DIGITAL TWINS FOR INTELLIGENT BUILDINGS

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***Abstract*—In recent years building automation system is an essential part of technical infrastructure of contemporary buildings. Real-time data streams carry a enormous amount of information and based on the digital twin data platform, study in the paper focus with Proportion-Integration (PI) controller and feasibility of adding semantics to the real-time data produced by sensors, faults in Heating, Ventilation, and Air Conditioning (HVAC) systems. When extracting the knowledge from heterogeneous data streams obtained from sensors, it is necessary to integrate them with solid knowledge in the form of taxonomies and class hierarchies defined by diverse domain. Digital twin enabled Fault Detection and Diagnosis (FDD) process, which aims at identifying abnormalities in building heating ,ventilation and air Conditioning. Adopted digital twin data platform deliberate integration of knowledge tags defined in the Brick model and real-time data from Building Management Systems (BMS) or IoT sensors. Semantics that is readily available in Building Information Model (BIM) models are more flexible with novel connections established using data associations which continuously learn from real-time data.**

***Keywords*—HVAC, Fault Detection and Diagnosis , Building Information Model, IoT sensors, PI controller, Neural Networks**

I. INTRODUCTION

Recently with the wide adoption of building automation system, and the advancement of data, sensing, and machine learning techniques, data-driven Fault Detection and Diagnostics (FDD) for building heating, ventilation, and air conditioning systems has gained increasing attention. Because the fault detection method is embedded in a Building Energy Management system (BEMS), all operations are performed while applying the control and monitoring capabilities of the system. Real-time data, referred to as stream data and these pieces of information about events or results of measurements at a specific time instant, for instance, humidity measured by a sensor are very much crucial. Renewable energy technologies for buildings use existing sensor data points which are used for control and manual monitoring. Furthermore, innovations in "Internet of Things" (IoT) devices have further led to connected power meters, lights, sensors and appliances that are capable of data collection and communication. During the past two decade, several HVAC system models have been proposed and discussed [1,2,3,4].

Digital twins are becoming increasingly popular in the Fault Detection and Diagnosis process due to their benefits, such as improved maintenance, production planning, reduced losses, energy savings, and increased visibility[4,5].Digital twin enabled Fault Detection and Diagnosis process, which aims at identifying abnormalities in building Heating, Ventilation and Air Conditioning is shown in figure (1).

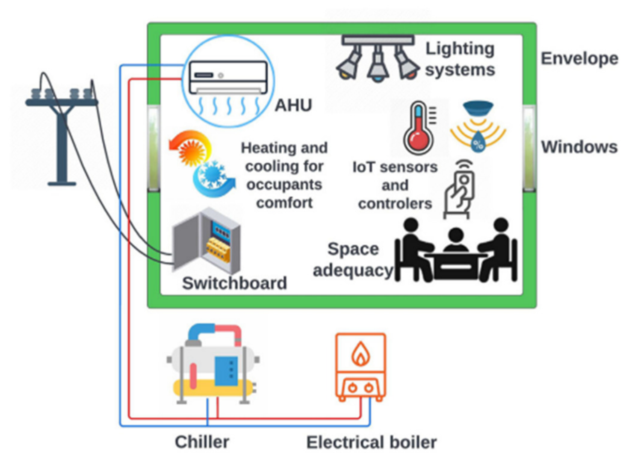

Fig.1 Components and Systems of the Digital Twin Framework for Buildings through FDD [5].

Faults in Heating, Ventilation, and Air Conditioning (HVAC) systems of buildings result in significant energy waste in building operation . Fault identification is determination of the size and time-variant behaviour of a fault. Fault diagnosis, which follows fault isolation and identification, is determination of the kind, size, location, and time of a fault. Intelligent methods such as Genetic Algorithm (GA), Neural Network (NN) and Fuzzy Logic had been applied for HVAC systems.

FDD methods are classified as two major methods as knowledge-based and data-driven approaches. Normally, the knowledge-based approaches are further divided as physics-based modeling, Diagnostic Bayesian Network, and performance indicator-based methods. Data-driven approaches include supervised learning, unsupervised learning, and regression and statistics-based methods. In building sector, SVM has been used for forecasting of cooling and heading loads, electricity consumption[6] and energy consumption forecasts in residential buildings are studied in [7] . In building sector SVM was applied for estimation monthly electricity usage for non-domestic building in tropical country of Singapore in 2005 and it considers three input parameters including temperature, humidity and solar radiation and targets four different buildings[6] . Many SVM methods have been developed and with the advancement of data science [8,9,10].

This paper reports study of adopted digital twin data platform which is defined for real-time data which is obtained from Building Management Systems (BMS) or IoT sensors. This article is structured as follows. Section 2 introduces theory of Fault Detection and Diagnosis Monitoring System and HVAC system . HVAC model with PI controller is discussed in section 3. Semantic web technologies play a key role in integrating and managing data and information for the development of building digital twin are presented in Section 4 with Simscape simulation results for the basic models. Conclusions of this study are given in Section 5.

II. HAVC SYSTEM

Many FDD methods have been developed and with the advancement of data science and the wide adoption of Building Automation Systems (BAS) or other smart building technologies, data-driven FDD is gaining increased attention.

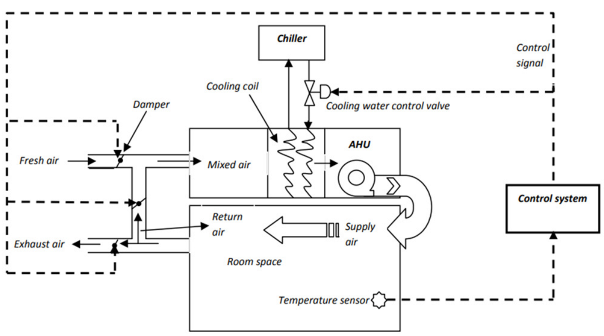

Fig 2 Block diagram of HVAC model with PI controller[11]

Simple schematic of a HVAC system is shown in Figure 2 . In HVAC system fresh air passes from a heat exchanger cooling coil section to change heat between fresh air and cooling water. Cooled fresh air is forced by a supply fan to the room within the constrained time, the return damper opens to allow room air come back to Air Handling Unit (AHU). Then the mixed air passes from cooling coil section to decrease its temperature and humidity. A trade off among exhaust, fresh and return air is decided by control unit. Normally the temperature of the room is regulated by adjusting the flow rate of cooling water by a certain control valve. The automated detection and diagnosis of multiple faults in HVAC systems may have one fault and its impact can inculcate one or more other faults. The combination of several faults makes difficult in the identification of individual faults . Three examples are listed herein: (i) One fault has a positive or negative impact on another fault. (ii) Two faults occur, but their combined effect is not observed on the third sensor, which indicate normal operation, and (iii) Two faults occur, but only the effect of one fault on the third sensor is observed. The FDD methods are studied into three groups as process history-based models ,quantitative model-based, qualitative model-based methods. Historical measured sensor data of the system operation are analyzed and evaluated Process history-based models.These are also called the data-driven models, which can be classified into supervised and unsupervised learning-based models. The process history-based models which are based on the monitored historical data of the system, are more popular due to less complexity in developments. Quantitative models are Physics-based models and also named white box models or first principal models. These models can predict the thermal environment in a space due to the building envelope, weather conditions (e.g., radiation, outdoor temperature, wind velocity), and HVAC operating conditions [11,13]. They can predict the space thermal environment, HVAC operating conditions, and energy use [12]. Single and hybrid physics-based models for FDD of HVAC system components planned to capture steady and transient operation with acceptable accuracy and flexibility. Because of the complexity of this class of models, it has got the least popularity towards FDD applications. Qualitative Models use a series of rules derived from experts' knowledge, and from energy and mass balance equations, hence also known as Rule-Based Models[14]. The rule-based models are used alone or combined with physics-based models or process history-based models, such as decision trees , Bayesian networks and principal component analysis (PCA), to develop the hybrid models for FDD applications. Rules-based models can be developed without proper understanding and information about physical processes in HVAC systems. Since the rules are extracted from a specific system, the addition of new rules or generalization to other systems is challenging[15,16,17].

III. HVAC SYSTEM WITH A SIMPLE PI CONTROLLER

Accurate modelling of the HVAC system is vital for the physical model-based FDD and for the control of HVAC system, the most popular method is Proportion-Integration (PI) control . Selection of PI controller, and tuning of the controller is very crucial in real time implementation with extensive research methods. The cascaded control system shown in Figure 3 comprises two tunable controllers, the PI controller for the inner loop, C2 , and the PID controller for the outer loop, C1. The ideal FDD scheme is depicted in Figure 4.

The existence of faults is first detected, followed by the diagnosis of the type of fault and location, after which the severities of the diagnosed faults are determined.

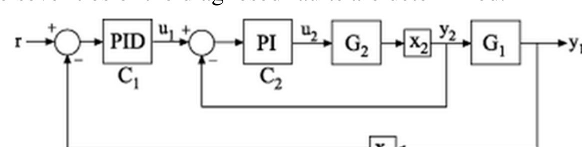

Fig 3 Cascaded control system with the PI controller

The severity of the fault determines the fault that is to be eliminated first; hence, identification is included in this scheme.

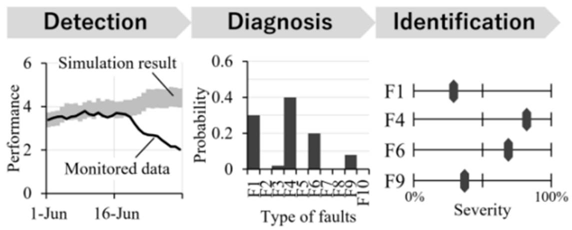

Fig 4: FDD scheme

Figure 5 shows the block diagram of the HVAC system with a simple PI controller. The model is consisting of eight variables in which six variables define as states variables. Air supply pressure Ps , room air pressure Pa and four temperature variables as wall temperature Tw , cooling coil temperature Tcc , air supply temperature Ts , and room air temperature Ta. Cooling water flow rate is considered as control signal. Also all six mentioned states variables with cooling water outlet temperature is considered as system outputs. But just one of them (room temperature Ta) acts as feedback signal. T_water_out is not used as a state variable in this modelling and it is just used as auxiliary parameter for finding faults.

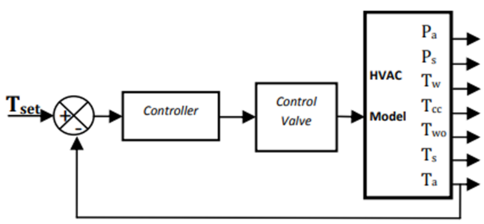

Fig 5. HVAC system with a simple PI controller

IV. SEMANTIC MODEL AND HEAT TRANSMISSION THROUGH BUILDINGS

The design of digital twin-based systems involves consideration of a physical entity, a virtual entity, and main concept is the connection between these two entity. Hence Semantic web technologies play a key role in expressing, integrating and managing data and information for the development of building digital twin. The usage of semantics conventionally focused on overcoming the interoperability issues amongst software tools and improving information exchange processes and connecting data across different domains. The Digital Control pattern follows the behavior of a smart feedback control system. Mainly its analysis and implementation requires the development of sensors, definition of control parameters, implementation of the comparison algorithms and the decision module, and finally the actuator mechanism. The control parameters are characteristically defined by the client. The decision making for the suitable action can be guided by the Semantic web technologies.

System with a thermal control considered for basic study of air heat exchanger and uses Simscape blocks shown in Figure 6a and 6b. Air heat exchanger absorbs heat from the system. In this case air heat exchanger system is analysed for water temperature in cold water system and fluid properties of as a function of pressure and temperature.

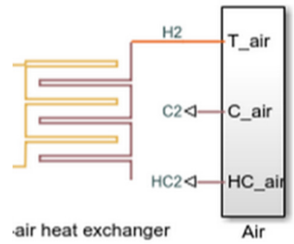

Fig 6 a

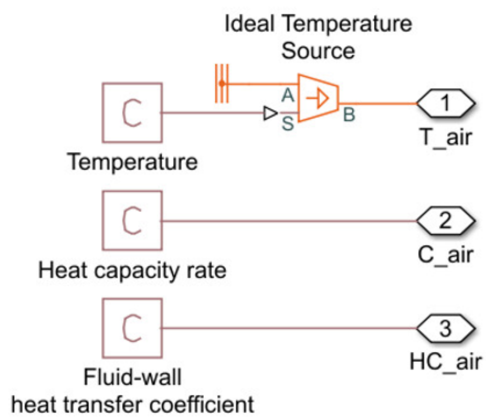

Fig 6 b Simple Hydraulic system with thermal control variables

The study model exchanges heat with the environment through its walls, windows, and roof. As per house thermal network subsystem shown in Figure 7 depicts about each path and its simulation as a combination of a thermal convection, thermal conduction, and the thermal mass.The analytic study by computer simulations as shown in the graphs reflects the thermal behaviours of the study model and other modifications of the envelopes can be preferred in terms of the employment of different materials and also it may indicates the resulting energy consumption

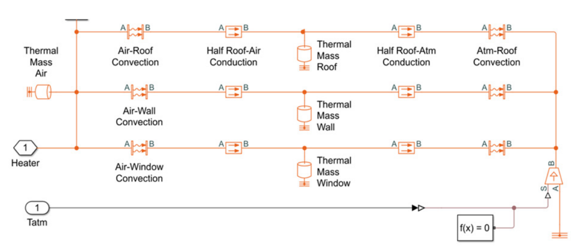

Fig 7 Study model for air heat exchanger.

In many simulation tools building model consists of a single or several thermal zones, a single or several air handling units and a single primary system. When a new model is initiated at the standard level in the simulation , default air handling units and primary systems are normally automatically inserted . For many studies nothing needs to be altered in the HVAC systems. The default systems normally have unlimited capacity for providing the zones with air and water at given temperatures. For example by default, the supply air temperature is kept constant at 17°C, the chilled water temperature to zones is 15°C and the heated water temperature is a function of the outdoor air temperature.

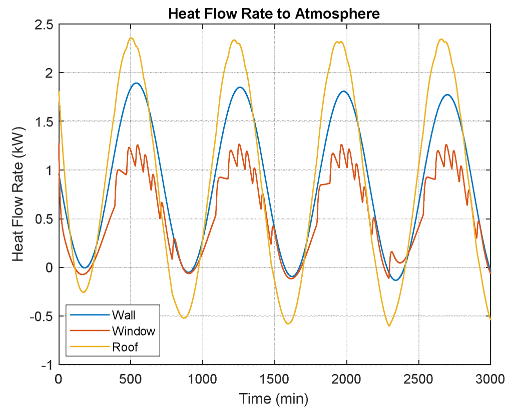

Fig 8 Heat flow rate to atmosphere.

The results are validated through plotting heat flow rate to atmosphere with simple model of heating system as shown in Figure 8

V. CONCLUSION

This paper is a research and an attempt to improve the set-backs in the earlier HAVC system. This study investigated the potential of the digital twin data platform which is adopted to integrate the defined knowledge tags with real-time data. The key motivations for adopting digital twins are to be able to design, test, manufacture, and use the virtual version of the systems. The results are validated through plotting heat flow rate to atmosphere with simple model of heating system. The application of digital twins is in essence a control system activity to enhance the intelligence of the system and in further research , low-latency ,high bandwidth real-time data streams , automatic extraction and its feed to the FDD will be enhanced with qualitative Models .

VI. REFERENCES

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