Chapter 4
Introduction to HVAC Systems

4.1 Introduction

As we observed in previous Chapter exercises, buildings generally benefit from HVAC systems that are designed to regulate their internal environmental conditions. As the name implies, in addition to heating and cooling, these systems also provide fresh outdoor (ventilation) air to dilute CO_2 and other contaminants produced by building occupants, processes, and materials. Modeling HVAC systems correctly is one of the most challenging aspects of energy modeling because of the variety of systems and controls available and the design considerations that drive their selection. The goal of this Chapter is to discuss some of the general concepts needed to understand HVAC system modeling in the context of OpenStudio.

4.2 Model Zoning

As described in Chap. 2, OpenStudio Models are divided into Spaces. A Space is a collection of Surfaces and Sub-Surfaces that enclose a volume of air. A Space contains internal loads as described in Chap. 3. In both Chapters, we also briefly touched on the concept of a Thermal Zone. Thermal Zones are served by HVAC systems, and are comprised of one or more Spaces. By extension, a Thermal Zone is a collection of all the Surfaces and Sub-Surfaces that enclose all Zone's Spaces, plus all the Internal Loads contained in those Spaces.

Figure 4.1 shows a building that contains Four Spaces and Two Thermal Zones. One Thermal Zone contains only a single Space, while the other Thermal Zone
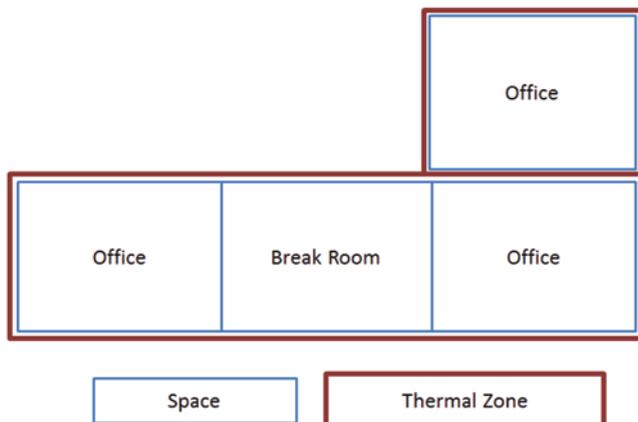
Fig. 4.1 Two Thermal Zones containing one or more spaces

contains the remaining Three Spaces. Although the Spaces in a Thermal Zone are not required to be adjacent, as described later, this is a best practice.

At every simulation time step, EnergyPlus performs a heat balance calculation for each Thermal Zone. Depending on the thermal boundary conditions discussed in Chap. 2 heat is transferred into or out of a Thermal Zone through its Surfaces. As we learned in Chap. 3, the Thermal Loads within Spaces also transfer heat to the associated Thermal Zone. EnergyPlus generally assumes that all of the air inside of a Thermal Zone is well mixed. This means that all of the heat transferred into the air within a Thermal Zone is instantaneously spread around evenly. There are no hot or cold spots within a Thermal Zone.

Another Model Object closely associated with the Thermal Zone is a Thermostat. As we saw in the previous Chapter Thermostats are associated with temperature setpoints, or targets, and related schedules. HVAC systems attached to Thermal Zones attempt to provide sufficient heat transfer into a Thermal Zone to achieve the target setpoint temperature. Achieving the setpoint takes time based on the size of the HVAC system and attached Thermal Zones, and it is quite possible that target temperatures will not be achieved if the system is undersized for the Thermal Zone Load and boundary conditions. These factors must be considered when "zoning" a building or dividing it into Thermal Zones. Other zoning considerations include the location of Spaces relative to the building façade, variation in heating and cooling setpoints within Spaces, and more. Zoning is in some sense more art than science, but there are a few heuristics that can guide us.

4.2.1   Rules of Thumb for Combining Spaces into Thermal Zones

When a Model contains a large number of Spaces, there are many possible ways to combine them into Thermal Zones. While there are no exact rules, the following "rules of thumb" can provide reasonable results:

Similarity of External Boundary Conditions (Surface Area) Think about how much external area (walls, roofs, windows, etc.) each Space has. If the Spaces have similar surface areas, then the well-mixed assumption is probably valid. However, if one Space has many exterior windows and walls, and another Space has none, our engineering judgment and life experience suggests that the Space with no exterior surfaces will be a different temperature than the one with exterior surfaces, especially on very hot or very cold days. Such Spaces should <u>not</u> be grouped together into a common Thermal Zone.

Similarity of External Boundary Conditions (Timing) Consider <u>when</u> external loads are likely to ramp up and down for each Space. For example, if two Spaces are on the top floor of the East side of the building, solar heat transfer will be most intense in the morning, and less so in the late afternoon. Such Spaces are good candidates to combine. Grouping Spaces on East and West façades into a single Thermal Zone may produce less desirable results because they may experience very different exterior boundary conditions at the same time of day.

Proximity and Connectedness of Spaces Think about where in the building the Spaces are located. Although physical adjacency is not a prerequisite for simulation, in reality, it is unlikely that air in two Spaces would be well mixed if the Spaces were not adjacent or not connected by a doorway or corridor that allows air to pass through unimpeded. Proximity may mean adjacency on the same floor or adjacency from one floor to the next. Ask yourself how reasonable is EnergyPlus' "well-mixed" assumption for the collection of Spaces you propose to group together into a single Thermal Zone.

Size Sometimes large Spaces may need to be broken into smaller Spaces if the well-mixed assumption is not reasonable for the entire Space. For example, a large warehouse might seem like a single Space, but is it valid to assume that air heated by exposure to a hot South facing wall will mix with cool air on the North façade? In this case, it may be better to break the warehouse into several smaller Spaces and assign each to a separate Thermal Zone.

Variation in Internal Loads Consider the case of an IT closet with a large number of internal Loads per area and a nearby corridor with little to no Load. Unless there is a direct connection or fan circulating air between these Spaces, it is unlikely that much of the heat from the IT closet will mix into the air in the corridor. These Spaces are candidates for assignment into distinct Thermal Zones.

Controllability Some Spaces may require unique setpoints and schedules. For example, individual rooms in a hotel must offer each guest the ability to set a temperature they find comfortable. In this case, each guest room must be individually zoned.
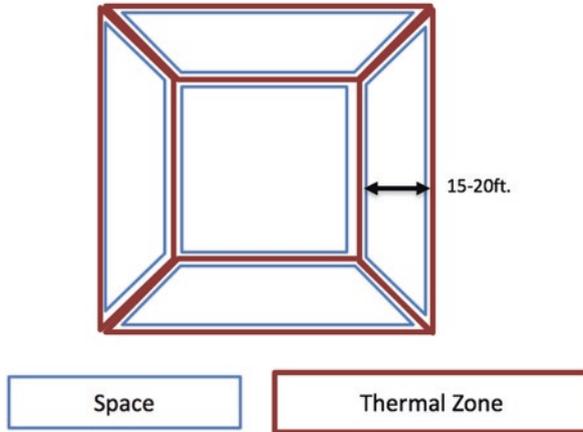
Fig. 4.2 Core and Perimeter Zoning

4.2.2 Zoning During Early Design

It is sometimes desirable to perform simulations after the initial building envelope has been defined but before detailed Spaces have been assigned. In this situation, best practice is to use "Core and Perimeter Zoning." This method divides the building up into a Space for each façade, and then assigns each Space to its own Thermal Zone. Typically, the exterior Spaces are between 15 and 20 feet deep as shown in Fig. 4.2.

4.3 HVAC System Types

The HVAC industry offers a large variety of system designs and products. OpenStudio and EnergyPlus are able to model commonly used systems, as well as designs that are far more esoteric. OpenStudio organizes HVAC systems into three basic categories: Zone HVAC, Air Systems, and Plant Systems.

4.3.1 Zone HVAC Equipment

Zone HVAC Equipment in OpenStudio refers to a family of components designed to represent a specific, preconfigured, HVAC system that is meant to serve exactly one Thermal Zone. One example of a Zone HVAC component is "Zone HVAC Packaged Terminal Air Conditioner (PTAC)." A common application for a PTAC is in a hotel room, which requires independent air conditioning.

All Zone HVAC types in OpenStudio include a prescribed arrangement of sub-components. In the case of Zone PTAC, these include a fan, a cooling coil, and a heating coil. It is generally not possible to add another sub component, such as a backup heating coil or a humidification device, unless the specific Zone HVAC component was pre-configured to include those sub-components. Just as the component layout is preconfigured for Zone Equipment, so is the associated control logic. Zone Equipment usually includes a limited set of user input fields that can somewhat modify the Equipment's control algorithms. Zone HVAC control logic attempts to follow the Thermal Zone's Thermostat setpoint to the best of the Equipment's ability.

4.3.2   Add a Zone HVAC Component

Zone HVAC Equipment such as the PTAC is added to a Thermal Zone using the Application's Thermal Zones (▣) Tab. As with other objects we have used in previous Chapters, simply select the Zone Equipment then drag and drop it onto the desired Thermal Zone as shown in Fig. 4.3. Thermostat Schedules must also be dragged onto the Thermal Zone for the Equipment to function properly.

As with other objects in OpenStudio, we can inspect the properties of the Zone Equipment by clicking on it and looking in the right side of the window (Fig. 4.4). This panel shows all of the detailed properties of the Zone Equipment, as well as the properties of any child components nested inside of it. The PTAC for example has two coils and a fan as children, and the properties of those components are viewable when you inspect the PTAC instance.

Zone Equipment can be useful, but by definition, it is limited to serving single Thermal Zones. The lack of customizability is also a drawback. For greater control of HVAC system configuration, we need to learn about OpenStudio Air Systems.
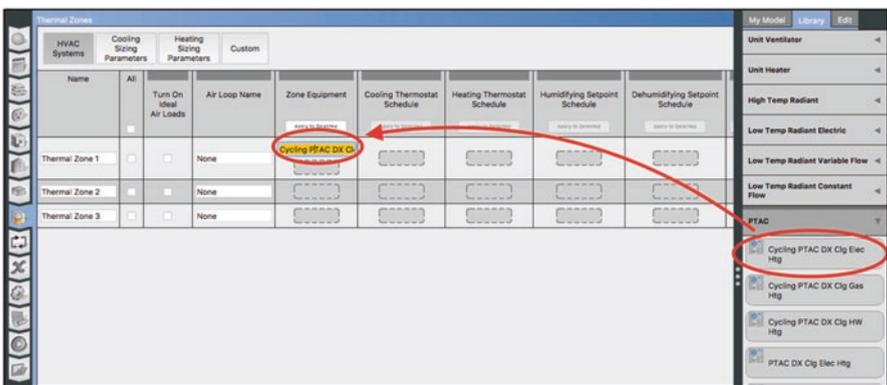

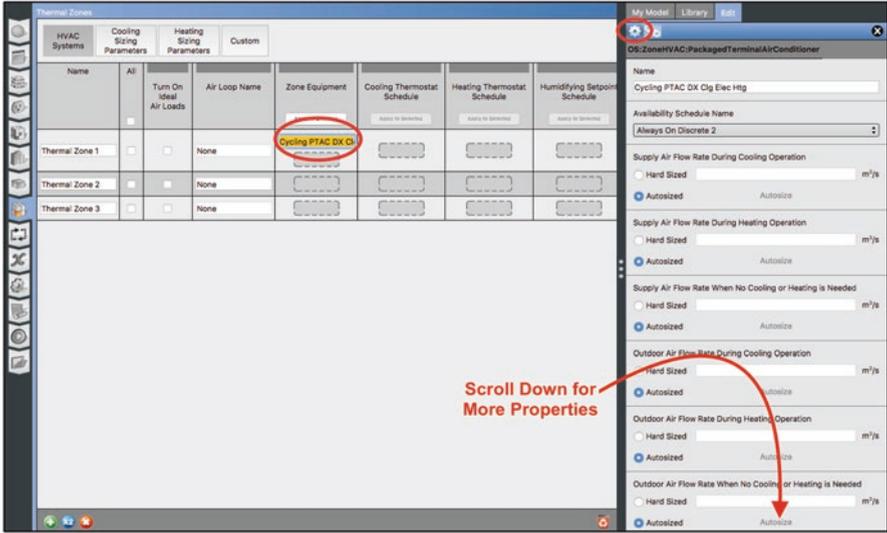**Fig. 4.3** Adding a piece of Zone Equipment

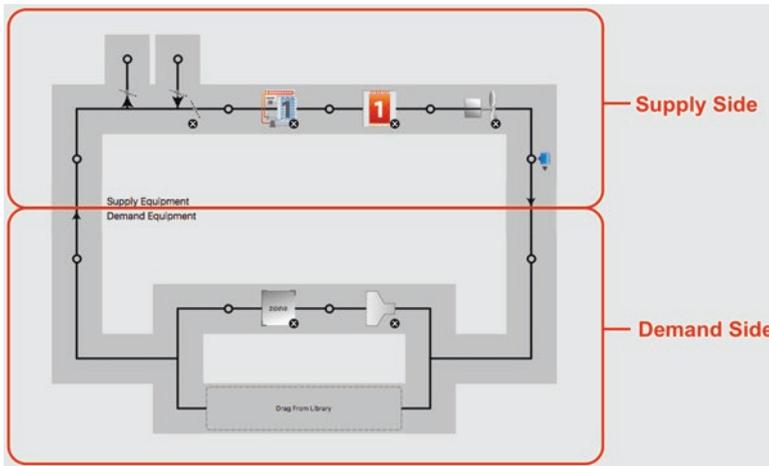**Fig. 4.4** Setting properties for a piece of Zone Equipment

Fig. 4.5 Supply and demand sides of an Air Loop

4.3.3 Air Loop Systems

OpenStudio is capable of modeling complex single and multi-Zone air handlers using the "AirLoop HVAC" Model. AirLoop HVAC is a modeling container in which you can explicitly drag and drop sub-components such as fans, heating coils, cooling coils, and a wide variety of other equipment. As the name implies AirLoop HVAC is built around the concept of a closed loop with distinct supply and demand

sides (Fig. 4.5). The supply side may contain a large variety of fans, coils, heat recovery devices, and outside air systems. The demand side is used to connect Thermal Zones and associated Air Terminal devices.

Compared to Zone Equipment, Air Loops allow for far greater configurability. The user has nearly complete[1] flexibility in the selection and placement of subcomponents, as well as more customizable control options. Additionally, Air Loop HVAC can be attached to one or many Thermal Zones using a variety of Zone Terminal units.

When modeling single Thermal Zone systems, OpenStudio modelers often have a choice between using the Air Loop Model or alternately using one of the Zone HVAC Objects pre-built for a specific purpose. In fact, there is overlap in the capabilities of the two approaches. Because of the configurability that Air Loop offers, it is capable of modeling many practical single Thermal Zone air-based systems. That said there are single Thermal Zone systems that are only possible to model properly in OpenStudio as Zone Equipment. In general, it is recommended to use Zone Equipment when there is a suitable model available and the Equipment serves a single Thermal Zone.

Lastly note that OpenStudio allows for multiple pieces of Zone Equipment to be attached to a single Thermal Zone, however Thermal Zones may only have one Air Loop Connection. A common scenario is to use Zone Equipment to condition a single Thermal Zone, for instance the "Zone HVAC Four Pipe Fan Coil" Object and reserve the more configurable Air Loop to model a dedicated outside air system (DOAS). These options will become clearer in subsequent sections and exercises.

4.3.4   Plant Loop Systems

Liquids are frequently used as a heat transfer medium in HVAC systems. All liquid based systems, including chilled and hot water plants, condenser systems, and potable hot water, are modeled using the Plant Loop component Model. Like Air Loops, Plant Loops are closed loops incorporating the concept of a supply side and demand side. The supply side of a Plant Loop typically contains heat producing or extracting components such as chillers, boilers, and cooling towers. The demand side is typically composed of consumers, such as chilled and hot water coils. Thus, the demand side of Plant Loops are frequently connected to the supply side of Air Loops as shown in Fig. 4.6.

Plant Loops allow some limited flow path branching. Specifically, splitters and mixers paired on the supply side enables configurations like gangs of chillers. Plant Loops also allow a single splitter and mixer to be paired up on the demand side,

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[1] OpenStudio does impose some limits on placement of components relative to the supply and demand side of Air Loops to prevent the user from accidentally creating Models that won't simulate in EnergyPlus.
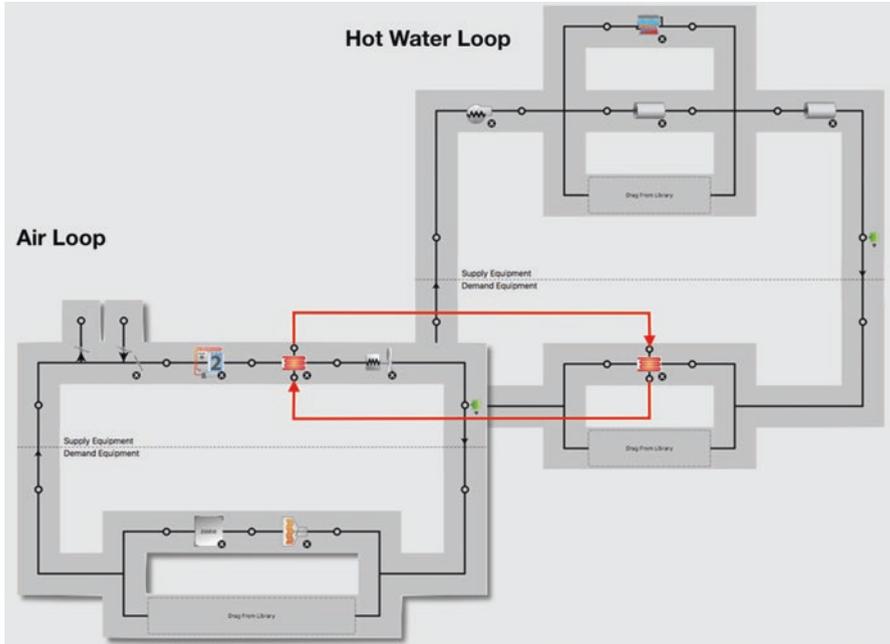
Fig. 4.6 A typical Plant and Air Loop relationship
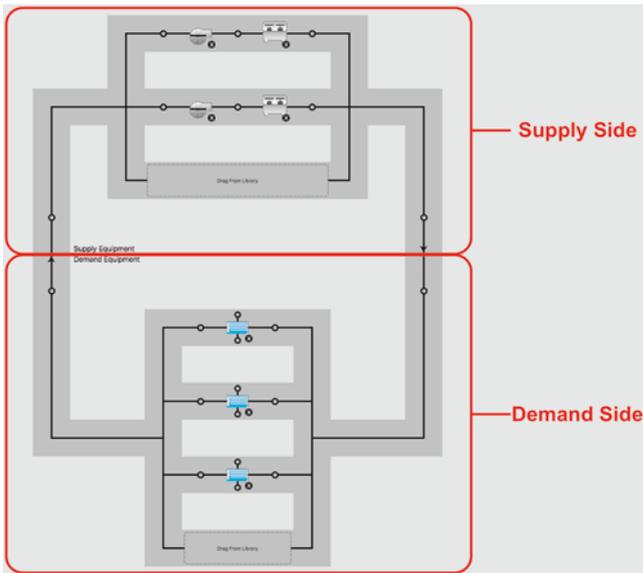

Fig. 4.7 Plant Loop branch examples

typically with parallel branches serving various plant loads such as water coils. Figure 4.7 illustrates common Plant branching scenarios.

One constraint on Plant Loop topologies is that it is not possible to have a splitter follow another splitter to form a sub-branch (Fig. 4.8). This is a limitation of the underlying EnergyPlus simulation engine. In practice, Plant Loop branching options in OpenStudio are adequate to model the majority of real world systems. Nevertheless, it is helpful to keep the concepts of supply and demand side and constrained branching, in mind when designing plant systems in OpenStudio.

4.4   HVAC System Templates

Compared to Zone Equipment, Air and Plant Loop systems are more complex to create from scratch. We will discuss custom built Loop-based systems in Chap. 5, but for now let's take a look at using "templates" that OpenStudio provides to quickly construct commonly used HVAC systems. These templates roughly correspond to a subset of the ASHRAE 90.1 Appendix G system types.[2] Template systems may also be used as a starting point and modified as needed.

Consider ASHRAE 90.1 Appendix G system type seven. System seven is a built-up system that has a multi-Zone, variable air volume (VAV), central air handler (Fig. 4.9). There are chilled and hot water coils in the air handler, which are fed by chilled and hot water plants respectively. The chilled water plant is cooled by a
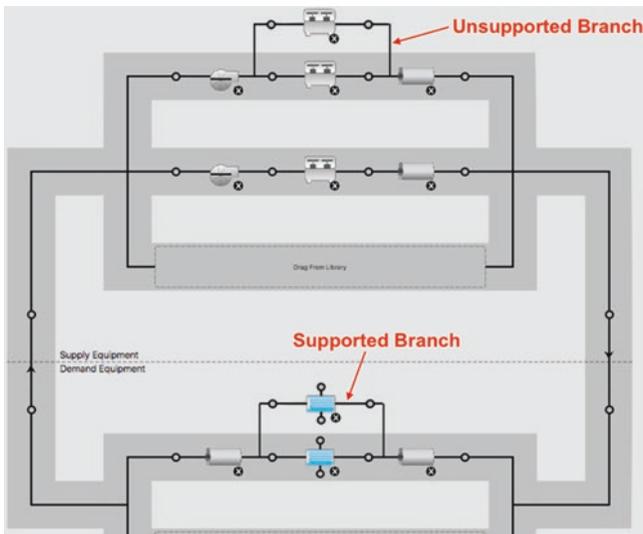

Fig. 4.8 An unsupported Plant Loop topology
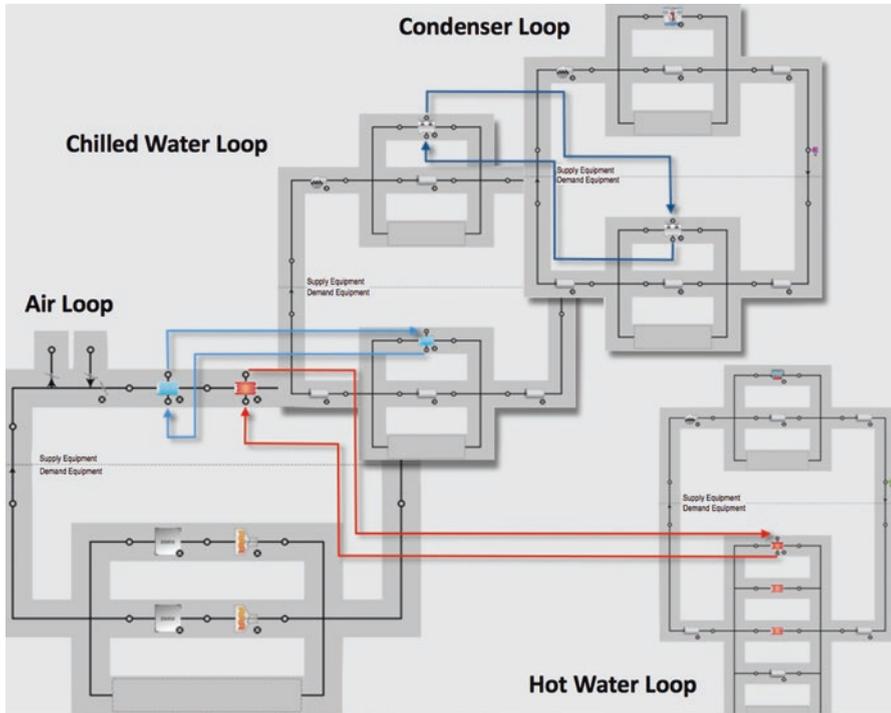
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[2] ASHRAE (2016).

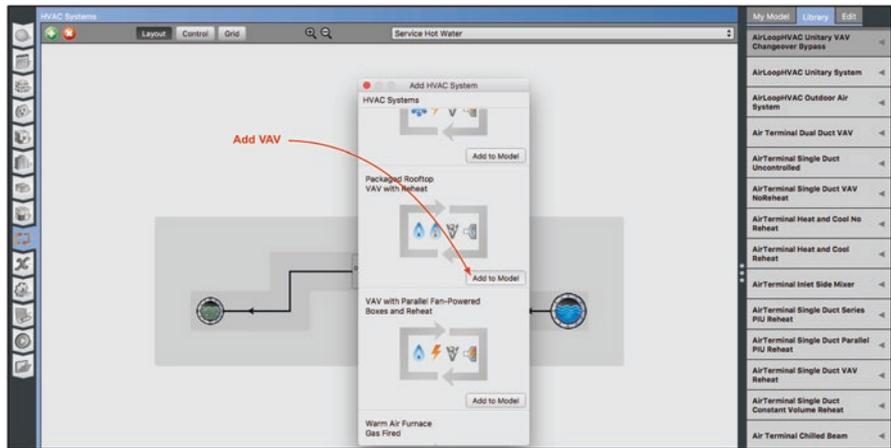**Fig. 4.9** ASHRAE 90.1 Appendix G system type seven

Fig. 4.10 Adding a template HVAC system to a Model

water-cooled chiller, which is rejecting heat to another Plant Loop serving as the condenser system, which rejects heat via a cooling tower. In total, there are three Plant Loop instances and one Air Loop HVAC instance used to model system type seven in OpenStudio. It is possible to build up these systems from scratch using Air and Plant Loops and HVAC components, but it is far easier to start from an OpenStudio template.

4.4.1   Add a Template Air Loop HVAC System

Template HVAC systems are added using the HVAC (■) Tab in the Application. In the upper left corner of the user interface, there is a ⬇ Button to select and add template systems. Clicking this Button opens an "Add HVAC System" dialog as shown in Fig. 4.10. Scrolling through the options reveals a number of common system configurations. ASHRAE system type seven most closely resembles the "Packaged Rooftop VAV with Reheat" template. Clicking the Add to Model Button adds all of the necessary Plant and Air Loops along with the requisite sub-components to the Model.

This particular template adds four new Loops to the Model including one Air Loop representing the central air handler, a hot water Plant Loop, a chilled water Plant Loop, and a condenser Plant Loop. The template is preconfigured with components linking the Loops together. After the template has been added, the system selector field near the top of the HVAC (■) Tab changes from "Service Hot Water" to "VAV with Reheat," displaying the Air Loop representing the central air handler (Fig. 4.11). This field may be used to navigate between Loops and other systems that may be present in the Model.
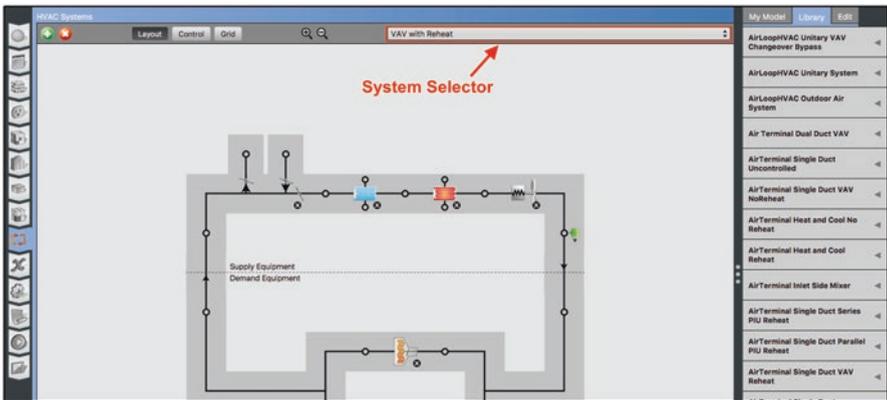

Fig. 4.11   Air handler included in Packaged Rooftop VAV with reheat templatesystem
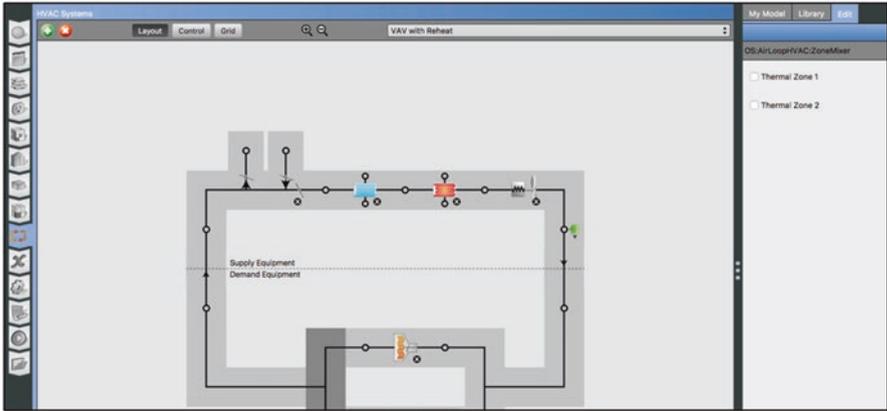
Fig. 4.12 Connecting Thermal Zones to an Air handler
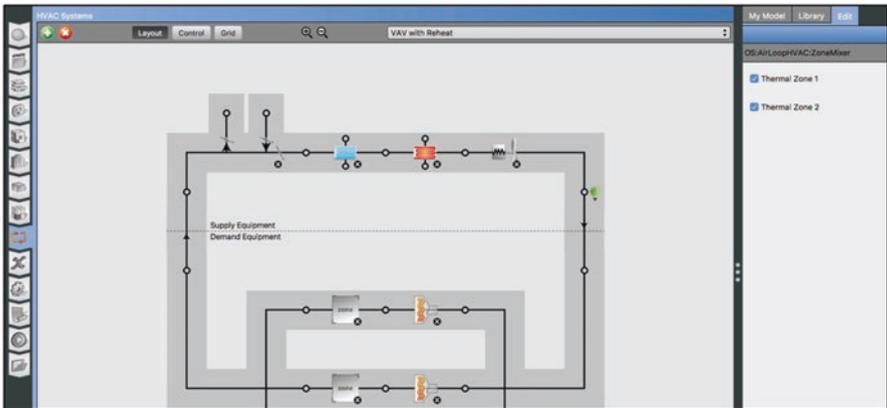
Fig. 4.13 Two Thermal Zones Connected to a Single Air Handler

Note that the upper and lower halves of the Air Loop are separated by a dotted line. The region above the dotted line represents the supply side of the Loop, while the lower region is the demand side. The template has conveniently added several Objects to the supply side including an outside air handler, cooling coil, heating coil, supply fan, and a setpoint controller. The demand side contains a Zone Splitter and Mixer, with one branch containing a single Air Terminal that is not yet connected to any Thermal Zone. The new air handler must be connected to one or more Thermal Zones in order to produce a functional simulation. The quickest way to attach a Thermal Zone is by clicking on either the Zone Splitter or Mixer on the demand side, then selecting the Thermal Zones to attach using the inspector interface on the right as shown in Fig. 4.12.

After checking Thermal Zones 1 and 2, the Air Loop updates to reflect two demand side branches, each containing a VAV Air Terminal serving a Thermal Zone as shown in Fig. 4.13.

It is also possible to add a Thermal Zone by selecting a Thermal Zone from the My Model Sub-Tab and dragging it either to the region labeled "Drag From Library," or on a Node immediately after an Air Terminal.

Chapter 5 will go into greater detail regarding the OpenStudio HVAC interface, but let's take a moment to describe a few rudimentary features at this point. Most importantly, all of the components shown in the HVAC interface may be inspected. Clicking an icon will usually present an Object's properties in the right-hand side of the window. As with Zone Equipment, these include all Object parameters as well as the properties of any children the component may include. For example, clicking on the VAV Air Terminal brings up the Air Terminal properties, as well as the properties for the hot water heating coil contained inside the terminal as shown in Fig. 4.14. Some Objects offer more options next to the ⬚ Sub-Tab, which contains most general Properties. These may include a ⬚ Sub-Tab, which summarizes component "linkages" with other Loops, and a ⬚ Sub-Tab, which contains controls-related options. Additional Sub-Tabs will appear when the selected Object supports them.

Nodes are the little ⬤ symbols scattered around a Loop and are used to separate all of the Objects contained within Loops. This is an important concept in OpenStudio, because Nodes represent points where physical fluid properties, such as temperature, humidity ratio, and flow rate are known and can be reported. Nodes may also be associated with control points. In Chap. 5 we will discuss how control setpoints may be applied to Nodes in order to drive supply components to follow constant or scheduled performance targets.
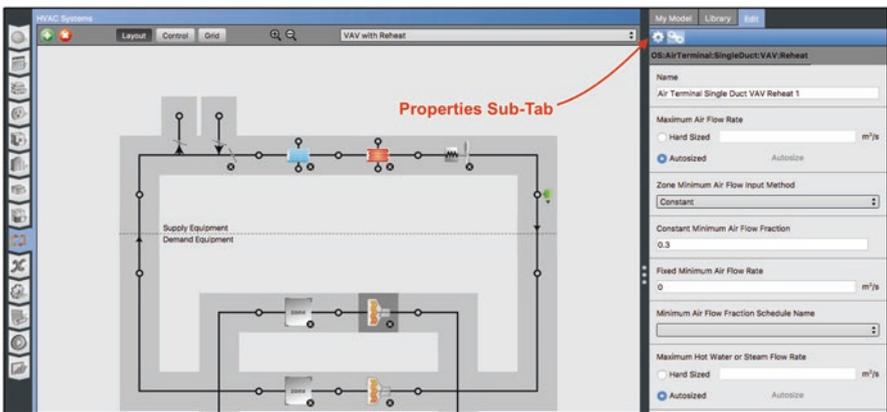

Fig. 4.14 Examining the Properties of an Air Terminal

Managing Nodes and Connections between Objects can be a very tedious and error prone task when using EnergyPlus directly, however OpenStudio's Object model helps take care of this tedious work automatically. Objects may be removed by clicking on their corresponding ⊗ Button. New Objects may be added by dragging them from the [Library] on the right side of the interface and dropping them on to existing Nodes. In either case, OpenStudio adds and remove Nodes as needed so that the user does not need to worry about maintaining Node Connections manually.

Air and Plant Loops are shown individually in OpenStudio and may be browsed using the system selector field at the top of the window. OpenStudio also makes it easy to navigate between interconnected Loops. In this example, the air handler is connected to chilled- and hot-water plants through chilled- and hot-water coils respectively. To navigate to these associated Plant Loops, simply click on either of the smaller Node icons directly above or below a coil as shown in Fig. 4.15.

The interface immediately switches to the correct Plant Loop shown in Fig. 4.16. The chilled water Plant Loop contains the same coil shown on the supply side of the Air Loop. However, from the Plant Loop's perspective the coil appears on the demand side of the chilled water Plant. The chilled water coil's Node links may be used to navigate back to the Air Loop from the Plant Loop.

The Plant Loop contains a pump feeding a single chiller on the supply side of the chilled water plant. Note that the chiller contains its own Nodes above and below the chiller icon that may be used to navigate to the chiller's associated condenser
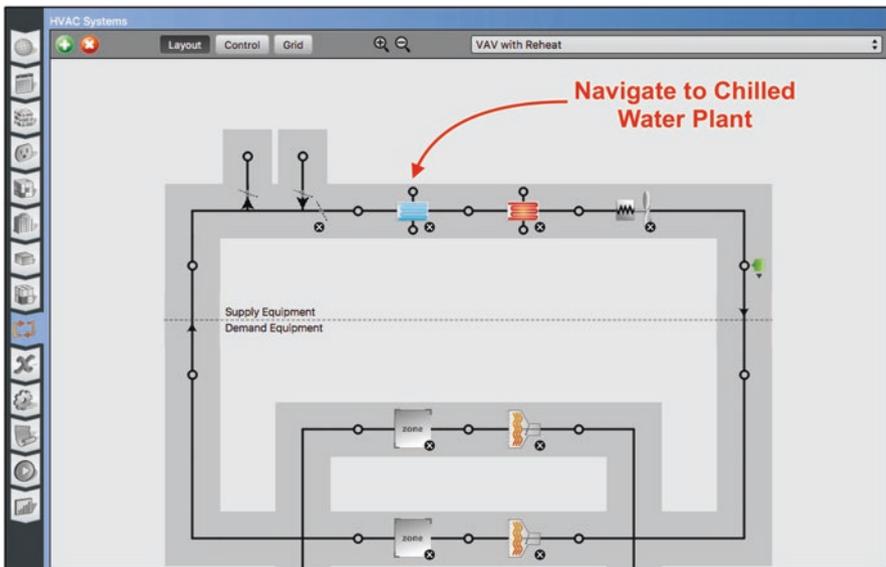

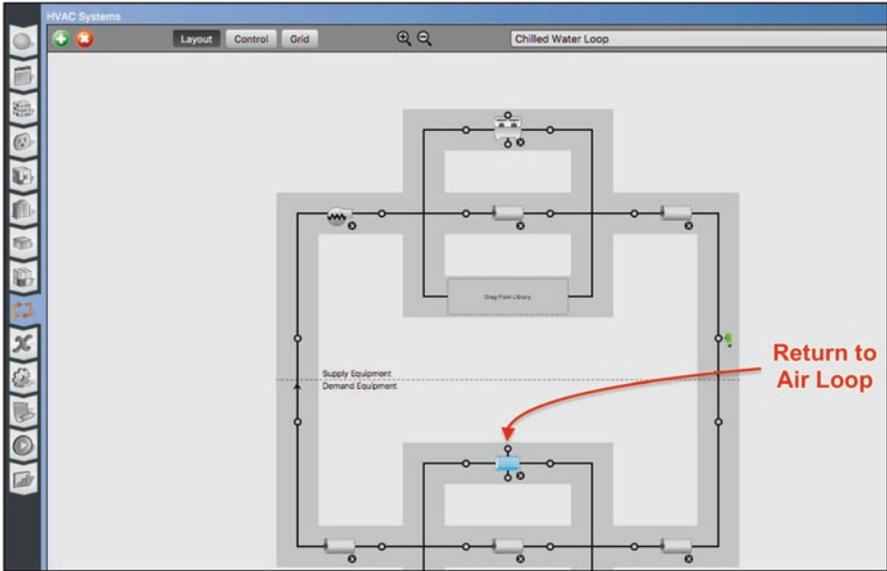**Fig. 4.15** Clicking a Chilled Water Coil Node to Navigate to the Associated Plant Loop

Fig. 4.16   Plant Loop Serving the Air Handler Chilled Water Coil
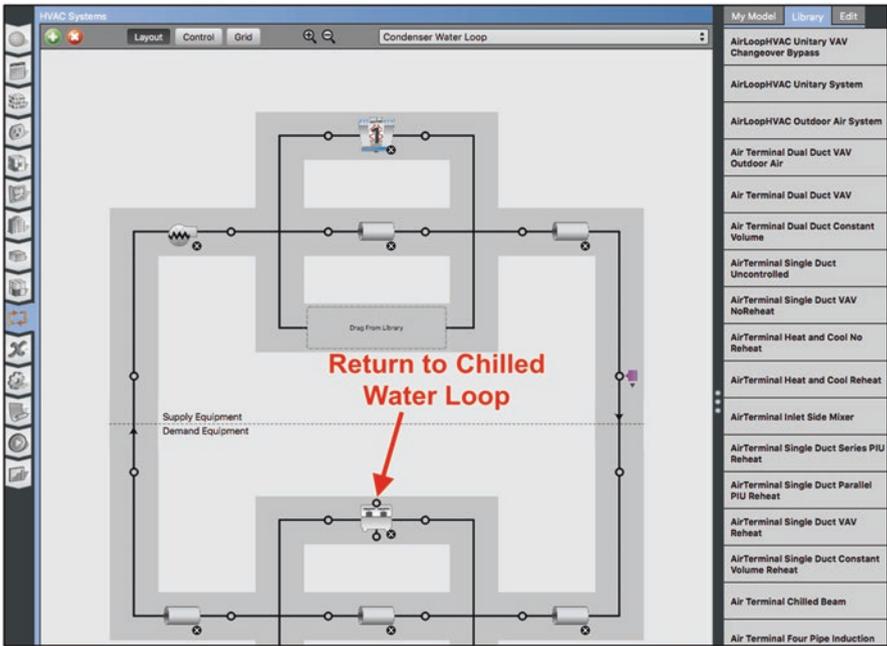

Fig. 4.17   Condenser Loop Serving the Chilled Water Plant

Plant Loop (Fig. 4.17). In this case, the chiller is water-cooled and is modeled as a demand component on the condenser system. Since one Loop's supply objects may often be part of another Plant Loop's demand, Node links are a helpful navigation aid in traversing complex HVAC system topologies.

4.5   Auto-Sizing HVAC Systems

HVAC systems and components in OpenStudio are "Autosized" by default. This means that equipment flow rates, heating and cooling capacities, and other capacity related characteristics are automatically determined by the EnergyPlus simulation engine using sizing algorithms that are driven by the load originating from the Thermal Zones.

The sizing algorithm is a cascading process. First, a load calculation is performed for each Thermal Zone based on extreme weather conditions. This process is similar to the "Ideal Air Load" method we explored in the previous Chapter, and identifies the energy required to maintain a cooling or heating setpoint under peak loading conditions. All of the Thermal Zone Loads associated with HVAC systems are added together to arrive at a total system Load. Individual component sizes are computed using that total Load as a starting point. For forced air-driven system involving fans, system sizing begins by calculating a supply airflow rate based on the Thermal Zone Load calculation and an assumed supply air temperature. In the case of multi-Zone systems, the design supply airflow rates for each Thermal Zone are added together to determine the total system supply airflow rate and supply fan capacity. Finally, the computed airflow rates are used along with design heating and cooling temperatures in order to size the individual heating and cooling coil capacities.

This is an extreme generalization of the sizing process. The actual process used by EnergyPlus is sufficiently sophisticated[3] to handle the breadth of system configurations that may be modeled. Nevertheless, it is useful to have a general understanding about how the process works. The most important takeaway is that HVAC components ultimately have specific capacities in the OpenStudio simulation that are determined by EnergyPlus' auto-sizing algorithms subject to extreme weather conditions and internal loads.

Auto-sized values do not necessarily correspond to realistic systems that are available for purchase. Sizing calculations may result in system components that are unrealistically small or large compared to what are available on the market. In many cases, these artificial sizes can be the result of simplifications in the Model, particularly around Zoning assumptions. Lastly, in most cases HVAC components may be explicitly "hard-sized" to fixed values using available Object parameters.

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[3] Refer to the EnergyPlus Engineering Reference for discussion of the sizing process. http://bigladdersoftware.com/epx/docs/8-7/engineering-reference/.

4.5.1   Design Day Files

As mentioned in Chap. 2, DDY weather files describe the extreme weather conditions used for auto-sizing. Any OpenStudio Model that contains auto-sized HVAC systems must have at least one Design Day input in order to simulate without error. In practice, almost all OpenStudio Models that contain HVAC have at least one auto-sized property and therefore must have Design Day inputs defined. Recall from Chap. 2 that design day DDY files are imported using the Site (◉) Tab (Fig. 4.18).

A DDY file typically contains several different design points for heating and cooling. OpenStudio imports only the subset corresponding to the 0.4% Summer design day point, and the 99.6% Winter design day. This means that in the Summer the design temperature will only be exceeded 0.4% of the time, and in the Winter the temperature will remain above the design temperature for 99.6% of the hours in the year. After importing a DDY file, the Site (◉) Tab updates to show the imported design days (Fig. 4.19). It is possible to add and remove design days manually, using the ■ and ■ Buttons.

4.6   Checkpoint Five: Adding a Template HVAC System to a School Model

In this exercise, we will remove the Ideal Air Loads we added to our primary school Model and replace them with a proper HVAC system. To begin the exercise:

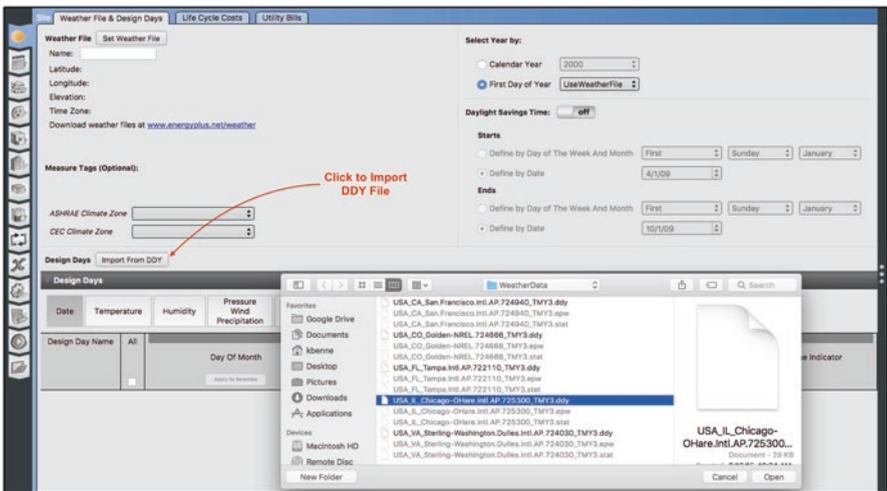1. Open your Primary School Model (or a copy of it) from Checkpoint Four.

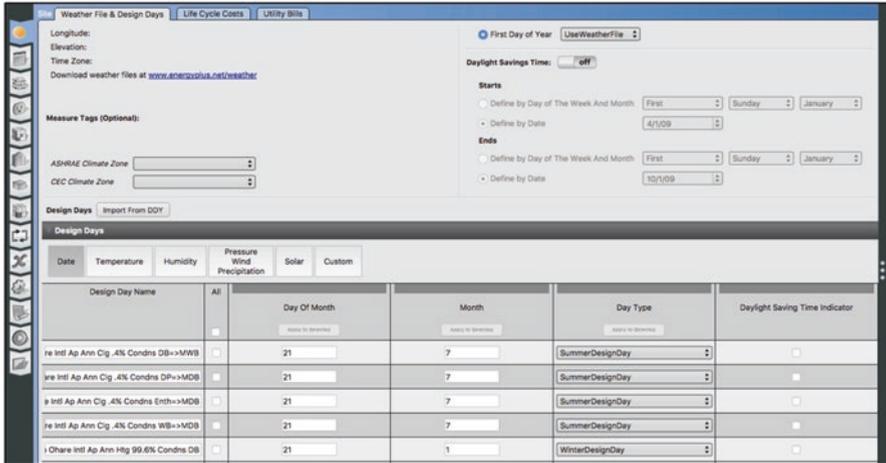**Fig. 4.18**   Adding Design Days from a DDY File

Fig. 4.19 Design Days Added to an OpenStudio Model

2. Use Save As to make a copy of the Model called *MyPrimarySchoolHVAC.osm*.
3. Navigate to the (◼) Tab and import design days from *USA_CO_Golden-NREL.724666_TMY3.ddy*.
4. Navigate to the Thermal Zones (◼) Tab, check all of the Zones, and delete them with the ◼ Button since we are going to rezone the Model.
5. Save your Model.

Begin by Zoning the school Model as shown in Fig. 4.20. The Model should include four Thermal Zones named Thermal Zone 1, Thermal Zone 2, Thermal Zone 3, and Thermal Zone 4. Feel free to perform this task with the floor plan editor or in the Thermal Zones (◼) Tab, whichever you are most comfortable using.

Save your work. We also recommend you make a spare copy of the Model at this point, perhaps called *MyPrimarySchoolZoned.osm* for use in the next Chapter.

Once saved, proceed to the HVAC (◼) Tab. Use the ◼ Button to add four "Packaged Rooftop VAV with Reheat" systems using the available templates. Then add one Thermal Zone to each of the four Air Loops as shown in Fig. 4.21. You can switch between the four Air Loops using the system selector at the top of the window. By default, the Air Loops are named VAV with Reheat, VAV with Reheat 1, VAV with Reheat 2, and VAV with Reheat 3.

Take a few moments to explore some of the Objects that have been automatically added to the Air Loops for you. You may also wish to use the available Node links to examine the Plant Loops connected to the hot and cold coils as well. For example, the hot water Plant loop for Thermal Zone One's air handler is shown in Fig. 4.22. Note that this Plant Loop has <u>two</u> hot water coils on the demand side. Does this make sense? Can you locate the second coil located in the Air Loop?

Fig. 4.20 Primary School
Model with Four Thermal
Zones
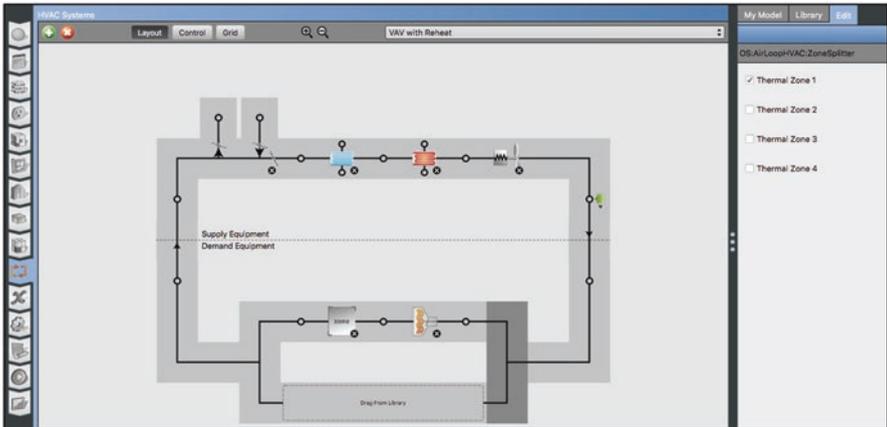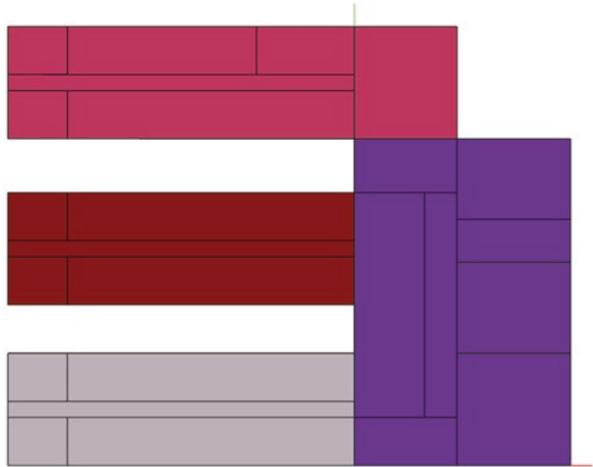
Fig. 4.21 Adding Thermal Zone One to an Air Handler

Run the simulation and examine the OpenStudio Results report. We've looked at
the monthly overview and Thermal Zone overview sections of this report in Chap.
3. The district system heating and cooling energy used by the Ideal Air Loads in
Checkpoint Four have now been replaced with increased electricity and gas use
(Fig. 4.23). The Thermal Zone condition portion of the report shown in Fig. 4.24
indicates that the system is doing a reasonably good job of maintaining the setpoint
temperatures throughout the year.

Along with the Thermal Zone overview shown in Fig. 4.25, additional sections
of the report are now populated with details related to our HVAC systems (Fig. 4.26).

Fig. 4.22 Hot Water Loop Serving Air Handler for Thermal Zone One

Fig. 4.23 Monthly Electricity and Gas Consumption for School with Four Packaged VAV Units

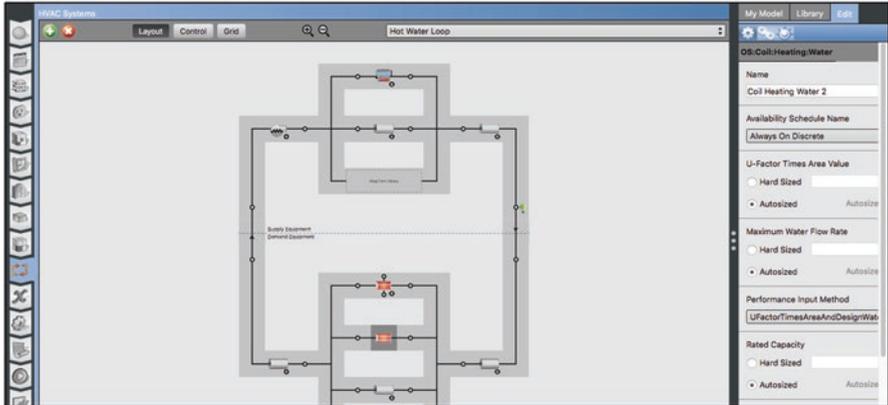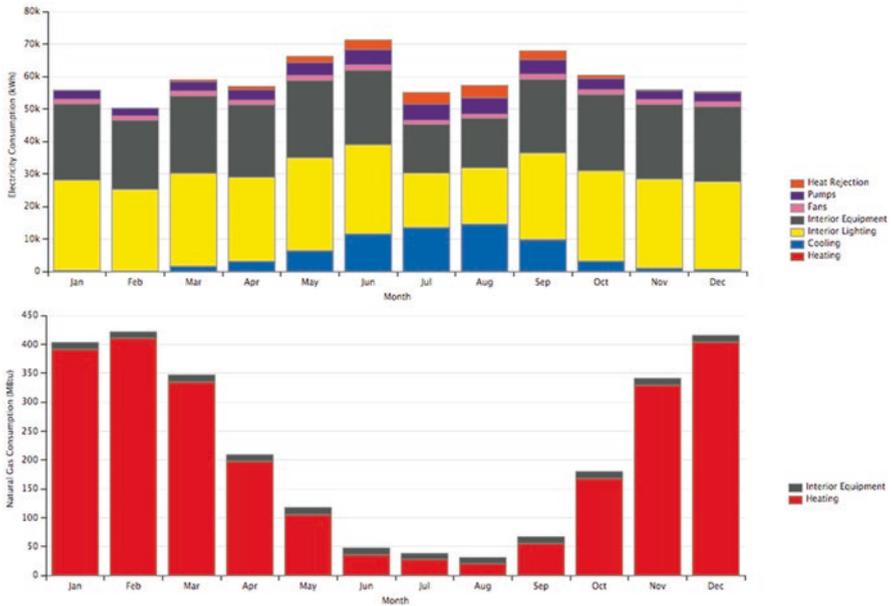| Zone	Unmet Htg (hr)	Unmet Htg - Occ (hr)	< 56 (F)	56-61 (F)	61-66 (F)	66-68 (F)	68-70 (F)	70-72 (F)	72-74 (F)	74-76 (F)	76-78 (F)	78-83 (F)	83-88 (F)	>= 88 (F)	Unmet Clg (hr)	Unmet Clg - Occ (hr)	Mean Temp (F)
THERMAL ZONE 1	105	0	0	1239	1664	354	2559	747	778	1419	0	0	0	0	0	0	68.4 (F)
THERMAL ZONE 2	105	0	0	1229	1667	357	2549	755	777	1426	0	0	0	0	0	0	68.4 (F)
THERMAL ZONE 3	104	0	0	1220	1678	358	2506	727	779	1492	0	0	0	0	0	0	68.4 (F)
THERMAL ZONE 4	123	0	0	954	1848	442	2536	761	886	1333	0	0	0	0	0	0	68.5 (F)

Zone	< 30 (%)	30-35 (%)	35-40 (%)	40-45 (%)	45-50 (%)	50-55 (%)	55-60 (%)	60-65 (%)	65-70 (%)	70-75 (%)	75-80 (%)	>= 80 (%)	Mean Relative Humidity (%)
THERMAL ZONE 1	5032	723	695	668	532	413	350	153	122	65	7	0	30.4 (%)
THERMAL ZONE 2	5040	718	699	669	528	415	347	150	124	63	7	0	30.4 (%)
THERMAL ZONE 3	5034	731	699	673	516	425	339	151	124	61	7	0	30.3 (%)
THERMAL ZONE 4	5142	756	640	656	502	459	287	149	125	44	0	0	29.6 (%)

Fig. 4.24 Zone Conditions for School with Four Packaged VAV Units

	Area (ft^2)	Conditioned (Y/N)	Part of Total Floor Area (Y/N)	Volume (ft^3)	Multiplier	Above Ground Gross Wall Area (ft^2)	Underground Gross Wall Area (ft^2)	Window Glass Area (ft^2)	Lighting (W/ft^2)	People (ft^2/person)	Plug and Process (W/ft^2)
THERMAL ZONE 1	14280.05	Yes	Yes	185640.03	1.00	6344.03	0.0	1903.17	1.15	47.25	0.91
THERMAL ZONE 2	14280.05	Yes	Yes	185640.03	1.00	6344.03	0.0	1903.17	1.15	47.25	0.91
THERMAL ZONE 3	18495.95	Yes	Yes	240448.03	1.00	8033.97	0.0	2410.15	1.17	46.18	0.93
THERMAL ZONE 4	26000.01	Yes	Yes	337999.85	1.00	6006.05	0.0	1801.77	0.91	56.73	5.01
Total	73055.95			949727.95		26727.97	0.0	8018.36	1.07	49.94	2.38
Conditioned Total	73055.95			949727.95		26727.97	0.0	8018.36	1.07	49.94	2.38

Fig. 4.25 Zone Overview for School Divided into Four Thermal Zones

The EnergyPlus standard report is also full of insightful information. For example, the Comfort and Setpoint Not Met Summary shown in Fig. 4.27 corroborates what we noted in Fig. 4.25 above.

Also, note a link in the report's table of contents summarizing "component sizing." These are results from EnergyPlus' auto-sizing algorithm and appear in Fig. 4.28 below. The values in these tables correspond to the calculated Thermal Zone Loads, as well as information pertaining to the capacities of each HVAC component found in the Model. If components were hard-sized then the component sizing summary will echo out the Equipment capacities provided by the user.

As we will see in Chap. 5, we have just scratched the surface of OpenStudio and EnergyPlus capability to model HVAC systems.

VAV with Reheat

Object	Sizing	Sizing Units	Description	Value	Value Units	Count
(supply)						
OS:AirLoopHVAC:OutdoorAirSystem	Autosized	cfm	Minimum Outdoor Air Flow Rate	0.00	cfm	
OS:Coil:Cooling:Water	Autosized	gal/min	Plant Loop	Chilled Water Loop		
OS:Coil:Heating:Water	Autosized	gal/min	Plant Loop	Hot Water Loop		
OS:Fan:VariableVolume	Autosized	cfm	Pressure Rise	2.01	inH_{2}O	
OS:SetpointManager:Scheduled			Control Variable - Temperature	55.0 to 55.0	F	
(demand)						
Thermal Zones			Total Floor Area	14,280	ft^2	1
Thermal Zones			thermostat ranges for cooling	75.2 to 80.6	F	
Thermal Zones			thermostat ranges for heating	60.8 to 69.8	F	
Terminal Types Used			OS:AirTerminal:SingleDuct:VAV:Reheat			1
(controls)						
HVAC Operation Schedule				Always On Discrete		
Night Cycle Setting				StayOff	Choice	
Economizer Setting				NoEconomizer	Choice	
Demand Controlled Ventilation Status				false	Bool	

VAV with Reheat 1
VAV with Reheat 2
VAV with Reheat 3

Chilled Water Loop

Object	Sizing	Sizing Units	Description	Value	Value Units	Count
(supply)						
OS:Pump:VariableSpeed	Autosized	gal/min	Rated Power Consumption	Autosized	W	
OS:Chiller:Electric:EIR	Autosized	Btu/h	Reference COP	5.50		
OS:Chiller:Electric:EIR (cont)			Chiller Source	Condenser Water Loop		

Fig. 4.26 Air and Plant Loop Detail for the Revised School Model

4.7 Additional Exercises

1. Recommended additional exercises involving the Checkpoint Five Model include further study of template HVAC systems and the impact of zoning on system performance.

   - **Be sure to keep a "clean" copy of the Checkpoint Five model before proceeding with these activities.**
   - Replacement of the "Packaged Rooftop VAV with Reheat" template system
   - Remove the existing air and plant loops and replace them with new template systems
   - Reattach the original zones to the new air loop(s)
   - Visually inspect the resulting air and plant loops noting the differences
   - Run the new models and compare their performance with Checkpoint Five.

Setpoint Not Met Criteria

	Degrees [deltaC]
Tolerance for Zone Heating Setpoint Not Met Time	0.20
Tolerance for Zone Cooling Setpoint Not Met Time	0.20

Comfort and Setpoint Not Met Summary

	Facility [Hours]
Time Setpoint Not Met During Occupied Heating	0.00
Time Setpoint Not Met During Occupied Cooling	0.00
Time Not Comfortable Based on Simple ASHRAE 55-2004	1225.67

Fig. 4.27   EnergyPlus Unmet Hours Report

AirTerminal:SingleDuct:VAV:Reheat

	Design Size Maximum Air Flow Rate [m3/s]	Design Size Constant Minimum Air Flow Fraction	User-Specified Constant Minimum Air Flow Fraction	Design Size Minimum Air Flow Rate [m3/s]	Design Size Maximum Flow per Zone Floor Area during Reheat [m3/s-m2]	Design Size Maximum Flow Fraction during Reheat []	Design Size Maximum Reheat Water Flow Rate [m3/s]	Design Size Reheat Coil Sizing Air Volume Flow Rate [m3/s]	Design Size Reheat Coil Sizing Inlet Air Temperature [C]	Design Size Reheat Coil Sizing Inlet Air Humidity Ratio [kgWater/kgDryAir]
AIR TERMINAL SINGLE DUCT VAV REHEAT 1	4.53	0.223283	0.300000	1.36	0.001024	0.300000	0.001848	3.13	12.80	0.008000
AIR TERMINAL SINGLE DUCT VAV REHEAT 2	4.55	0.221990	0.300000	1.37	0.001030	0.300000	0.001845	3.12	12.80	0.008000
AIR TERMINAL SINGLE DUCT VAV REHEAT 3	5.96	0.219805	0.300000	1.79	0.001040	0.300000	0.002340	3.96	12.80	0.008000
AIR TERMINAL SINGLE DUCT VAV REHEAT 4	7.46	0.246697	0.300000	2.24	0.000927	0.300000	0.002555	4.32	12.80	0.008000

User-Specified values were used. Design Size values were used if no User-Specified values were provided. Design Size values may be derived from alternate User-Specified values.

Coil:Heating:Water

	Design Size Rated Capacity [W]	Design Size Maximum Water Flow Rate [m3/s]	Design Size U-Factor Times Area Value [W/K]
COIL HEATING WATER 2	85074.12	0.001848	1742.71
COIL HEATING WATER 4	84936.53	0.001845	1739.89
COIL HEATING WATER 6	107710.89	0.002340	2206.41
COIL HEATING WATER 8	117587.12	0.002555	2408.68
COIL HEATING WATER 1	41623.17	0.000904	540.15
COIL HEATING WATER 3	41865.55	0.000910	543.30
COIL HEATING WATER 5	54764.80	0.001190	710.69
COIL HEATING WATER 7	68591.72	0.001490	890.13

User-Specified values were used. Design Size values were used if no User-Specified values were provided.

AirLoopHVAC

	Design Supply Air Flow Rate [m3/s]
VAV WITH REHEAT	4.53
VAV WITH REHEAT 1	4.55
VAV WITH REHEAT 2	5.96
VAV WITH REHEAT 3	7.46

User-Specified values were used. Design Size values were used if no User-Specified values were provided.

Fig. 4.28   EnergyPlus Auto-Sizing Report

- Rezoning of the Model

- Modify the Thermal Zones from the original Model and compare the performance difference with:

  - Fewer Thermal Zones,
  - More Thermal Zones, and
  - Different Space groupings in the Thermal Zones

- What are the impacts on energy usage?
- What happens to system sizing?
- Do the number of unmet hours change?

2. Use the "Additional Exercises" Model you created in Chap. 3.

- Attempt to zone your Model as accurately as possible by:

- Interviewing your building's facility manager to understand how the building is zoned
- Identifying individual thermostats located within your building's spaces and grouping Spaces within the Model based on their locations.

- Apply one or more template HVAC systems to your Model

- Compare the performance of the systems you've selected
- Modify your Thermal Zoning assumptions and see how performance changes

References

ANSI/ASHRAE/IES Standard 90.1-2016 energy standard for buildings except low-rise residential buildings, ASHRAE, 2016
http://bigladdersoftware.com/epx/docs/8-7/engineering-reference