

Master thesis suggestion from SINTEF Community and
Relynk

AI-Based Automated Fault Detection and Diagnosis (AFDD) in Building Systems



Keywords: Machine learning, time series analysis, building energy and indoor comfort optimization, AI for building sustainability applications.

Supervisors/consultants: In cooperation with professor(s) at your university, Dr. Hicham Johra (SINTEF), Dr. Kamilla Heimar Andersen (SINTEF), Simen Bakken (Relynk) & Petros Petro (Relynk). Kamilla will be the main contact person/supervisor for the master thesis at SINTEF and Relynk.

Location: Flexible but preferable at SINTEF Community Oslo, your university or Relynk (optional: sitting at Startuplab Oslo).

Required competencies: building systems, HVAC, machine learning, data treatment and analysis, Python.

Personal competencies: We are focused on creating a good master thesis for you, so that you will develop necessary and highly relevant skills for industry and research and deliver high-quality results in an ongoing

research project. Hicham and Kamilla have supervised a total of 40 master thesis students. We are looking for candidates that are self-driven, solution oriented, deliver results, communicative and not afraid of a challenge.

This is a unique opportunity to work in the field of the built environment and computer science, in collaboration with a research institute and an innovative startup company.

Number of students: The master thesis project can be adjusted according to your interests and competencies. We strongly recommend that two master students work together on one thesis, or that two separate master theses be conducted on similar topics but with different focuses to distinguish the results.

Background and motivations: Buildings are the largest energy end-users in industrialized countries. They are thus a key target to reach sustainability goals and lower the overall energy demand while ensuring better indoor comfort for occupants. However, most buildings suffer from poor energy efficiency and cannot maintain proper indoor climate because of malfunctioning building systems, especially heating, ventilation and air conditioning (HVAC) units. The proper commissioning of building systems is rarely conducted thoroughly, and there is very little continuous monitoring and analysis of these systems during the operation phase of the buildings. Maintenance is often restricted to only tackling severe system failures but does not address lesser faults which, although they do not impair the basic functions of the building, take a huge toll on the energy efficiency and indoor comfort, and thus productivity and well-being of occupants.

With the rapid deployment of building management systems, controllable appliances and so-called “smart control systems”, buildings produce a large amount of data, which could be leveraged to provide a number of services. In particular, the massive digitalization of building systems offers the opportunity to automate data analyses identifying abnormal system behavior and performance, which can then trigger preventive maintenance.

The concepts of computer-aided or fully automated fault detection and diagnosis (AFDD) algorithms for building systems have been advertised for several decades but have fallen short in their scalable implementation. A large number of actors pretend to perform AFDD. In reality, the vast majority of those so-called AFDD solutions are data analysis dashboards that help system experts visualize building data and perform fault detection and diagnosis manually, or a set of rudimentary rule-based alarms with arbitrary thresholds. More elaborate solutions are usually limited to outlier detection or comparison between a reference model (which is very costly to develop and tune adequately) and the current operational data stream. Advanced machine learning model/algorithm-based AFDD solutions are very scarce because of the severe lack of training/testing datasets with labeled ground truth on the system’s fault status and fault nature.

Project objectives: The goal of this research project is to use state-of-the-art machine learning methods on curated datasets of building HVAC systems operation data with fault detection and diagnosis ground truth to develop accurate AFDD models. These datasets are generated from building monitoring campaigns with real fault emulation in the buildings (e.g., physically blocking a valve). To ensure scalability, these models are based on a data-driven black box approach (e.g., neural networks or random forests). To improve accuracy and portability, physics-informed black box models should be explored.

Tasks for a master thesis 30 ECTS (can be adjusted to longer or shorter):

- If time, contributes to development of the dataset.
- Review current AI-based AFDD solutions that have open-source documentation.

- Review open datasets for AFDD training and testing.
- Review typical faults occurring in buildings and building systems in Norway.
- Perform feature importance analysis for AFDD in different types of HVAC systems.
- Benchmark different machine learning methods/pipelines and black box models to perform AFDD on the available training and testing data.
- Identify the most suitable accuracy metrics for training and testing/performance assessment of AFDD models with different types of test datasets (variability of dataset size, quality, number of available features, imbalance ratio, fault prevalence).

Preferable:

- Explore training of deep neural networks (DNNs) with different architectures and attention mechanisms to identify patterns in the system data time series which can clearly be associated with distinct classes of faults.
- Explore transfer learning methods and physics-informed DNNs to fine-tune deep neural networks and ensure better portability and scalability of AI-based AFDD solutions.

Side tasks (optional):

- Exploring leveraging building system ontologies for AFDD.
- Exploring the use of large language models to generate or streamline the instantiation of ontologies for building systems from semi-structured data.
- Explore the quantification of data quality in the context of building systems.

Relevant literature:

- Fault Detection and Diagnosis Encyclopedia for Building Systems: A Systematic Review: <https://doi.org/10.3390/en15124366>
- Barriers and drivers for implementation of automatic fault detection and diagnosis in buildings and HVAC systems: An outlook from industry experts: <https://doi.org/10.1016/j.enbuild.2023.113801>
- Development and implementation of automated fault detection and diagnostics for building systems: A review: <https://doi.org/10.1016/j.autcon.2019.04.002>
- <https://github.com/bbartling/open-fdd/blob/master/README.md>
- A labeled dataset for building HVAC systems operating in faulted and fault-free states: <https://doi.org/10.1038/s41597-023-02197-w>
- Empirical analysis of the prevalence of HVAC faults in commercial buildings: <https://doi.org/10.1080/23744731.2023.2263324>