Problem statement and Data collection

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Abstract

This report describes the procedure by which the data from SE2 HVAC system is obtained, stored and preprocessed. A database is designed to store all the information regarding the status of the HVAC system in SE2, this report also discuses its design and implementation.

1. Introduction

This documents presents and describes the procedure by which the data from the SE 2 HVAC system is gathered and stored. A brief description of HVAC systems is given and a database model that will be used for storing the raw data coming from the sensors in the HVAC network is presented and discussed in detail. The report is organized as follows: In Section 2 a brief discussion on how HVAC systems operate and how they are comprised is presented along with a brief review of some of the current fault detection methods used in HVAC. Section 3 describes the BACnet protocol on how it is used to access the raw data from the sensors. Finally Section 4 describes in detail how the database was designed and what are its advantages over other approaches for storing the data.

2. Background

Heating, ventilation and air conditioning (HVAC) is a technology of indoor environmental comfort. It is usually implemented in large office, commercial and industrial buildings such as schools, airports, malls, factories, hospitals, etc. Its ultimate goal is to maintain thermal comfort and create healthy indoor air quality while keeping an affordable maintenance cost, being energy efficient and environmentally friendly.

Currently, HVAC is comprised of numerous components, advanced sensing technologies, advanced control algorithms and even artificial intelligence techniques, which have been introduced to help the system meet its operational objectives across different types of buildings worldwide. Hence HVAC systems are regarded as highly interdisciplinary and complex mechanical systems.

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According to the U.S. Energy Information Administration, residential and commercial sectors account for 40% of the total share of energy consumed in the United States in 2016 [1]. Heating, ventilation and air conditioning make up almost 50% of the total energy consumption [2, 3].

As with any other mechanical system, HVAC systems are prone to faults and as its scale and complexity increases the detection, identification and pinpointing of such faults within the HVAC network becomes a very challenging and hard to achieve task. Here, faults include not only complete equipment failures, but also non-optimal operating conditions, e.g., occupant discomfort, energy inefficiency, poor choice of operating targets, sensor calibration error, poor controller tuning, etc. Some common faults that an HVAC system may be prone to are: a stuck damper, stuck water valve, coolant leakage, airflow leakage (due to breaches in the ducts), fan malfunction, etc. Such failures may degrade the overall performance of the HVAC system and thus lead to energy waste. Therefore, it is of great potential to develop automatic, quick responding, intelligent, and reliable monitoring and diagnosis tools to ensure the normal operation of the system, increasing, as a direct consequence, its energy consumption efficiency.

According to the National Institute of Standards and Technology (NIST), Fault Detection and Diagnosis (FDD) methods have a potential to save 10%-40% of HVAC energy consumption [4]. FDD tools for HVAC is therefore critical to increase the energy efficiency for buildings. Since the 1980s, researchers have been striving to improve the energy efficiency of the system due to rising energy costs and increased awareness of the environment.

2.1. Fault Detection in HVAC systems

As mentioned in the previous section, FDD tools can help improve the overall energy consumption of and HVAC system by timely detecting, isolating (classifying) and pinpointing the location of the faults so that they can be fixed as soon as they are detected. Several methods have been proposed for achieving this goal.

Fault Detection and Isolation (FDI) is a subfield of control engineering concerned with monitoring a system, identifying when a fault has occurred, and pinpointing the type of fault and its location. Usually the methods and techniques for doing FDI can be divided in two groups:

- A model based approach that measures the discrepancies between the actual sensor readings and the expected values derived from the model.
- A pattern recognition approach that looks for patterns in the data that may indicate a fault.

In the first group some model of the system is used to decide about the occurrence of a fault. The model may be mathematical or knowledge based, here energy and thermal models have been used to successfully identify certain faults and tune the controllers as in [5, 6, 7]. In the second group some mathematical or statistical operations are performed to the measurements, this approach also considers machine learning algorithms that will look for patterns in the data which may be indicative of a fault. Such approaches have been specially considered in the domain of machine learning as in [8, 9, 10, 11].

In this work the pattern recognition approach is considered over the model based one, this will allow the system to detect, classify and locate faults within the system without specific knowledge of the network except for its topology.

2.2. A generic HVAC system

A generic HVAC is comprised of several components, among the most noticeable ones we can find are: the Air Handling Unit, the Variable Air Volume, the Staged Air Volume and the Thermafuser. The Air Handling Unit (AHU) is the main component of the HVAC network. The function of the AHU is to regulate, condition and distribute the conditioned air to the other components of the system though a ductwork ventilation system which is also used for returning air to the AHU. AHU is usually a large metal box containing inside fans, heating and/or cooling elements, filter racks or chambers, sound atenuators and dampers. Figure 1 shows an inside view of how the majority of AHUs are built, while Figure 1 shows and outside view of an AHU.

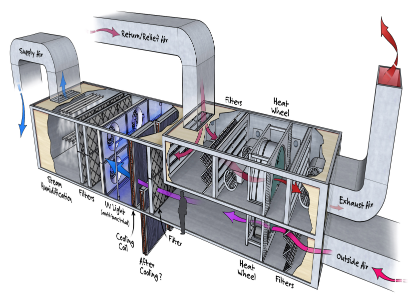

Figure 1: Inside view of AHU

Figure 2: Outside view of AHU

In the second level of the HVAC topology we have the Variable Air Volume (VAV) and the Staged Air Volume (SAV). The main goal of these two components is two vary the airflow and the temperature of the supply air to be further distributed, they achieve this goal by controlling the damper position at the entrance of the VAV/SAV and modifying the temperature by means of cooling and heating coils. Figure ... shows the inside composition of a generic VAV while Figure ... shows the inside composition for a generic SAV.

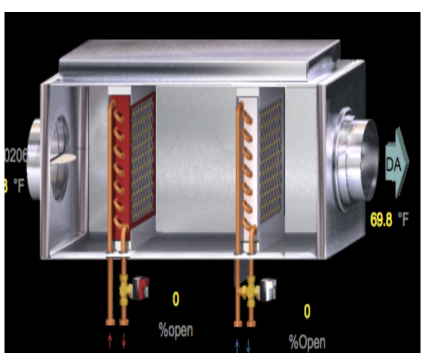

Figure 3: Inside view of a VAV

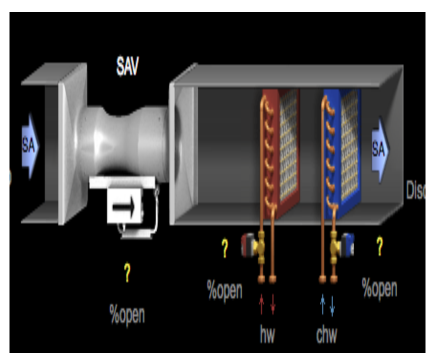

Figure 4: Outside view of a SAV

Finally, the last component in the chain are the Thermafusers, these components are where the air comes out into the room and their purpose is to regulate the airflow that comes into the room, it achieves this goal by using a set of dampers along its edges. Figure 5 shows a generic thermafuser mounted on the ceiling of a room.

Figure 5: View of a thermafuser

Although a description of the top-down air supply chain is given here, it is important to emphasize that some of the air used in the rooms goes back into the system for its reuse by means of return air grilles on the roof of the rooms, which travels all its way back to the AHU where some of it is reused.

Finally, it is worth to mention that the HVAC system of SE 2 is comprised by 4 AHU, about 150 VAVs/SAVs and about 150 thermafusers.

3. Data Acquisition

A description of how the data is acquired from the SE2 HVAC is given in this section. As mentioned earlier, each major component of an HVAC system is made up of smaller components such as cooling and heating coils, air filters, fans, dampers, etc. Among each of these components there also a number of sensors installed throughout the HVAC network that provide real time information of the systems measurements such as airflow velocity, airflow pressure, airflow temperature, water valve opening percentage, damper opening percentage, among many others. There are in total about 3100 different sensors installed throughout SE2 HVAC network. The information provided by such sensors will be used to perform the pattern recognition on the different readings of the system in order to perform the fault detection and isolation.

3.1. BACnet

BACnet is a communications protocol for Building Automation and Control (BAC) networks that leverage the ASHRAE, ANSI, and ISO 16484-5 standard [12]. Bacnet was designed to allow communication of building automation and control systems for applications such as HVAC control, lighting control, access control, and fire detection systems and their associated equipment. The BACnet protocol provides mechanisms for computerized building automation devices to exchange information, regardless of the particular building service they perform.

The BACnet protocol defines a number of services that are used to communicate between building devices. The protocol service includes Who-Is, I-Am, Who-Has, I-Have, which are used for device and object discovery. Services such as Read-Property and Write-Property are used for data sharing. As of ANSI/ASHRAE 135-2016, the BACnet protocol defines 60 object types that are acted upon by the services.

The BACnet protocol defines a number of data link/physical layers, including ARCNET, Ethernet, BACnet/IP, BACnet/IPv6, Point-To-Point over RS-232, Master-Slave/Token-Passing over RS-485, ZigBee, and LonTalk.

3.2. Data Collection

By making use of the BACnet protocol and the services such as Who-Is, I-am and Read-Propertyl the data from each of the sensors in the HVAC network can be pulled. As mentioned in earlier sections, the HVAC system in SE2 has about 3100 different sensors. The recorded data, considered as the raw data in this study, is made up of samples taken from each of the sensors in the network every 5 minutes. For the data retrieval a python script that makes use of the BACnet protocol was written and is running as a service in order to constantly pull data from the system. This data is stored locally in a database that is to be described in the next section.

4. Database Design

To store the raw data, a method that provides reliability, scalability, ease of maintenance and good performance is required. The easiest solution would be to store all of the raw data in plain text files or as comma separated values (CSV) files, nevertheless this approach is neither scalable nor good for performance, furthermore, there is no straightforward way to ensure the data consistency. Instead, a database design is proposed here, this design overcomes most of the drawbacks exhibited by a plain text file approach.

Before getting into the details of the database design it is important to remark the concept of a *primary key* in the context of databases. Within an entity (table) in a database a specific instance of such entity can be uniquely identified by means of the so called primary key. It is also important to mention that for the design of the database we have considered two kinds of mechanical components in the HVAC network. The so called basic components are the smaller "logical" building blocks for the HVAC system; fans, dampers, cooling and heating coils (generalized here as heat exchanger coils), filters and VFDs belong to this category. The major components are the more complex and larger pieces of equipment of the HVAC system, they are made up of a number of the basic components that work together to achieve a specific goal (like controlling the amount of airflow that is distributed to a certain area in the case of VAVs).

Some further considerations need to be taken for the development of the database that will store the sensor readings, the most relevant ones are listed next

- The data must allow the storage of the readings as time-series.
- The database must reflect the general layout of the HVAC system.

- The database should help pinpoint the location of the faults.
- The database should allow the aggregation of other sensor readings easily.
- Each one of the component in the HVAC network must be easily identifiable.

To comply we the above requirements the following database was designed

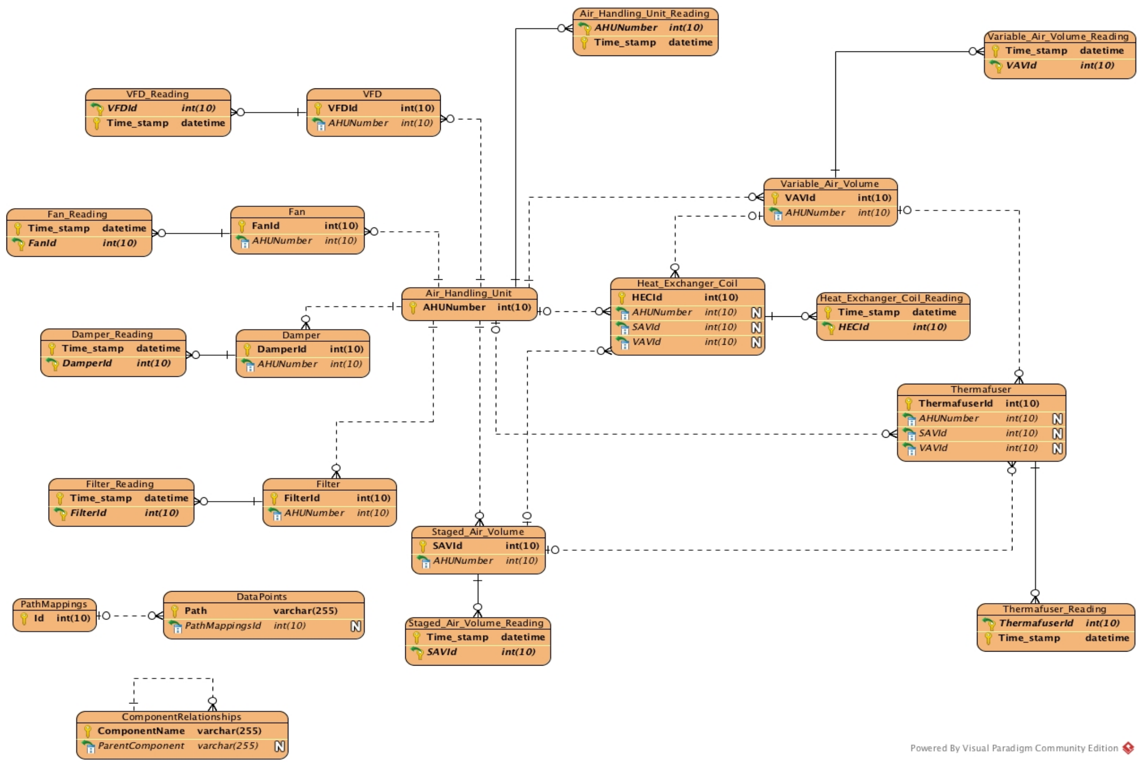

Figure 6: Proposed Database Design

To save space only the tables, its primary and foreign keys and the relationships between tables are shown in Figure 6. The specific attributes for each table can be found in the Appendix A. Next, a discussion of the structure of the database is presented.

As can be observed in the diagram presented in Figure 6, the central element is the AHU table. An AHU can supply conditioned air to many VAVs/SAVs while a VAV/SAV can only be supplied air by a single AHU (with one exception in the case of the SE 2 HVAC which will be addressed further), this relationship is modeled in the database as a one-to-many relationship between the AHU table and the VAVs/SAVs tables.

Moving downwards in the hierarchy of the HVAC network we find VAVs/SAVs, this components are represented by its own tabled in the database. Each VAV/SAV can supply air to a number of thermafusers in the last level of the HVAC hierarchy, nevertheless a thermafuser can only be supplied air by a single VAV/SAV, once again, this represents a one-to-many relationship between the VAVs/SAVs tables and the thermafuser table.

As stated earlier, each one of the major components in the HVAC system (AHUs, VAVs, SAVs) may be made up of some more basic components. In general, any of the major components can contain a number of fans, dampers, cooling and heating coils (generalized here as heat exchanger coils), filters and VFDs, each of these components is represented in the database by its own table. Notice here, that while a particular major component can contain many of these components a particular instance of such components can only belong to one and only one AHU, this is again reflected as a one-to-many relationship between the major and the minor components in the database.

Finally, each one of the components of the system (major and minor) have a number of sensors that provide readings and measurements of certain variables pertinent to each device. For each device, its own readings are represented as a table (with the prefix "Reading" on the name of the table) where a device may have many reading but a particular set of readings can belong to only one component, once again, this is represented as a one-to-many relationship between the component and its readings in the database. For a full description of the variables pertinent to each component please refer to Appendix A.

This database design not only allows for a more reliable and efficient storage of the raw data, but also will help make the fault localization more accurate, since once a fault is detected by analyzing the data, its location can be accurately given by means of the primary keys of each table and the relationships among tables.

Acronyms

AHU Air Handling Unit. 3, 4, 6, 7, 11

BAC Building Automation and Control. 4

FDD Fault Detection and Diagnosis. 2

FDI Fault Detection and Isolation. 2

HVAC Heating, ventilation and air conditioning. 1–7

NIST National Institute of Standards and Technology. 2

SAV Staged Air Volume. 3, 4, 6, 7, 12

VAV Variable Air Volume. 3–7, 12

References

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Appendices

A. Sensor readings for each of the components in the HVAC system

A.1. HEC Readings

This table describes the variables used for HEC readings

Sensor Name	Type
Supply Water Temperature	real
Return Water Temperature	real
Valve Opening Percentage	real

Table 1: HEC Readings

A.2. Thermafuser Readings

This table describes the variables used for Thermafuser readings

Sensor Name	Type
Room Occupied	bit
Zone Temperature	real
Supply Air	real
Airflow Feedback	real
CO2 Input	real
Max Airflow	real
Min Airflow	real
Unoccupied Heating Setpoint	real
Unoccupied Cooling Setpoint	real
Occupied Cooling Setpoint	real
Occupied Heating Setpoint	real
Terminal Load	-

Table 2: Thermafuser Readings

A.3. AHU Readings

This table describes the variables used for AHU readings

Sensor Name	**Type**
Zone Temperature	real
Static Pressure	real
Return Air Temperature	real
Supply Air Temperature	real
Exhaust Air Temperature	real
Outside Air Temperature	real
Smoke Detector	bit
Outside CO2	real
Return Air CO2	real
Spare	real
Hi Static	bit
Duct Static Pressure	real
Mixed Air Temperature	real
Outside Air CFM	real
CoolingRequest	real
Cooling Setpoint	real
Heating Request	real
Heating Setpoint	real
Economizer Setpoint	real
Occupied Mode	bit
Return Air CO2 Setpoint	real
Static Pressure Smoothed	real
Static SP	real
Supply Air Setpoint	real
STReq	-
StaticSP1	-
StaticSP2	-

Table 3: AHU Readings

A.4. SAV Readings

This table describes the variables used for SAV readings

Sensor Name	Type
Misc Spare Input	real
Zone Temperature	real
Discharge Temperature	real
Misc Input	bit
Condensate Detector	bit
Valve Output Percentage	real
GEX Damper Position	real
CoolingRequest	real
Cooling Setpoint	real
Heating Request	real
Heating Setpoint	real
Damper Position	real
Exhaust Airflow	real
Supply Airflow	real
Flow Difference	real
Exhaust Airflow Setpoint	real
Cooling Percentage	real
Heating Percentage	real
CER Temprature	real
Ht Request	real
Cl Request	real

Table 4: SAV Readings

A.5. VAV Readings

This table describes the variables used for VAV readings

Sensor Name	Type
Flow Input	real
Misc Spare Input	real
Zone Temperature	real
Discharge Temperature	real
Condensate Detector	bit
Duct Static Pressure	real
Zone CO2	real
Damper Position	real
Cooling Setpoint	real
Heating Setpoint	real

Table 5: VAV Readings

A.6. Fan Readings

This table describes the variables used for Fan readings

Sensor Name	Type
Fan Type	bit
Air Velocity Pressure	real
VFD Speed	real
Fan Status	bit
VFD Fault	bit
Hi Static Reset	bit
FA Return fan Shutdown	bit
Fan VFD	bit
Isolation Dampers	bit
Fan SS	bit
Air Velocity CFM	-

Table 6: Fan Readings

A.7. Filter Readings

This table describes the variables used for Filter readings

Sensor Name	Type
Difference Pressure	real

Table 7: Filter Readings

A.8. Damper Readings

This table describes the variables used for Damper readings

Sensor Name	Type
Input Voltage	real
Opening Percentage	real
Isolation Damper	bit

Table 8: Damper Readings