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Research Article

Building Systems and Components

Multi-objective optimal control of an air-to-water heat pump for residential heating

Clara Verhelst[1] (✉), David Degrauwe[1], Filip Logist[2], Jan Van Impe[2], Lieve Helsen[1]

1. Department of Mechanical Engineering, Katholieke Universiteit Leuven, Celestijnenlaan 300a — 3001 Heverlee, Belgium
2. Department of Chemical Engineering, Katholieke Universiteit Leuven, W. de Croylaan 46 — 3001 Heverlee, Belgium

Abstract

The current study investigates the optimal operation of an air-to-water heat pump system. To this end, the control problem is formulated as a classic optimal control or dynamic optimization problem. As conflicting objectives arise, namely, minimizing energy cost while maximizing thermal comfort, the optimization problem is tackled from a multi-objective optimization perspective. The adopted system model incorporates the building dynamics and the heat pump characteristics. Because of the state-dependency of the coefficient of performance (COP), the optimal control problem (OCP) is nonlinear. If the COP is approximated by a constant value, the OCP becomes convex, which is easier to solve. The current study investigates how this approximation affects the control performance. The optimal control problems are solved using the freely available Automatic Control And Dynamic Optimization toolkit ACADO. It is found that the lower the weighting factor for thermal discomfort is, the higher the discrepancy is between the nonlinear and convex OCP formulations. For a weighting factor resulting in a quadratic mean difference of 0.5°C between the zone temperature and its reference temperature, the difference in electricity cost amounts to 4% for a first scenario with fixed electricity price, and up to 6% for a second scenario with a day and night variation in electricity price.

Keywords

heat pump,
floor heating,
multi-objective,
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1 Introduction

Heat pumps are devices that extract heat from the environment and deliver this heat at a higher temperature at supply side. The efficiency of a heat pump is characterized by its coefficient of performance (COP) which is amongst others a function of both the source and the supply temperature. The smaller the temperature difference to be bridged, the higher the COP. Heat pumps are therefore ideally suited for combination with low temperature heat emission systems such as floor heating. At the source side, the COP of an air-source heat pump can be increased by extracting heat from the ventilation exhaust air (e.g., Sakellari and Lundqvist 2005), or even further, by integrating solar air collectors to preheat the air (e.g., Badescu 2002a, b, 2003). If the ambient air is directly used without any form of preheating, the ambient temperature will directly influence the COP. The question arises when it is optimal to operate an air-source heat pump given the diurnal variation of the ambient air temperature. The answer is not straightforward, as a trade-off is expected between operating at times with higher ambient temperature (and thus higher COP) versus operating at times with lower ambient temperature (and thus higher building losses). Moreover, when energy costs are envisaged, the day-night variation of the electricity price will influence the answer. These questions motivate the research on heat pump control in a system's perspective.

Current heat pump systems are controlled by a heating curve which determines the set point for the supply or return water temperature as a function of the ambient temperature. This heating curve is tuned such that in stationary conditions the heat loss of the building is exactly compensated. This control strategy is suitable for fast reacting systems such as high temperature radiators in buildings with a small heat capacity. For heat pumps combined with a low-temperature heating system, e.g., floor heating, this control is not suited

E-mail: Clara.Verhelst@mech.kuleuven.be