KI4HVACS

Advanced HVAC systems: Combining energy efficiency and maintenance through AI

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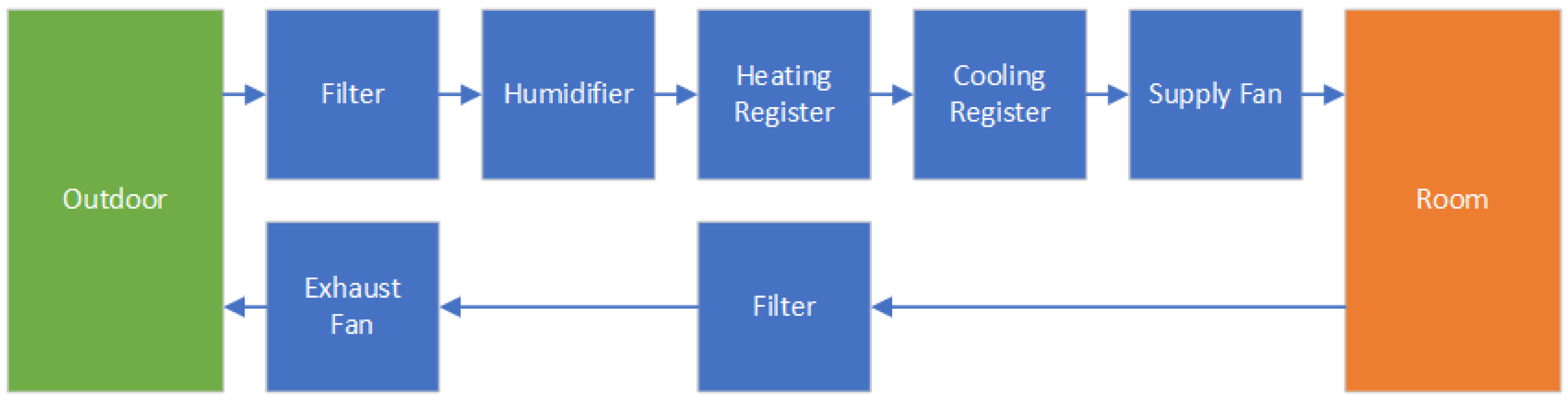
Motivation

- HVAC (Heating, Ventilation, and Air Conditioning) systems typically account for more than 40% of energy consumption in residential and commercial buildings, making efficiency optimization a key priority.
- As climate change intensifies, the demand for HVAC systems will continue to grow.
- Most HVAC systems, new or existing, are usually only configured during the planning and commissioning stages.
- Continuous monitoring, reconfiguration or optimization of the system is usually neglected.

HVAC system

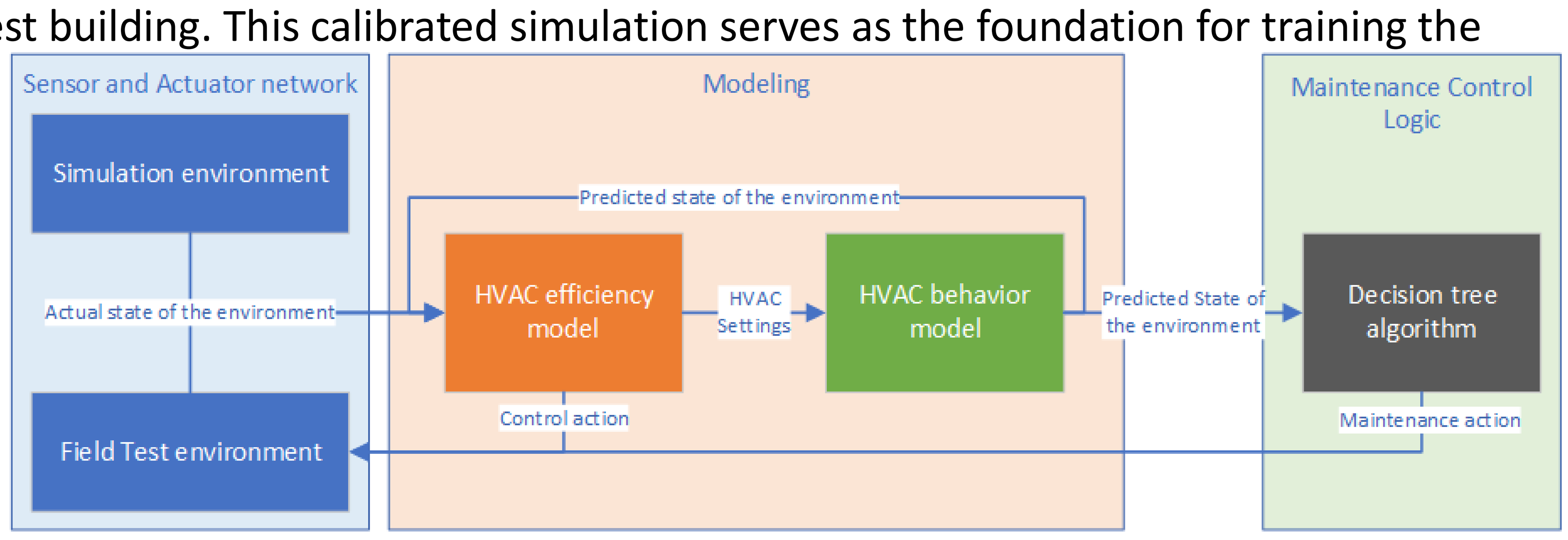
The generic HVAC model is structured so that all relevant parameters and control variables can be mapped to the specific components of the ventilation system, ensuring accurate representation of each element's impact on overall performance.



- The HVAC model tracks the supply and exhaust airflow paths between the outdoor environment and the indoor space.
- The scope of this setup is not to determine each component, but each sensor and actuator in the system.
- The HVAC system used in the field test is modeled in the TRNSYS environment, which is then calibrated with real-world measurements from the test building. This calibrated simulation serves as the foundation for training the machine learning models.

KI4HVACs architecture

KI4HVAC's approach integrates a data-driven methodology, combining reinforcement learning for optimizing HVAC efficiency with supervised learning for predictive maintenance.



The system operates with two control loops: 1) energy efficiency is managed by the HVAC optimization model, and 2) preventive maintenance is governed by a decision tree algorithm, based on predictions from the HVAC behavior model.

System Components

- **Sensor and Actuator network** monitors and controls the building's environment, including the HVAC system. It is combined with the simulation environment, which enables virtual monitoring and control of the HVAC system and speeds up the training process.
- **HVAC efficiency model** uses reinforcement learning to optimize the HVAC system's energy consumption based on the current state of the environment. By analyzing data from the sensor and actuator network, the model can adjust the HVAC system's settings to achieve optimal energy use.
- **HVAC behavior model** uses supervised learning to predict the future state of the environment based on the current sensory data and the HVAC settings. The model is trained on historical and synthetic data to identify patterns and trends in the environment, allowing it to predict future environmental conditions accurately to determine maintenance needs.
- **Maintenance control logic** uses a decision tree algorithm to determine when maintenance is required. By monitoring the HVAC system's performance, the maintenance control logic can detect potential issues and schedule maintenance to prevent downtime and minimize energy waste.

HVAC efficiency model

- The Reinforcement Learning model is designed to identify the optimal HVAC system settings at each step.
- Its objective is to maximize a reward function that balances various factors, such as energy consumption and occupant comfort.
- The model takes into account inputs including outdoor and indoor temperature, humidity, CO2 levels, supply and extract air volume flow, heating demand, and energy consumption.
- Based on these inputs, the model outputs actions that adjust parameters such as temperature, humidity, air volume flow rate, the fraction of recirculated air, and the type of control logic applied.

HVAC behavior model

- The HVAC behavior model operates in two modes: 1) short-term predictions for the HVAC settings control loop, and 2) long-term predictions to guide maintenance decisions.
- A hybrid approach is developed, combining an iterative LSTM (Long-Short-Term Memory) transformer model with a statistical long-term model.
- The long-term model's role is to correct errors that accumulate in the short-term predictions due to the iterative nature of the model's operation.
- The iterative model uses the same inputs as the HVAC efficiency model—environmental state data—along with the output of the efficiency model, which represents the action state.

HVAC systems are known for their rigid and complex internal behavior, which constrains efficiency optimization efforts. **KI4HVAC** seeks to leverage machine learning to enhance the operational and maintenance efficiency of HVAC systems in office buildings. Reinforcement learning is employed to optimize energy consumption, while supervised learning is used for predictive maintenance. These models are integrated into an MPC-based framework and a decision tree algorithm for preventive maintenance.

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