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Research paper

# Self-optimizing control of air-source heat pump with multivariable extremum seeking

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## HIGHLIGHTS

- Multi-input ESC.
- Air-source heat pump.
- Cooling and heating.
- Modelica based model.

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## ABSTRACT

The air-source heat pump (ASHP) is widely adopted for cooling and heating of residential and commercial buildings. The performance of ASHP can be controlled by several operating variables, such as compressor capacity, condenser fan speed, evaporator fan speed and suction superheat. In practice, the system characteristics can be varied significantly by the variations in ambient condition, operation setpoint, internal thermal load and equipment degradation, which makes it difficult to obtain accurate plant models. As consequence, the model based control strategies for ASHP could limit the achievable energy efficiency. Model-free self-optimizing control strategies are thus more preferable. In this study, a multi-input extremum seeking control (ESC) scheme is proposed for both heating and cooling operation of ASHP. The zone temperature is assumed to be regulated by the compressor capacity, while the expansion valve opening is used to regulate the suction superheat at the given setpoint. The total power consumption of the compressor, the condenser fan and the evaporator fan is measured as input to the ESC, while the ESC controls the evaporator fan speed, the condenser fan speed and the suction superheat setpoint. The proposed scheme is evaluated with a Modelica based dynamic simulation model of ASHP under both cooling and heating modes of operation. Simulation results show the effectiveness of the proposed scheme to achieve the maximum achievable efficiency in a nearly model-free manner.



## 1. Introduction

The air-source heat pump (ASHP) has been widely used for cooling and heating for commercial and residential buildings because of its flexibility, convenience and potential for energy saving. As shown in Fig. 1, a typical ASHP consists of the major components for a vapor-compression cycle: compressor, condenser, evaporator, expansion valve, and heat exchangers and the fans for condenser and evaporator. Heating and cooling can be achieved with one physical loop under different manners of operation. The energy efficiency of ASHP is affected by equipment characteristics, ambient and load conditions. The operation of ASHP determines that its energy efficiency is affected by several manipulative inputs including compressor capacity, evaporator and condenser fan speeds, and suction superheat.

In the past couple of decades, modeling, control and optimization techniques have been investigated for the ASHP systems. It is desirable to minimize the power consumption while maintaining the zone temperature setpoint. Tsai et al. [1] presented a cascaded fuzzy control strategy which retains the merits of both fuzzy control and cascade control structures. Their results show the effectiveness in temperature regulation. Also, the proposed method

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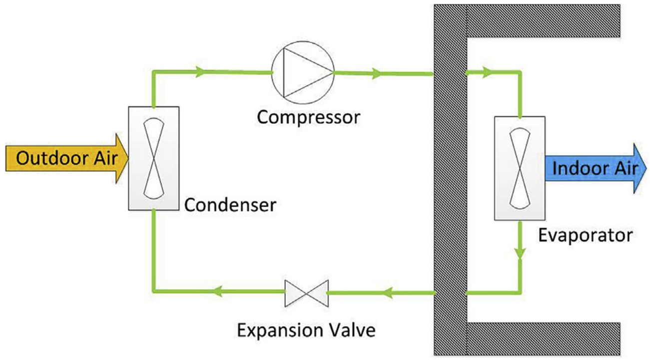


**Fig. 1.** Schematic of air-source heat pump operation.

outperforms a cascaded PI controller in terms of settling time and temperature overshoot. Liang et al. [2] described a sensible heat defrosting method for ASHP. The sensible heat defrosting method avoid many shocks that could have caused by reverse cycle defrosting. A self-organizing fuzzy control system was developed by introducing the self-learning and self-organizing adaptation algorithm to the basic fuzzy control strategy. Their experimental results showed good control quality. Jiang et al. [3] reported another effective defrosting control method, based on the degree of refrigerant superheat. And also for their further work reported, the novel defrosting control method was conducted on another ASHP unit with an electronic expansion valve (EEV) as a throttle device, under simulated frosting and defrosting conditions. The experimental results show that by applying their method, defrosting was initiated before the operating performances of ASHP unit rapidly deteriorated. Jiang et al. [4] presented a dual fuzzy-controller for an ASHP water heater. By controlling the EEV, the compressor discharge temperature can be substantially lowered especially when the ambient temperature is high. The coefficient of performance (COP) of the ASHP water heater is improved.

Ibrahim et al. [5] presented dynamic modeling and optimal energy management for an ASHP water heater with mini-tubes condenser. The developed optimization model is applied for a typical winter day of Beirut, with more than 41% of the energy saving compared with a conventional control strategy with a thermostat only. Guo et al. [6] reported an experimental study on optimal operation of an ASHP water heater, investigating the effect of outside area of the evaporator and condenser coil on energy efficiency. It reveals that the average COP becomes less sensitive if outside area of condenser coil and evaporator increases beyond certain value. Wallace et al. [7] describe the application of an offset-free model predictive controller (MPC) to a vapor compression cycle (VCC). The model is identified from data generated from a first-principle model of a VCC, and the predictive controller is designed that includes an augmented model and associated Luenberger observer to estimate the disturbance at steady-state and eliminate it. Mahmoud et al. [8] perform system identification techniques to obtain models of a vapor compression plant using experimental data, and then a set of model based controller design methods are used to control thermodynamic states of the VCC system based on the identified models. Pollock et al. [9] present a model-based control scheme of VCC for transient heat flux removal for an electronic cooling application. Linearized models are used to design controllers for avoiding critical heat flux situation. A decoupled approach using proportional-integral (PI) control of compressor speed and accumulator heating is taken for single-evaporator VCC. Experimental results validate the proposed

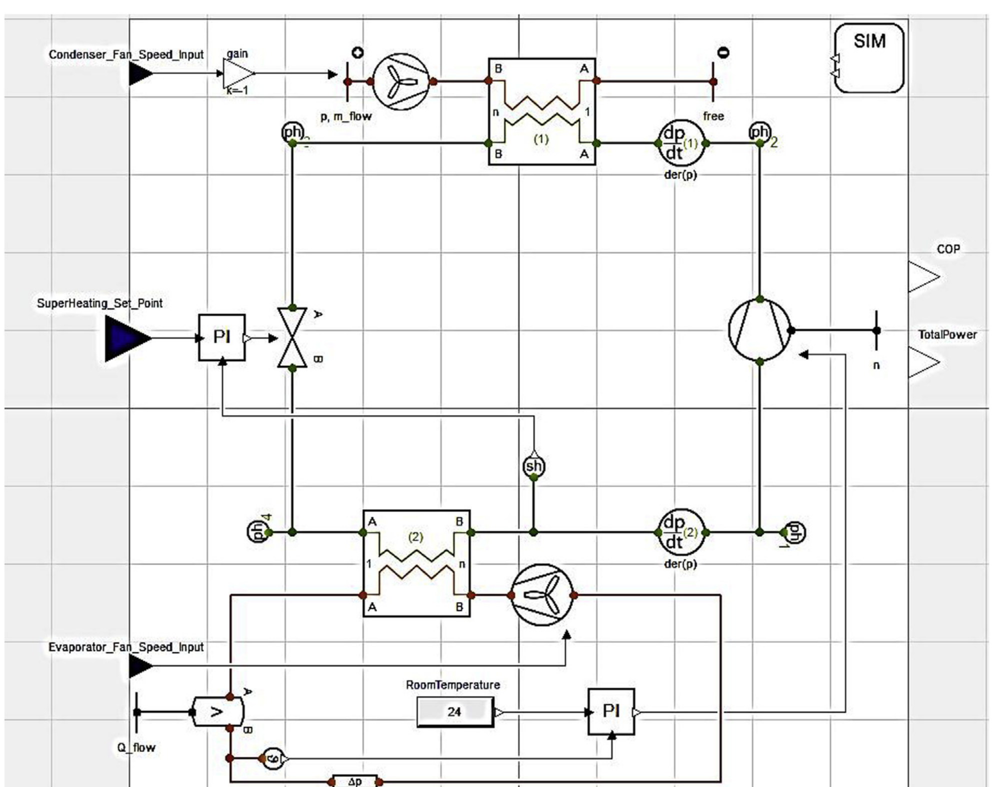


**Fig. 2.** Dymola layout for the ASHP simulation model.