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# Compensation of flow maldistribution in fin-and-tube evaporators for residential air-conditioning

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ABSTRACT

Compensation of flow maldistribution in multi-channel fin-and-tube evaporators for residential air-conditioning is investigated by numerical modeling. The considered sources of maldistribution are distribution of the liquid and vapor phases in the distributor and non-uniform airflow distribution. Fin-and-tube heat exchangers usually have a predefined circuitry, however, the evaporator model is simplified to have straight tubes, in order to perform a generic investigation. The compensation of flow maldistribution is performed by control of the superheat in the individual channels. Furthermore, the effect of combinations of individual maldistribution sources is investigated for different evaporator sizes and outdoor temperatures. It is shown that a decrease in cooling capacity and coefficient of performance by flow maldistribution can be compensated by the control of individual channel superheat. Alternatively, a larger evaporator may be used.



# Compensation de la mauvaise distribution de l'écoulement dans les évaporateurs à tubes ailetés utilisés dans le conditionnement d'air résidentiel

*Mots clés :* Distribution de l'écoulement ; Compensation ; Conditionnement d'air ; Tube aileté ; Modélisation ; Simulation

## 1. Introduction

Flow maldistribution in multi-channel fin-and-tube evaporators has been shown to decrease the performance of air-conditioning systems (Kærn et al., 2011). Maldistribution can be caused by different effects such as non-uniform airflow, non-uniform air temperature, condensation or frost, fouling, an improper heat exchanger, distributor design and installation, or combinations of all these factors.

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**Nomenclature**

*Roman*

| | |
|---|---|
| $F_x$ | Phase distribution parameter (–) |
| $F_{air}$ | Airflow distribution parameter (–) |
| $T_{sh}$ | Superheat temperature (K) |
| V | Velocity (m $s^{-1}$) |
| x | Vapor quality (–) |

*Subscripts*

| | |
|---|---|
| fr | Frontal |
| in | Inlet |
| m | Mean |

Recently Kærn et al. (2011) conducted a numerical study of flow maldistribution in fin-and-tube evaporators for residential air-conditioning (RAC). It was reported that the non-uniform airflow significantly reduces the cooling capacity and COP, whereas the liquid/vapor phase maldistribution in the distributor does not reach similar impacts on performance. Different feeder tube bending was shown to have a minor effect on the degradation of the cooling capacity and COP. The COP decreased as much as 13% in the worst case of liquid/vapor phase distribution in the distributor and by 43% in the worst case of non-uniform airflow distribution, respectively.

Most efforts to compensate for flow maldistribution have addressed the design of the evaporator and, to a less extent, the refrigerant distributor. Domanski and Yashar (2007) applied a novel optimization system called ISHED (intelligent system for heat exchanger design) to optimize refrigerant circuitry in order to compensate for airflow maldistribution. They measured the air velocity profile using particle image velocimetry (PIV) and used that as an input to their numerical model, and found that the cooling capacity increased by 4.2% compared to an interlaced type of circuitry. Nakayama et al. (2000) and Li et al. (2005) studied different distributors and compensation for refrigerant flow maldistribution by changing the design of the distributor. Nakayama et al. (2000) reported that their novel distributor, which had a capillary mixing space, achieved the best refrigerant distribution. Li et al. (2005) reported that, in general, a spherical base distributor achieved the best refrigerant distribution, and that the orifice should be located closest to the distributor base.

Studies regarding the benefits of controlling individual superheat have also been conducted. Choi et al. (2003) conducted an experimental study on a fin-and-tube evaporator and found that a non-uniform airflow could be recovered to within 2% of the original cooling capacity under uniform airflow conditions, while keeping the airflow rate constant. The individual channel pressure drops were adjusted by needle valves to achieve the same individual channel superheat. Kim et al. (2009a, b) studied the benefits of upstream vs. downstream control of individual channel superheat on a fin-and-tube five channel R410A heat pump. Two and three of the channels, respectively, were treated similarly. Essentially, there were two circuits, where one had 50% larger area than the other. Their method involved fine-tuning the miniature valves located upstream or downstream of the evaporator along with an overall thermostatic expansion valve. Essentially, the method controlled the individual superheats by adjusting the pressure drop through the channels. The study showed that the upstream control outperformed the downstream control. They also found that the capacity reduction due to maldistribution could be recovered up to 99.9% by using upstream control. Using downstream control resulted in minor benefits due to the increased pressure drop at the exit of the evaporator.

Flow maldistribution can be compensated for by using an expansion valve for each channel. Another option is to increase the size of the evaporator. The first option is unfeasible due to the costs associated with installing additional expansion valves. The second option may have restrictions on the size of the air ducts. For economical reasons, any type of refrigerant distribution control must be less expensive than the costs of increasing the size of the evaporator in order to deliver the same cooling capacity.

To compensate for maldistribution, a new method was evaluated in the current study with respect to cooling capacity and the coefficient of performance (COP). This method involved a coupled expansion and distributor device that was able to control the individual channel superheat by measuring only the overall superheat (Funder-Kristensen et al., 2009; Mader and Thybo, 2010).

In a previous study considering the effects of flow maldistribution, Kærn et al. (2011) developed a model of an 8.8 kW R410A RAC system. The model was capable of simulating refrigerant and airflow maldistribution in fin-and-tube evaporators as well as the effects of maldistribution on cooling capacity and the coefficient of performance (COP). The model was verified under uniform flow conditions with the commercial software Coil-Designer (Jiang et al., 2006). The same model was used in the current study to exploit the benefits of compensating for flow maldistribution. The evaporator was an A-coil and consisted of two coils each with two channels. In order to perform a generic investigation, each evaporator coil model was simplified to be two straight channels where each channel was aligned in the first row and meet the same inlet air temperature. Furthermore, each coil was assumed to have similar flow distribution conditions.

The objective of the current study was to perform a generic investigation of the benefits of compensating for flow maldistribution by controlling individual superheats. As a baseline for comparison, an analysis of flow maldistribution was carried out where different combinations of maldistribution sources were considered with different evaporator sizes and outdoor temperatures. In particular, inlet liquid/vapor phase distribution and airflow distribution in the evaporator were considered. The new method of compensation was then compared to the baseline results of combined flow maldistribution.

This paper includes a brief description of the modeling framework, an analysis of the new method for compensation and a comparison of the method against the combined maldistribution with different evaporator sizes and outdoor temperatures.