IFC-based Information Extraction and Analysis of HVAC Objects to Support Building Energy Modeling

H. Li[a] and J. Zhang[a]

[a]Automation and Intelligent Construction (AutoIC) Lab, School of Construction Management Technology, Purdue University, West Lafayette, IN 47907, USA
E-mail: li4016@purdue.edu, zhan3062@purdue.edu

Abstract –
The heating, ventilation, and air conditioning (HVAC) system is a highly complex part of a building that requires high specialty and expertise to understand and analyze for energy modelling and simulation purposes. Significant manual effort is needed for information extraction from the mechanical designs, to support the creation of an energy model, including information such as HVAC system type, cooling/heating load, pressure drop, and thermal zones, etc. However, such information can be readily available in Building Information Modeling (BIM)-based mechanical, electrical, and plumbing (MEP) models. In this paper, data analysis and information extraction were conducted on HVAC systems of industry foundation classes (IFC)-based MEP models. By following the state-of-the-art Data-driven Reverse Engineering Algorithm Development (D-READ) method, an algorithm was developed to automatically parse and extract HVAC information from the IFC models. The algorithm was tested on a commercial building with 1 hot water boiler and 19 radiators, which achieved error-free information parsing and extraction. This is expected to reduce the manual effort in information extraction of HVAC systems for building energy modeling (BEM). It also is built upon and supports the open and neutral IFC-based information workflow, which could be a solid step towards automation and interoperability between BIM and BEM in the HVAC domain.

Keywords –
Building Information Modeling (BIM); Building Energy Modelling (BEM); Heating, Ventilation, and Air Conditioninng (HVAC); Industry Foundation Classes (IFC); Automation; Information Extraction; Interoperability

1 Introduction

In both commercial and residential building sectors, the heating, ventilation, and air conditioning (HVAC) component has been a top contributor to energy consumption, among all building components. According to a report from the U.S. Environmental Protection Agency, the HVAC systems in commercial and residential buildings contribute up to 15.6% of the electricity use in the US. [1]. Considering such a significant energy consumption from the HVAC systems and the increasing emphasis on energy conservation in the society [2], there is an urgent need of an efficient method for evaluating the energy consumption of HVAC systems, which is expected to help better inform owners and professionals of the energy performance and potential energy savings throughout their building's lifecycle. However, the traditional energy evaluation method is a time-consuming process. Mechanical engineers/designers and energy modelers still heavily rely on 2D mechanical drawings for HVAC information interpretation and analysis as the standard industry practice. It requires a large number of labor hours to manually retrieve HVAC information from 2D mechanical drawings. With such consideration, researchers nowadays are seeking digital alternatives to the manual approach used in the state of the practice, to automatically extract and analyze HVAC information from Building Information Modeling (BIM) [3].

BIM can provide an object-orientated data repository for managing information of building projects including architectural, structural, and mechanical, electrical, and plumbing (MEP) systems, among others. As an important part of the MEP system, the HVAC system can also be modeled in BIM including information such as system type, cooling/heating load, pressure drop, and associated thermal zones. The information-rich nature of BIM has been shown successful in supporting many tasks in the architectural, engineering, and construction (AEC) industry such as quantity takeoff [4] and structural analysis [5]. The extensive adoption and associated benefits of BIM have also increased the demand to leverage BIM for energy analysis. The importance of BIM to energy analysis is further supported by the increasing levels of BIM adoption by architects and the need to improve the energy modeling processes to better fit into the architectural design workflow [6].

Industry Foundation Classes (IFC) is an international open standard that is independent of proprietary BIM authoring tools. The neutral and transparent feature of IFC can provide flexibility for data sharing and collaboration across platforms and stakeholders. In this paper, the authors developed a new systematic methodology for extracting essential information of HVAC systems from IFC-based BIM by following the state-of-the-art Data-driven Reverse Engineering Algorithm Development (D-READ) method [4]. The developed information extraction algorithm following the proposed methodology was also tested on a commercial building model and achieved error-free performance.

2 Model Description

Two IFC models were collected for HVAC information analysis and extraction. The first model was a 2-story duplex apartment building [7]. Figure 1 and Figure 2 show the architectural model and MEP model of the duplex apartment building, respectively. There were 926 entity instances in total in the IFC-based MEP model of the duplex apartment building. Essentially, the building consisted of 3 levels: Level 1, Level 2, and Roof Level. Each level contained multiple types of IFC entities such as *IfcFlowControllers*, *IfcFlowSegments*, and *IfcSpaces*, etc. It was found there were 21 *IfcSpace* entity instances in total.

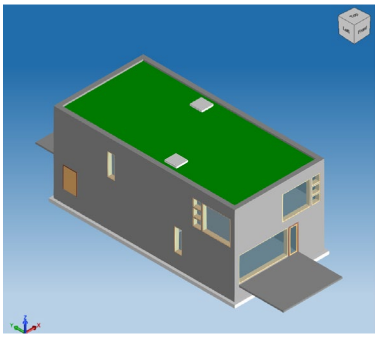

Figure 1. Architectural model for the duplex apartment building

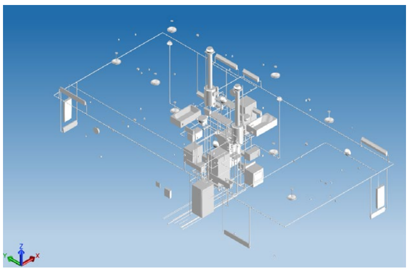

Figure 2. MEP model for the duplex apartment building

The second model was an office building with a different HVAC system type from the first model [7]. Figure 3 and Figure 4 show the architectural model and MEP model of the office building, respectively. There were 5697 entity instances in the IFC-based MEP model. The data structure of the office building model was the same as the duplex apartment building model.

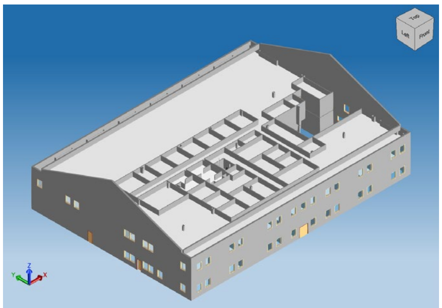

Figure 3. Architectural model for the office building

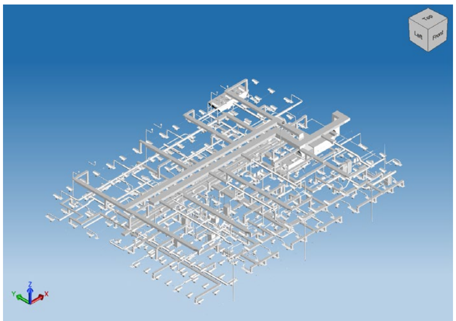

Figure 4. MEP model for the office building

3 Preliminary Analysis

By analyzing the MEP models of the two buildings in a data-driven manner, it was found that the main HVAC components such as boilers and chillers were defined as *IfcEnergyConversionDevice* in IFC. And all the pipes/ducts and elbows for constructing and connecting the HVAC loops were defined as *IfcFlowSegments* and *IfcFlowFitting*, respectively. The pumps or fans for circulating the flow through the loops were defined as *IfcFlowMovingDevice*. The diffusers for distributing the conditioned air to the targeted thermal zones were defined as *IfcFlowTerminal*. Table 1 summarizes all the corresponding IFC entities for HVAC components.

Table 1. Corresponding IFC entities for HVAC components

HVAC components	Corresponding IFC entity
Boiler	*IfcEnergyConversionDevice*
Radiator	*IfcEnergyConversionDevice*
Chiller	*IfcEnergyConversionDevice*
Pump/fan	*IfcFlowMovingDevice*
Variable air volume (VAV) unit	*IfcFlowMovingDevice*
Air handling unit (AHU)	*IfcFlowMovingDevice*
Pipe	*IfcFlowSegment*
Duct	*IfcFlowSegment*
Elbow	*IfcFlowFitting*
Diffuser	*IfcFlowTerminal*

There were 16 *IfcEnergyConversionDevice* entity instances (i.e., 14 radiators and 2 hot water boilers) in the duplex apartment model. Table 2 and Table 3 summarize the number of IFC entity instances corresponding to each HVAC component for the duplex apartment model and the office model, respectively.

Table 2. Number of HVAC related entity instances for the duplex apartment model

HVAC component	Number of entity instances
Boiler	2
Radiator	14
Pump	2
Pipe	417

Table 3. Number of HVAC related entity instances for the office model

HVAC component	Number of entity instances
Screw chiller	1
AHU	2
VAV unit	21
Pump	1
Duct	643
Diffuser	245

4 Proposed Methodology

Figure 5 illustrates the four-step methodology of the HVAC information extraction the authors proposed. Firstly, the HVAC system type is identified by analyzing the main HVAC components represented by *IfcEnergyConversionDevice* entity in the IFC-based MEP model. For example, a chiller with VAV units can help determine the system type to be a VAV system. Secondly, the HVAC plant loops are extracted (e.g., hot water loops, the chilled water loop, and the air loop) and corresponding components in each loop are identified. In the third step, detailed parameters for HVAC components are parsed such as the heating capacity of the boiler, volume flow rate of the pump, etc. In the final step, the related thermal zones served by each HVAC terminal are identified.

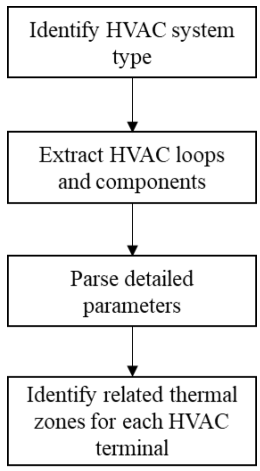

Figure 5. The proposed four-step methodology of HVAC information extraction

5 Application of the Proposed Methodology

5.1 Identify HVAC System Type

Based on the preliminary analysis results as shown in Table 2, the HVAC system type for the duplex apartment model was identified as a hot water boiler radiator system. A standard hot water boiler radiator system consists of supply equipment and demand equipment. The supply equipment in this case included a hot water boiler for generating hot water and a pump for circulating the water through the loop. On the demand side, several radiators were connected to targeted thermal zones. The hot water flew through the radiators and provided heating to the thermal zones.

For the office model, a VAV system consisting of a chilled water loop and an air loop was identified. The chilled water loop included a chiller and a pump for creating cooled water for the air handling units. And the air loop consisted of an air handling unit, an electric heating coil, and a fan for providing conditioned air through the loop. The VAV boxes on the demand side received the conditioned air and distributed it to the targeted thermal zones.

5.2 Extract HVAC Loops and Components

Through the Data-driven Reverse Engineering

Algorithm Development (D-READ) method [4], the authors developed an algorithm to extract the HVAC loops and corresponding components. For example, the system name and system type were two features for distinguishing the two hot water loops of the duplex apartment model. System names "Unit A Hydronic Supply In" and "Unit B Hydronic Supply In" were used to distinguish and extract all the *IfcFlowSegment*, *IfcFlowFitting,* *IfcFlowMovingDevice*, and *IfcEnergyConversionDevice* entity instances in Hot Water Loops A and B, respectively. The extraction results for Hot Water Loops A and B are shown in Figure 6 and Figure 7, respectively. Similarly, system types "supply air" and "return air" were used to extract all the related HVAC entity instances in the air loop of the VAV system from the office model (Figure 8 and Figure 9).

The loop extraction is important in HVAC system analysis because it defines the relationships of components and the functionality of each loop. For example, Figure 6 and Figure 7 show the two hot water plant loops extracted from the IFC-based MEP model of the duplex apartment building, respectively. It can be seen that each loop consisted of a boiler, with multiple radiators serving corresponding thermal zones. By extracting and separating the two hot water loops, information such as the service relationship between boiler A and radiator 1, and the number of radiators served by boiler A in the hot water loop A, were obtained (as shown in Figure 6). In addition, The pressure drop along the pipe in each loop configuration can also be calculated based on the pipe length.

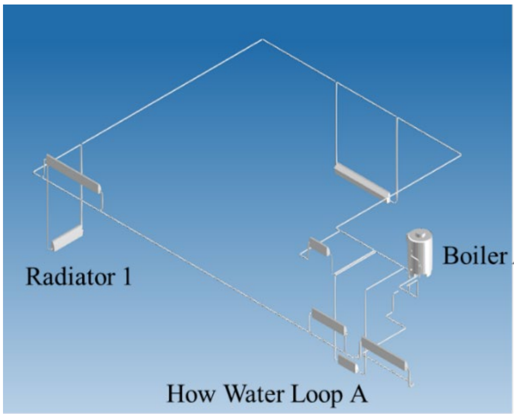

Figure 6. Extracted hot water plant loop A from the duplex apartment MEP model.

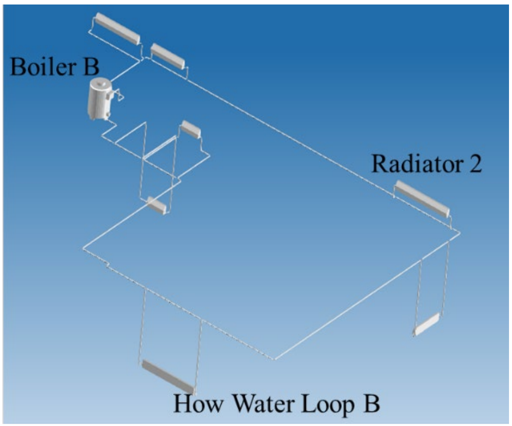

Figure 7. Extracted hot water plant loop B from the duplex apartment MEP model.

Figure 8 and Figure 9 show the extracted chilled water loop and air loop for the office building, respectively. The chilled water loop consisted of a screw chiller, a chilled water pump, air handling units, and cooling coils. A chilled water pump pushes chilled water through the chiller and the chilled water line around the building. The AHU or cooling coil serves as the heat transformation media that connects the chilled water loop to the air loop. The air is cooled by the chilled water in the AHU and delivered to the thermal zones through the HVAC terminals (i.e., diffusers). The air loop consisted of VAV boxes, air handling units, ductwork, fans, and diffusers.

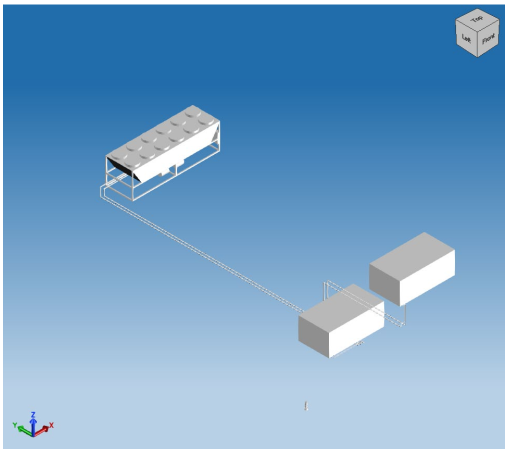

Figure 8. Extracted chilled water loop from the office building MEP model.

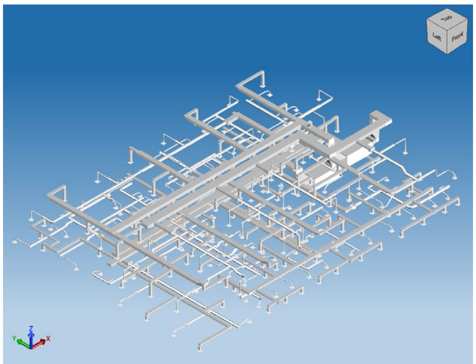

Figure 9. Extracted air loop from the office building MEP model.

5.3 Parse Detailed Parameters

The next step was to retrieve detailed parameters for each HVAC component. Some of the basic parameters such as the system type (e.g., natural gas boiler or electric boiler) were contained in the attributes of the corresponding IFC object. The mechanical properties were extracted through the *IfcPropertySet* entity instance related to each HVAC component. For example, the most essential mechanical parameters of the boiler include heating capacity, efficiency, etc. By retrieving the output heat and input heat as 2949311 Watts and 3465979 Watts, respectively, the thermal efficiency of the boiler was calculated by Equation (1).

$$boiler\ efficiency = \frac{output\ heat}{input\ heat} = \frac{2949311W}{3465979W} = 85\% \quad (1)$$

Table 4 shows the summary of detailed parameters of the HVAC components of the boiler radiator system in the duplex apartment model.

5.4 Identify Related Thermal Zone for HVAC Terminals

One of the most important parameters for an HVAC terminal (e.g., a radiator or diffuser) is the thermal zone that it serves. In the IFC data, this relationship was defined by the *IfcRelContainedInSpatialStructure* entity (as shown in Figure 10), which consisted of *RelatedElements* and *RelatingStructure*. The *RelatedElements* attribute specified the HVAC terminal such as radiators and diffusers. The *RelatingStructure* attribute specified the spaces or thermal zones that the related equipment served. By iteratively parsing through the *IfcRelContainedInSpatialStructure* entity instance, the related thermal zones for each HVAC terminal were extracted.

6 Case Study

The information extraction algorithm developed by following the proposed methodology was then tested on the testing model - a commercial building with 4 stories as shown in Figure 11. The IFC-based MEP model was parsed through our developed algorithm. The HVAC system was identified as the boiler-radiator system. The hot water loop was extracted correctly, and the related HVAC components including 1 boiler and 19 radiators were successfully parsed including their detailed parameters. And the 19 thermal zones served by corresponding radiators were identified. Table 5 summarized the testing results of the information extraction algorithm, 396 entity instances were successfully extracted without error.

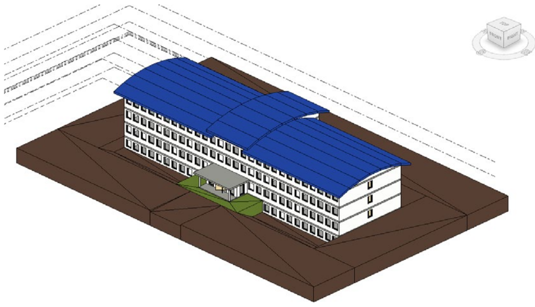

Figure 10. Testing model visualized in Revit

7 Conclusion

In this paper, the authors proposed a four-step methodology for parsing and extracting HVAC information from the IFC-based building information models. Two types of HVAC systems from two BIM models were analyzed following the proposed methodology, namely the VAV system and the boiler-radiator system, respectively. Information including HVAC system type, HVAC loops, detailed component parameters, and related thermal zones for HVAC terminals were identified and parsed systematically. The HVAC information extraction algorithm following the proposed methodology was tested on a commercial building model with the boiler-radiator system and achieved error-free extraction. This is expected to help reduce the time and effort in information extraction of HVAC systems from BIM compared to that by manual extraction from 2D mechanical drawings.

7.1 Contributions to the Body of Knowledge

This research contributes to the body of knowledge in three main ways: First, the authors proposed a new methodology for extracting essential HVAC information from IFC-based BIMs. The proposed methodology was used to develop an automated HVAC information extraction algorithm based on existing IFC-based BIM.

Table 4. Summary of parameters of the boiler radiator system in the duplex apartment model

HVAC components	Number of entity instances	System type	Capacity	Pressure drop	Efficiency
Boiler	2	Natural gas	147kW	99974.4 Pa	85%
Radiator	14	Baseboard	2744.47 Btu/Feet	0.28 meters H_2O	N/A
Pump	2	Centrifugal	3.9 Liters/Second	0.8 meters H_2O	Motor: 90%


```
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 'RelatingStructure': #2839=IfcSpace('0CRPz_SEr94Ah74P8LhwKx',#1,'A203','',$,#3633,#134081,'Bedroom 2',.ELEMENT.,.INTERNAL.,$)}
```


Figure 11. An example of *IfcRelContainedInSpatialStructure* entity instance

Table 5. Testing results of the developed information extraction algorithm

HVAC components	Corresponding IFC entity	Number of entity instances in IFC-based MEP model	Number of objects correctly parsed by developed algorithm	Accuracy
Water Loop	-	1	1	100%
Boiler	*IfcEnergyConversion Device*	1	1	100%
Radiator	*IfcEnergyConversion Device*	19	19	100%
Pump	*IfcFlowMovingDevice*	1	1	100%
Pipe	*IfcFlowSegment*	355	355	100%
Thermal zones	*IfcSpace*	19	19	100%
Overall	-	396	396	100%

data. In contrast to manually extracting HVAC information from 2D mechanical drawings, the developed algorithm is expected to extract HVAC information more efficiently and objectively. Second, this work facilitates the transition from 2D drawings to 3D digital representations by supporting the automated information extraction from IFC-based BIMs. It also builds a solid step towards automation and interoperability between BIM and BEM in HVAC information exchange. Third, some HVAC components were found missing from the IFC-based BIMs. For example, in the office building model, no cooling coil was found in the chilled water loop. The cooling coil can be defined as IfcCoil according to BuildingSMART [8]. Regarding the missing elements, the extraction algorithm can be converted/adapted to one for model design verification, i.e., checking if there are any missing HVAC components in the IFC model.

7.2 Limitations, and Future Work

Two main limitations of this study are acknowledged. First, the lack of comprehensive industry standards for classifying IFC entity instances could render the extraction error-prone in some circumstances. For example, as it is shown in Figure 12, four types of HVAC components were classified as the *IfcFlowMovingDevice* entity for the office building model (as highlighted in different colors). However, they were on different loops. The centrifugal fan, air handling units, and VAV units were on the air loop, whereas the pump was on the chilled water loop. Although it was correct to regard both air and water as flow (as defined by *IfcFlowMovingDevice*). This could make the loop extraction process confusing. To address this issue, future work should investigate a more thorough industry standard for creating the IFC-based MEP model so that components can be classified more rigorously. Second, the scope of this study currently focuses on the extraction of high-level information in four essential categories: (1) HVAC system type, (2) HVAC loops and components, (3) detailed parameters for components, and (4) related thermal zone for HVAC terminals. The HVAC system types used in the experiment were limited to the boiler-radiator system and VAV system. More advanced HVAC system types were not investigated in this paper, such as the variable refrigerant flow (VRF) system, dedicated outdoor air system, heat pump, etc. In addition, air distribution components (e.g., diffusers and grilles for distributing conditioned air) and detailed parameters (e.g., size of ducts/pipes), as well as the control strategies such as operation schedules/modes required by BEM, have not been extracted yet, due to limitations of our experimental IFC model. A more comprehensive and robust algorithm can be developed in future work to cover a broader set of IFC-based MEP models with more detailed parameters by following the proposed methodology. In addition, automated methods/approaches in semantic enrichment of IFC-based BIM and model validation/checking could help facilitate the IFC-based BIM interoperability with BEM, which should be investigated in future work as well.

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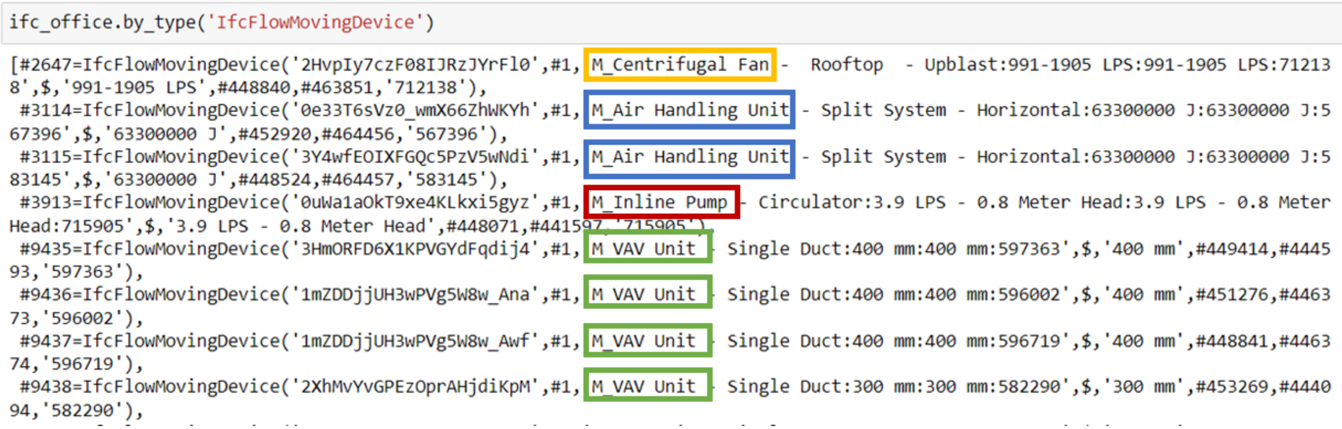

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Figure 12. *IfcFlowMovingDevice* entity in the office building