

DZWi - Fault Detection and Diagnosis

RWTH Aachen



Figure 1: First results of fault detection service for evaporator fouling and resulting user notification.

Motivation

The efficiency of heat pumps is strongly dependent on a fault-free operation of the system. Numerous factors, such as the ongoing shortage of qualified specialists, the gas crisis, or the increasing demand due to the decision of the Heat Pump Summit 2022 in Germany, bear the risk that many new installations and maintenance of heat pumps cannot be managed. As a result, specialized companies are overwhelmed, meaning that both system efficiency and comfort may be reduced. To ensure fault-free operation, efficiency reductions can be detected, localized, and eliminated early by Fault Detection and Diagnosis (FDD) tools. These tools allow maintenance scheduling before significant performance degradation or system downtime occurs.

As a trailblazer in developing low-emission building energy technology (DZWi, FKZ: 03EN1022B), the German project Digital Twin of Heat Generation Systems aims to

develop such algorithms for FDD in residential heat pumps to reduce maintenance costs and downtime and increase the system efficiency. FDD methods are typically integrated as follows: The simulation of the fault-free behavior of a system is compared with the behavior of the real system where a fault has been injected or occurred. Here, two modeling techniques are usually used to represent fault-free behavior. First-principle models partly rely on physical knowledge of the underlying physical phenomena to describe the system. However, the equations describing the real systems are often complex and typically difficult to solve. Therefore, data-driven models are attracting more and more attention, especially for the operation mode. The application involves using experimental or simulated data to learn the relationship between the inputs and outputs of the system and to build both linear and nonlinear models. Besides established methods like Support Vector Machine (SVM) or Partial Least Squares

(PLS), Artificial Neural Networks (ANN) have shown comparatively better results, which is the reason for using them in the DZWi project.

Approach and Results

In a first attempt, ANN has already been developed for simulating the COP of heat pumps, using only features (input variables) which are hardly sensitive to a fault mode and thus represent the fault-free state of the system. The focus here was on the fault of evaporator fouling, which is typical for air-to-water heat pumps. Although changes in the COP of the heat pump system do not indicate the fault type, it was shown that emulation of reduced heat transfer in the evaporator due to evaporator fouling decreases the COP of the real system. The fault was injected into the system by continuously decreasing the fan speed in the evaporator. By comparison with the ANN model, a growing difference in the COP between the simulation and the real system was detected. Within the scope of the project, threshold-based algorithms are used for this purpose to notify the user. After properly training the fault-free model, this process is fully automated within the cloud platform developed in the DZWi project for communication between simulation models and the real plant.

The first results of a proof-of-concept of fault detection are shown in Figure 1, where the blue area is used to learn the fault detection module, a fault-free operation, and the fault was initiated in the red area. A physical simulation model is compared to the real measured data via the monitoring service, and increased fouling in the heat pump evaporator could be detected by calculating the standard deviation. In this case, the notification module provides information about the occurrence of a fault to the user afterward.

Outlook

In the future, apart from pure fault detection, fault diagnosis will also be enabled by predicting so-called decoupled variables via the ANN, which indicates a specific fault in the case of abnormal behavior. For evaporator fouling, for example, this would be the external air volume flow.

FACTS ABOUT THE IOT CASE

IoT category: Optimize heat pump operation, Predictive maintenance, Installation and operation error analysis

Goal: Reduce costs and emissions during development and operation

Beneficiary: user, manufacturer, assembler (fault detection)

Data required: weather forecast, operation data

Analysis method: simulations, visualization, fault detection, alarming, energy balances, control engineering

Modelling requirements: dynamic models (Grey-box) as well as static models and Data-driven models

Quality-of-Service: daily near real-time

Project participants: Technische Universität Dresden, RWTH Aachen University, Viessmann Werke Allendorf GmbH, Glen Dimplex Deutschland

Time schedule: from 2020-2023

Technology availability: TRL 8-9

Link to webpage: <https://dzwi-waerme.de/>

Contact information

RWTH Aachen University, Institute for Energy Efficient Buildings and Indoor Climate (EBC)

Sebastian Borges, Sebastian.Borges@eonerc.rwth-aachen.de

Fabian Wüllhorst, fabian.wuellhorst@eonerc.rwth-aachen.de

Stephan Göbel, Stephan.goebel@eonerc.rwth-aachen.de

Tim Klebig, tim.klebig@eonerc.rwth-aachen.de

Christian Vering, cvering@eonerc.rwth-aachen.de

Prof. Dirk Müller, dmueller@eonerc.rwth-aachen.de