Lecture 13. BEM: Building Systems, Part II
Heating, Ventilation, & Air Conditioning

"A study of 60 buildings by Lawrence Berkeley National Laboratory showed that, before intervention, at least half had problems with their system controls, a minimum of 40% had faulty HVAC equipment, and 25% or more had problems with specific 'green' HVAC features (Piette, Nordman, Greenberg, 1994). One group of researchers estimated that finding and fixing these types of problems can save $18 billion or more per year in commercial buildings in the U.S. alone (Mills et al., 2004)."

— Samuelson, Ghorayshi, and Reinhart [8]

1 EnergyPlus

To allow EnergyPlus to incorporate HVAC equipment, we need to provide it with information about [5]:

- Equipment types
- Operating schedules
- Control information

There are many more types of HVAC systems than we could hope to cover, even having an entire semester to study HVAC. However, if you have a very basic amount of technical knowledge on a certain type of system, the Engineering Reference document [3] contains the basic math describing how it's implemented in EnergyPlus. Unless your system is very unusual or new, it's likely someone has implemented it in EnergyPlus already. Figure 1 shows a simple abstracted illustration of a VAV system (Guest 1 Lecture), and the documentation explains the mathematical implementation of this system in EnergyPlus at the building level, zone level, and down to the coils in an individual VAV box [3].

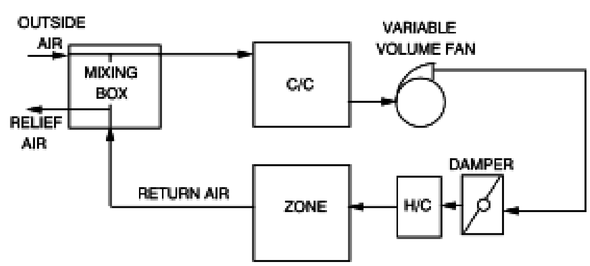

Figure 1: Simplified Variable Volume Air System from EnergyPlus Engineering Reference [3]

2 OpenStudio

In OpenStudio, the HVAC Systems tab shows us a representation of the air systems distributing air through a building, or other "plant loops" circulating fluids (e.g. hot water or chilled water) within the building. In this tab, we can leverage templates that are already compiled (e.g. BCL [1] or libraries added through File -> Load Library), which gives us a lot of drag & drop functionality and ways to quickly set up HVAC systems.

We have three sub-tabs within the right panel:

My Model displays items that are part of your model already. [7]

Library includes components and measures that come with the application or are downloaded from the Building Component Library (BCL). [7]

Edit allows you to select certain components and edit the settings for that component. It is used in the HVAC tab to edit component settings, assign thermal zones to loops, and to add plenums. [7]

The "Creating Your Model" page in the OpenStudio documentation [7] shows examples of your options for air and plant loops in the OpenStudio interface–click on Air, Plant and Zone HVAC Systems.

3 Ventilation

The EnergyPlus documentation defines ventilation and explains the minimum information needed to model it:

> **Ventilation** (Object: ZoneVentilation:DesignFlowRate) is the purposeful flow of air from the outdoor environment directly into a thermal zone in order to provide some amount of non-mechanical cooling . . . Simple ventilation in EnergyPlus can be controlled by a schedule and through the specification of minimum, maximum and delta temperatures. [3]

The outdoor air used for ventilation can be quantified by [9]:

- CFM (cubic feet per minute) per person
- CFM per square foot (area) of the space
- Air Changes per Hour (ACH)
- Percent of total supply air

The collections of fans, heating and cooling coils, and terminal units shown in OpenStudio's HVAC tab make up an air loop:

> In EnergyPlus an **air loop** is a central forced air HVAC system. The term 'loop' is used because in most cases some air is recirculated so that the air system forms a fluid loop. The air loop is just the 'air side' of a full HVAC system. The input objects related to these air loops begin 'AirLoopHVAC.' For simulation purposes the air loop is divided into 2 parts: the primary air system (representing the supply side of the loop) and the zone equipment (representing the demand side of the loop).

When we talk about ventilation, we also have to acknowledge **infiltration**, which is "air leakage" or more generally any air flow to the interior that isn't directed by design (such as through mechanical systems bringing air in through an air handling unit). This needs to be included in the model for the airflow and overall heat balance models to be correct.

4 Sizing HVAC equipment

EnergyPlus has a "sizing manager" module that can do sizing calculations for equipment, including some newer advanced options for HVAC equipment. The general method includes [3]:

> 1. A zone by zone heat balance load and air-flow calculation for multiple design days;
> 2. Significant user control with modest input requirements;
> 3. Zone, system and plant level calculations of design heating and cooling capacities and fluid flow rates;
> 4. Modular, component-specific sizing algorithms for each HVAC component.
> 5. Options for monitoring how the initial sizes operate over multiple design days and then making adjustments and repeating plant level calculations

5 Controls and temperature setpoints

EnergyPlus has many ways to implement control of HVAC systems, some of which might correspond directly to an actual piece of equipment that implements control logic, and some which are more abstract or much more high-level. One simple type of control which you will be familiar with and may interact with in your simulation models is the thermostat controlling a zone. Because a zone is assumed to be at uniform temperature (Lecture 12), this is the most detailed level of thermostat control that's possible.

This is managed in EnergyPlus using the ZoneControl:Thermostat object, which has a few valid types of control:

0 Uncontrolled (No specification—temperature will be determined using energy balances but the equipment will not attempt to reach or maintain a temperature)

1 Single Heating Setpoint (No cooling specification)

2 Single Cooling SetPoint (No heating specification)

3 Single Heating/Cooling Setpoint (Same setpoint whether in heating or cooling mode)

4 Dual Setpoint (Heating and Cooling) with deadband

6 Heating

Here are a few types of equipment that you may see in HVAC models for heating [4]:

Baseboard Heat baseboard heating system, controlled by a thermostat and heated with hot water or electric resistance heating.

Heat Pump generic term for a device that moves heat from a cold source to a hot sink—like a refrigerator, but we're interested in Q_H instead of Q_L [2].

Boiler heating device that heats up water to provide thermal energy, often by burning natural gas

Furnace heating device that heats up air, often by burning natural gas

7 Cooling

Here are a few types of equipment that you may see in HVAC models for cooling [4]:

Chiller generic term for a device that removes heat from a liquid, often water

Vapor-compression chiller a chiller that operates on the vapor-compression refrigeration cycle (and here we care about Q_L)

Chilled beam a heat exchanger at ceiling level, as seen in the MEK building. Basic idea:

> Warm air from the space rises toward the ceiling, and the air surrounding the chilled beam is cooled, causing it to descend back toward the floor, creating convective air motion to cool the space. This allows a passive chilled beam to provide space cooling without the use of a fan. [6]

8 Ideal System Air Loads

EnergyPlus has a useful capability to study the "loads" or demands on an HVAC system without being tied a given type of system. This is handled within the ZoneHVAC:IdealLoadsAirSystem object.

> It is not connected to a central air system—instead each ZoneHVAC:IdealLoadsAirSystem object supplies cooling or heating air to a zone in sufficient quantity to meet the zone load or up to its limits, if specified . . . It is modeled as an ideal VAV terminal unit with variable supply temperature and humidity. The supply air flow rate is varied between zero and the maximum in order to satisfy the zone heating or cooling load, zone humidity controls, outdoor air requirements, and other constraints, if specified. [3]

Note that because it's "ideal" you won't get proper quantification of the costs and needs of an actual HVAC system (e.g. fan energy, electricity or fuel costs).

> The energy required to condition the supply air is metered and reported as DistrictHeating and DistrictCooling. [4]

References

[1] *Building Component Library*. `https://bcl.nrel.gov/`. Accessed: 2016-6-23. URL: `https://bcl.nrel.gov/`.

[2] Yunus Cengel and Michael Boles. *Thermodynamics: An Engineering Approach (Mechanical Engineering)*. en. 8 edition. McGraw-Hill Education, Jan. 2014. ISBN: 9780073398174.

[3] *Engineering Reference | EnergyPlus*. U.S. Department of Energy. 2018. URL: `https://energyplus.net/documentation`.

[4] *Input Output Reference | EnergyPlus*. U.S. Department of Energy. 2018. URL: `https://energyplus.net/documentation`.

[5] *Introduction to Building Simulation and EnergyPlus University Course Teaching Material*. Department of Energy. 2003. URL: `https://energyplus.net/support`.

[6] John Murphy and Jeanne Harshaw. "Understanding chilled beam systems". In: *TRANE Enginnering Newsletter* 38 (2009), pp. 1–12. URL: `https://www.trane.com/content/dam/Trane/Commercial/global/products-systems/education-training/engineers-newsletters/airside-design/adm_apn034en_1209.pdf`.

[7] *OpenStudio® User Docs*. `http://nrel.github.io/OpenStudio-user-documentation/`. Accessed: 2019-2-5. URL: `http://nrel.github.io/OpenStudio-user-documentation/`.

[8] Holly W Samuelson, Arash Ghorayshi, and Christoph F Reinhart. "Analysis of a simplified calibration procedure for 18 design-phase building energy models". In: *Journal of Building Performance Simulation* 9.1 (Jan. 2016), pp. 17–29. ISSN: 1940-1493. DOI: `10.1080/19401493.2014.988752`. URL: `https://doi.org/10.1080/19401493.2014.988752`.

[9] *VENTILATION, INFILTRATION & EXFILTRATION | Energy-Models.com*. `http://energy-models.com/ventilation-infiltration-exfiltration`. Accessed: 2019-2-5. URL: `http://energy-models.com/ventilation-infiltration-exfiltration`.