

## KI4HVACS

Energieeffizienzoptimierung von HLK-Systemen durch prädiktiver Algorithmen und Modellbildung mittels maschinellem Lernen

<b>Programm / Ausschreibung</b>	Energieforschung (e!MISSION), Energieforschung, Energieforschung 7. Ausschreibung	<b>Status</b>	abgeschlossen
<b>Projektstart</b>	01.04.2022	<b>Projektende</b>	28.02.2025
<b>Zeitraum</b>	2022 - 2025	<b>Projektlaufzeit</b>	35 Monate
<b>Keywords</b>	Modellbasierte Gesamtoptimierung, Prädiktive Wartung, Betriebseffizienz von HLK-Anlagen		

### Projektbeschreibung

HLK-Systeme sind in der Regel für mehr als 40% des Energieverbrauchs von Wohn- und gewerblichen Gebäuden verantwortlich, wodurch die Optimierung der Anlageneffizienz zu einer Priorität in der wirtschaftlichen aber auch ökologischen Betriebsführung wird. Es ist zu erwarten, dass mit zunehmenden Folgen des Klimawandels der Bedarf an HLK-Anlagen steigt. Insbesondere im gewerblichem und industriellem Umfeld wird der Bedarf an unmittelbarer Kühlleistung und Lüftung steigen. Eine umfassende Optimierung von HLK-Anlagen kann den Energieverbrauch und die Kosten in der Regel um 20 bis 40% senken, die Systemzuverlässigkeit durch einen effizienteren Betrieb verbessern und den CO<sub>2</sub>-Fußabdruck eines Gebäudes wesentlich senken. Demgegenüber steht die Tatsache, dass in Bestandsgebäuden aber auch in Neubauten HLK-Anlagen meist nur während der Planungsphase und Inbetriebnahme parametrisiert werden. Danach wird meist auf ein laufendes Monitoring, verbunden mit einer Rekonfiguration/Optimierung der Anlage, verzichtet.

Ziel dieses Projektes ist es mittels maschinellem Lernen, und ohne explizite Modellbildung, System- und Betriebszustände zu bewerten und zu optimieren, sowie prädiktive Instandhaltung nicht nur nach Verschleiß und Kosten sondern nach deren Auswirkungen auf den Gesamtenergieverbrauch zu planen. Der Fokus der Optimierungen liegt hierbei auf der Konfiguration von HLK-Settings und auf der Effizienz der Wartungsplanung. Der Mehrwert dieses Ansatzes liegt darin, dass nicht in die Regelung des HLK-Systems eingegriffen werden muss. Somit ist dieses System auch als Retrofit für bestehende Anlagen herstellerübergreifend einsetzbar. Zusätzlich kann die Optimierung auch auf Basis von multiplen Anlagen erfolgen und durch vortrainierte Modelle wird die Lernphase der eingesetzten KI-Algorithmen massiv verkürzt. Den Kern der technischen Innovation bildet ein Ansatz aus einer Kombination von Reinforcement-Learning, Supervised-Learning und einer iterativen Kontrollstrategie auf Basis einer Model Predictive Control (MPC)-Architektur, welche die Abweichungen zwischen den tatsächlichen und den erwarteten Werten, die z.B. aus Modellungenauigkeiten entstehen, minimiert.

Die Evaluierung des Systems und der erwarteten Einsparungen von 30% Energie und 40% Kosten im Vergleich zu bestehenden Systemen wird in einer dynamischen System-in-the-Loop-Simulation durchgeführt, die es ermöglicht die entwickelte Technologie in einem breiten Spektrum von Anwendungsfällen zu testen. Letztendlich wird der entwickelte Ansatz aber in einer realen Anlage in einem Testgebäude der Projektpartner längerfristig getestet, um auch eine experimentelle Bestätigung der Simulationsergebnisse zu erhalten. Die Ergebnisse und der vorgeschlagene KI-Ansatz haben

große Relevanz für GebäudeeigentümerInnen und Facility Manager, PlanerInnen und Systemintegratoren, Hersteller und Zulieferer von HLK-Systemen und Gebäudeleittechnik, Gebäudebetreiber und eingemieteten Firmen, die alle gefordert sind die Energieeffizienz von HLK-Anlagen, z.B. aufgrund der EU-Richtlinie 2012/27/EU, wesentlich zu steigern. Sie erschließen aber auch neue Marktsegmente für Firmen, die Daten bereitstellen und auswerten.

## **Abstract**

HVAC systems are usually responsible for more than 40% of the energy consumption of residential and commercial buildings, making optimizing system efficiency a priority both economic and ecologically. It is expected that as the impacts of climate change increase, the need for HVAC systems will increase too. In particular, in commercial and industrial environment the need for direct cooling and ventilation will raise strongly. Comprehensive optimization of HVAC systems can typically reduce energy consumption and costs by 20 to 40%, improve system reliability through more efficient operation, and significantly reduce a building's carbon footprint. In opposite, in real life HVAC systems in existing buildings but also in new buildings are usually only parameterized during the planning and commissioning. Thereafter, ongoing monitoring, combined with a reconfiguration or optimization of the system, is usually neglected.

The aim of this project is to use machine learning, without explicit modeling, to evaluate and optimize system and operating states, as well as to plan predictive maintenance not only according to wear and associated costs but also in respect to their effects on building energy consumption. The focus of the optimization strategy is on the configuration of HVAC settings and the efficiency of maintenance planning. The added value of this approach is that there is no need to intervene in the control of the HVAC system. The developed AI can therefore also be used as a retrofit for existing systems across all manufacturers. In addition, the optimization can also take place on data from multiple systems and the learning phase of the AI algorithms used is massively shortened through pre-trained models. The core of the technical innovation is an approach consisting of a combination of reinforcement learning, supervised learning and an iterative control strategy based on a Model Predictive Control (MPC) architecture, which compensates the deviations between the actual and expected values, e.g. minimization of model inaccuracies.

The evaluation of the system and the expected savings of 30% energy and 40% costs compared to existing systems is carried out in a dynamic system-in-the-loop simulation, which enables the developed technology to be tested in a wide range of use cases. Ultimately, however, the developed approach will be tested in a real system in a test building of the project partners over the long term in order to obtain experimental confirmation of the simulation results. The results and the proposed AI approach are of great relevance for building owners and facility managers, planners and system integrators, manufacturers and suppliers of HVAC systems and building management systems, building operators and tenants, all of whom are required to improve the energy efficiency of HVAC systems, e. g. due to the EU Directive 2012/27 / EU, significantly. Results will also open up new market segments for companies that provide and evaluate data.

## **Endberichtkurzfassung**

KI4HVACs project aimed to evaluate and optimize system and operating states through machine learning, without explicit model building, and to plan predictive maintenance not only based on wear but also on their impact on overall energy consumption.

The project resulted in an integrated solution that include:

Two versions of the RL-modeling and optimization for temperature and valve based control for HVAC energy efficiency. Simulation environment for complex (based on existing building) and simplified generic buildings.

Decision tree control algorithm for maintenance requirements determination developed in Matlab and transferred into Python for integration.

HVAC behaviour models using transformer architecture for predicting HVAC single and multiple parameters over the long planning horizon.

Linear regression models for maintenance indicators threshold monitoring.

MQTT based communication platform for monitoring and control.

The following objectives of the proposal were addressed and/or achieved:

“Identification of energy-efficient configurations to optimize the energy consumption of an HVAC system without compromises in user comfort”.

Simulation of a multi-zone office building was developed and analyzed that identified systems components and parameters that affect energy efficiency. The user comfort was an integral part of the evaluation criterion using the acceptability ranges for comfort.

“Energy-driven predictive configuration and maintenance planning. The cost function for predictive planning is energy-based with the aim of increasing the efficiency of the system.”

The energy efficiency model and control algorithm was developed and tested extensively on the simulation environment as well as its feasibility was tested in the field test. The results showed a drastic improvement of the energy cost savings without compromising the user's comfort. Analysis of the historical measurements that are used for predictive maintenance models was performed as well as preliminary models on a subset of sensory data were developed. A decision tree based control algorithm for maintenance was developed. However, the analysis of the cost comparison between costs of degrading performance and the cost of components exchange showed that there are no economic benefits of the early maintenance and therefore, the focus was shifted towards determination of the latest time of maintenance instead of the most cost-efficient. Linear regression models for predictive maintenance were developed to determine the breakdown time for maintenance indicators.

The corresponding technical sub-goals are:

“Development of a hybrid architecture that combines short-term optimization of HVAC settings with long-term HVAC maintenance planning based on reinforcement and supervised learning algorithms.”

An integrated solution based on the simulation of an office building was developed that combined, Reinforcement Learning model for energy efficiency optimization, Linear regression models for maintenance indicators predictions and the decision tree control algorithm for maintenance requirements determination. The system showed significant improvement in energy efficiency and proof of concept for maintenance handling.

“Improvement of HVAC settings through reinforcement learning algorithms based on optimization criteria for energy and

CO2 balance.”

The RL model was developed and used multiple optimization criteria that included minimization of energy consumption, user’s comfort and CO2 balancing.

“Improvement of energy consumption efficiency and CO2 balance through predictive maintenance using supervised learning algorithms in combination with model predictive control (MPC).”

System architecture that defines the iterative nature of the MPC algorithm was defined with the interfaces and data to facilitate the control architecture. The control strategy is based on the decision tree for maintenance indicators and the reinforcement learning for the energy efficiency was developed and tested.

“Determination of the minimum necessary sensor equipment (number and type of sensors) for the machine learning-derived models to make accurate predictions of system states. The approach includes feature selection methods and evaluates them based on the weighting of different subsets.”

Schemes of different ventilation systems were examined and based on this, a generic model was developed to cover all ventilation systems. This model was used to identify all possible sensors and actuators of a ventilation system and, based on this, find the metrics for system optimization. In addition, a separate study was conducted to define an algorithm on how to minimize the number of sensors that is required without compromising the performance.

“Simulation-based multi-phase learning to radically shorten training phases and accelerate adaptation to a single system.”

Online learning modeling and control algorithm was developed allowing utilization of the RL-model from the beginning of the system operation, removing the need for a long training period.

“Iterative improvement of the optimization function to create additional flexibility in the use of fluctuating energy costs for renewable energy sources and to mitigate inaccuracies in the models.”

Analysis of the energy prices on the maintenance was done and can be integrated into the concept. A price prediction model was developed allowing integration of prices in the prediction based system control.

“Optimization of learning and control algorithms for the best possible resource efficiency, as the algorithms used require a lot of computing power and therefore also require additional energy.”

Computational requirements of the model during the training and running were evaluated and analyzed. It was established that the system can run on embedded devices. However, testing of such an operation was out of scope for the project.

## **Projektkoordinator**

- Universität für Weiterbildung Krems

## **Projektpartner**

- Fachhochschule Technikum Wien
- Technische Universität Wien
- Radel - Hahn Klimatechnik Ges.m.b.H.
- Reisenbauer Solutions GmbH