

Chapter 5

Advanced HVAC Topics



5.1 Introduction

As described in Chap. 4, there are three main categories of HVAC Equipment in EnergyPlus: Plant Loops, Air Loops, and Zone Equipment. This chapter goes into more detail for each of these categories, describing their configuration, sizing, control, and operation. HVAC is a complex topic, and for that reason this chapter only covers the most critical concepts and topics. The authors suggest reading the EnergyPlus Engineering Reference as a supplement to this chapter to learn more.

5.2 Air Loops

Recall that Air Loop are a series of Objects representing HVAC systems that conditions air, which is provided to Thermal Zones for heating, cooling, and ventilation.

5.2.1 Air Loop Configuration

In OpenStudio, an Air Loop is represented by the diagram shown in Fig. 5.1. Air always flows in the directions shown by the red arrows. An Air Loop, assuming it has an outdoor air system with an outdoor air intake and exhaust, is an open system, where some amount of the return air is exhausted and replaced with fresh outdoor air for ventilation.

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Electronic Supplementary Material: The online version of this chapter (https://doi.org/10.1007/978-3-319-77809-9_5) contains supplementary material, which is available to authorized users.

Fig. 5.1 Flow direction in an empty Air Loop

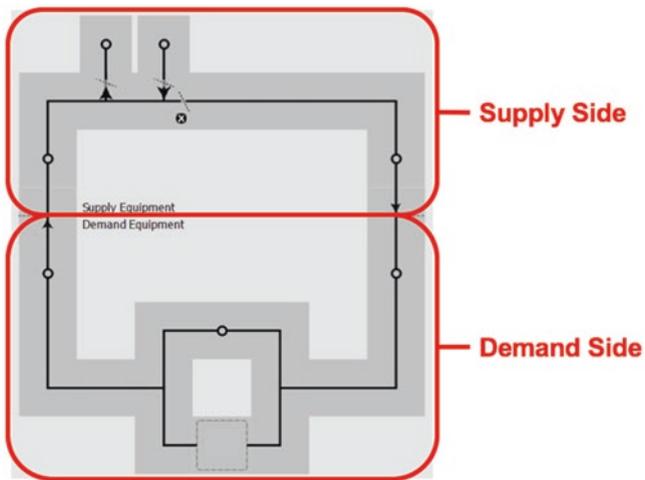
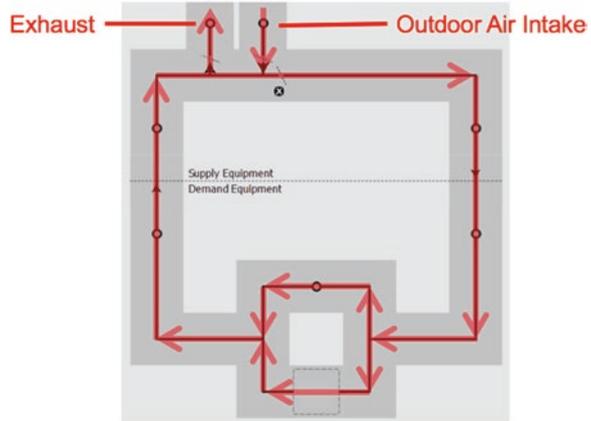


Fig. 5.2 Supply and demand sides of an empty Air Loop

As shown in Fig. 5.2, an Air Loop can first be broken into two pieces, supply and demand sides.

5.2.1.1 Air Loop Supply Side

The supply side of an Air Loop is responsible for:

- Consuming air returning from Thermal Zones via the supply inlet Node,
- Exhausting some of that air to an outdoor air system,
- Consuming replacement air via an outdoor air system,
- Heating, cooling, and humidifying it to the correct supply air conditions, and
- Supplying it to the Thermal Zones via a supply outlet Node.

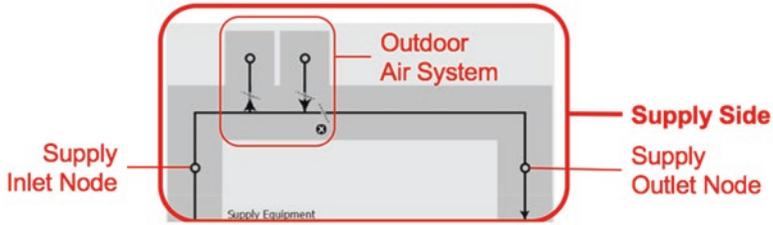
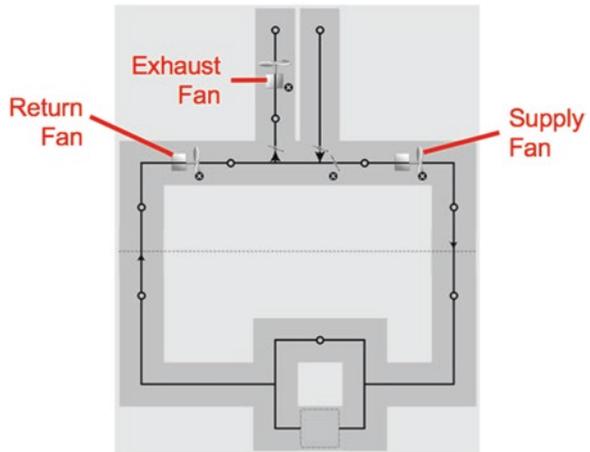


Fig. 5.3 Empty supply side Air Loop detail

Fig. 5.4 Typical fan locations within an Air Loop



An empty supply side portion of an Air Loop is shown in Fig. 5.3. Supply side components may be added to Loop between the supply inlet and outlet Nodes. Outdoor air system components may be added just below the outdoor air exhaust and intake Nodes.

In EnergyPlus, an Air Loop must contain at least one fan on the supply side but may include more than one. Figure 5.4 illustrates three typical locations for a fan. A fan positioned before the outdoor air system is commonly called a return fan. A fan positioned adjacent to the outdoor air system exhaust Node is frequently referred to as an exhaust or relief fan. A fan positioned downstream of the outdoor air system is often called a supply fan.

In EnergyPlus, unlike in real HVAC systems, fans do not drive airflow around the loop. Instead fan Objects utilize the amount of air flowing through them along with prescribed pressure drop and efficiency curves to calculate the energy that would be consumed to move that much air. Supply and return fans must accommodate the full flow rate of the Air Loop, while exhaust fans only experience the exhaust air flow rate. This may seem an odd role for EnergyPlus fan Objects but will become more clear when we discuss how air flow rates are calculated in Sects. 5.2.2 and 5.2.4.

Besides fans, common supply side Equipment includes:

- Outdoor air systems required for systems with ventilation,
- Direct Expansion (DX) or chilled water cooling coils, and
- Electric resistance, gas, or hot water heating coils.

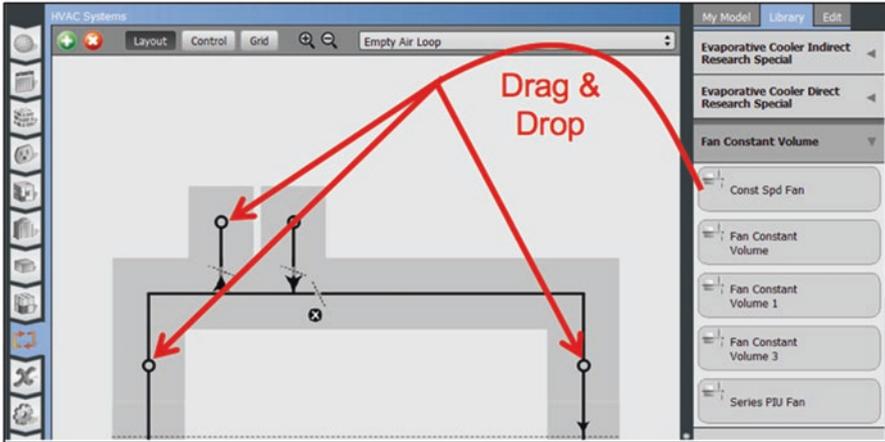


Fig. 5.5 Adding supply side Equipment in OpenStudio

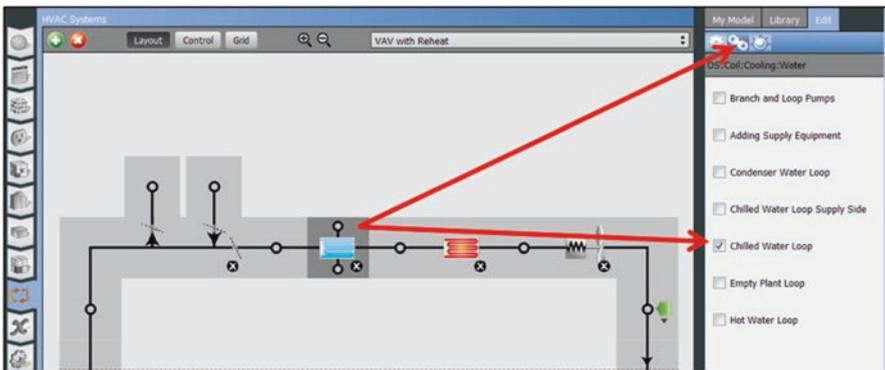


Fig. 5.6 Connecting a coil to a Plant Loop

To add a piece of Equipment to the supply side, first, select the **Library** Sub-Tab in the right-hand pane, then drag and drop Equipment onto a Node (Fig. 5.5). Not everything in the Library may be added to an Air Loop. OpenStudio attempts to help the user avoid nonsensical component placement by displaying a warning dialog and refusing to add the Object. This prevents the creation of invalid Air Loops that EnergyPlus cannot simulate.

Recall from Chap. 4 that Objects such as chilled water cooling coils and hot water heating coils must be connected to Plant Loops. For these components, Plant Loops supply the hot or cold water that the coils require for heat transfer. To connect a coil to a Plant Loop, first click on the coil Object on the diagram to select it. Next, click the **Plant** Sub-Tab under the **Edit** Sub-Tab and check the box to select a Plant Loop. Once a coil is connected, a circle will appear above and below the coil. In Fig. 5.6, the Chilled Water Coil (blue) is connected to the Plant Loop named “Chilled Water

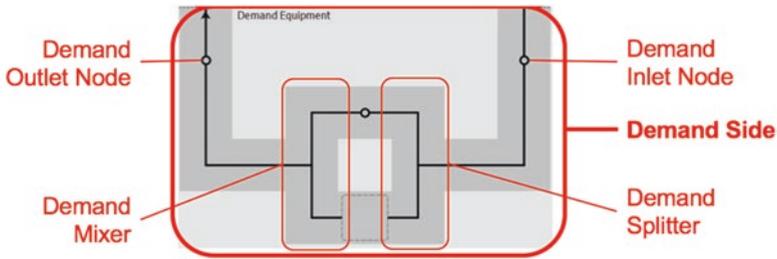


Fig. 5.7 Empty demand side Air Loop detail

Loop,” while the Hot Water Coil (red) is not yet connected, as indicated by the absence of circles above and below the coil icon.

Creating Plant Loop linkages is just one of many required steps that the template systems from Chap. 4 performed for us automatically. However, understanding how such connections are made from Air Loop supply side components is important to understand when creating systems that may not be represented by an HVAC template.

5.2.1.2 Air Loop Demand Side

The demand side of an Air Loop is responsible for:

- Consuming conditioned air from the supply side via the demand inlet Node,
- Distributing it through one or more Thermal Zones, and
- Returning it to the supply side via the demand outlet Node.

As shown in Fig. 5.7, the demand side of an Air Loop includes a splitter and a mixer. The splitter distributes the incoming supply airflow through multiple branches. The mixer recombines the flow from the branches prior to returning it to the supply side for reconditioning.

Air from the Air Loop is supplied to Thermal Zones via Air Terminal Objects. An Air Terminal may be as simple as an air diffuser or more complex like a VAV terminal with integrated reheat. Air terminals are added to Air Loops like other components by dragging them from the **Library** Sub-Tab into the “Drag from Library” drop zone. Each Thermal Zone must be attached via an Air Terminal or the simulation will not run.

Recall from Chap. 4 that Thermal Zones may be added by dragging and dropping from Thermal Zone Objects from the **My Model** Sub-Tab or by clicking on the demand splitter or mixer. The latter method allows the user to check boxes next to the Thermal Zones, quickly adding several at the same time (Fig. 5.8). As an added convenience, OpenStudio automatically pairs additional Thermal Zones with the same Air Terminal used with the first Thermal Zone. When adding multiple Thermal Zones, best practice is to attach the first Thermal Zone and Air Terminal pair, then check the boxes to attach the rest of the Zones.

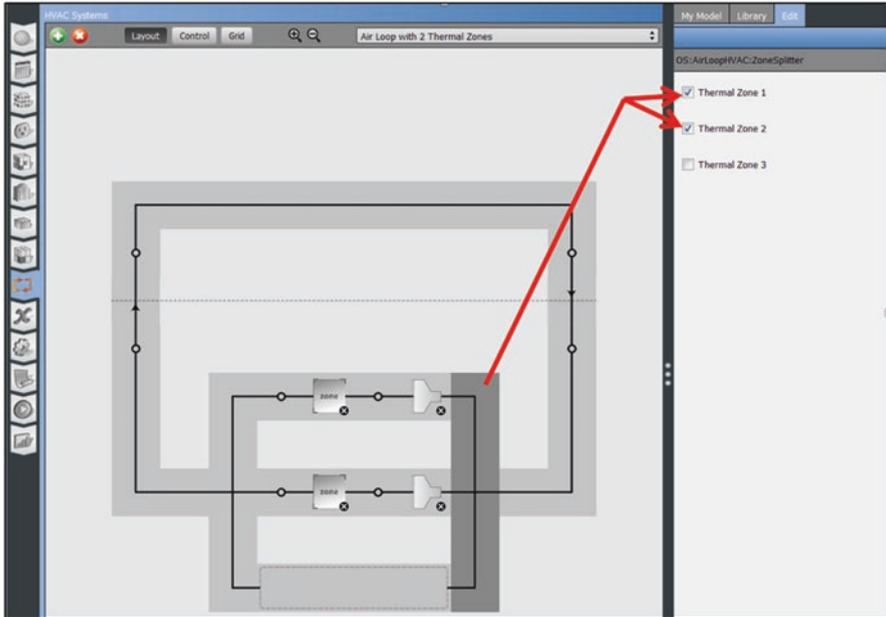


Fig. 5.8 Connecting demand side Air Loop with two Thermal Zones and Simple Air Diffusers

5.2.2 Sizing Air Loops

Recall our high-level discussion of HVAC autosizing in Chap. 4. The sizing of Air Loops begins with the determination of heating and cooling loads for associated Thermal Zones and temperature setpoints for extreme days. One detail we glossed over in Sect. 4.5 was the specification of Thermal Zone sizing parameters. These are defined on the Thermal Zones (🗑️) Tab, as shown in Fig. 5.9 below and specify key supply air conditions for the Air Terminals serving each Thermal Zone. Knowing the Thermal Zone supply air conditions, EnergyPlus can determine the airflow rates required to achieve each Thermal Zone's setpoint for the prevailing thermal loads.

The supply side airflow that must be accommodated by an Air Loop is the sum of all individual Thermal Zone flow rates. This requisite airflow is considered along with the outdoor air (OA) ventilation requirements and the supply air sizing design targets. The sizing parameters associated with a particular Air Loop may be accessed by clicking on the dashed supply/demand line for the Loop shown in Fig. 5.10. These sizing parameters govern the Air Loop design supply air conditions, meaning the conditions delivered by the system before the Air Terminals, sometimes referred to as the deck temperature. For many types of systems, the deck temperature will be different than the Thermal Zone supply air temperature, because the Zone terminal units provide further heating or cooling in order to trim to each Thermal Zone's specific load.

Thermal Zones				
HVAC Systems		Cooling Sizing Parameters	Heating Sizing Parameters	Custom
Name	All	Zone Cooling Design Supply Air Temperature	Zone Cooling Design Supply Air Humidity Ratio	
Thermal Zone 1	<input type="checkbox"/>	57.200000 F	0.008500	Apply to Selected
Thermal Zone 2	<input type="checkbox"/>	57.200000 F	0.008500	Apply to Selected
Thermal Zone 3	<input type="checkbox"/>	57.200000 F	0.008500	Apply to Selected

Fig. 5.9 Thermal Zone design supply air sizing parameters

The screenshot shows the HVAC Systems software interface. On the left, a schematic diagram of an air loop is displayed, with a red oval highlighting a specific section of the loop. On the right, the 'OS:AirLoopHVAC' properties panel is open, showing various design parameters. A red arrow points from the highlighted section of the air loop diagram to the 'Central Cooling Design Supply Air Temperature' field in the properties panel, which is set to 55 F.

Property	Value
Name	Empty Air Loop
Design Supply Air Flow Rate	Autosized
Type of Load to Size On	Sensible
Design Outdoor Air Flow Rate	Autosized
Minimum System Air Flow Ratio	0.3
Preheat Design Temperature	45 F
Preheat Design Humidity Ratio	0.008
Precool Design Temperature	55 F
Precool Design Humidity Ratio	0.008
Central Cooling Design Supply Air Temperature	55 F
Central Heating Design Supply Air Temperature	42 F

Fig. 5.10 Specifying sizing parameters for a particular Air Loop

It is important to note that these parameters only govern how the system is sized, and not how it will actually operate during the course of the simulation. The sizing parameters specify the design heating and cooling supply air temperature, however there are separate input parameters that govern the actual supply temperature during operation. The input Objects and parameters governing the supply air temperature during operation will be described in the forthcoming Air Loop control discussion. For now, note that the parameters governing sizing are distinct from those controlling operation and if there are large discrepancies between the two sets of inputs, then the system will be incorrectly sized for the requested operating range.

Another important aspect of sizing Air Loops is setting available parameters for Air Terminals attached to Thermal Zones. Parameters such as minimum damper position of VAV terminals can impact the sizing of airflow rates. When in doubt about the potential impact of a component parameter on the autosizing process, refer to the EnergyPlus Input Output Reference for more information.

5.2.2.1 Outdoor Air (OA) Sizing

In addition to the determination of heating and cooling airflow requirements, the sizing of an Air Loop involves the determination of minimum OA requirements to provide sufficient ventilation for occupant health. OA sizing starts with the Spaces inside the Thermal Zones attached to the Air Loop. Recall from Chap. 3 that each Space may have a design specification OA Object assigned to it. This Object contains minimum OA requirements for the Space, which may be specified on a per person or per area basis, in terms of air changes per hour, or as a specific flow rate. At the beginning of a simulation, these requirements are multiplied by the appropriate occupancy level, area, volume, etc. and summed to determine the minimum OA flow rate for each Space. The values for all Spaces in a Thermal Zone are summed to determine the minimum OA flow rate that supply-side Equipment must condition to the sizing supply air design targets.

Once the minimum OA flow rates for all Thermal Zones are known, the sizing of the minimum OA flow rate for the Air Loop can happen. Scrolling down further in Fig. 5.10 reveals that the algorithm used to compute OA sizing parameters may be specified by the user as shown in Fig. 5.11. If this field is set to “ZoneSum,” then the minimum OA flow rates for all Thermal Zones attached to the Air Loop are summed to create the minimum OA flow rate for the Air Loop. If this field is set to “VentilationRateProcedure,” then an algorithm defined in ASHRAE 62.1¹ is used. Broadly speaking, this algorithm takes into account system diversity and other Zone and system characteristics to determine the minimum value. This option is generally used for multi-zone VAV Air Loops to ensure that all Zones on the Air Loop receive at least the minimum OA required, even during the worst-case conditions.

¹ANSI/ASHRAE (2016).

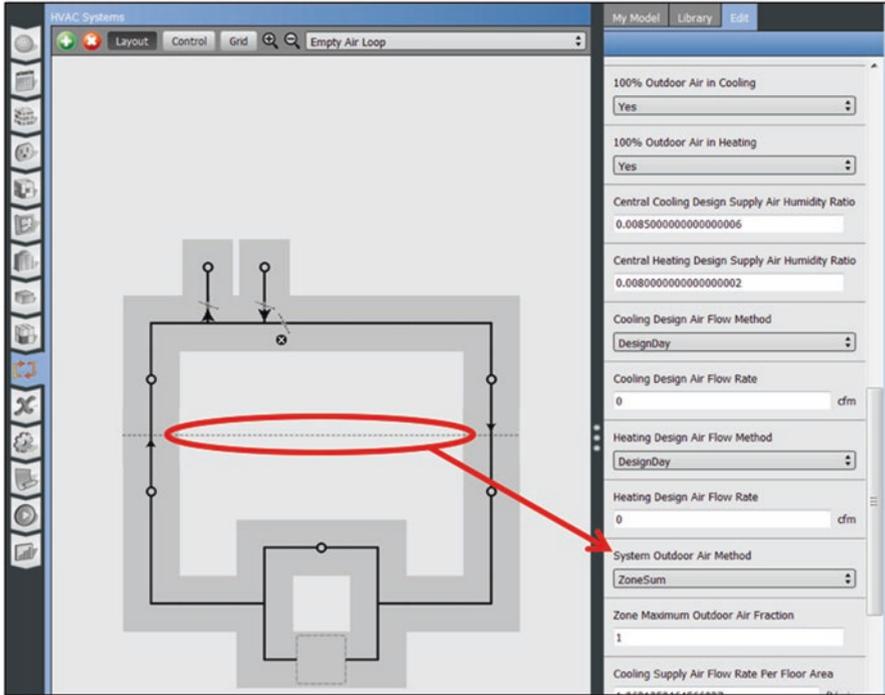


Fig. 5.11 Specifying Outdoor Air Sizing Algorithm for a particular Air Loop

5.2.3 Air Loop Control

5.2.3.1 Air Loop Temperature Control

Air Loops are primarily controlled by setting the temperature (and sometimes humidity) of the supply air. This is accomplished using Setpoint Managers. These objects allow a user to define a temperature or humidity setpoint on a particular Node in the system. Some types of common Setpoint Managers are:

Scheduled: The setpoint follows a schedule, which may be set to a constant temperature. This method is most commonly used on VAV systems where the system is always supplying cool air to the terminals. In these systems, heating is performed by reheat coils integrated directly in the Air Terminals on a Zone-by-Zone basis.

Warmest: This approach increases the temperature of cool supply air until it just meets the cooling load of the Zone with the greatest cooling demand. This is also commonly used with VAV systems to model the “supply air temperature reset” control strategy. For these systems, the control method saves cooling energy while decreasing the use of reheat.



Fig. 5.12 Setpoint Manager on supply outlet Node

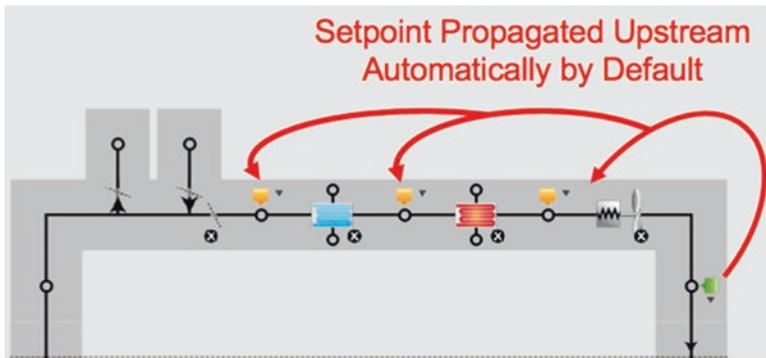


Fig. 5.13 Default OpenStudio Setpoint Manager propagation

SingleZone Reheat: This method adjusts the setpoint to whatever temperature is required to meet the Zone heating or cooling load. It is typically used on Air Loops that serve a single Thermal Zone and the Air Loop is designed to supply hot or cold air as necessary.

The most common configuration, shown in Fig. 5.12, places a single Setpoint Manager on the supply outlet Node. In this case, all of the Equipment upstream of the manager works to meet the setpoint.

Behind the scenes, EnergyPlus actually requires each component to have a setpoint established for its outlet Node. OpenStudio does this automatically by assigning the appropriate Setpoint Managers to all upstream Nodes, while keeping the diagram free of this additional, but necessary clutter. Figure 5.13 illustrates what OpenStudio is doing behind the scenes, and is shown here for completeness. The user is not required to add these additional Setpoint Managers in the user interface.

If a user does not want this default behavior, they may explicitly attach Setpoint Managers to the outlet Node of any supply side components. As an example, in Fig. 5.14 the user elected to set a cooling coil outlet temperature to 50 °F for

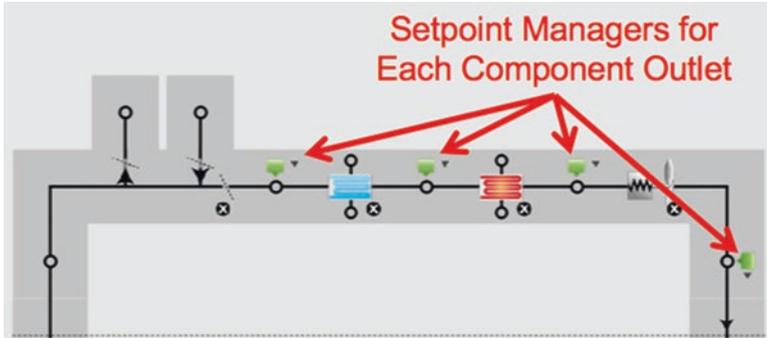


Fig. 5.14 Adding Explicit Setpoint Managers for each supply side component

dehumidification purposes. A manager downstream of the fan could then set the heating coil and fan outlet to 60 °F to avoid condensation problems on uninsulated ductwork leading to the Air Terminals.

5.2.3.2 Air Loop Availability Control

So far, we have considered Setpoint Managers, which are primarily used to control conditions at Nodes throughout an Air Loop. OpenStudio also allows us to specify when control systems may operate. As shown in Fig. 5.15, a **Control** Button allows us to specify control characteristics for our HVAC systems.

The “HVAC Operation Schedule” field identifies a discrete (0/1) Schedule that determines when the selected Air Loop is allowed to operate. During times when this Schedule contains a one, the Air Loop operates normally. When the Schedule outputs a zero, Air Loop operation is determined by the “Use Night Cycle” field. This field may be used to specify one of three operating modes whenever the Schedule evaluates to zero:

- Follow the HVAC Operation Schedule:** The Loop will not operate.
- Cycle on Full System if Heating or Cooling Required:** The Loop only activates for 30 min when the Thermal Zone temperatures get too hot or too cold.
- Cycle on Zone Terminal Units if Heating or Cooling Required:** Any fan-powered Air Terminals attached to the Air Loop will run when the Thermal Zone temperatures get too hot or too cold, but the rest of the Air Loop will not.

5.2.3.3 Outdoor Air Control

Air Loops with an OA system contain three additional control considerations. The first is the Schedule when OA is supplied, and is made available when the OA Object in an Air Loop is selected as shown in Fig. 5.16. This is determined via the

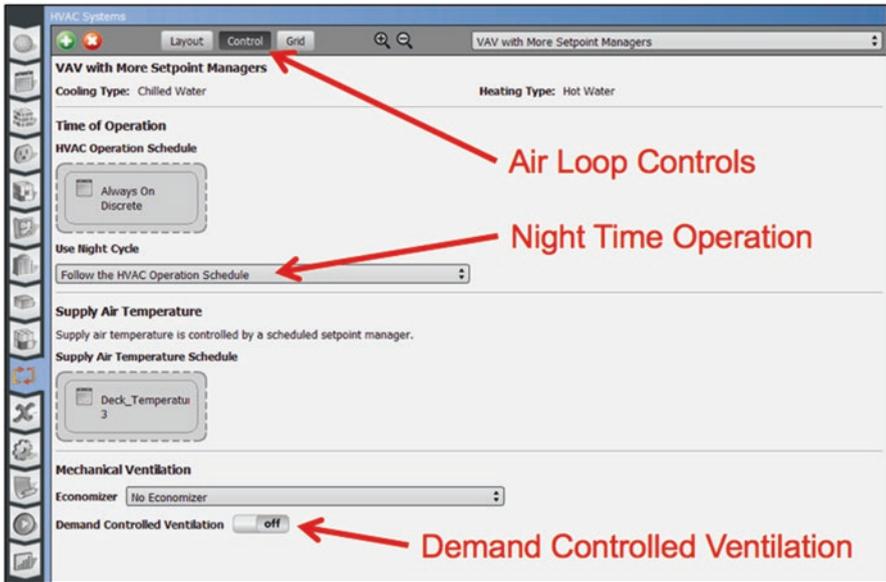


Fig. 5.15 Specifying Air Loop availability control

discrete Schedule listed in the “Minimum Outdoor Air Schedule Name” field shown in the Figure. When this Schedule outputs a zero and the Air Loop is running, OA is not supplied. When this Schedule is set to one and the Air Loop is running, OA is supplied.

HVAC systems with gravity dampers generally have OA supplied whenever the system is operating. These systems should use an “Always On Discrete” schedule in this field. HVAC systems that have motorized dampers generally close the OA intake at night when the building is unoccupied. These systems may also use the “HVAC Operation Schedule” described above to turn off OA at night, even if the night cycle mode is set to manage heating or cooling loads.

The second OA control option relates to economizer operation. Economizers are devices that allow cool OA to be drawn into the system to provide free cooling when OA conditions are favorable. The type of economizer and associated settings may be found in the Controller OA Object, as shown in Fig. 5.16.

A third control option specifies whether the OA system uses demand-controlled ventilation (DCV). This is controlled via a switch on the controls page (Fig. 5.15). DCV is a control strategy that involves monitoring occupancy levels, typically via a proxy like CO₂, and reduces OA below the design flow rate when the occupancy levels are lower.

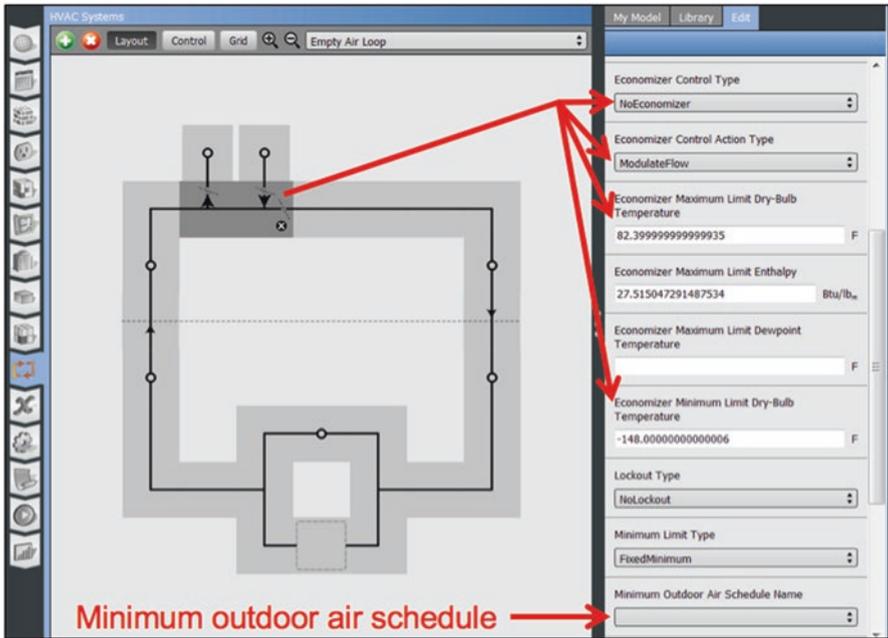


Fig. 5.16 Specifying OA control for an Air Loop

5.2.4 Air Loop Simulation Process

The overall simulation process for each time step may be summarized as follows.

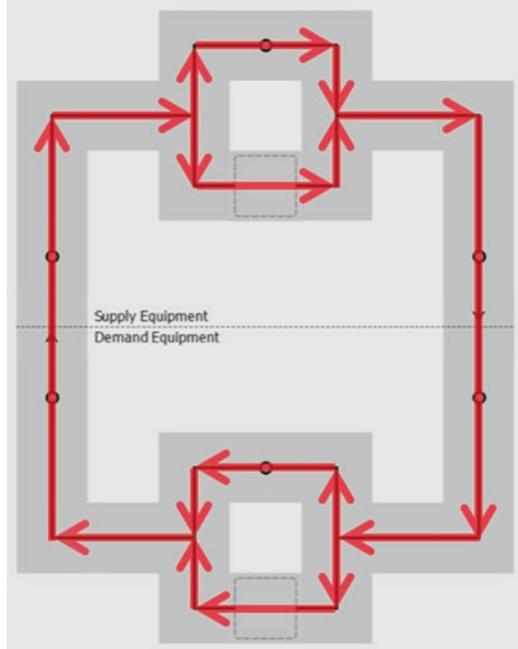
1. EnergyPlus calculates the heating or cooling load in the Thermal Zone.
2. The Air Terminals connected to the Thermal Zone convert this load to an airflow rate given the temperature of air set by the Zone sizing parameters.
 - This is critically important and deserves reiteration in bold text: **the airflow rate in an Air Loop is driven by the Air Terminals**. The parameters of these terminals are the first place to check when understanding flow rate behavior.
3. Once the flow rates for each terminal are determined, they are summed and the total request is passed to the Air Loop itself.
 - If Air Loop parameters limit the total flow rate below this amount, the Air Terminals will be supplied less than they request.
4. Two types of fans may be used in an Air Loop: constant volume or variable volume. The names are a bit misleading however, because both fans will modulate the airflow rate according to the volume of air requested by the Air Terminals. Remember the Air Terminals are in charge. The primary difference between the constant and variable volume fans is that the variable volume fan contains a fan

power curve that modifies the fan efficiency as the requested airflow moves away from the design point, while the constant volume fan simulates a constant efficiency regardless of the airflow rate moving through it.

5. After determining the total supply airflow rate, the Air Loop then uses parameters associated with the OA controller to determine how much of the total Air Loop flow rate will be OA and how much will be return air.
 - If the minimum OA schedule is zero for this time step, no OA is supplied.
 - If the Air Loop needs cooling and the OA conditions are favorable according to the economizer settings, the OA flow rate is calculated to get as close to the setpoint as possible.
 - In the event that no economizing is happening and DCV is enabled, the OA flow rate is calculated by multiplying the per person ventilation requirements for each Zone by the current occupancy level and adding this to the per area and air change per hour requirements.
 - Note that in a multi-Zone system, there is no guarantee that the appropriate amount of OA will reach each Air Terminal, only that the total OA being supplied to the system meets the total minimum OA requirements of all Thermal Zones at this time step. For this reason, it is prudent to review the time series OA outputs to ensure that Zones are being ventilated adequately at all times. Furthermore, mechanical design engineers and OpenStudio users often try to group similar Zones on the same system, to minimize the potential for over or under ventilation of a particular Zone on a multi-Zone system.
 - If DCV is not enabled, the OA flow rate is the design size OA flow rate for the Air Loop.
6. After the return air and OA flow rates are determined, the combined air temperature and humidity are determined by mixing these airstreams at their respective temperatures and humidity levels.
7. The mixed air is then passed to downstream components, which attempt to condition the air based on their outlet Node setpoints.
8. Hopefully, depending on the capacities of these components and their control settings, the supply outlet Node air achieves the desired design temperature and humidity values before it is passed to the Air Terminals.

Sometimes the components cannot hit the setpoints they have been assigned. Perhaps the components have been scheduled to be unavailable, or they simply don't have sufficient capacity. In these cases, the supply air may not be hot or cold enough to meet Zone thermal loads. In these cases, air in the Thermal Zones goes above or below the cooling or heating setpoint. Each hour that a Thermal Zone misses its heating or cooling setpoint beyond an allowable tolerance is defined as an unmet hour. Unmet hours are used as a quality metric to determine whether a Model is generally meeting its setpoints. As a rule of thumb, 350 or fewer total unmet heating or cooling hours during occupied times is considered the threshold for acceptable Model behavior.

Fig. 5.17 Flow direction in an empty Plant Loop



5.3 Plant Loops

A Plant Loop is a series of objects that represent a hydronic piping system inside of a building. A loop may supply hot water, chilled water, or condenser water to various HVAC components within the building. These components turn this water into a service like heating or cooling for some particular part of the building.

5.3.1 Plant Loop Configuration

In OpenStudio, a Plant Loop is represented conceptually by the diagram shown in Fig. 5.17. Water always flows in the directions shown by the red arrows. A Plant Loop is a closed system, so water circulates continuously without leaving.

As shown in Fig. 5.18, Plant Loops like Air Loops break down into supply and the demand sides.

5.3.1.1 Plant Loop Supply Side

The supply side of a Plant Loop is responsible for:

Fig. 5.18 Supply and demand sides of an empty Plant Loop

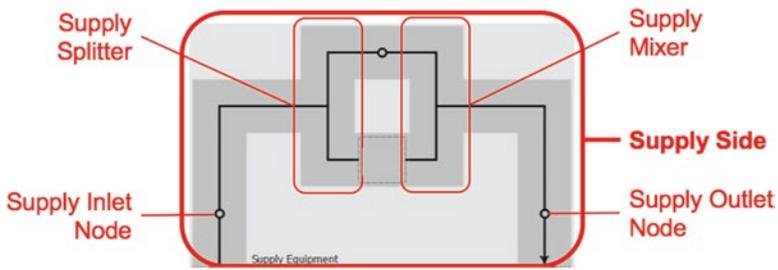
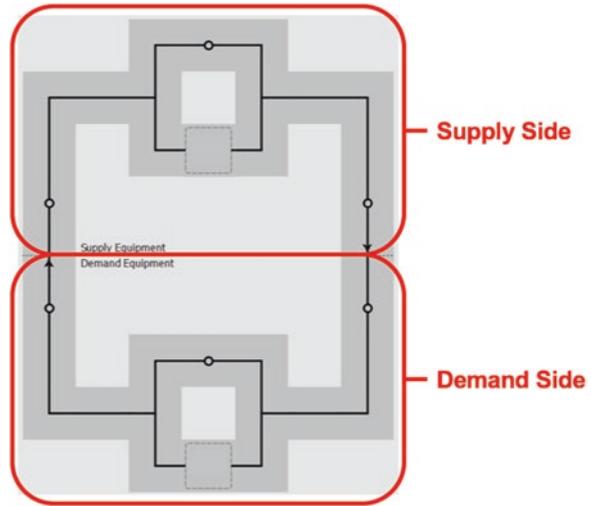


Fig. 5.19 Empty Plant Loop supply side detail

- Consuming water returning from building's HVAC Equipment via the supply inlet Node,
- Heating or cooling it to the correct temperature, and
- Supplying it to the building's HVAC Equipment via a supply outlet Node.

An empty supply side portion of a Plant Loop is shown in Fig. 5.19. Supply side components may be added to Loop between the supply inlet and outlet Nodes.

The supply side of a Plant Loop contains a splitter and mixer. The splitter diverts the incoming flow through multiple branches. The mixer recombines the flow from the branches. For example, Fig. 5.20 illustrates a Plant Loop with two supply side chillers. A walkthrough of the process is as follows:

1. Water enters the supply side at the supply inlet Node and travels to the supply splitter,
2. The flow is divided between the two chillers based on the control sequence,
3. The chillers cool the water,
4. The supply mixer recombines the flows from the chillers, and
5. Water exits the supply side at the supply outlet Node.

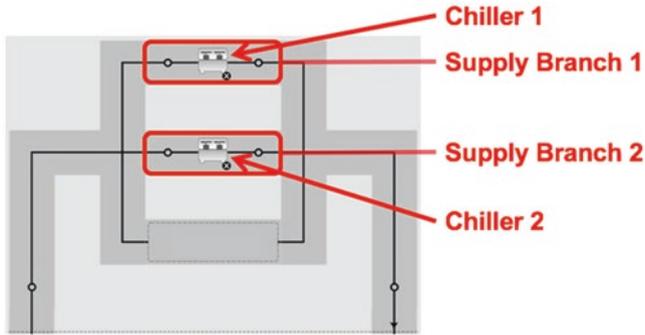


Fig. 5.20 Plant Loop supply side containing two chillers

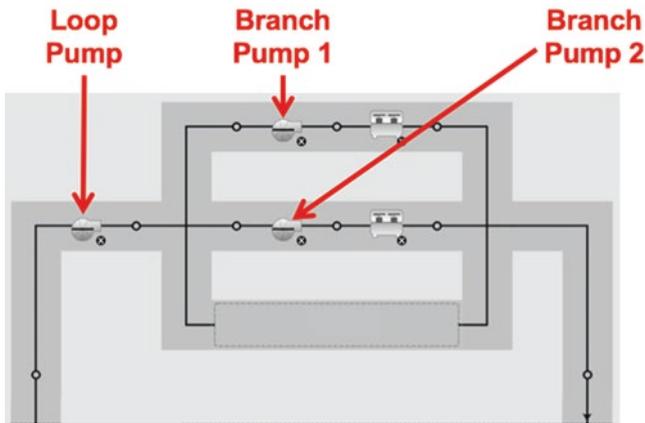


Fig. 5.21 Plant Loop with one Loop and two branch pumps

In EnergyPlus, a Plant Loop must contain at least one pump on the supply side. A pump may be located either on the loop itself or on a branch as shown in Fig. 5.21. Just as we saw with Air Loop fans, pumps in EnergyPlus do not drive water flow around the loop. Instead, the water flow rate through the pumps is established by the flow requests made by the Equipment on the demand side of the Plant Loop. The pumps merely respond to the requested water flow rate and apply lookups for pressure drop and efficiency to account for the energy that would be consumed to move that much water. Loop pumps experience the full flow rate of the Plant Loop, but branch pumps only accommodate the flow rate through their particular branch. The Plant Loop simulation process is discussed further in Sect. 5.3.4, and is similar to the process used for Air Loop calculations.

In addition to pumps, common supply side Equipment may include:

- Chillers,
- Boilers,
- Cooling Towers,

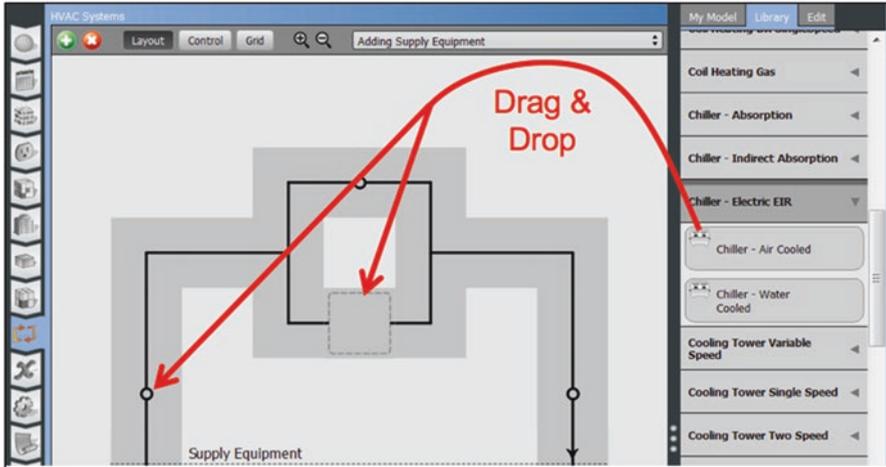


Fig. 5.22 Adding Equipment to the supply side of a Plant Loop

- Fluid Coolers, and
- Heat Exchangers.

To add a piece of Equipment to the supply side, select the **Library** Sub-Tab in the right-hand pane, then drag and drop Equipment onto a Node (Fig. 5.22) or onto the “Drag from Library” drop zone. Not everything in the Library may be added to a Plant Loop. OpenStudio attempts to help the user avoid nonsensical component placement by displaying a warning dialog and refusing to add the Object. This prevents the creation of invalid Plant Loops that EnergyPlus cannot simulate.

5.3.1.2 Plant Loop Demand Side

The demand side of a Plant Loop is responsible for:

- Consuming conditioned water from the supply side via the demand inlet Node,
- Distributing it through the building’s HVAC Equipment, and
- Returning it to the supply side via the demand outlet Node.

As shown in Fig. 5.23, the demand side of a Plant Loop includes a splitter and a mixer. The splitter distributes the incoming supply water flow through multiple branches. The mixer recombines the flow from the branches prior to returning it to the supply side for reconditioning.

Like the supply side of the Plant Loop, the demand side also includes a splitter and a mixer. The splitter distributes the incoming flow through multiple branches. The mixer recombines the flow from the branches before returning it to the demand outlet Node. Figure 5.24 below shows a Plant Loop with two Cooling Coils on the demand side.

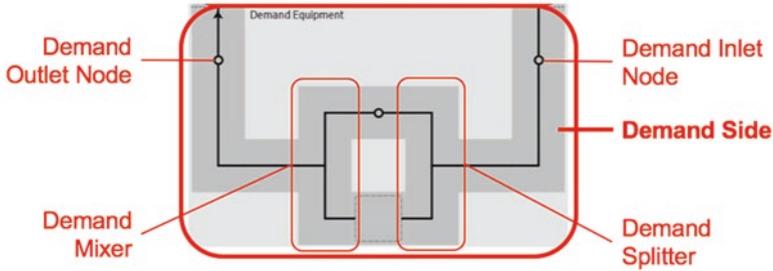


Fig. 5.23 Demand side details of an empty Plant Loop

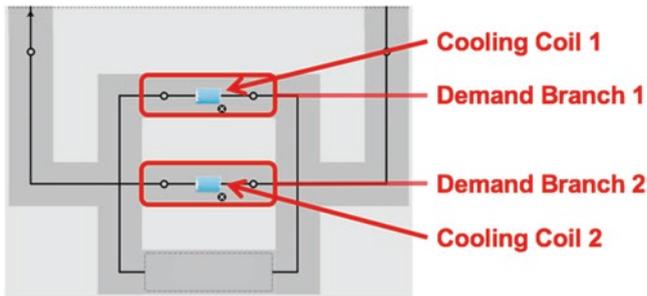


Fig. 5.24 Demand side of a Plant Loop serving two Cooling Coils

A walkthrough of this demand side is as follows:

1. Water enters the demand side at the demand inlet Node and travels to the demand splitter,
2. The flow is divided between the two cooling coils depending on their requested flow,
3. The cooling coils absorb heat from the building, warming the water,
4. The demand mixer recombines the flows from the cooling coils, and
5. Water exits the demand side at the demand outlet Node.

5.3.2 Plant Loop Sizing

The sizing of Plant Loops takes place after the sizing of Air Loops. This is because the heat transfer requirements of the Plant Loop working fluid are dictated by the heat exchange needs of the Air Loop. Figure 5.25 illustrates how air passes through the coil, exchanging heat with the working fluid provided by the Plant Loop.

Recall from previous sections that the Air Loop sizing process determines heating or cooling capacity requirements corresponding to the airflow rate and design supply temperature for each coil. Using the coil sizing parameters shown in Fig. 5.26

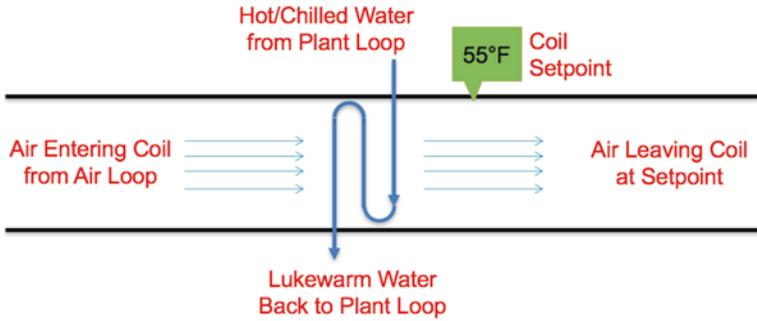


Fig. 5.25 Air and Water Flow through a Coil

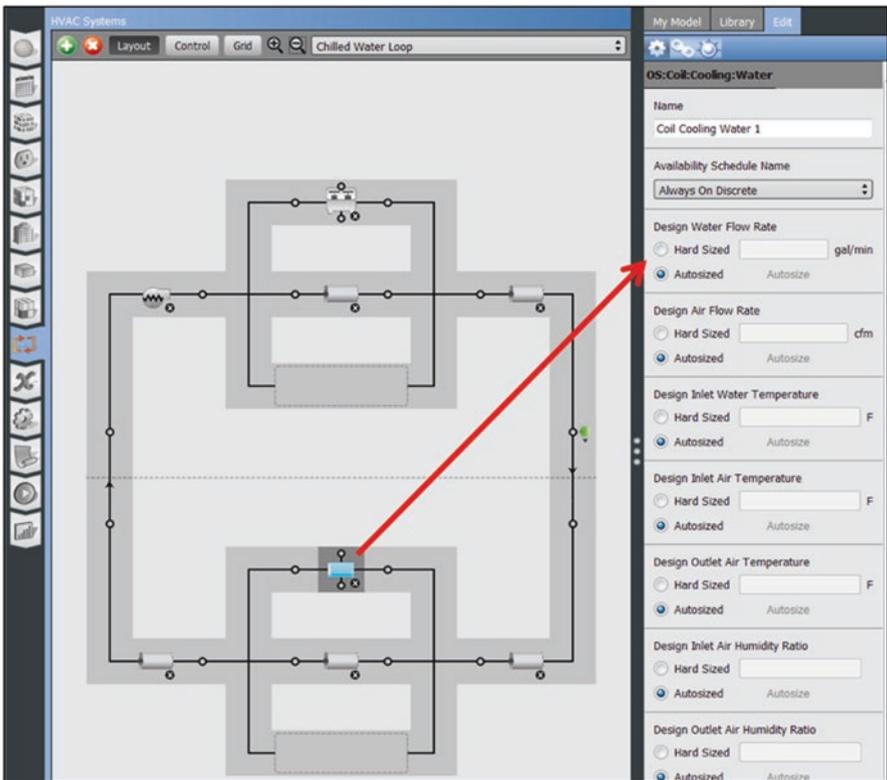


Fig. 5.26 Plant Loop Coil Sizing parameters for hard or autosizing

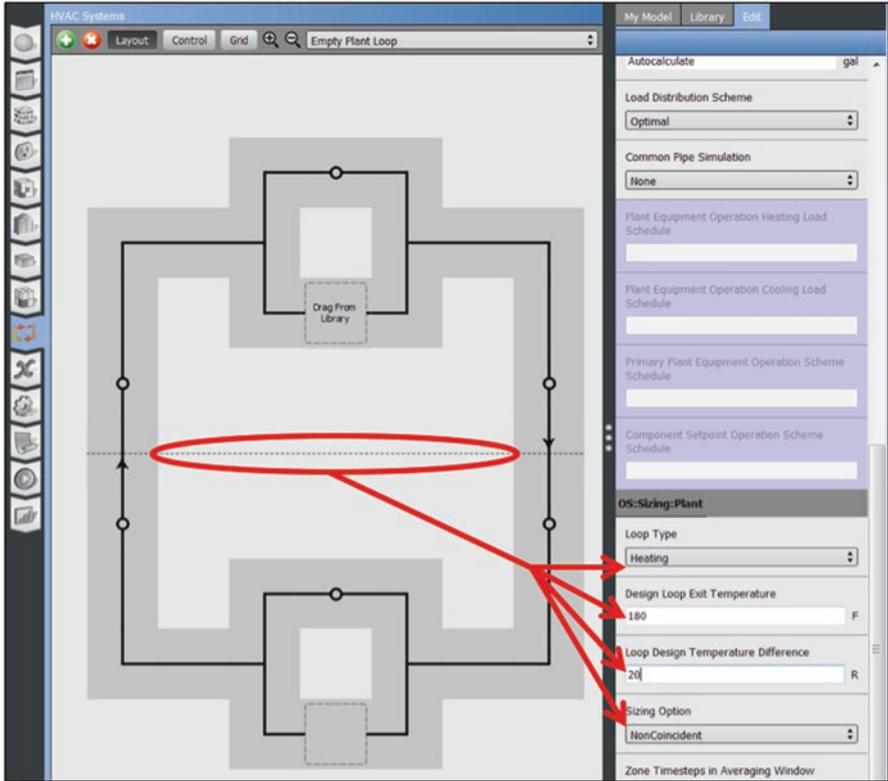


Fig. 5.27 Specifying Plant Loop sizing parameters

and prescribed Plant Loop design temperatures, the water mass flow rate required to achieve a particular heating or cooling capacity may be calculated.²

Clicking the supply and demand dashed line on the diagram displays the Plant Loop parameters, including autosizing values. Figure 5.27 shows the Plant Loop sizing parameters, which include the design Loop supply temperature and desired temperature delta across the demand side. It is important to inspect these parameters for a given application, as they vary depending on the type of Loop - e.g. hot, cold, or condenser water. In addition, the previous discussion about Air Loop sizing applies here, in that the plant sizing parameters are distinct from the properties governing operation. It is important to coordinate sizing parameters with control parameters governing operation. Once the design flow rates and capacities are known for each Plant Loop coil, the flow rates are summed to determine the design flow rate and capacity for the Loop.

²Note in this particular example, all coil sizing parameters are set to autosize and will be computed using the process outlined previously. However, hard sized values could also have been selected for a specific piece of equipment.

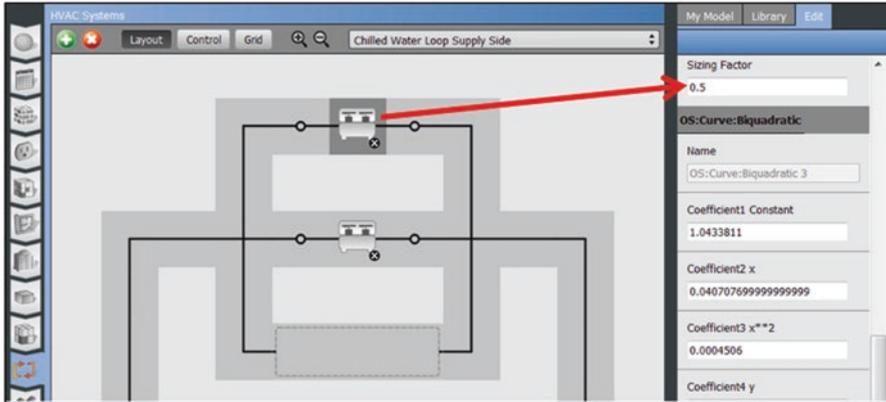


Fig. 5.28 Sizing factor used for components installed on branches

At this point, the Equipment on the supply side of the Plant Loop may be auto-sized. By default, each piece of Equipment on the supply side is sized to accept 100% of the design flow rate and capacity. In instances where multiple pieces of Equipment are intended to operate in parallel, this may not be desirable. A sizing factor for each piece of Equipment determines how much of the total capacity parallel components will be designed to handle (Fig. 5.28).

5.3.3 Plant Loop Control

5.3.3.1 Plant Loop Temperature Control

Plant Loops are primarily controlled by setting the temperature of the water at various points on the loop. As with Air Loops, this is accomplished using Setpoint Managers. These objects allow a user to define a temperature setpoint on a particular Node in the system. Some types of common Setpoint Managers used on Plant Loops include:

Scheduled: Setpoint follows a schedule, generally set at a constant temperature.

This method is most commonly used on VAV systems, where the system is always providing cool air (e.g. 55°F) to the terminals, and heating, if needed, is provided by reheat coils in the Air Terminals on a Zone-by-Zone basis.

Outdoor Air Reset: Modifies the setpoint of the water by linearly interpolating between two points based on two corresponding OA conditions. This is used to apply the “OA temperature reset” control strategy, where for example chilled water temperature is increased when it is cold outside, because less cooling is likely to be needed, or hot water temperature is decreased when it is warm outside, because less heating is likely to be needed.

Follow OA Temperature: Sets the setpoint to the OA temperature (dry bulb or wet bulb) plus or minus a specified offset. Most commonly used to control the temperature leaving cooling towers.

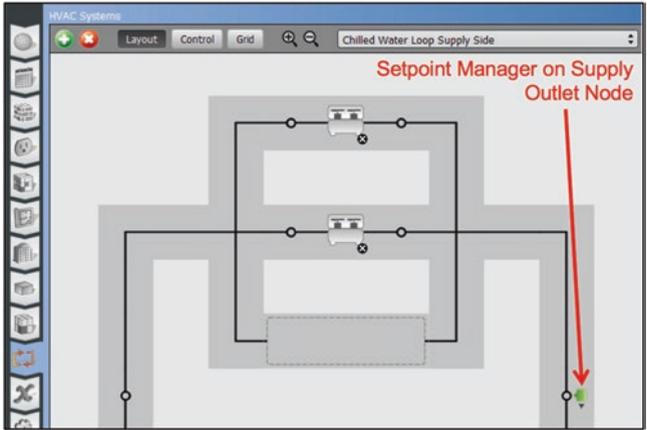


Fig. 5.29 Plant Loop supply control

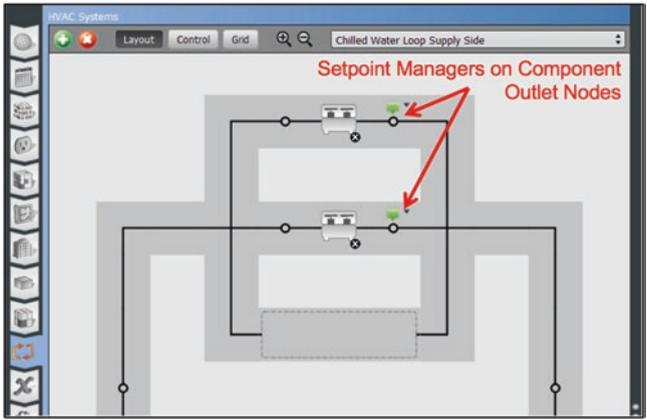


Fig. 5.30 Multiple Setpoint Managers for component control

The placement of Setpoint Managers around the loop determines which type of control scheme is used. There are two main options: Loop level control and component setpoint control. The most common configuration, shown in Fig. 5.29, is to place a single Setpoint Manager on the supply outlet Node. In this case, if the loop needs to provide cooling to meet this setpoint, cooling Equipment on the loop will be dispatched. If the loop needs to provide heating to meet this setpoint, heating Equipment on the Loop will be dispatched. The order of dispatch will be described in the next Section.

The other type of control is component setpoint control. For this type of control, Setpoint Managers are attached to the outlet Nodes of each piece of heating or cooling Equipment (Fig. 5.30). Components will be dispatched to meet these outlet setpoints.

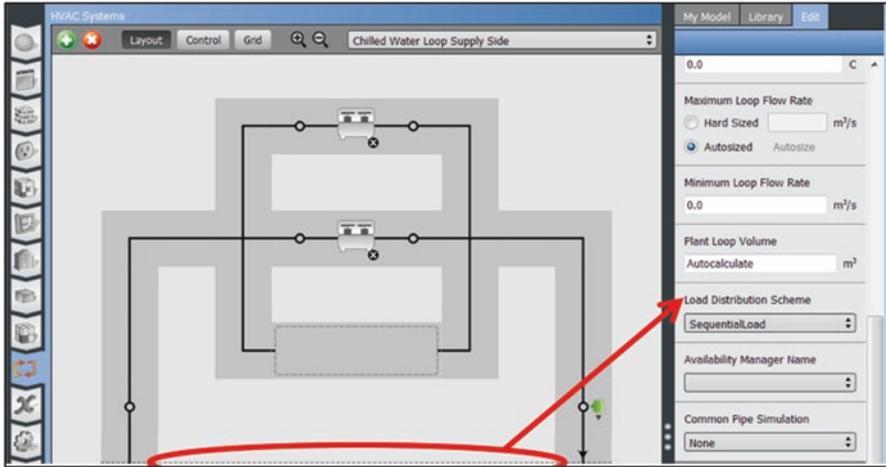


Fig. 5.31 Plant Loop Load Distribution Scheme

5.3.3.2 Plant Loop Equipment Dispatch Control

The order in which Equipment is dispatched to meet a setpoint is based on the setting of the “Load Distribution Scheme” field in the Plant Loop, as shown in Fig. 5.31. Descriptions for each setting are:

Optimal: This setting operates each piece of Equipment at its optimal part load ratio (PLR). This is typically the operating point at which the equipment is most efficient. The last component operates between its minimum and maximum PLR in order to meet Loop demand. For example, if there were three chillers with an optimal PLR of 75%, the first two chillers would operate at 75% capacity and then the third chiller would operate at whatever capacity was required to meet the remaining demand.

SequentialLoad: With this approach, each piece of Equipment operates sequentially from top to bottom on the Plant Loop diagram. Each component is loaded to its maximum PLR. The last required component operates at a PLR between its minimum and maximum required to meet remaining Loop demand.

UniformLoad: This dispatch algorithm evenly distributes Loop demand across all available components.

SequentialUniformPLR: Using this method, components are loaded sequentially from top to bottom on the Plant Loop diagram. If the first unit cannot meet the required load, then a second unit is brought online and both unit PLRs are set equally. Additional units are added in this manner until the load is met.

UniformPLR: The final setting loads all Equipment to a uniform PLR. No Equipment is loaded below its minimum PLR, and one or more units may be shut off to keep the remaining units above minimum PLR.

5.3.3.3 Prescribing Plant Loop Load Ranges

Some dispatch methods limit certain pieces of Equipment between specified bands. For example, only operate chillers one and two when the load is less than 200 tons but operate chillers two and three when the load is between 200 and 500 tons. It is possible to define these load ranges and corresponding sequences of operation in EnergyPlus, but this feature is currently not implemented in the OpenStudio user interface.

5.3.4 Plant Loop Simulation Process

The simulation process for each Plant Loop is similar to how Air Loops are evaluated.

1. EnergyPlus calculates the flow rate demanded by each coil served by the Plant Loop.
2. These are summed to determine the total design flow rate that must be supplied by the Plant Loop for the next time step.
3. Two types of pumps that can be used on a Plant Loop: constant and variable speed. Constant speed pumps process 100% of the design flow rate.
4. If the coils are requesting the full design flow rate, then the entire flow passes through the coils.
 - When less coil flow is required, the difference is bypassed directly to the supply inlet Node. This bypass takes place via an implicit branch not shown in the diagram and behaves just as if a bypass pipe Object was dropped into a branch.
5. Based upon the selected dispatch scheme, the Plant Loop flow is split between each heating or cooling component accordingly.
6. Conditioned water flows are combined by the mixer before being returned to the supply outlet Node.

Sometimes components may not achieve their designated setpoints. This may occur due to component schedules, availability, or lack of capacity. In these cases, the water may not be hot or cold enough to provide sufficient coil heat transfer. These coils, in turn, may not provide sufficient conditioning for Zone loads, resulting in unmet hours. When troubleshooting unmet hours issues, it is often valuable to examine the temperatures and flow rates on Nodes throughout the Plant Loop to understand whether the various setpoints are being met.

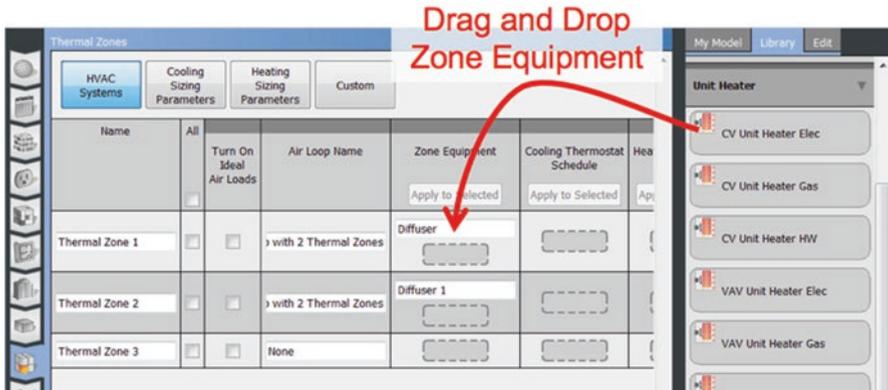


Fig. 5.32 Adding Zone Equipment to a Thermal Zone

5.4 Zone Equipment

Zone Equipment is the third category of HVAC Equipment in EnergyPlus. As discussed in Chap. 4, each piece of Zone Equipment is dedicated to a single Thermal Zone, and operates based on its heating, cooling, and ventilation needs.

5.4.1 Zone Equipment Configuration

Recall that Zone Equipment is added to a Thermal Zone on the Thermal Zones (🏠) Tab. It is dragged from the [Library](#) in the right-hand pane into a specific Thermal Zone's Equipment column (Fig. 5.32). Multiple pieces of Zone Equipment may be assigned to a single Thermal Zone.

A piece of Zone Equipment may be a single Object or contain child components such as fans, heating coils, and cooling coils. The objects that comprise a piece of Zone Equipment may be reviewed by clicking on the Object and scrolling through its properties as shown in Fig. 5.33.

5.4.2 Zone Equipment Sizing

As with Air Loops, the sizing of Zone Equipment begins with determination of heating and cooling loads and required airflow rates for the Thermal Zone it serves. The design flow rate is used to calculate the capacities and flow rates required for any heating, cooling, or ventilation components included within the Zone Equipment. Some types of Zone Equipment contain their own sizing parameters, so it is prudent to review these settings and ensure that they align with the Thermal Zone sizing parameters. Mismatched sizing design parameters may result in over- or under-sized Equipment.

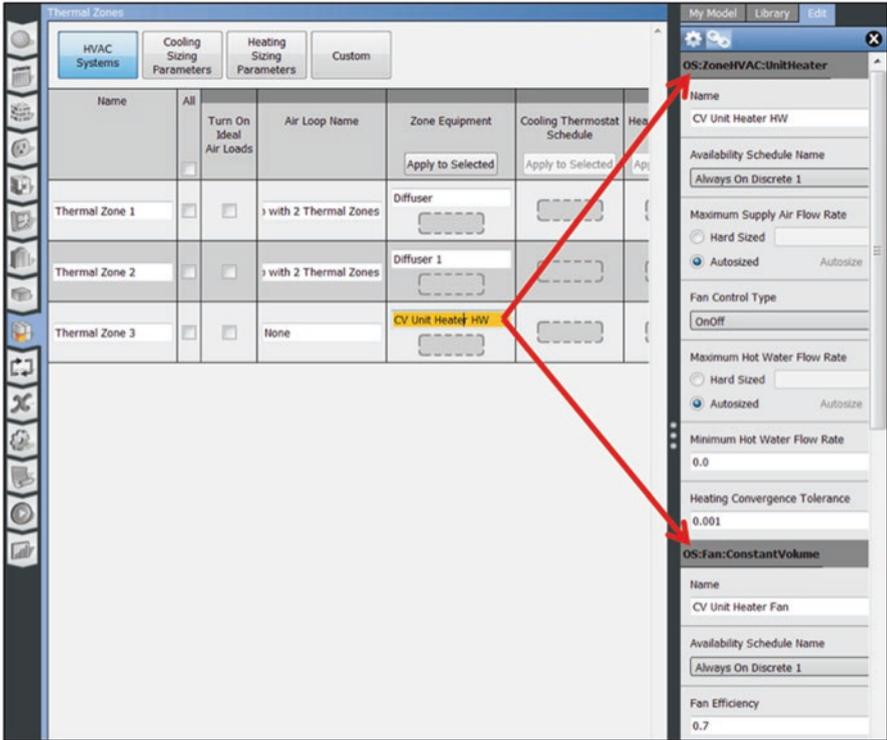


Fig. 5.33 Examining child objects within a piece of Zone Equipment

5.4.3 Zone Equipment Control

Controls are specific to each type of Zone Equipment and are defined in the component **Edit** Sub-Tab. Generally, Zone Equipment responds to the heating and/or cooling set-points in the Thermal Zone being served. Some types of Zone Equipment cycle on and off only to meet loads, while other types meet load and provide OA. Zone Equipment that includes a fan may use a fan operation schedule to denote whether the fan cycles with heating and cooling or runs continuously.

5.4.4 Zone Equipment Simulation Process

The simulation process for Zone Equipment is similar to that used for Air or Plant Loops with the exception that the Equipment is sized to meet the heating or cooling load of its associated Zone. In the event that multiple pieces of Zone Equipment are attached to a single Thermal Zone, they are sized and simulated in order from top to bottom. This means that if additional load remains after the first piece of Zone Equipment is simulated, that load is passed along to the next piece of Equipment listed in the Equipment column.

5.5 Service Water Systems

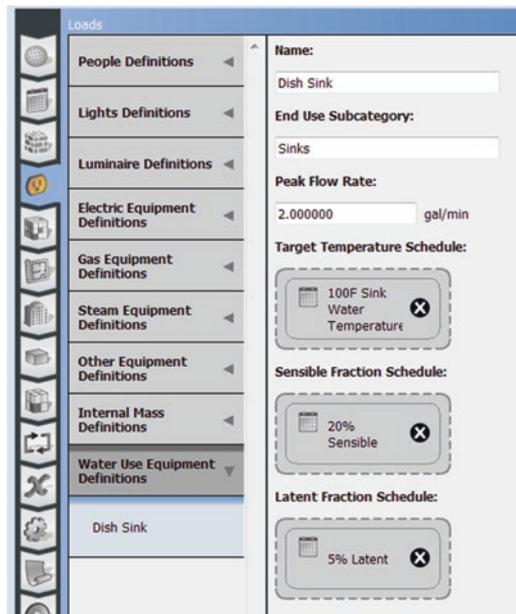
Service Water Systems, sometimes known as domestic water systems, are the systems in buildings that supply water for purposes of drinking, cooking, washing, flushing toilets, irrigation, etc. Sometimes this water is cold, and sometimes this water is heated. EnergyPlus, and, by extension, OpenStudio, can model the usage of cold and hot water, and the energy required to heat the water.

5.5.1 Defining Water Use Equipment

Water Use Equipment is modeled in a similar manner to electric Equipment or lights. First, a definition is created to represent a piece of Equipment such as a toilet or sink. Like other loads, Water Use Equipment definitions are created on the Loads (🔌) Tab. As shown in Fig. 5.34, a user may specify the peak flow rate, a target temperature, and the sensible and latent fractions, which will be introduced to the Space.

The target temperature schedule determines how hot or cold the water being supplied will be. In many cases, especially in commercial buildings, the hot water being provided by the water heater may be set to a temperature like 140 °F that is too hot for some uses like hand washing. In this case, OpenStudio mixes cold water in with

Fig. 5.34 Creating a Water Use Equipment definition



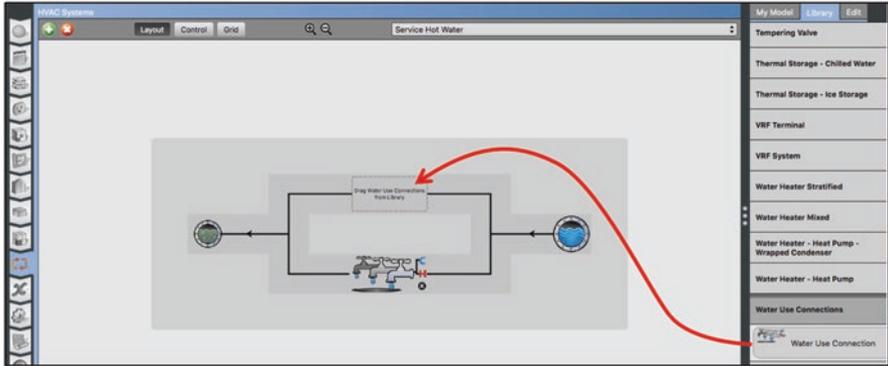


Fig. 5.35 Adding a water use connection to the service Hot Water Loop

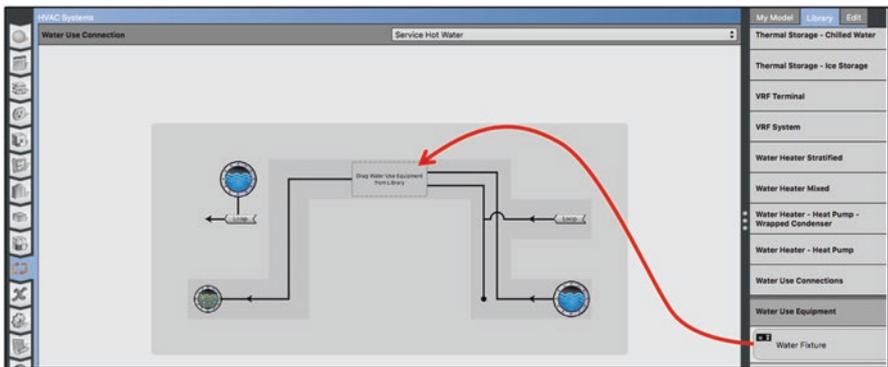


Fig. 5.36 Adding a sink to an empty water use connection

the hot water to match the target temperature. For Equipment that uses cold water like toilets and irrigation, the target temperature schedule may be set to a value below that of the temperature supplied by the water mains.

5.5.2 Adding Water Use Equipment to a Model

Adding Water Use Equipment to the Model requires multiple steps on the HVAC (HVAC) Tab. Begin by selecting “Service Hot Water” from the system selector at the top of the window. Water use Connection Objects are added to the Model by dragging them from the Library as shown in Fig. 5.35.

This Object connects the Water Use Equipment inside it with the cold-water main entering the building and, optionally, a hot water Loop. By clicking on the Water Use Connections Object, a new view appears (Fig. 5.36) into which Water

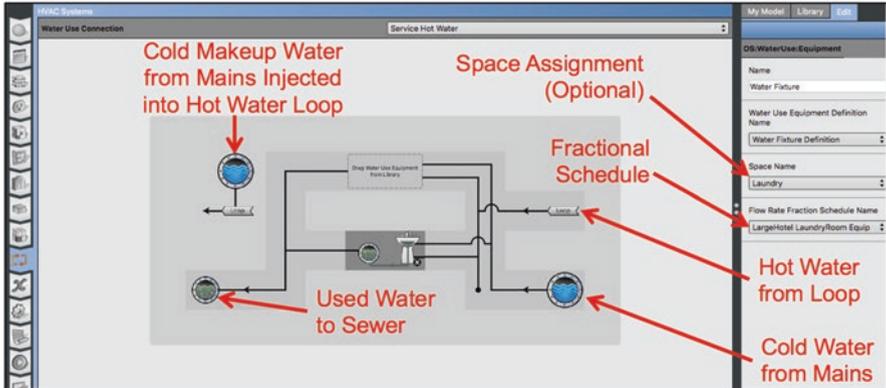


Fig. 5.37 Adding Equipment to a water use connection

Use Equipment may be dragged and dropped. Water use Equipment may be added from either **My Model** or **Library**.

Figure 5.37 illustrates a Water Use definition for a sink that has been added to a Water Use Connection diagram. Cold water is always supplied to every Water Use Connection. This is unheated water straight from the water mains. A fractional schedule is required for each piece of Equipment that is added. Like other loads, the value of this schedule is multiplied by the peak flow rate at each time step to determine how much water is used. Water Use Equipment may be optionally added to a Space to reflect additional sensible and latent loads. If only cold water is being used, this step may be omitted.

For Water Use Equipment that requires hot water, an additional step is needed. The Water Use Connection containing the Water Use Equipment must be attached to the demand side of a Plant Loop with a water heater or boiler. Figure 5.38 shows a service water Loop with a hot water heater on the supply side and a Water Use Connection on the demand side. EnergyPlus requires a pump on any Plant Loop.

Tip: Some buildings do not contain a recirculation pump, instead relying on mains pressure to drive flow. To model these cases, a variable speed pump can be added to the Plant Loop with a pressure rise of zero so that the pump does not consume power.

Because water heaters in OpenStudio cannot be auto-sized, capacities must be entered manually. This means that a water heater may not be able to keep up with the demand from the Water Use Connections. For unmet heating and cooling hours, there is a convenient internal variable in EnergyPlus that tracks whether setpoints

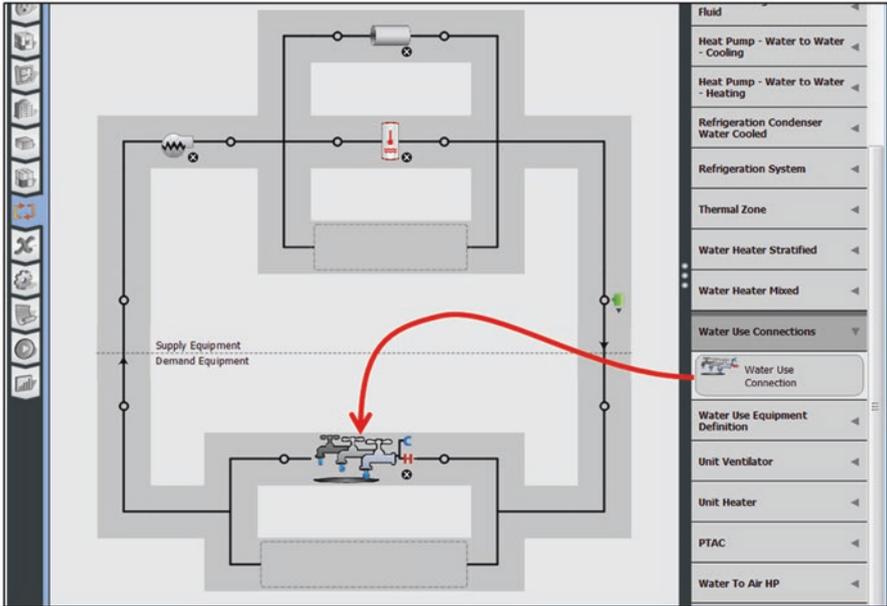


Fig. 5.38 Adding a hot water connection to a Hot Water Loop

are met. There is no equivalent for whether or not the setpoint of Water Use Equipment is met. For this reason, it is advisable to review the detailed time series output of the leaving temperature of Water Use Equipment to ensure that it is meeting the target temperature schedule. If it is not, the size of the water heater may need to be increased.

5.6 Checkpoint Six: Air Loops

In this and subsequent Chap. 5 exercises we are going to build up from scratch the VAV systems that were created using templates in Chap. 4. This will allow us to gain familiarity with OpenStudio’s capability for modeling complex HVAC systems, while comparing our results from the known results we achieved in the previous exercise. If you followed our instructions from Chap. 4, you made a copy of your rezoned school Model called *MyPrimarySchoolZoned.osm*. Open this Model and proceed to the HVAC (H) Tab to begin. Alternately, you can open *MyPrimarySchoolHVAC.osm* and delete all Air and Plant Loops from that Model with the (X) Button.

We need to begin by creating an empty Air Loop. Empty loops are found amidst the other template systems. Use the (A) Button on the HVAC (H) Tab to add one as shown in Fig. 5.39.

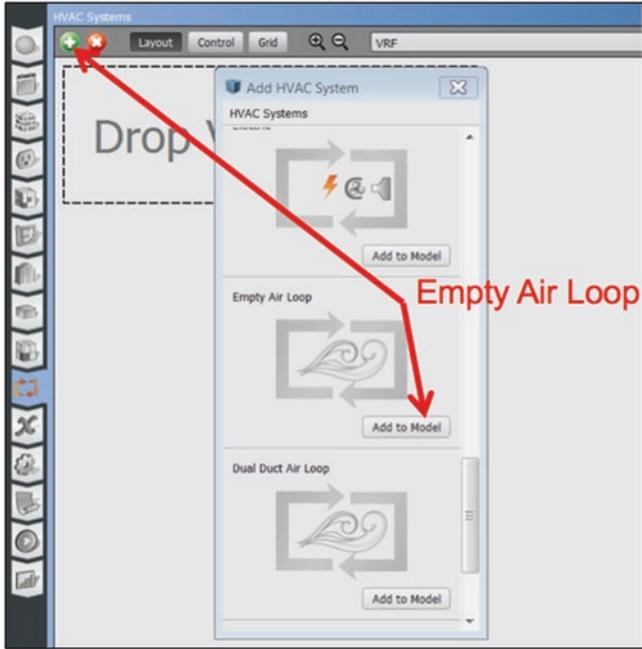


Fig. 5.39 Adding an empty Air Loop

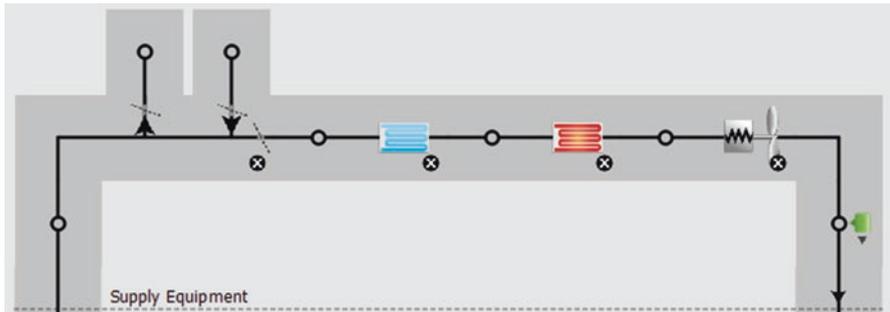


Fig. 5.40 Air Loop with initial supply Equipment components

Once the empty Loop has been added follow these steps:

1. Add Objects to the Loop by dragging them from the [Library](#) onto Nodes as shown in Fig. 5.40:
 - (a) OA
 - (b) Coil Cooling Water
 - (c) Coil Heating Water
 - (d) Fan Variable Volume
2. Click on the dashed supply/demand line in the Loop to open the Loop Object.
3. Name it “My VAV Air Loop.”

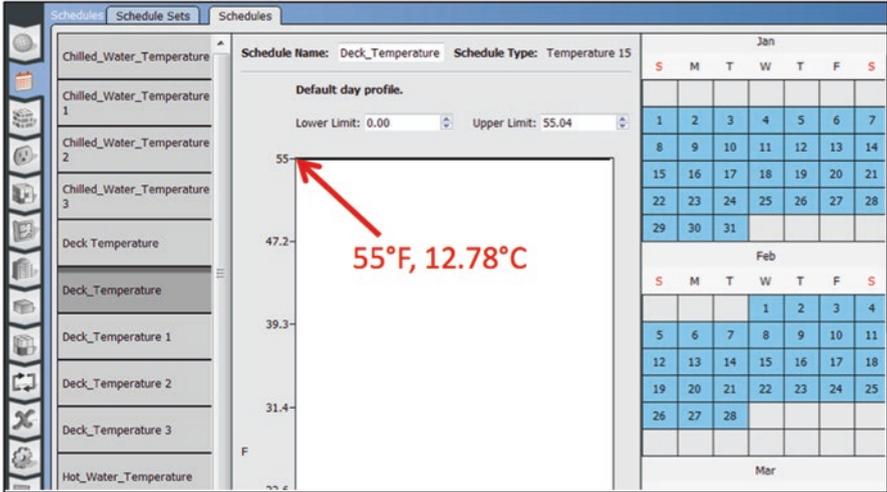


Fig. 5.41 VAV outlet setpoint temperature

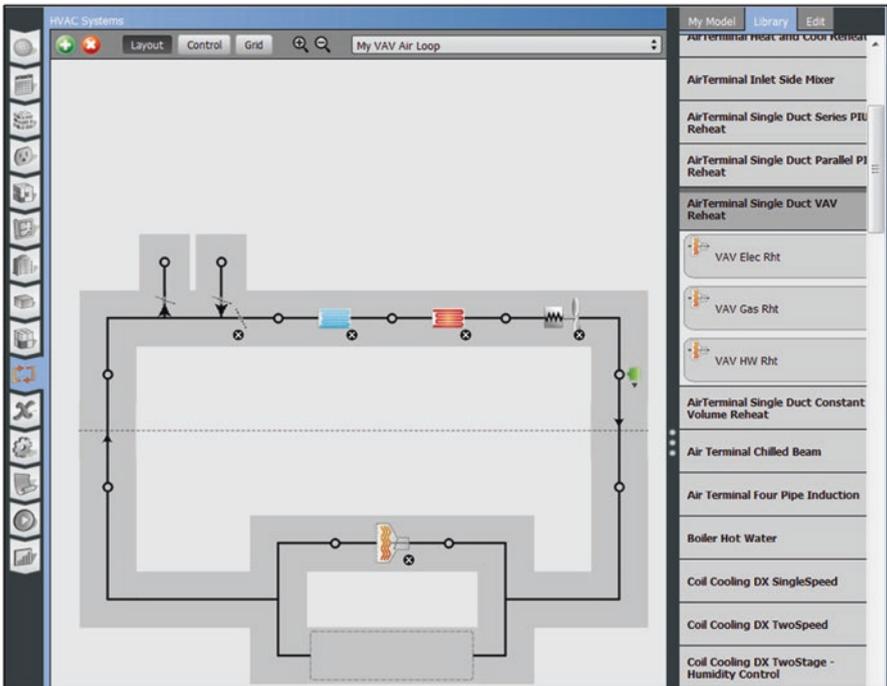


Fig. 5.42 Air Loop with VAV reheat terminal

1. Add a “Setpoint Manager Scheduled” Object to the supply outlet Node. We need to assign a constant 55 °F supply air temperature to this Object.
2. Use the Schedules (📅) Tab to create a constant “Deck Temperature” Schedule as shown in Fig. 5.41.
3. Return to the HVAC (🔧) Tab and assign it to the Setpoint Manager’s Schedule.

Next navigate in the [Library](#) to locate the “AirTerminal Single Duct VAV Reheat” terminal Objects. Select the “Hot Water (HW) Reheat” Object and drag it to the demand side. The result should now look like Fig. 5.42.

Save your work, and then compare this diagram with the VAV air handler from Chap. 4. Can you spot anything missing? Full marks if you identified that the Thermal Zone and Plant Loop Connection Nodes are missing from both coils. We will correct all three omissions in the next exercise, but we have successfully built our first Air Loop by hand.

5.7 Checkpoint Seven: Plant Loops

In this exercise we will add chilled, condenser, and hot water Loops to our Model by building them up from individual Objects. Begin by adding a chilled water Loop. Use the [+](#) Button on the HVAC (🔧) Tab to create an empty Plant

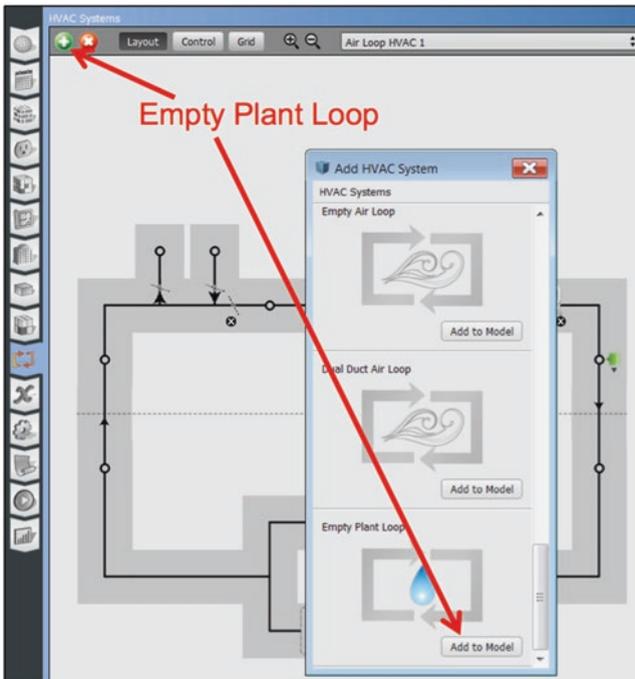


Fig. 5.43 Add an empty Plant Loop

Loop, as shown in Fig. 5.43. Click on the dashed supply and demand line to open the Plant Loop Object in the editor and change its name to “My Chilled Water Loop.”

1. Add Objects to your Loop by dragging them from the **Library** onto Nodes as shown in Fig. 5.44:
 - (a) Pump Variable Speed
 - (b) Water Cooled Chiller Electric EIR
 - (c) Bypass Pipe Adiabatic
 - (d) Setpoint Manager Scheduled
2. Name the chiller “My Water Cooled Chiller.”
3. Add a Setpoint Manager that will maintain a constant supply water temperature of 44 °F.
4. Click on the supply/demand line to set the Loop sizing parameters, ensuring that:
 - (a) The Loop type is Cooling

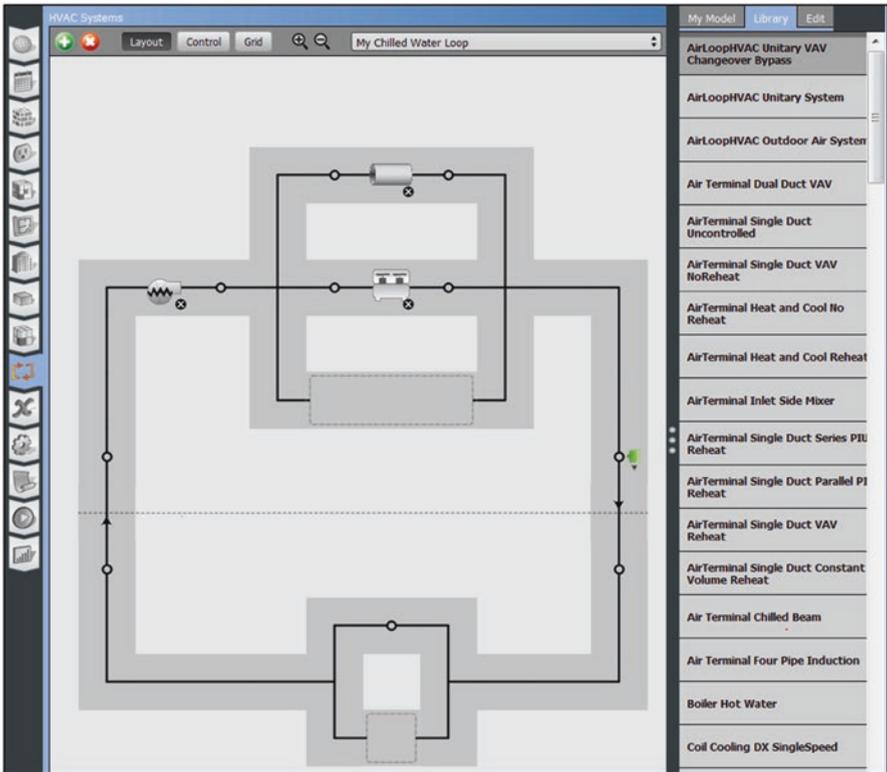


Fig. 5.44 Chilled Water Loop with initial components

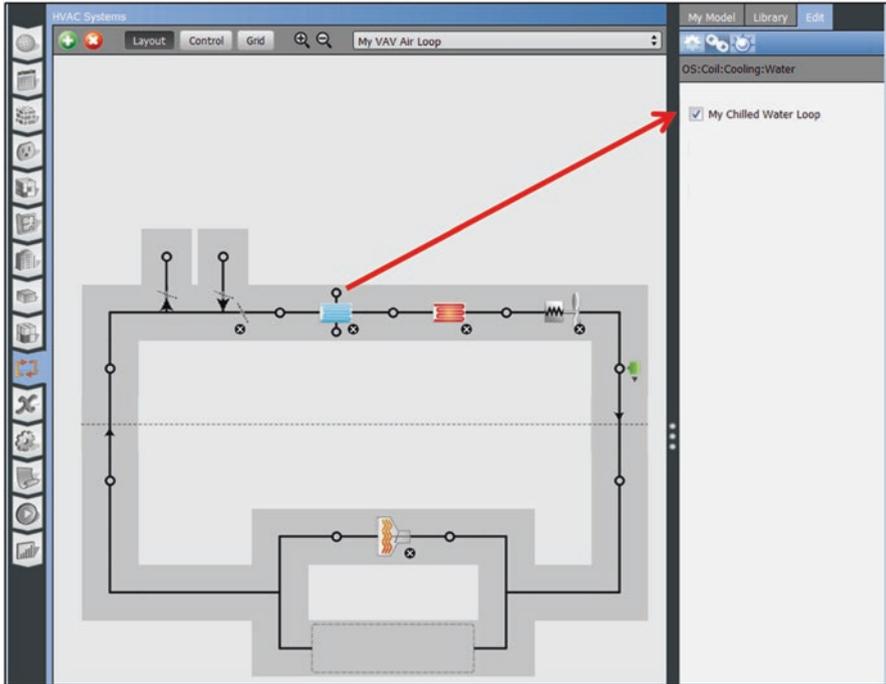


Fig. 5.45 Connecting a Cooling Coil to the Chilled Water Loop

- (b) The Loop design exit temperature matches the setpoint, and
- (c) The Loop design temperature difference is 12 °R.

Now that the chilled water Loop is complete, the chiller water-cooling coils from “My VAV Air Loop” may be connected. Use the system selector at the top of the window to navigate back to “My VAV Air Loop.” Click on the cooling coil and  Sub-Tab to establish a connection between the coil and correct Plant Loop. In this case, we want to check the “My Chilled Water Loop” box to connect this coil to the chilled water loop, as shown in Fig. 5.45.

Once this has been accomplished successfully, click the Node above or below the cooling coil icon to navigate back to the associated chilled water Loop. It should look like Fig. 5.46, with the cooling coil on the demand side of the Loop.

Now we need to create a second Plant Loop to serve as the condenser water loop for the water-cooled chiller in the chilled water Loop.

1. Add the second Plant Loop
2. Name it “My Condenser Water Loop.”
3. Add Objects to your Loop by dragging them from the  onto Nodes as shown in Fig. 5.47:

- (a) Pump Constant Speed

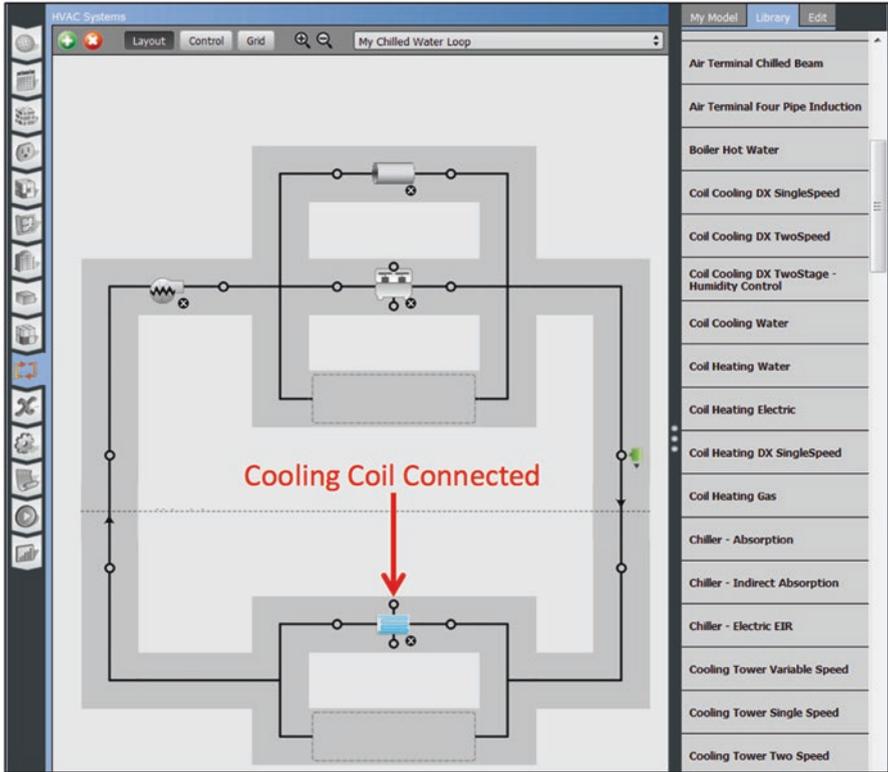


Fig. 5.46 Chilled Water Loop with Cooling Coil connected

- (b) Cooling Tower Single Speed
 - (c) Bypass Pipe Adiabatic
 - (d) Setpoint Manager Follow Outdoor Air Temperature
4. Ensure that the setpoint:
 - (a) Follows the Outdoor Air Wet Bulb with an offset of 4 °R,
 - (b) Has a minimum of 70 °F, and
 - (c) Has a maximum of 95 °F.
 5. Click on the supply/demand line to set the Loop sizing parameters, ensuring that:
 - (a) The Loop type is Condenser
 - (b) The Loop design exit temperature to 85 °F, and
 - (c) The Loop design temperature difference is 10 °R.

Once the condenser Loop has been completed, attach it to the chiller called “My Water-Cooled Chiller” from “My Chilled Water Loop” to the demand side of the Loop. Click on [My Model](#) and drag “My Water-Cooled Chiller” to the

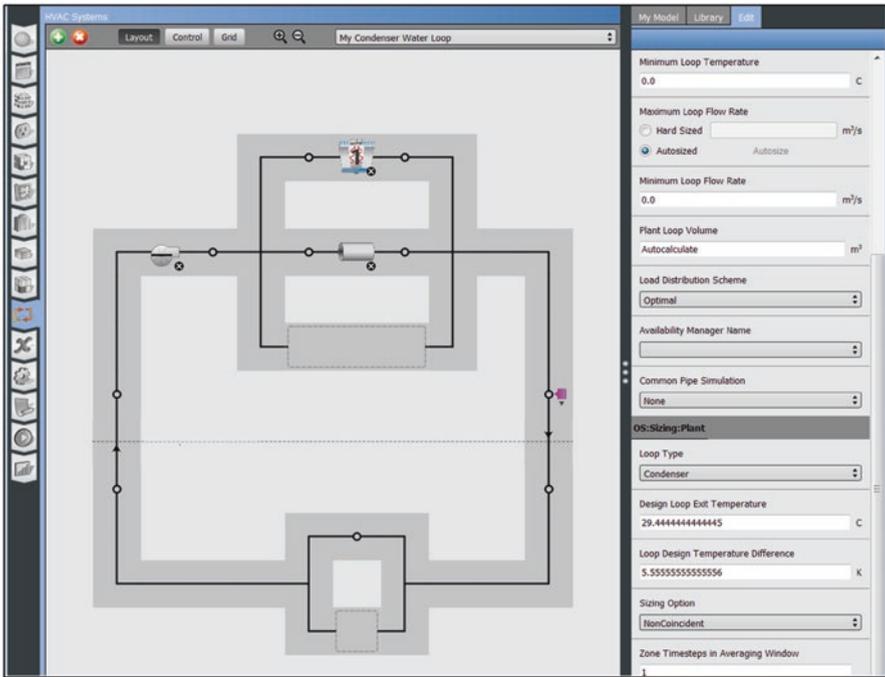


Fig. 5.47 Condenser Water Loop with initial components

demand side. After successfully attaching the chiller, the Loop should look like Fig. 5.48.

Tip: If you do not see the Node links above and below the chiller, you likely selected a second chiller from the [Library](#) and have accidentally added it to the model.

We still need to add a Loop to serve hot water to our hot water coil.

1. Add the third Plant Loop
2. Name it “My Hot Water Loop.”
3. Add Objects to your Loop by dragging them from the [Library](#) onto Nodes as shown in Fig. 5.49:
 - (a) Pump Variable Speed
 - (b) Boiler Hot Water
 - (c) Bypass Pipe Adiabatic

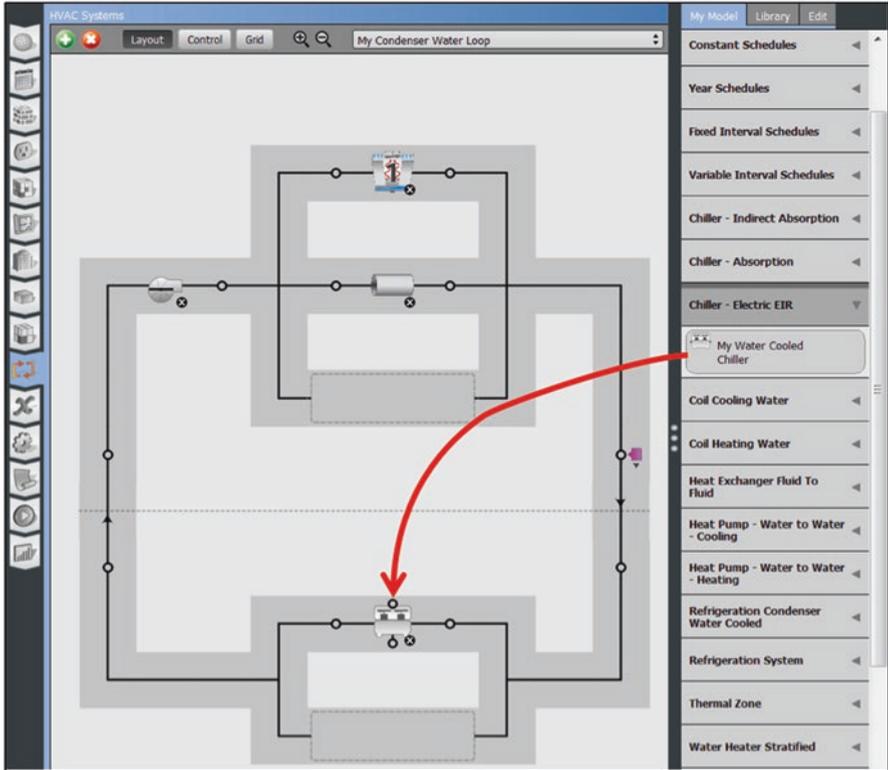


Fig. 5.48 Condenser Loop with chiller attached

(d) Setpoint Manager Scheduled

4. Ensure that the Setpoint Manager Schedule is 140 °F at all times.
5. Click on the supply/demand line to set the Loop sizing parameters, ensuring that:
 - (a) The Loop type is Heating
 - (b) The Loop design exit temperature matches the setpoint, and
 - (c) The Loop design temperature difference is 20 °R.

Now that the hot water loop is ready, navigate back to “My VAV Air Loop” and follow the same process used to connect the cooling coil to connect the heating coil and air terminal to the hot water Loop. Verify that both the main heating coil and the coil inside the reheat terminal are connected. Afterward, the hot water Loop should look like Fig. 5.50.

Now that the reheat coil in the reheat terminal has been connected to the hot water loop, Thermal Zones can be assigned to the Air Loop. Navigate to “My VAV

Fig. 5.49 Hot Water Loop with initial components

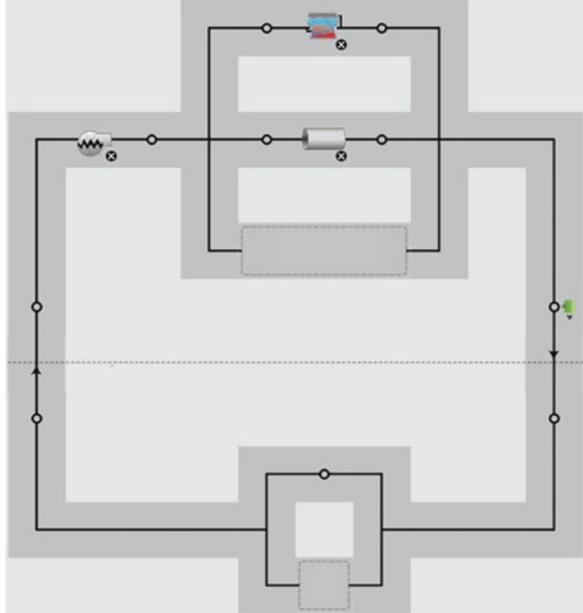
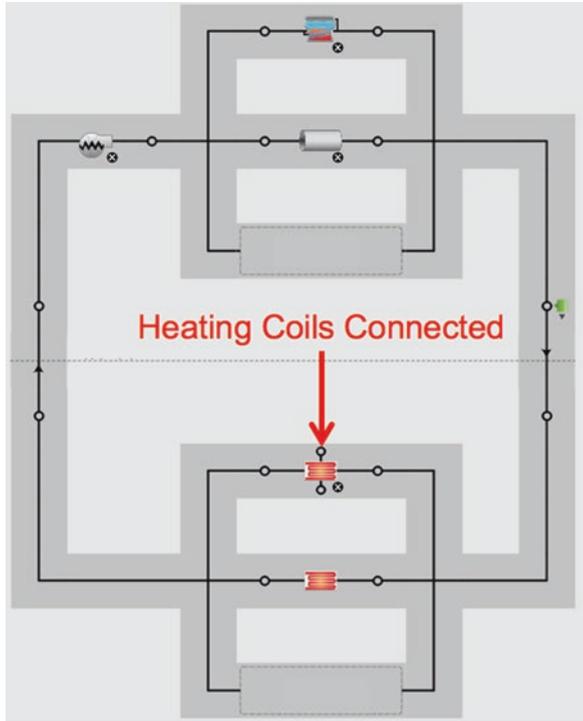


Fig. 5.50 Hot Water Loop with Heating Coils connected



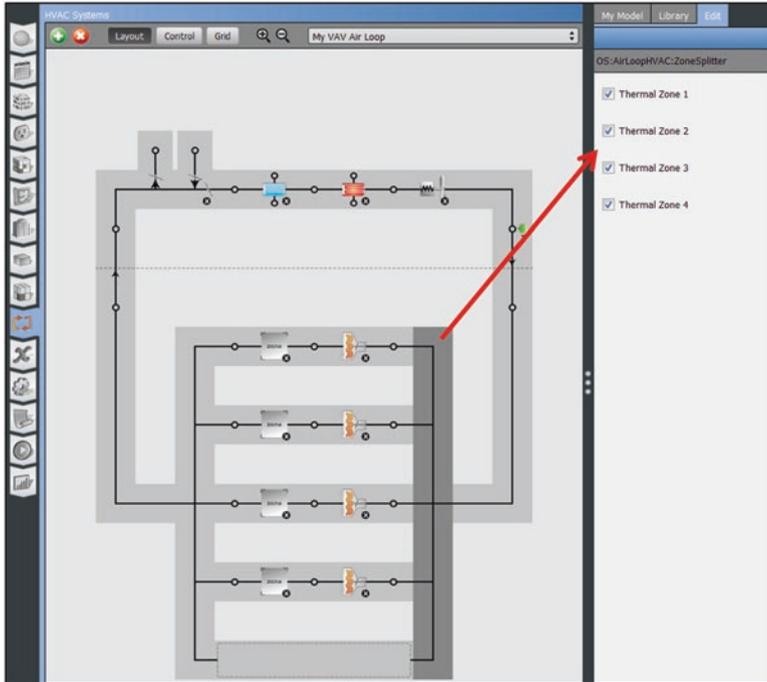


Fig. 5.51 Assign Thermal Zones to Air Loop

Air Loop.” In the Air Loop, click on the demand splitter and use the check boxes to assign all of the Thermal Zones to the Air Loop, as shown in Fig. 5.51.

Tip: The reason we did not add Thermal Zones immediately after initial creation of the Air Loop is that the heating coils in the VAV terminals had not yet been connected to the hot water Loop. Adding additional Zones at that point would have automatically brought in the same, unconnected, terminal units. This would require us to manually assign each terminal coil to the hot water Loop.

Assuming this process was performed correctly, the hot water Loop should now have five heating coils attached to the demand side – one main coil for the VAV and four terminal reheat coils.

5.8 Checkpoint Eight: Zone Equipment

In this final HVAC exercise, we are going to remove one of the Thermal Zones in the Model from the VAV system and assign it to a dedicated piece of Zone Equipment. Begin by navigating to the Thermal Zones (🏠) Tab. For “Thermal Zone 1,” select the “VAV HW Rht” Air Terminal and remove this from the Zone using the ✕ Button in the edit pane, as shown in Fig. 5.52. This disconnects the Zone from our Air Loop.

Locate a “Four Pipe Fan Coil” in the 📖 and add it to “Thermal Zone 1,” as shown in Fig. 5.53.

Use the ⚙️ Sub-Tab in the Edit pane to connect the coils inside of the Zone Equipment to “My Hot Water Loop” and “My Chilled Water Loop” as shown in Fig. 5.54. Be sure that each coil is connected to the correct loop by reading the type of coil in the dark grey area of the Edit pane.

Run the simulation and examine the now familiar OpenStudio Results report. Look at the HVAC Load Profiles and Zone Conditions reports shown in Figs. 5.55 and 5.56. Verify that the heating and cooling load correlates to the outside air temperature and that the Thermal Zones are properly conditioned by reviewing the number of hours for unmet heating and cooling loads.

Finally, armed with knowledge about how detailed mechanical systems are created in OpenStudio, the Air Loops (Fig. 5.57) and Plant Loops (Fig. 5.58) detail reports should be comprehensible. Review both to verify that the systems were configured as intended.

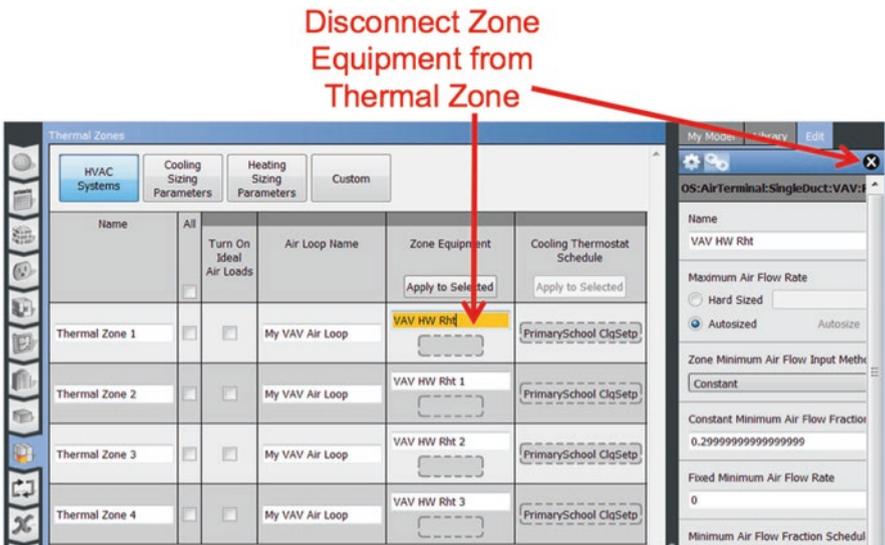


Fig. 5.52 Disconnecting the Thermal Zone from the Air Loop

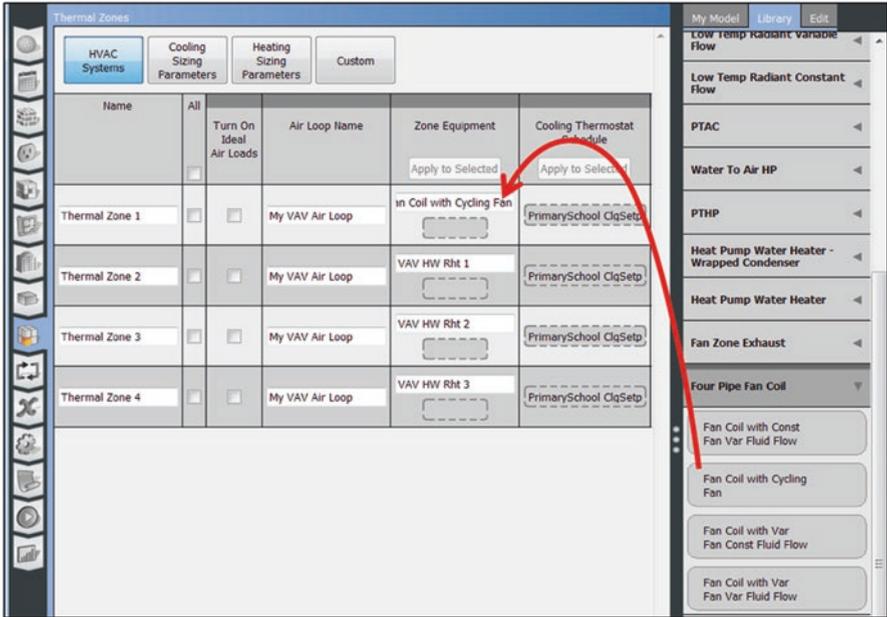


Fig. 5.53 Adding Four Pipe Fan Coil Zone Equipment

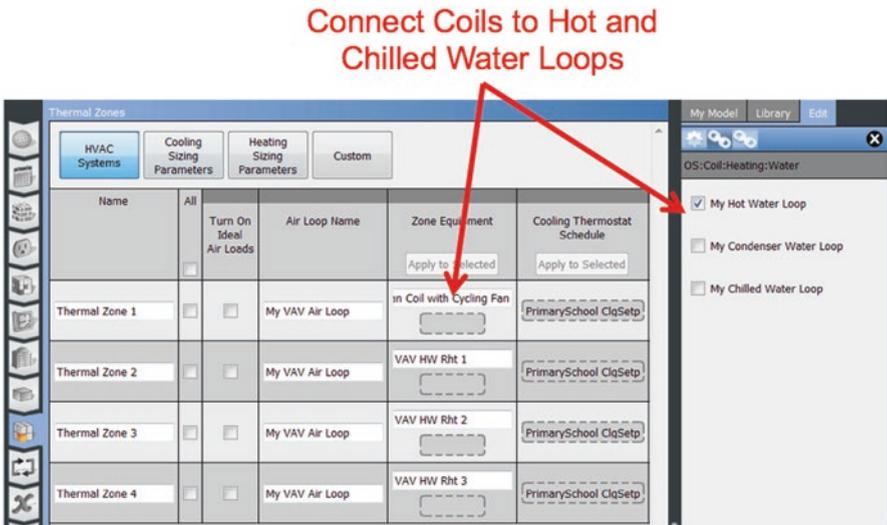


Fig. 5.54 Connecting Zone Equipment Coil to a Plant Loop

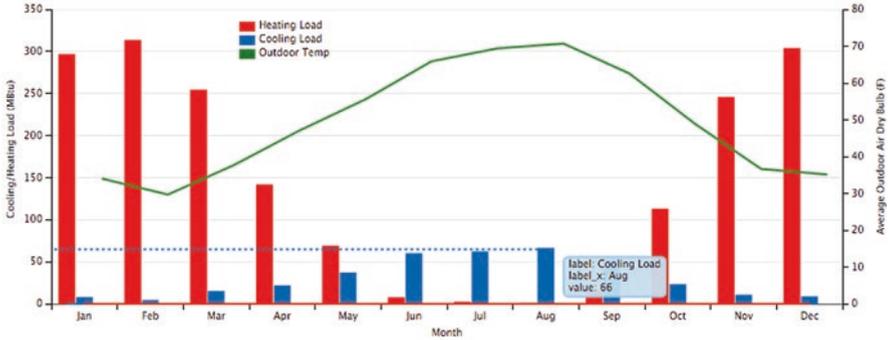


Fig. 5.55 HVAC Monthly Load Profile for school with advanced HVAC systems

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	27	0	0	196	851	416	1087	569	647	4272	369	353	0	0	0	0	72.5 (F)
THERMAL ZONE 2	56	0	0	538	1350	457	2161	949	792	2493	20	0	0	0	0	0	70.0 (F)
THERMAL ZONE 3	57	0	0	548	1349	465	2149	939	795	2495	20	0	0	0	0	0	70.0 (F)
THERMAL ZONE 4	106	1	0	199	1512	453	2087	992	917	2592	8	0	0	0	0	0	70.3 (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	4383	1389	1507	978	417	62	24	0	0	0	0	0	29.5 (%)
THERMAL ZONE 2	5327	822	761	640	605	345	205	55	0	0	0	0	28.2 (%)
THERMAL ZONE 3	5328	818	763	639	606	346	204	56	0	0	0	0	28.2 (%)

Fig. 5.56 Zone conditions for school with advanced HVAC systems

Hopefully these exercises have helped you appreciate the effort OpenStudio can save us when using template HVAC systems. The next Chapter introduces one of the most powerful time saving features of the platform - OpenStudio Measures.

5.9 Additional Exercises

Recommended additional exercises involving the Checkpoint Seven Model include further study of HVAC system control and sizing.

- Be sure to keep a “clean” copy of the Checkpoint Seven model before proceeding with these activities.
- Change the supply air temperature setpoint for the VAV system.

My VAV Air Loop						
Object	Sizing	Sizing Units	Description	Value	Value Units	Count
<i>(supply)</i>						
OS:AirLoopHVAC:OutdoorAirSystem	Autosized	cfm	Minimum Outdoor Air Flow Rate	Autosized	cfm	
OS:Coil:Cooling:Water	Autosized	gal/min	Plant Loop	My Chilled Water Loop		
OS:Coil:Heating:Water	Autosized	gal/min	Plant Loop	My Hot Water Loop		
OS:Fan:VariableVolume	Autosized	cfm	Pressure Rise	4.09	inH ₂ O	
OS:SetpointManager:Scheduled			Control Variable - Temperature	55.0 to 55.0	F	
<i>(demand)</i>						
Thermal Zones			Total Floor Area	55,197	ft ²	3
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:AirTerminat:SingleDuct:VAV:Reheat			3
<i>(controls)</i>						
HVAC Operation Schedule				Always On Discrete		
Night Cycle Setting				StayOff	Choice	
Economizer Setting				NoEconomizer	Choice	
Demand Controlled Ventilation Status				false	Bool	

Fig. 5.57 Air Loops detail for school with advanced HVAC systems

My Chilled Water Loop						
Object	Sizing	Sizing Units	Description	Value	Value Units	Count
<i>(supply)</i>						
OS:Pump:VariableSpeed	Autosized	gal/min	Rated Power Consumption	Autosized	W	
OS:SetpointManager:Scheduled			Control Variable - Temperature	44.1 to 44.1	F	
OS:Chiller:Electric:EIR	Autosized	Btu/h	Reference COP	5.50		
OS:Chiller:Electric:EIR (cont)			Chiller Source	My Condenser Water Loop		
<i>(demand)</i>						
OS:Coil:Cooling:Water			Air Loop	My VAV Air Loop		
Air Terminal Connections						1
<i>(controls)</i>						
Loop Flow Rate Range	Autosized	gal/min	Minimum Loop Flow Rate	0.0	gal/min	
Loop Temperature Range				32.0 to 212.0	F	
Design Loop Exit Temperature				44.00	F	
Loop Design Temperature Difference				12.00	R	

Fig. 5.58 Plant Loops detail for school with advanced HVAC systems

- Change the deck temperature schedule from 55 °F to 60 °F.
- Compare the heating and cooling energy with Checkpoint Seven. Can you explain the reason for the changes?
- Explore different equipment staging methods.
 - Add a second Chiller to the Chilled Water Loop.
 - Change the sizing factor for each Chiller to 0.5.
 - Change the Load Distribution Scheme to UniformPLR for the Chilled Water Loop.
 - Run the simulation and look at the time series results for each Chiller.
 - Can you tell that the load is split between both Chillers?
 - Change the Load Distribution Scheme to SequentialLoad for the Chilled Water Loop.
 - Run the simulation and look at the time series results for each Chiller.
 - Is one of the Chillers loaded first?
 - Can you tell which Chiller runs for more hours in the year?
- Study different Fan control approaches.
 - Replace the Variable Volume Fan from the VAV system with a Constant Volume Fan.
 - Compare the fan energy with Checkpoint Seven. Can you explain the reason for the change?
- Experiment with the impact of design targets on system sizing.
 - Change the Central Heating Supply Air Temperature and Central Cooling Supply Air Temperature in the VAV system to 65 °F.
 - Leave the Deck Temperature set to 55 °F.
 - Run a simulation and note the number of unmet hours and system sizes.
 - Now change the Load Distribution Scheme to UniformPLR for the chilled water loop.
 - Run the simulation again.
 - Was there an increase or decrease in unmet hours? If so, why?
 - How did the size of the chiller change? If so, how did changing the sizing of the air loop affect the size of components on a chilled water loop?

Reference

ANSI/ASHRAE Standard 62.2-2016 ventilation for acceptable indoor air quality, ASHRAE, 2016