

# EXchange



## Modeling Variable Refrigerant Flow (VRF) Systems in HAP – Part 2

This is Part 2 of an [earlier EXchange](#) article that was a high-level overview of how to setup a VRF system model in HAP. This article goes into much more detail than the [previous article](#) by illustrating how to zone the building and define the VRF system equipment inputs.

This discussion will provide a high-level overview of how to model VRF in HAP. Users should also consider attending the [HAP Advanced Modeling Techniques Training Course](#) which covers this topic and many others.

VRF system usage has been rapidly increasing in the U.S., primarily for commercial buildings due to the anticipated efficiency benefits of these systems and especially for LEED® projects where designers strive for energy savings. The inherent design and operational advantages are also influencing the popularity of VRF systems in North America due to the reduced space requirements and potential energy savings utilizing heat recovery.

**NOTE:** When designing and applying VRF systems, it is always a good idea to consult the **specific** manufacturer's specific product literature for application and design information because application limitations and requirements can vary from manufacturer to manufacturer.

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# Modeling Variable Refrigerant Flow (VRF) Systems in HAP – Part 2

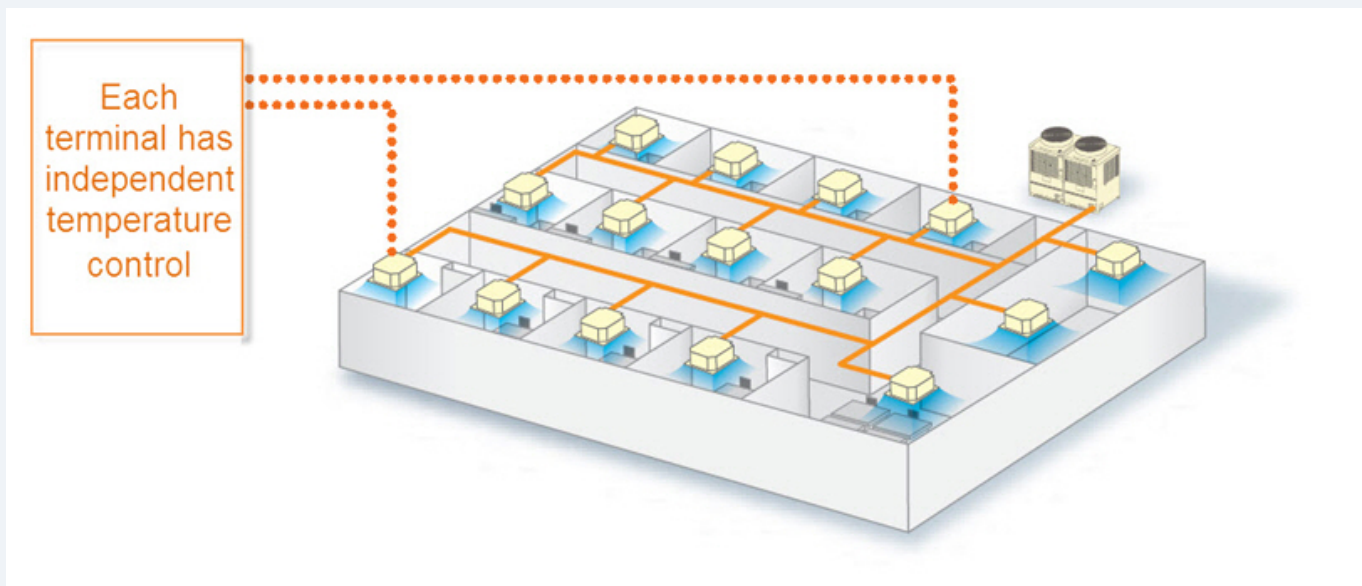
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Figure 1 illustrates a VRF system utilizing in-ceiling, 4-way cassette terminals. Each zone has a dedicated indoor (ID) terminal unit connected to the central outdoor (OD) unit(s), which may be cooling-only or reverse-cycle heat pump.

Discrete capacities for the OD units exist, however multiple OD units may be “multiplexed” together to achieve nearly any capacity required. Total refrigerant equivalent line lengths can run as much as 700' (213m) and longer (according to published literature from some manufacturers). However, from a practical standpoint,

line lengths exceeding several hundred feet can result in a significant degradation of capacity and efficiency. Some manufacturers may not publish line length correction factors but **equivalent line length should not be neglected in the design phase or equipment selection as it is a significant design consideration.**

The HAP VRF energy simulation model takes into consideration the effects of total equivalent line length and vertical separation (height) between indoor and outdoor units.



**Figure 1. VRF System (In-Ceiling 4-Way Cassette Terminals Shown)**

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## Setting-up a VRF Model in HAP

System options available for modeling VRF systems in HAP include:

- Two ventilation options: Direct Ventilation or Dedicated Outdoor Air System (DOAS)
- Multiple compressor types including Variable-Speed Rotary (VSR), Variable-Speed Scroll (VSS) and Digital Scroll (DS)
- Heat recovery
- Multiple heating options including air-source heat pump (using backup auxiliary electric resistance heat) or primary electrical resistance heat-only.

Selections made from these options will affect the efficiency levels of the system being designed. The requirements of specific options depend on the geographical location, building design and part-load profile.

The following explanation illustrates the detailed design process in HAP to create a VRF system model, however there is an alternate approach that can be used – the Equipment Wizard – which is often used in the schematic design phase of a project. Even when the Equipment Wizard approach is used we recommend inspecting the detailed model data that is automatically generated to evaluate and, if necessary, adjust settings for key details such as compressor type, refrigerant line length and component vertical separation height.

One of the most common errors users make when entering terminal systems is they create a **separate** air system in HAP for each of the terminals or zones. **This is incorrect and results in inaccurate results.** The correct way to enter terminal unit systems is to **define all zones in a single air system**. In the VRF industry, all connected IDU and ODU components are thought of as a single “refrigerant system.” That refrigerant system should be represented as a single HAP “air system”. For example, if your actual system has 25 IDUs connected to one ODU, then the most accurate model is to specify a single VRF air system with 25 zones and one ODU. HAP will then simulate the operation of each of the 25 indoor terminal units separately, and the outdoor unit will serve the combined load from those 25 indoor units.

HAP allows up to 100 zones (terminals) in a terminal system. If you have more than 100 zones you may either create additional VRF systems, consolidate similar zones into larger control zones or use multipliers to assign thermally-similar spaces to the system or thermally-similar systems to the Building.

The number of zones should be equal to the number of thermostats you require, which is entered on the General tab of the system input screen, as shown in Figure 2. A “zone” is a collection of one or more spaces with similar thermal load characteristics on a single thermostat. Care should be taken when assigning spaces to zones such that only spaces with similar thermal load characteristics are on the same zone, otherwise some spaces may not be properly controlled to meet the desired comfort levels. The *HAP Zone Sizing Summary Report* indicates the peak load and time of peak loads for each space and should be used to determine coincident load peak times for zone assignment purposes.



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# Modeling Variable Refrigerant Flow (VRF) Systems in HAP – Part 2

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A simple 15-zone office VRF system example will be used to illustrate the input procedure. The HAP Building Wizard was used to define the spaces. There are 3-floors and 5-zones per floor (1 zone per exposure + core).

To define a VRF system, create a new Air System, specify *Equipment Type* as **Terminal Units** and *Air System Type* as **Variable Refrigerant Flow (VRF)**, as indicated in Figure 2.

**Figure 2. System Input Screen – General Tab**

Set the number of zones, or ID terminal units used, under the *Number of Zones* input field.

Finally, select whether you are directly supplying unconditioned ventilation air to the VRF fan coils (Direct Ventilation) or if you are preconditioning the ventilation air using a DOAS system. It should be noted that if using Direct Ventilation, this means the VRF terminals must be sized to handle the additional ventilation load. For some VRF applications, the latent capacity is insufficient to condition this ventilation air. In this case a separate DOAS system may be utilized. If using a DOAS, the DOAS Components tab will become enabled. When selecting Direct Ventilation this tab is disabled. For this example we will use a DOAS system.

Under the DOAS Components tab define the appropriate inputs for your design. In this example we used an air-cooled DX cooling unit with Heating Coil and Ventilation Reclaim, as shown in Figure 3.

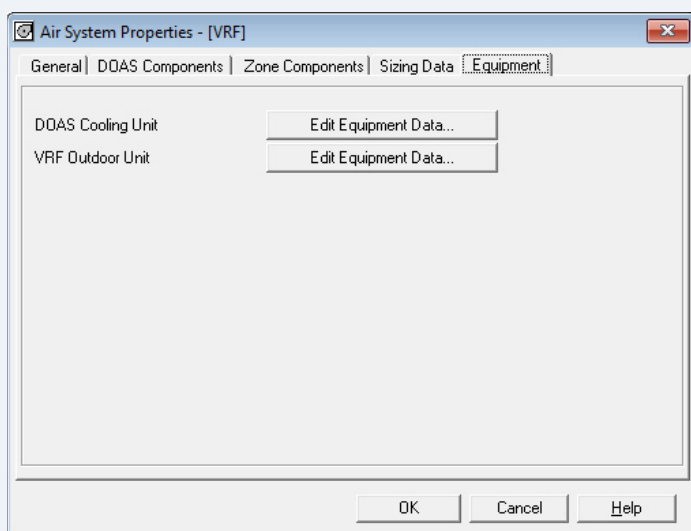
**Figure 3. System Input Screen – DOAS Components**

Under the Zone Components tab assign each space to the appropriate zone unless done previously using the Equipment Wizard.

**Figure 4. System Input Screen – Zone Components Tab**

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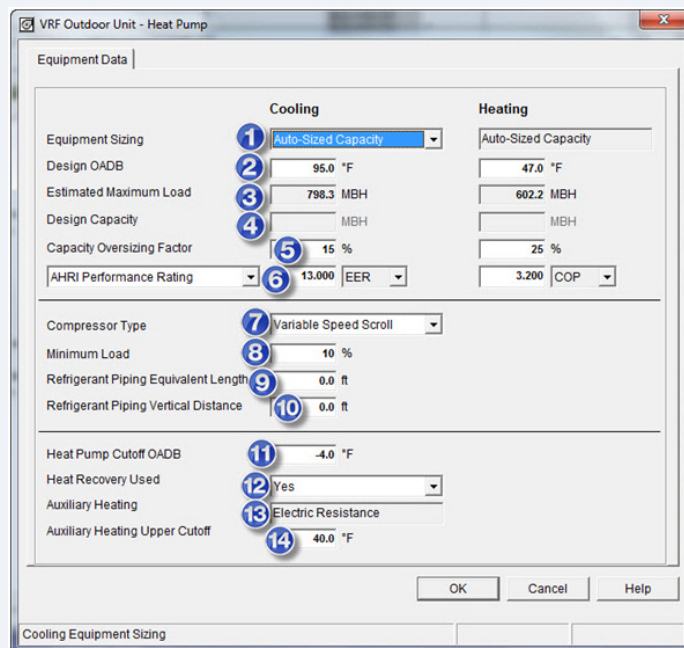
Additionally, set the appropriate inputs for Thermostat, Common Data and Terminal Units. We will not cover each of those inputs here because they are similar to all other terminal system types. The remaining discussion will focus on the unique inputs for VRF systems, as listed under the Equipment tab.



**Figure 5. System Inputs – Equipment Tab**

Under the Equipment tab (Figure 5) there are two buttons. The first one applies only to the DOAS Cooling Unit. The second one, the VRF Outdoor Unit button, is the one we will focus on here. Click on the Edit Equipment Data button for VRF Outdoor Unit. This opens the Equipment Data input screen shown in Figure 6.

Inputs on this screen describe the equipment performance characteristics of the single OD unit which serves all of the ID units (zones) in the system. Whether the OD unit is a single VRF condensing unit module, or multiple modules interconnected, this screen describes the overall performance of the OD unit(s). As you can see there are numerous input values listed. Each input is discussed briefly below; refer to the HAP Help system (Chap 11.6) for a more in-depth explanation of each of these inputs.



**Figure 6. System Input Screen – VRF Equipment Inputs**

1. **Equipment Sizing** specifies either “Auto” computer-sizing based on the estimated design loads or User-Defined Capacity. For initial or preliminary design stage of a project it is often appropriate and faster to choose the “Auto-Sized Capacity” option. During the energy simulation the program will set the cooling capacity to the estimated maximum load plus the cooling capacity oversizing factor if specified. The gross heating capacity will be calculated as peak heating coil load plus the heating capacity oversizing factor if specified. The resulting capacities will then be shown on the air system Zone Sizing Summary report. For energy analysis during detailed design if you are modeling a specific unit, choose “User-Defined Capacity” so you can directly enter the cooling and heating capacities of the specific model of equipment you are using in your design.

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# Modeling Variable Refrigerant Flow (VRF) Systems in HAP – Part 2

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2. **Design OADB** is the outdoor air temperature at which a gross cooling capacity and gross heating capacity are defined. For cooling this is often set to 95 F (35 C) which is the AHRI rating point, or this is set to the outdoor air temperature (OAT) at the time of the peak cooling load. For a reverse cycle air source heat pump, design OADB for heating is typically specified as 47 F (8.3 C) which is the AHRI rating point.
3. **Estimated Maximum Load.** This display-only item lists the computer calculated peak equipment loads for cooling and heating. The peak load is generated during design calculations for the system. This load provides guidance when specifying the gross capacity. If system design load calculations have not been run for the air system, then this item will be blank. **NOTE:** the estimated maximum load is the peak coincident load for all terminals in the system, not the sum of the individual terminal peak loads.
4. **Design Capacity** defines the gross cooling capacity of the VRF outdoor unit(s) at the cooling design OADB and the gross heating capacity at the heating design OADB. This value is typically obtained from equipment selection software or manufacturer's product catalogs. This capacity value, together with design OAT and input power, serve as the anchor point for off-design and part-load performance calculations. This input is only enabled if you selected "User-Defined Capacity" for the Equipment Sizing input.
5. **Capacity Oversizing Factor** defines the additional capacity added when using the "Auto-Size Capacity" option. For example if the estimated maximum load for a unit is 100 MBH (29.3 kW) and the oversizing factor is 15%, the Auto-Size feature will set the gross cooling capacity to  $100 \times (1.15) = 115$  MBH (33.7 kW). This input is only enabled when the "Auto-Size Capacity" option is selected. Separate oversizing factors are specified for cooling and heating. Note you can "auto-size" and set the oversizing factors to zero if you like.
6. **Performance Value** defines the energy performance of the unit at design. Separate values are specified for cooling and heating duty. Two options are provided for defining this data:
  - a. *AHRI Performance Rating* allows entry of an AHRI standard EER or SEER value for cooling or an AHRI standard COP or HSPF value for heating. For most large (3-phase) VRF systems, EER and COP will be typical efficiency metrics. SEER and HSPF only exist for smaller single-phase systems, per AHRI. The AHRI rating includes compressor, indoor fan and outdoor fan power and is determined at the standard rating outdoor air dry bulb of 95° F (35° C) for cooling and 47° F (8.3° C) for heating. During the energy simulation, the simulation software will automatically derive the compressor and outdoor fan kW from the rating, subtracting the indoor fan power (that is specified on the Zone Components Tab, Terminal Units screen) and adjusting for any difference between the AHRI rating condition and the design OADB you specified for this equipment.
  - b. *ODU Input Power* requires input of the sum of compressor and outdoor fan power at the design OADBs specified earlier on this screen. Typically this option is used when modeling a specific equipment unit. The data is obtained from product data, an engineering manual or performance data generated by electronic catalog software. The input kW is used together with the design OAT and gross capacity as the anchor point for off-design and part-load performance calculations.
7. **Compressor Type.** The VRF performance model contains performance curves for three common types of units – those containing variable-speed rotary, variable-speed scroll and digital scroll compressors. Choose the compressor type which most closely matches the equipment you are modeling.

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8. **Minimum Load.** Below minimum load % the equipment cycles on and off to meet the load, except on rotary compressor models which do not require this input field. Above minimum load %, the equipment adjusts compressor speed or duty cycle to meet the load.

9. **Refrigerant Piping Equivalent Length.** For variable speed rotary VRF equipment, specify the physical length of refrigerant piping from the VRF outdoor unit to the most distant indoor unit. For variable speed or digital scroll VRF equipment specify the equivalent length for refrigerant piping from the VRF outdoor unit to the most distant indoor unit. The length must consider both horizontal and vertical sections of piping. When long lines exist, the VRF outdoor unit will have to generate extra cooling or heating output to overcome refrigerant pressure drop in the lines to satisfy loads at the indoor unit. Capacity correction factors for line loss are reported in charts or tables in manufacturer's literature. For example, if the reported capacity correction factor for a given pipe length is 0.9, the outdoor unit will have to provide 100/0.9 or 111 MBH of cooling output in order to meet a load of 100 MBH at the indoor units. Separate correction factors are calculated for cooling duty and heating duty based on the piping length.

Note that while HAP enforces reasonable general limits for piping length, actual limitations on line length vary with the specific system configuration therefore **engineers should always consult manufacturer's product literature for guidance on line length limitations for an application.**

10. **Refrigerant Piping Vertical Distance.** Specify the greatest vertical distance from any indoor unit to the outdoor unit. **Specify a positive value if the outdoor unit is above the indoor unit (for example a roof-mounted outdoor unit). Specify a negative value if the outdoor unit is below the indoor unit (for example a ground-level outdoor unit serving indoor units on upper floors).** This distance is used for a purpose similar to the refrigerant piping equivalent length above.

The greater the vertical distance between outdoor unit and indoor units, the larger the cooling or heating output required to meet loads at the indoor units. **NOTE:** *the Equipment Wizard, if used, will automatically compute a vertical piping length and riser distance from Building Wizard inputs (# floors, dimensions), however you should verify that these auto-generated values match your actual design.*

11. **Heat Pump Cutoff OADB** is the outdoor air temperature below which the heat pump turns off and the equipment runs with 100% auxiliary heat.
12. **Heat Recovery Used** specifies whether the system has heat recovery controls. With heat recovery hot gas returning from indoor units in cooling can be used to satisfy part of the demand of other indoor units in heating, or cold liquid refrigerant returning from indoor units in heating can be used to satisfy part of the demand of other indoor units in cooling.
13. **Auxiliary Heating** is a display-only item which documents that auxiliary heating for the system is provided by electric resistance heat in the indoor units.
14. **Auxiliary Heating Upper Cutoff** specifies the outdoor air dry-bulb temperature above which auxiliary heating is locked out. For heat pump VRF (non-heat recovery), the outdoor unit operates in cooling priority. Therefore if the majority of the load is cooling, the system operates in cooling mode. Any zone requiring heating during this time will be conditioned with auxiliary heat. However, if the outdoor dry-bulb is above the specified cutoff, auxiliary heat will not be provided to the zone.

This concludes the discussion of modeling VRF systems in HAP.

# How to Model Service Hot Water (SHW) Systems in HAP

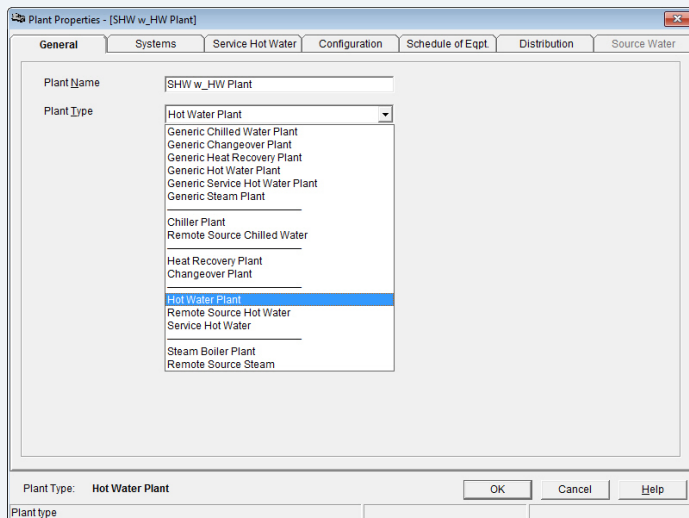
## How to Model Service Hot Water (SHW) Systems in HAP

There are two possible configurations available in HAP for modeling a SHW system:

1. A single HW Plant & Boiler serving both building heating coils + SHW loads simultaneously
2. Multiple HW Plants & Boilers, one for building heating loads, the other dedicated to SHW only

### Modeling Single HW Plant Serving Combined Building Heating Loads + SHW

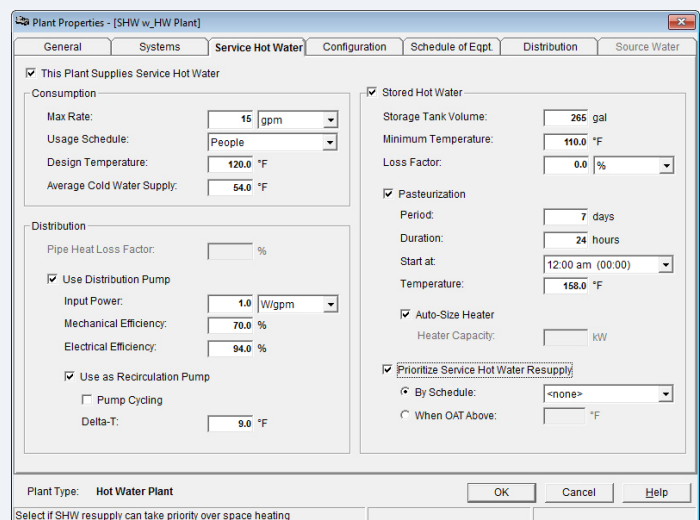
If you desire to use a single HW plant for both heating coils and SHW (option 1 above) define a "Hot Water Plant" under the Plant Type drop-down, as shown in Figure 1 below:



**Figure 1. Plant Input Screen – Hot Water Plant – General Tab**

After assigning the Air Systems to the plant under the Systems tab open the SHW tab (Figure 2) and check the box at the top left, "This Plant Supplies Service Hot Water". If left unchecked the Hot Water Plant will only serve the Air System heating coils and the SHW tab inputs will become disabled (grayed-out).

Next define the design inputs, as shown in Figure 2. The SHW tab contains information about the SHW consumption, and the SHW distribution and storage systems (if used). **NOTE:** all options are enabled in Figure 2 for illustration purposes only, however not all may be necessary depending on the particular configuration you have.



**Figure 2. Plant Input Screen – Hot Water Plant – SHW Tab**

Please refer to the HAP Help system (Chapter 12.4) for a detailed description of each of the inputs on the SHW tab. The SHW tab is divided into four parts:

1. **This Plant Supplies Service Hot Water** – plant types which serve space heating loads can additionally serve SHW loads by checking this box. When defining a standalone Service Hot Water plant, this input does not appear because the sole purpose of the plant is to serve SHW demands.
2. **Consumption** – inputs define the service hot water demand profile and the supply and source water temperatures for the system. These inputs must be specified.

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3. **Distribution** – inputs define the equipment and controls used to deliver service hot water to its point of use, including the pumping system. When municipal water supply pressure is sufficient to deliver SHW to its points of use in the building, this group of inputs is not used.
4. **Stored Hot Water** – inputs define characteristics and control of a hot water storage tank, if one is used. For Tankless, On-Demand or Instantaneous SHW systems, inputs in this group are not used.

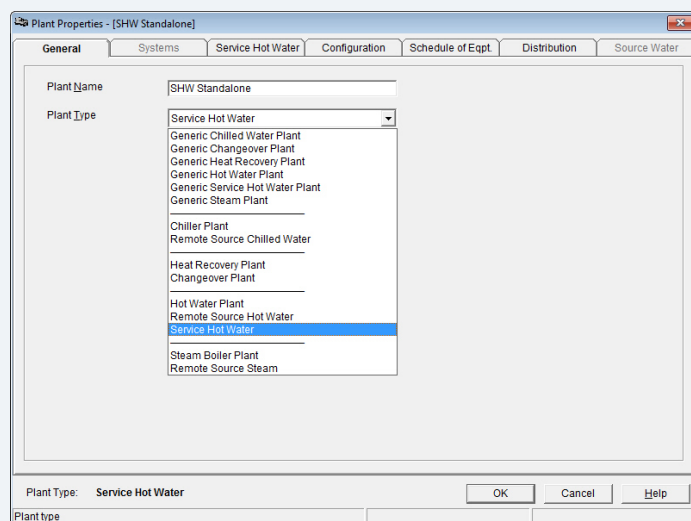
**Types of SHW Applications** – three common SHW applications are described below.

- **Tankless, On-Demand or Instantaneous Water Heater** – This type of system produces hot water as SHW demands occur. There is no storage tank. The Consumption group of inputs is always needed to define demand. If the pressure provided by the municipal water supply system is sufficient to deliver SHW to its point of use, then no inputs in the Distribution group are needed other than a pipe loss factor, if desired. When a distribution pump is needed, inputs in the Distribution group would be used.
- **Storage Tank Heater, No Pumping** – This type of system generates hot water and stores it in a tank. Water from the storage tank is supplied to the SHW points of use as demands occur. When the pressure provided by the municipal supply system is sufficient to deliver the SHW to its points of use, a distribution pump is not needed.
- **Storage Tank Heater, With Distribution Pump** – This system is the same as #2 but requires a distribution pump to deliver the SHW to its points of use within the building.

### Modeling Separate HW Plants – One Serving Building Heating Loads, One Serving SHW

To model separate HW Plants for building loads and SHW you will need to input two separate heating plants, each with its own dedicated boiler. The heating plant serving

the building loads is modeled as described previously, and illustrated in Figure 1, however on the SHW tab uncheck the, “This Plant Supplies Service Hot Water” checkbox to disable this option in the plant. Then define another heating plant having Plant Type, “Service Hot Water”, as shown in Figure 3 below. This decouples the building heating loads from the SHW loads such that each is handled by their own dedicated heating equipment.



**Figure 3. Plant Input Screen –  
Service Hot Water Plant – General Tab**

**NOTE:** Selecting the Service Hot Water Plant Type disables the Systems tab since Air System coil loads are not included in the SHW loads. The only exception to this rule is when occupancy is used to specify consumption then air systems are required to be specified, however are only used for occupancy purposes. The SHW tab inputs should be completed as described previously. On the Configuration, Schedule of Eqpt. and Distribution tabs configure the remainder of the inputs, as usual.

If a standalone SHW plant is used it also needs to be attached directly to the building to properly account for its energy use, which is broken-out separately on the LEED Summary Report. However, if a combined HVAC + SHW plant is used the SHW costs are combined and cannot be distinguished separately.

# Frequently Asked Questions

**Question: I ran a comparison in HAP of a RTU with 2-speed supply fan versus 1-speed. As expected the annual fan energy is significantly reduced, however the heating energy required is significantly higher for 2-speed supply fan than for a 1-speed fan? What does the fan speed have to do with the amount of heating energy required?**

Table 1. Annual Costs

Component	ALT 2 - RTU - 2 spd fan (\$)	ALT 3 - RTU - 1 spd fan (\$)
Air System Fans	686	2,248
Cooling	805	841
Heating	6,567	5,717
Pumps	0	0
Heat Rejection Fans	0	0
<b>HVAC Sub-Total</b>	<b>8,058</b>	<b>8,806</b>
Lights	3,669	3,669
Electric Equipment	3,058	3,058
Misc. Electric	0	0
Misc. Fuel Use	0	0
<b>Non-HVAC Sub-Total</b>	<b>6,727</b>	<b>6,727</b>
<b>Grand Total</b>	<b>14,785</b>	<b>15,533</b>

**Answer:** Interesting anomaly here. This is solely due to the fan heat (high static motor), when the fan runs mostly on low speed the amount of fan heat produced declines significantly according to the fan law equations, therefore the central heating coil must operate much more to heat the building. The smaller the fan energy (BHP) the less of an effect this will have. This is also why the cooling energy increases slightly on the 1-speed fan; there is more fan heat to remove by the central cooling coil.

**Question: How do I model ECM (variable-speed) fan motors in Terminal Unit systems in HAP?**

All small terminal unit fans in HAP are constant-speed. At this time there is no input model for variable-speed small terminal fans. The fans either cycle on and off with the cooling/heating or run continuously depending on how the user sets the fan operation.

The best approach to account for variable speed operation of a small terminal fan is to enter the "weighted-average" fan power consumption (BHP, kW) over the entire operating year. So for example, say the full load power on the ECM terminal fan motor was 400 watts (0.4 kW) at full supply air CFM. Over the entire operating season most variable-speed fans operate between 60-75% of full airflow, if they are sized properly (not grossly oversized).

Using the fan law equation we know that the ratio of brake horsepower is proportional to the cubed ratio of the airflow:

$$\frac{BHP1}{BHP2} = \left[ \frac{CFM1}{CFM2} \right]^3$$

And if we assume that the motor efficiency curve is flat such that motor efficiency is constant over its operating range:

$$\frac{kW1}{kW2} = \frac{BHP1}{BHP2} = \left[ \frac{CFM1}{CFM2} \right]^3$$

We can now correct the full load power (kW1) to be the weighted-average power (kW2) over the full year of operation. So if kW1 = 0.4 kW and we assume CFM1 is 1.0 (100%) and CFM2 is 0.7 (70%) of full flow, then solve equation for the new kW2:

$$kW2 = kW1 / \left[ \frac{CFM1}{CFM2} \right]^3 = 0.137 \text{ kW}$$

So in HAP instead of entering 0.4 kW for the terminal fan power enter 0.137 kW. HAP will then run the fan at 0.137 kW for all operating hours, full-load and part-load, but the net result over the entire year will be that the fan will consume a weighted-average power of 34% of the full load value, compared to running at constant speed.

## Carrier Introduces eDesign Online Tutorial Video Series

To supplement our customer support and training efforts, Carrier has just released the first four of a continual series of short, tutorial videos beginning with the fundamentals, such as:

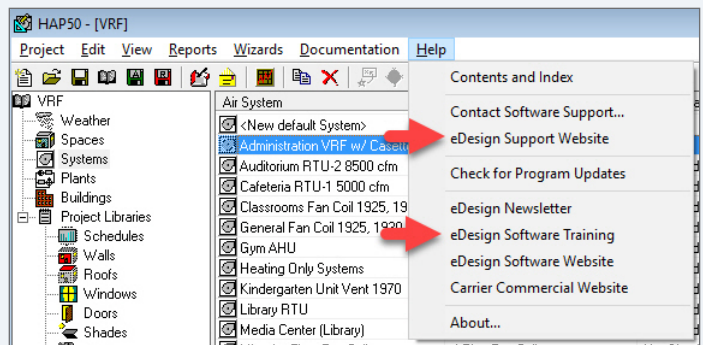
- program installation
- setting preferences
- utilizing HAP Building Wizards

For quick access, these tutorial videos are easily accessible from two locations:

1. On our public website ([carrier.com/commercial](http://carrier.com/commercial))
  - Select **Software** from the navigation bar
  - Go to **Software Training** or **Software Support**
  - Click on **HAP Training Videos**



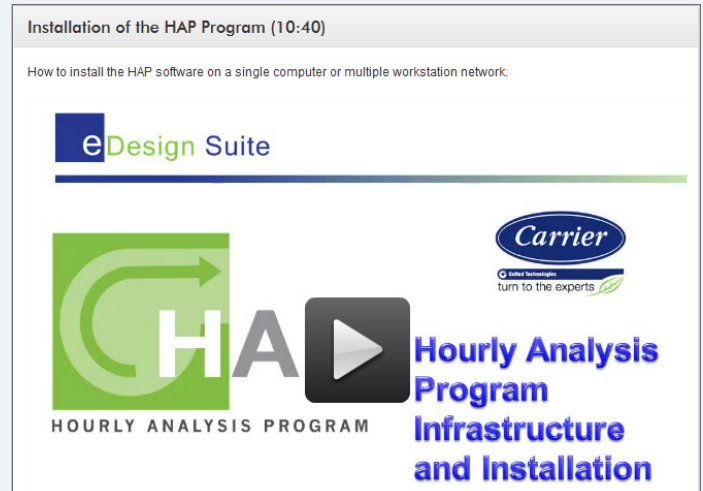
2. From inside the HAP program
  - Go to **Help** menu drop-down list
  - Select either **eDesign Support Website** or **eDesign Software Training**



Future videos will cover more advanced topics such as:

- applications
- systems and plant modeling
- troubleshooting and interpreting results

**Check-back periodically for new tutorial videos!**



## HAPpy 30th Birthday!

# 30!

**HAP is now  
in its 30th year and  
we are preparing  
to celebrate!**

If you have been using HAP all along and would like to contribute thoughts and experiences for the upcoming marketing campaign, please send us a note at [CarrierCommercialSystems@carrier.utc.com](mailto:CarrierCommercialSystems@carrier.utc.com).



## 2017 eDesign Suite Training Class Schedule







Location	Load Calculation for Commercial Buildings <i>System Design Load HAP</i>	Energy Simulation for Commercial Buildings <i>HAP</i>	Energy Modeling for LEED® Energy & Atmosphere Credit 1 <i>HAP</i>	Advanced Modeling Techniques for HVAC Systems <i>HAP</i>	Engineering Economic Analysis <i>EEA</i>	Block Load Basic <i>Block Load</i>
Washington DC	May 9	May 10	—	May 11	—	—
Grand Rapids MI	Jun 20	Jun 21	Jun 22	—	—	Jun 23 (AM)
Melrose Park IL	Sep 20	Sep 21	—	—	—	—

This schedule is current as of 22 March 2017. Items marked with \* have been added or updated since 22 March 2017.

Additional classes are being scheduled now, please check back again.

[Click here](#) to **REGISTER FOR UPCOMING CLASSES.**

### eDesign Suite Software Current Versions (North America)

Program Name	Current Version	Functionality
 Hourly Analysis Program (HAP)	v5.01	Peak load calculation, system design, whole building energy modeling, LEED® analysis
 Building System Optimizer	v1.50	Rapid building energy modeling for schematic design
 Block Load	v4.16	Peak load calculation, system design
 Engineering Economic Analysis	v3.06	Lifecycle cost analysis
 Refrigerant Piping Design	v4.00	Refrigerant line sizing
 System Design Load	v5.00	Peak load calculation, system design

Please send your feedback on eDesign Suite programs and/or this EXchange newsletter to [software.systems@carrier.utc.com](mailto:software.systems@carrier.utc.com).



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