A Systematic Classification for HVAC Systems and Components

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ABSTRACT HEADING

Depending on the application, the complexity of an HVAC system can range from a small fan coil unit to a large centralized air conditioning system with primary and secondary distribution loops, and central plant components. Currently, the taxonomy of HVAC systems and the components has various aspects, which can get quite complex because of the various components and system configurations. For example, based on cooling and heating medium delivered to terminal units, systems can be classified as either air systems, water systems or air-water systems. In addition, some of the system names might be commonly used in a confusing manner, such as "unitary system" vs. "packaged system." Without a systematic classification, these components and system terminology can be confusing to understand or differentiate from each other, and it creates ambiguity in communication, interpretation, and documentation. It is valuable to organize and classify HVAC systems and components so that they can be easily understood and used in a consistent manner. This paper aims to develop a systematic classification of HVAC systems and components. First, the HVAC component information and definitions were summarized based on published literature, such as ASHRAE handbooks, regulations, and rating standards. Then, common HVAC system types were identified, and their components were mapped in a meaningful way. Classification charts are generated and described based on the component information. Six main categories are identified for the HVAC components and equipment, i.e., heating and cooling production, heat extraction and rejection, air handling process, distribution system, terminal use, and stand-alone system. Components for each main category are further analyzed and classified in detail. More than fifty system names are identified and grouped based on their characteristics. The result from this paper will be helpful for education, communication, and systems and component documentation.

INTRODUCTION

Heating, ventilating, and air conditioning (HVAC) systems are developed to condition the indoor environment (primarily the air) to design requirements. A variety of systems and equipment have been developed to realize this functionality. Depending on the application, the complexity of an HVAC system can range from a small unitary system to a large centralized air conditioning system with primary and secondary distribution loops, and central plant components. The taxonomy of HVAC systems and components has a variable basis, which can get quite complex because of the various components and system configurations. The current literature provides limited classification approaches. *American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Handbook Systems and Equipment* (ASHRAE, 2016) is one of the most comprehensive references about HVAC systems and equipment. Its chapters are organized using seven categories, i.e., 1) air-conditioning and heating systems, 2) air-handling equipment

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and components, 3) heating equipment and components, 4) cooling equipment and component, 5) general components, 6) packaged, unitary, and split-system equipment, and 7) general. Within each main category, the chapters of systems or equipment were listed. Some of the chapters have classification meanings, for example, Chapter 1 Decentralized Cooling and Heating, vs. Chapter 2 Central Cooling and Heating, while most of the chapters were listed for the typical systems or equipment. Another book *HVAC Analysis and Design* (McQuiston, et al. 2005) classified the systems into air systems, water systems or air-water systems, based on cooling and heating medium delivered to the conditioned space. However, this classification is only under the scope of centralized systems. Thus, this book includes a separate section about "decentralized cooling and heating". An online webpage provides a classification based on ducted system vs non-ducted system (Shukla, 2009).

Meanwhile, the classification of HVAC system might be able to provide some insights for data analysis for fault detection and diagnosis (FDD). Previous work in this area focused on the analysis of individual systems or equipment, such as chiller (Beghi, et al. 2016) (Namburu, et al. 2007), VAV rooftop unit (Allen, et al. 2016), air handling unit (Yan, et al. 2016). If a systematic classification mapping becomes available, it might be interesting to incorporate classification results into systems and equipment data analysis and visualization. This might provide an opportunity to develop a generalized framework for FDD.

In summary, although there are several ways of classifying the HVAC systems and components, those classifications either partially cover the HVAC systems or have ambiguous meanings. Therefore, this work aims to develop a systematic classification of HVAC systems and components. First, the HVAC component information and definitions were summarized based on published literature, such as ASHRAE handbooks, regulations, and rating standards. Then, common HVAC system types were identified, and their components were mapped in a meaningful way. Classification charts are generated and described based on the component information. Six main categories are identified for the HVAC components, equipment, i.e., heating, and cooling production, heat extraction, and rejection, air handling process, distribution system, terminal use, and stand-alone system. Components for each main category are further analyzed and classified. The result from this work will be helpful for education, documentation, and understanding configurations of systems and components.

METHODOLOGY

The methodology is composed of two phases, 1) data collection, and 2) classification mapping. Specifically, the first phase is to collect HVAC system and components information. Closely related EnergyPlus objects will be linked to the component data field if applicable. These components information were collected and organized in a way that supports further exploration. The second phase is to identify typical components types. System classification charts were generated based on the components information per usage purpose. A software tool was used to develop the classification maps.

System and Components Data Sources

We reviewed the literature and decided to collect the systems and components information from a few main resources, including, 1) ASHRAE handbook 2016 (Systems and Equipment) (ASHRAE, 2016), 2) ASHRAE Standard 90.1-2013 (ASHRAE, 2013), 3) EnergyPlus Documentation (U.S. DOE, 2013), and 4). Building Energy Data Exchange Specification (BEDES) (U.S. DOE, 2016)

Classification Structure

With the systems and components data collected in the first step, a classification map was developed. Since many components have various attributes and each of them has several options, there is no fixed classification structure. Figure 1 shows a way of classification. For a sub-category of components, specific attributes can be selected as a 'node', which can be further divided into different types. Other attributes can then be treated as a 'path' with multiple options.

Each component's reference in the ASHRAE Handbook, EnergyPlus Reference Document and representative product information were also collected. Corresponding EnergyPlus object information is linked to the 'component type' box in the example map. In future versions, rating methods and regulatory classifications can be added.

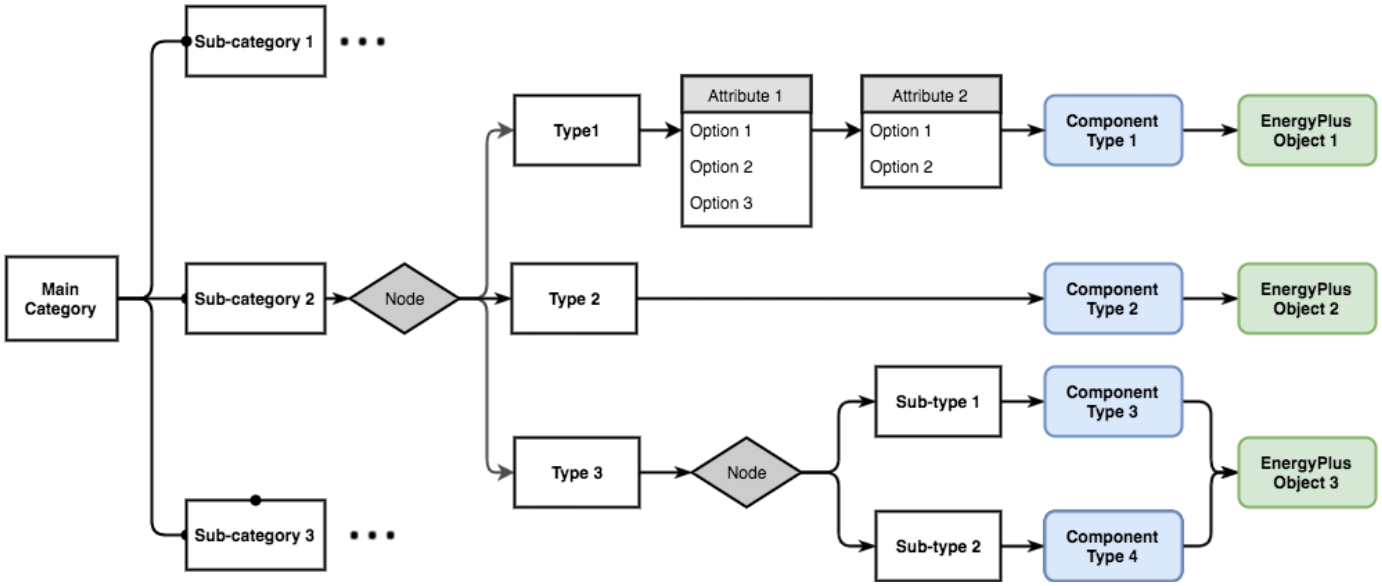

Figure 1 Components and system classification map template

COMPONENTS CLASSIFICATION

Based on the thermodynamic and air-conditioning principles, this study breaks down the HVAC components into the following main categories, i.e., 1) heating and cooling production, 2) heat extraction from and rejection to the environment, 3) air handling process, 4) heating and cooling medium distribution, and 5) terminal use. To distinguish small-scale decentralized systems from large-scale systems, 6) 'standalone system' category is also added. Within each category, subcategory and several key attributes are identified to further characterize different components. In this way, system classification tree charts can be generated based on the components glossary. The six categories share some attributes and each category contains their own unique attributes. Out of them, sub-category denotes the primary function and characteristics of a component. The 'Equipment Type' attribute denote the name commonly used in references. The 'Energy Source' attribute shows the energy type used by the component. The 'Working Principle' attributes denote the fundamental physics principle of the how the component work. Except for the shared attributes, each main category has its own attributes.

Heating and Cooling Production

Heating and cooling production are a type of process that convert energy from one form to another, and then the energy is used to satisfy space or process heating and cooling demands. Typically, cooling is achieved via the vapor compression cycle or liquid absorption cycle. Corresponding equipment types are vapor compressing chiller and absorption chiller. Heating is achieved via fuel burning, electric resistance heating or heat pump cycle (reverse Carnot cycle).

Heat Extraction from and Rejection to the Environment

Heat extraction & rejection are processes in which cooling and heating system extracts energy from ambient environment or releases energy to the environment. 1) In a water-cooled refrigeration system, heat is rejected through a cooling tower in the condenser loop. 2) In an air-cooled system where no condenser loop exists, heat is rejected through a heat exchanger (condenser of the refrigeration cycle) directly to ambient air. 3) In a water source heat pump system, heat is extracted from the environment via a water-to-water or ground-coupled heat exchanger, and then released to refrigerant through an evaporator in the heat pump cycle.

Air Handling Process

Air handling equipment provides means of handling outdoor/recirculating air before sending it to conditioned spaces via a distribution system. The main functions of air handling equipment include air cooling, air heating, humidifying, dehumidifying, heat exchanging, and air cleaning (filtering).

Heating and Cooling Medium Distribution

Distribution systems convey the cooling or heating medium from a centralized plant or air conditioner to certain zones. The cooling & heating medium can be chilled/hot water, steam, refrigerant and primary air. The system in which liquid cooling/heating medium is distributed is considered as a water distribution system. The system in which air is distributed is considered as air distribution system.

Terminal Use

Terminal Units include air-based, water-based and refrigerant-based devices installed in thermal zones. Their functions include: 1) introducing pre-conditioned primary air to each zone. 2) recirculating and handling secondary air (i.e., room air), and 3) cooling or heating the space through radiation & convection.

Standalone System

Stand-alone systems are HVAC systems with their heating and cooling production, heat extraction and rejection, air handling and distribution integrated into one or few integrated parts. Most of the stand-alone systems with cooling are Direct Expansion (DX) type. These systems often serve small-scale buildings or a special portion of large buildings. Based on their operation conditions, they can be classified into air-conditioners or heat pumps.

Key Attributes

After a thorough review of current systems, a set of key attributes for each main category except for 'standalone system' were selected. Table 1 shows the key attributes and their meanings. In this way, users could customize their classification map by choosing certain attributes as 'nodes' and others as 'options'. The structure allows dynamic addition of components and consistent maintenance.

Table 1 Key Attributes of Main Categories

Category	Attribute	Meaning
Heating and Cooling Production	Function	Functionality of a system or equipment
	Working Principle	Operation mechanism of a system or equipment
	Energy Source	Energy type used to operate a system or equipment
	Boiler Pressure	Boilers' working pressure
	Exhaust Condensing	Boiler's exhaust condensing capability
	Compressor Type	Chillers' compressor type
	Condenser Type	Chillers' condenser type
	Evaporator Type	Chillers' evaporator type
	Heat Source/Sink	Heat pumps' heat source and heat sink
	Direct/Indirect-Fired	Whether an absorption chiller is direct or indirect fired
	Regeneration Stage	Absorption chillers' regeneration stage
Heat Extraction from and Rejection to the Environment	Draft	Cooling towers' draft (e.g., natural, mechanical)
	Cooling Tower Flow	Air flow pattern in cooling towers
	Environment	Environment that acted as heat source or heat sink
	Air-water contact	Direct or indirect air-water contact
	Pipe Type	Vertical or horizontal
	Heat Exchanger Assembly	Liquid-to-liquid heat exchangers' configuration
Air Handling Process	Air Handling Process	Type of air handling process include
	Energy Transport Medium	Medium used to treat air in coils
	Means of Steam Generation	Steam generation method in humidifier
	Desiccant Material	Desiccant dehumidifier's material type
	Heat Exchanger Assembly	Air-to-air heat exchanger type
	Air Filtering Material	Type of air filtering material
Heating and Cooling Medium Distribution	Medium	Heating or cooling medium in distribution system
	Fan Design	Type of fan blade. (e.g., centrifugal, axial)
	Duct Shape	Duct's cross-sectional shape
	Impeller	Impeller type
	Pump Design	Type of pump blade
Terminal Use	Terminal Medium	Heating or cooling medium in terminal device
	Fan Power	Whether terminal device has fan
	Ductwork	Single duct or dual duct
	Airflow Pattern	Constant flow or variable flow
	Radiator Type	Radiator's configuration

SYSTEMS CLASSIFICATION

The HVAC system nomenclature can be confusing in many situations due to the lack of unified naming conventions and definitions. This section aims to identify typical system types, tag their key attributes according to the categories discussed in 'Components Classification' and find out their alias and derivatives. Common HVAC system

names are exhaustively searched among ASHRAE Standard 90.1-2013, ASHRAE Handbook HVAC Applications 2015, ASHRAE Handbook HVAC Systems and Equipment, CBECS microdata from U.S. Energy Information Administration (EIA). Similar to component data collection, each unique system is labeled with a unique ID. Two system categories and five component categories are identified for each system type. Table 2 shows the attributes selected to characterize a typical system.

Table 2 HVAC System Identification

Attribute		Meaning
ID		System's unique ID
System Name		Common system name
System Category (I)	Zone Medium Type	Cooling or heating medium used at zone level
System Category (II)	System Side	Primary or secondary system
System Category (III)	System Configuration	Degree of centralization
Heating/Cooling Production	Heating Production	Equipment type of heating production
	Cooling Production	Equipment type of cooling production
Heat Extraction & Rejection	Heat Extraction	Equipment type of heat extraction
	Heat Rejection	Equipment type of heat rejection
Air Handling Equipment	Air Cooling	Air cooling component
	Air Heating	Air heating component
	Air Humidifying	Air humidifying component
	Air Dehumidifying	Air dehumidifying component
	Air Heat Exchange	Air heat Exchange component
	Air Cleaning	Air cleaning component
Distribution System	Water	Pipe Design	Pipe configuration of water- or refrigerant- based system
		Pump Type	Circulating pump type
	Air	Duct Design	Duct work of air-based system
		Fan Type	Fan type
Terminal Unit		Terminal Type	Terminal device type
		Reheat	Terminal reheat option
Derivatives			Other closely related system

The 'System Classification' section is a derivative and supplement of the 'Components Classification' section. A classification map of the systems was developed. With the classification map, 1) core components of a system could be easily identified, 2) similar systems are grouped by physical principles.

POTENTIAL APPLICATIONS

The HVAC components and system information collected in this study can be used in several ways. A set of interactive classification maps were developed. Figure 2 shows an example of the classification map. The green blocks are linked to the EnergyPlus model description online, which could support efforts in HVAC system modeling. For example, one can learn about the HVAC systems and components and how they are modeled in EnergyPlus. The classification maps can also be expanded and customized to support different user preferences.

HVAC System Modeling

For modeling purposes, the classification mapping can be used as a guide to understanding the configuration of an HVAC system and assist users to find relevant EnergyPlus objects. For example, when the term of "single duct VAV system" shows up, the user can look up to the classification maps and understand that "single duct" only specifies the duct distribution type, and "VAV" only defines the fan speed control type. For configuring a whole HVAC system, there are still different components unspecified, e.g., what is the production of heating and cooling? What is the terminal equipment type? By looking at the classification map in those categories, the user can have an overview of what are the likely configurations of HVAC systems, and what are the main components and alternative options. Furthermore, each HVAC component has been linked to a relevant EnergyPlus object (shown in a green block in the HTML files if applicable). This aims to help connect the HVAC system configuration to the modeling process.

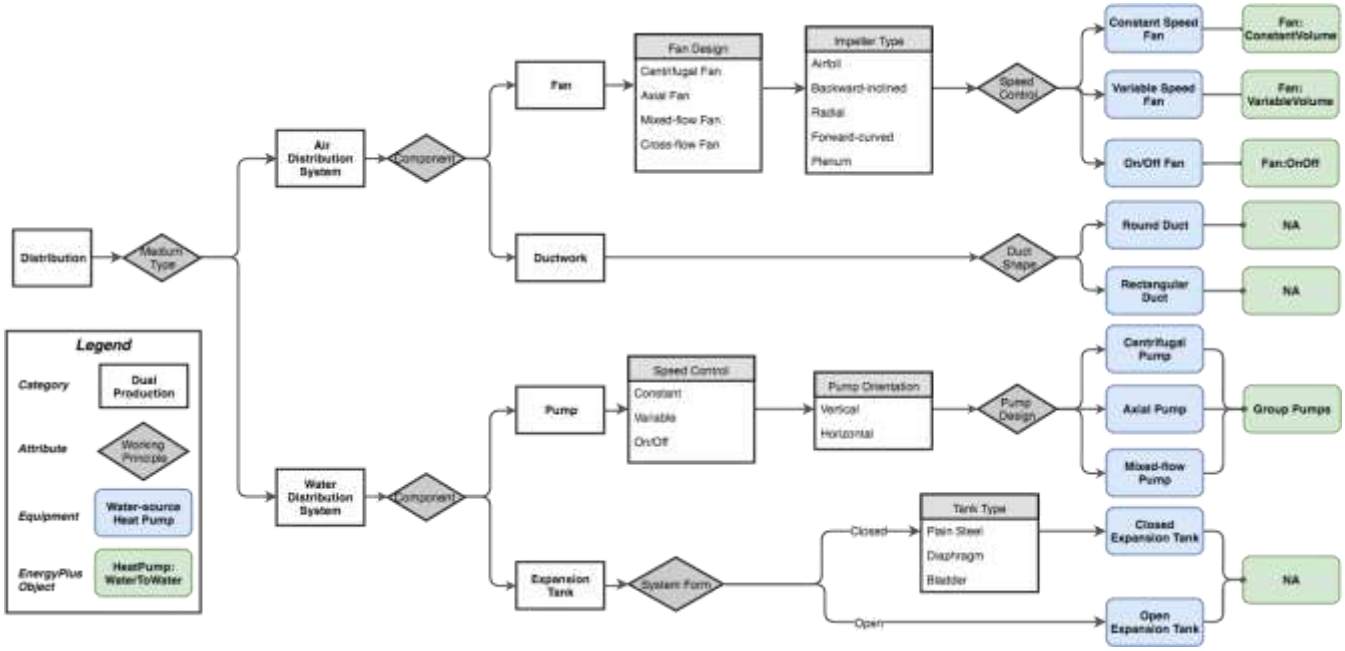

Figure 2 Classification map of heating and cooling medium distribution components.

Customized Classification Maps

As discussed earlier, the data collected in this study does not cover all HVAC systems and components, but it aims as a starting point to initiate this effort. It provides a repository where more components information and attributes could be added and organized in a meaningful way. Customized classification maps could be created based on the repository per user preferences. For example, mechanical designers could choose cooling capacity range, COP, airflow volume and heat exchange coefficient as the key attributes because they care more about performance parameters. Sustainable consultants could choose greenhouse gas emission, global warming potential, and product content disclosure as the key attributes because they may care more about life-cycle impacts. Building owners and contractors could choose initial cost, service life, and operation and maintenance requirements and as the key attributes because they may focus more on cost-effectiveness. The customized tool also allows users to select different levels of detail.

DISCUSSION

Through a literature review of current literature regarding the terminologies of HVAC systems, components, and equipment used in engineering handbooks, energy codes, regulations, and simulation guidelines, we confirmed that many terms are currently used interchangeably and sometimes ambiguously. The ambiguity could lead to different interpretations and miscommunication. This paper presented the basis for development of a systematic way to classify HVAC systems and components, which aims to benefit performance metrics evaluation, product regulations, communications and identifications of improvement opportunities for the industry.

We collected key attributes of HVAC systems and components and developed a preliminary classification methodology. The way we collect and organize component attributes allows the components and equipment to be linked to the HVAC systems. It also facilitates components information maintenance and future tool deployment. A components classification map and a system classification map were developed based on the data collected. Those maps could help engineers and energy modelers to relate the functions of their HVAC systems and the components used to perform those functions.

Currently, the classification mappings are manually developed. Modification and edits of the maps can be challenging. The next phase of work will develop programs to automatically generate the classification mappings so the users can select key components attributes based on their preferences and needs. It will also include a more extensive manufactured product literature review.

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