HP manufacturers to check performance on field and thus to ensure the energetic gains and economic benefits that user expects when purchasing an air-to-air HP. Besides, the methods could be used by a third party to verify independently the HP performance.

2. Methodology and experiments in laboratory

HP performance is defined as the ratio of the heat exchange in the indoor heat exchanger (noted hereafter IE) and the HP electric consumption over a period of time. The main difficulty of performance measurement is to measure the heat exchange rate, namely heating power. The two mentioned in situ methods are simultaneously tested on a residential air-to-