

# Mechanical System Modeling Guide

## Variable Refrigerant Flow (VRF) Systems



for EnergyPro v5



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## Introduction

All of the major CA utilities offer the Savings By Design (SBD) program to encourage designers and builders to incorporate integrated design principles, including efficient HVAC equipment into commercial new construction projects. On average, throughout commercial occupancies statewide, cooling and ventilation account for approximately 27% of total electricity usage (15% and 12% respectively), while heating energy is 36% of total natural gas consumption<sup>1</sup>.

Through experience working with many commercial new construction projects, the Savings By Design program technical staff have identified several common modeling assumptions that if used properly, could result in additional project savings beyond the code. The objective of this document is to provide information on modeling common HVAC system types to help consultants and designers take advantage of available energy efficiency opportunities, and increase customer savings.

In 2008, the CPUC adopted the CA Long Term Energy Efficiency Strategic Plan, a roadmap for energy efficiency in CA that outlines strategies for state agencies, local governments, and utilities to work collaboratively to increase the efficiency of all new residential and commercial construction. The Strategic Plan set a goal for all new residential construction to be zero net energy by 2020 and new commercial buildings by 2030. SBD is a key component of that strategy, providing technical and financial support to designers and builders to exceed the minimum efficiency requirements set by Title 24, accelerating the market adoption of new efficient technologies.

This guide provides an overview of several HVAC system types, typical applications, and step-by-step instructions for modeling each type of mechanical systems using the EnergyPro Title 24 compliance software. The guide also includes a discussion of results and error-checking, as well as recommendations for improving the system efficiency.

The baseline against which projects are compared is usually the CA Building Energy Efficiency Standards, Part 6 (Title 24). However, when Title 24 doesn't apply, SBD staff will work with the applicant to determine whether a custom baseline is appropriate for a specific project. All custom baselines require pre-approval from SBD. The information contained in this guide uses Title 24 baseline and calculation methodologies for all system types, unless otherwise noted. The Title 24 standard design energy budget for each mechanical system is determined according to the proposed system type, as shown in Table 1 below (Table N2-13 in the Nonresidential ACM Manual).

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<sup>1</sup> California Commercial End Use Survey (CEUS), CEC 400-2006-008, March 2006

**Table 1 – Title 24 Standard Design HVAC System Selection**

| Building Type  | System Type   | Heating Source | System  |
|--|---------------|----------------|---|
| Low-Rise Nonresidential (three or fewer stories above grade) | Single Zone   | Fossil         | System 1 – Packaged Single Zone, Gas/Electric                 |
|  |               | Electric       | System 2 – Packaged Single Zone, Heat Pump                    |
|  | Multiple Zone | Any            | System 3 – Packaged VAV, Gas Boiler with Reheat               |
| High Rise Nonresidential (four or more stories)              | Single Zone   | Any            | System 5 – Built-up Single Zone System with Central Plant     |
|  | Multiple Zone | Any            | System 4 – Central VAV, Gas Boiler with Reheat                |
| All Residential including Hotel / Motel Guest Rooms          | Hydronic      | Any            | System 5 – Four Pipe Fan Coil System with Central Plant       |
|  | Other         | Fossil         | System 1 (No economizer) – Packaged Single Zone, Gas/Electric |
|  |               | Electric       | System 2 (No economizer) – Packaged Single Zone, Heat Pump    |

## System Overview

Variable refrigerant flow (VRF) systems condition space by distributing refrigerant directly to indoor units located in multiple rooms or zones. The system controls the refrigerant flow provided to each indoor unit in response to its individual demand. Typical system configuration includes multiple indoor units connected to an outdoor condensing unit. The indoor units can be configured to act as evaporators in cooling mode and as condensers in heating mode.

There are two types of VRF systems, heat pump systems which allow for either cooling or heating operation for the zones served and the heat recovery systems which allow for simultaneous cooling and heating in various zones. In the case of the heat pump systems the outdoor unit will operate in either heating or cooling mode, depending upon if the system is currently configured to provide heating or cooling. Systems with heat recovery can provide heating and cooling simultaneously to different zones based on the individual zone demand. An additional advantage of heat recovery is the ability to utilize heat removed from zones providing cooling to heat zones requiring heat.

In large systems, condensing units typically contain multiple compressors of varying sizes. In most cases at least one of the compressors will be inverter-driven enabling the system to optimize operating efficiency at part-load. This modular structure makes the VRF system very flexible over a wide range of loads and, over time, as occupancies and loads change within a building. In addition, the size and weight of the individual components are less than those of other system types, which can result in reduced structural support requirements.

Indoor unit systems can either be ducted or ductless. Duct work can be eliminated with ductless indoor units or reduced with zoned ducting in place of central distributed ducting. A separate ventilation system may be required to ensure indoor air quality. However, ducts providing ventilation air only (and not conditioned air) can be significantly smaller saving valuable space within the building.

VRF systems can be either air-cooled or water-cooled. Water-cooled systems may be configured as central water-cooled systems using a single cooling tower to service all the condensers or as stand-alone condensers, each with its own dedicated cooling tower. It's also possible to couple water cooled VRF with a geothermal water loop.

### AHRI Standard 1230

The Air Conditioning, Heating and Refrigeration Institute (AHRI) recently approved Standard 1230: Performance Rating of Variable Refrigerant Flow (VRF) Multi-Split Air-Conditioning and Heat Pump Equipment. Standard 1230 establishes definitions, classifications, test, rating and data requirements, as well as nameplate and marking requirements for VRF systems. The standard is awaiting approval from US DOE.

One of the advantages of VRF systems is superior performance at part-load conditions; the part-load efficiency rating is a particularly important metric. As of January 1, 2010, the IEER (Integrated Energy Efficiency Ratio) replaced the IPLV as the standard part-load efficiency rating. Standard 1230 includes test conditions and rating requirements for the IEER, which is a required efficiency rating for a unit with a capacity greater than 65,000 Btu/h.

## **Common Applications**

VRF systems are appropriate for many types of applications, but they really shine in projects containing different rooms or zones with differing occupancy schedules, activities, uses, and temperature preferences. For example, VRF systems are particularly well-suited for use in hotels, skilled nursing facilities, and schools. In addition, historical buildings with limited space or other project constraints are also a good match for VRF systems.

VRF systems have several advantages over traditional built-up HVAC systems. The modular system design means systems can be expanded and contracted as needs change. In addition, smaller and lighter-weight equipment may require less structural support for the roof. Some system manufacturers advertise that all of their equipment will fit in a standard elevator so installation doesn't require cranes or other heavy equipment. Their modular design also provides sizing flexibility allowing systems to be tailored to fit individual project needs.

VRF systems can improve overall system efficiency by reducing or eliminating supply air fan energy use. However, projects may require a separate ventilation system to maintain adequate indoor air quality. Note, however, ducts that are only used for ventilation air (rather than ventilation and conditioned air) can be smaller, reducing the space required in the cavities between floors. This can potentially allow the designer to reduce the building height. VRF systems also increase the usable space within a building by reducing the space needed for mechanical rooms. In addition, because ventilation only ducts require less space, VRF systems are particularly well suited to retrofitting historic buildings and older buildings with no air conditioning, especially if there's an alternate method of meeting the ventilation requirements.

VRF systems typically modulate the compressor output in response to the demand using one of two methods: a variable capacity compressor or a variable speed driven compressor. Both methods modulate compressor capacity allowing tighter temperature control than on and off cycling using a preset deadband range. In addition, electronic expansion valves can be used to modulate refrigerant flow at the indoor units.

## Special Considerations

Because VRF systems may require a separate ventilation system they must be modeled differently than HVAC systems which provide both conditioning and ventilation. EnergyPro will calculate the ventilation requirements automatically, as described in the [Modeling the Ventilation System](#) section.

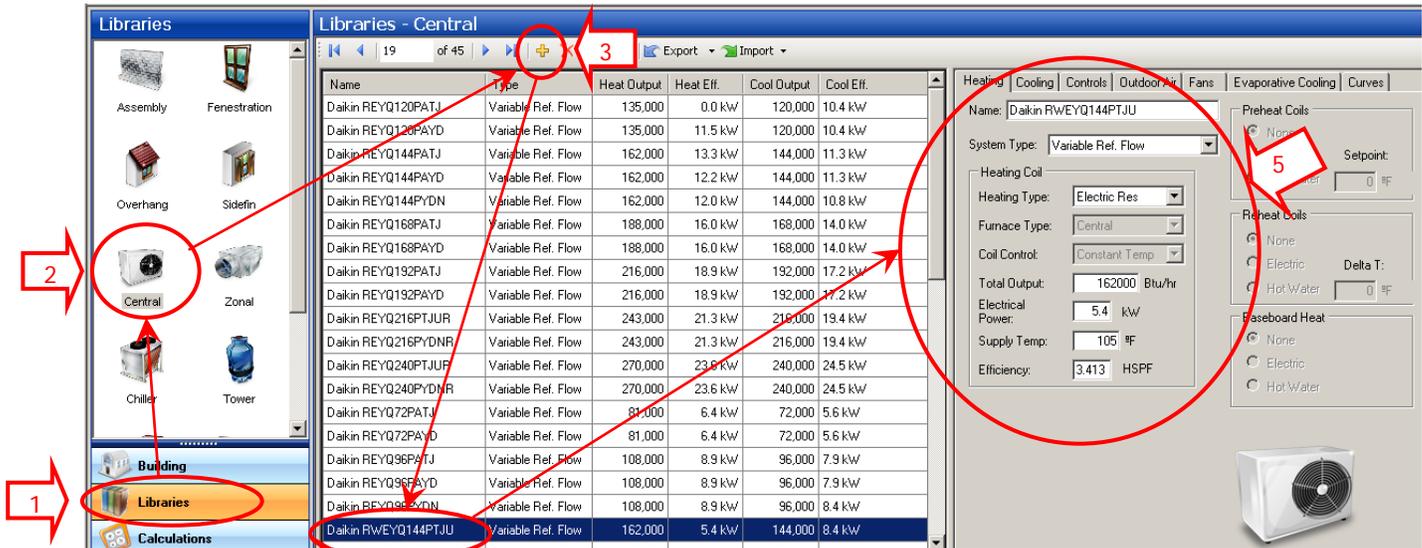
Sizing ratios between the indoor and outdoor units for VRV systems must conform to manufacturer specifications. Each manufacturer allows different size ratios, commonly ranging from 50 to 200%. Thus, the sum of the indoor unit capacities (tonnage) cannot be more than 200% of the outdoor unit capacity.

## Modeling and Input Approaches

Note: The input descriptions that follow assume you have already created the EnergyPro Building Tree, including entering the project location, envelope data, and creating the individual mechanical zones, and will focus only on the inputs directly related to the mechanical system. Specify the system features once you have completed the takeoff process and your input data is ready.

## Creating the Outdoor Unit(s)

Figure 1 Creating the Outdoor Units

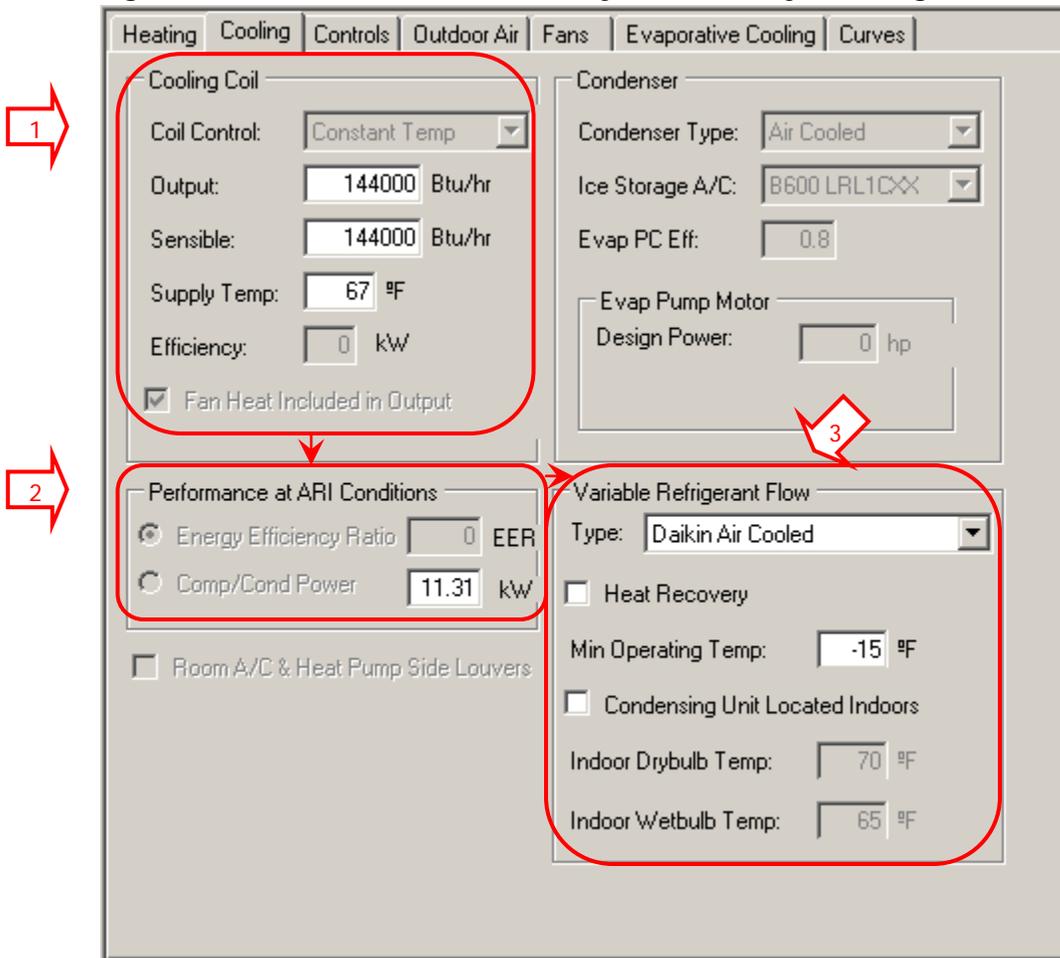


(See Figure 1)

Create the outdoor component of the VRF system in the project Central System Library.

1. Select Libraries from the choices in the bottom-left window pane. EnergyPro displays icons for each library in the top-left pane.
2. Select the Central library to view the editing window on the right.
3. Create a new system: select an entry that resembles the system you want to model as closely as possible (same Type and similar capacity). Select + (add) from the toolbar at the top of the list to create a copy of the selected system, which is placed at the bottom of the list.
4. Enter a name for the new System in the Name field, and select Variable Ref. Flow from the System Type drop-down list.
5. Enter the data describing the Heating System characteristics. Heating Type is used to specify the backup heating source, (the software knows that a VRF system is a heat pump) when the VRF is unable to meet the heating load. Enter the Total Output (capacity) of the VRF heating system and the kW Electrical Power requirements of the VRF at full load. Note that part load curves will adjust this number based upon manufacturer specifications. Indicate the Supply Temperature of heated air at the indoor system and the backup heating system Efficiency. You may need to add or modify data that is missing or differs from the information included in the EnergyPro Central directory.

**Figure 2: Outdoor Units, Central System Library, Cooling Tab**

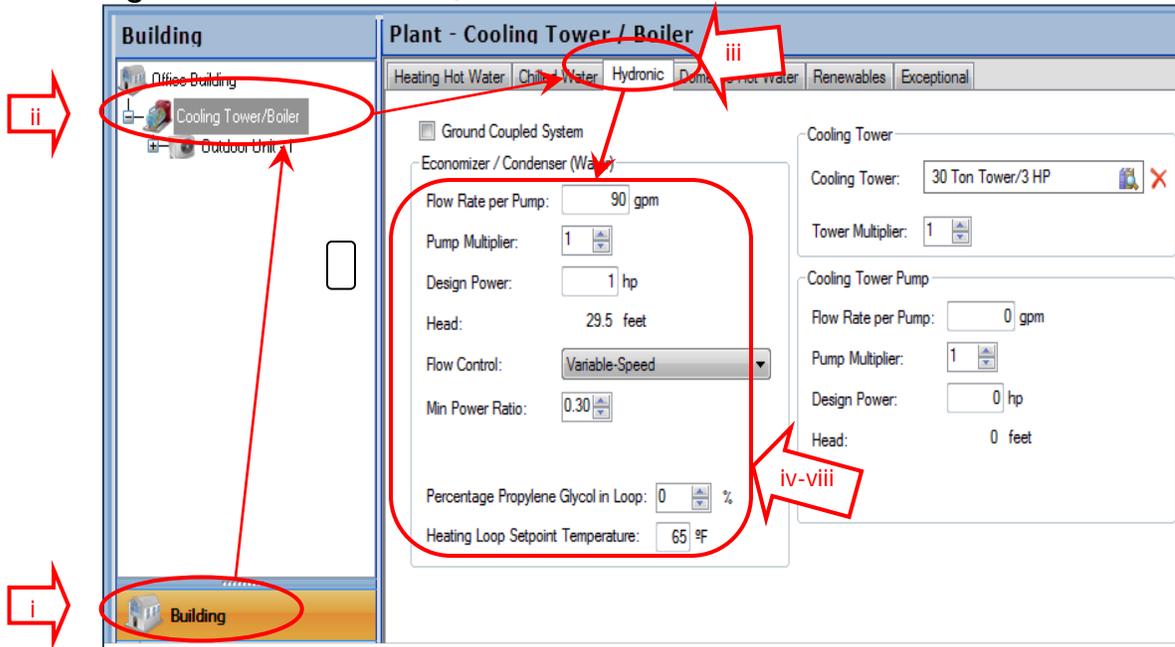


Next, select the Cooling Tab and enter the cooling data as shown in Figure 2 above.

1. Cooling Coil: Enter the cooling coil Output (total cooling) and Sensible output, and the Supply Temp.
2. Performance at ARI Conditions: Select the Comp/Cond Power radio button and enter the kW power demand for the outdoor unit, including both the compressor and condenser. Because there is no ARI Standard available at this time, enter the full-load power demand.
3. Variable Refrigerant Flow: Select the VRF system type (manufacturer and air- or water-cooled) from the drop-down list and check the box if the system includes heat recovery. Enter the Min Operating Temp, the minimum expected ambient temperature the VRF condenser will operate at. If the condensing unit is located indoors check the Condensing Unit Located Indoors box and input the Indoor (ambient) Drybulb Temp and the Indoor Wetbulb Temp where the unit is located

Repeat this process for each outdoor unit. If the project contains multiple identical outdoor units, you may also use the Multiplier field in the System Element of the Building Tree to indicate the number of identical outdoor units.

**Figure 3: Plant Element, Water-Cooled Condenser**



Water-Cooled Condensers (skip this step if the condenser is air cooled):

- If the condenser is a central water-cooled condenser (one condenser/tower serving all systems in the building) enter the pump and water loop characteristics in the Plant Element, Hydronic Tab (see Figure 3 above). The Plant Element is located in the Building Tree. To access it:
  - i. Select Building in the lower-left window pane.
  - ii. Select the Plant Element to view the Editing Window on the right.
  - iii. Select the Hydronic Tab.

Economizer / Condenser (Water) Entries:

- iv. Enter the Flow Rate per Pump, in gallons per minute, and the number of identical pumps in the Pump Multiplier field.
- v. Enter the pump Design Power (brake horsepower) at design conditions. If the pump power is expressed in kilowatts, divide kilowatts by 0.746 to convert to horsepower. EnergyPro automatically calculates the pump Head from the Flow Rate and Design Power inputs.
- vi. Choose one of the three Flow Control options: One-Speed/2 Way Valve; One-Speed/3 Way Valve, or Variable Speed. If the pump is a variable speed pump, enter the Min Power Ratio, the ratio of the minimum operating speed to the maximum pump speed (expressed as a decimal).
- vii. Next, enter the Percentage of Propylene Glycol in (the water) Loop, if any. Propylene glycol reduces the temperature at which the water/glycol mixture will freeze, providing anti-freeze protection in VRF condenser water loops. However, propylene glycol provides a lower heat transfer rate than water-only closed loop systems.
- viii. Finally, enter the Heating Loop Setpoint Temperature for the hydronic condenser heating loop.

Return to the Central System Library, Cooling tab to complete the Cooling System Inputs.

## Creating the Indoor Units:

Figure 4: Indoor Units, Zonal Library (General)

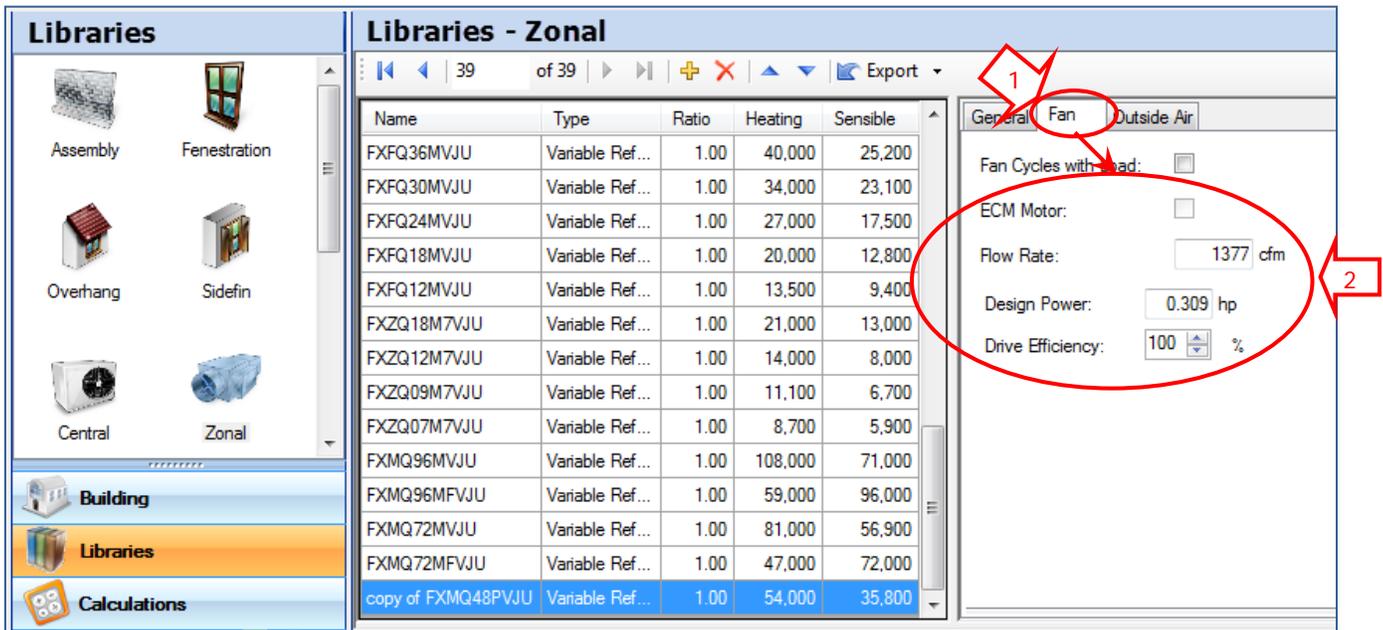
| Name               | Type                | Ratio | Heating | Sensible |
|--------------------|---------------------|-------|---------|----------|
| FXL(N)Q24MVJU      | Variable Ref. Fl... | 1.00  | 27,000  |          |
| FXMQ07PVJU         | Variable Ref. Fl... | 1.00  | 8,500   | 6,400    |
| FXMQ09PVJU         | Variable Ref. Fl... | 1.00  | 10,500  | 7,800    |
| FXMQ12PVJU         | Variable Ref. Fl... | 1.00  | 13,500  | 9,700    |
| FXMQ18PVJU         | Variable Ref. Fl... | 1.00  | 20,000  | 14,400   |
| FXMQ24PVJU         | Variable Ref. Fl... | 1.00  | 27,000  | 15,600   |
| FXMQ30PVJU         | Variable Ref. Fl... | 1.00  | 34,000  | 23,800   |
| FXMQ36PVJU         | Variable Ref. Fl... | 1.00  | 40,000  | 28,800   |
| FXMQ48MFVJU        | Variable Ref. Fl... | 1.00  | 30,000  | 48,000   |
| FXMQ48PVJU         | Variable Ref. Fl... | 1.00  | 54,000  | 35,800   |
| FXMQ72MFVJU        | Variable Ref. Fl... | 1.00  | 47,000  | 72,000   |
| FXMQ72MVJU         | Variable Ref. Fl... | 1.00  | 81,000  | 56,900   |
| FXMQ96MFVJU        | Variable Ref. Fl... | 1.00  | 59,000  | 96,000   |
| FXMQ96MVJU         | Variable Ref. Fl... | 1.00  | 108,000 | 71,000   |
| FXZQ07M7VJU        | Variable Ref. Fl... | 1.00  | 8,700   | 5,900    |
| FXZQ09M7VJU        | Variable Ref. Fl... | 1.00  | 11,100  | 6,700    |
| FXZQ12M7VJU        | Variable Ref. Fl... | 1.00  | 14,000  | 8,000    |
| FXZQ18M7VJU        | Variable Ref. Fl... | 1.00  | 21,000  | 13,000   |
| copy of FXMQ48PVJU | Variable Ref. Fl... | 1.00  | 54,000  | 35,800   |

(See Figure 4)

Create the indoor components of the VRF system in the Zonal Library.

1. Select Libraries from the choices in the bottom-left window pane. EnergyPro displays icons for each library in the top-left pane.
2. Select the Zonal Library in the top pane to view the Editing Window on the right.
3. To create a new zonal system, select an entry that resembles the new item as closely as possible (same Type and similar capacity). Select Add (+) from the toolbar at the top of the list to create a copy of the selected zonal system.
4. The new Zonal System is automatically placed at the bottom of the list, with the words "Copy of" added to the beginning of the name.
5. Enter a name for the new Zonal System in the Name field, and select Variable Ref. Flow from the Type drop-down list.
6. Select the Thermostat Type, typically, Proportional. Proportional thermostats gradually adjust system operating capacity rather than using an on/off strategy. Reverse action thermostats allow for variable volume heating as well as cooling. The Title 24 Standards assume systems with reverse action thermostats set the maximum airflow to 50% of the total volume when in heating mode. Two-position thermostats are simple on/off controls.
7. Enter the Heating Output and the Cooling Output of the zonal system (the sums of the individual heating and cooling coil capacities).

Figure 5: Indoor Units, Zonal Library (Fan)



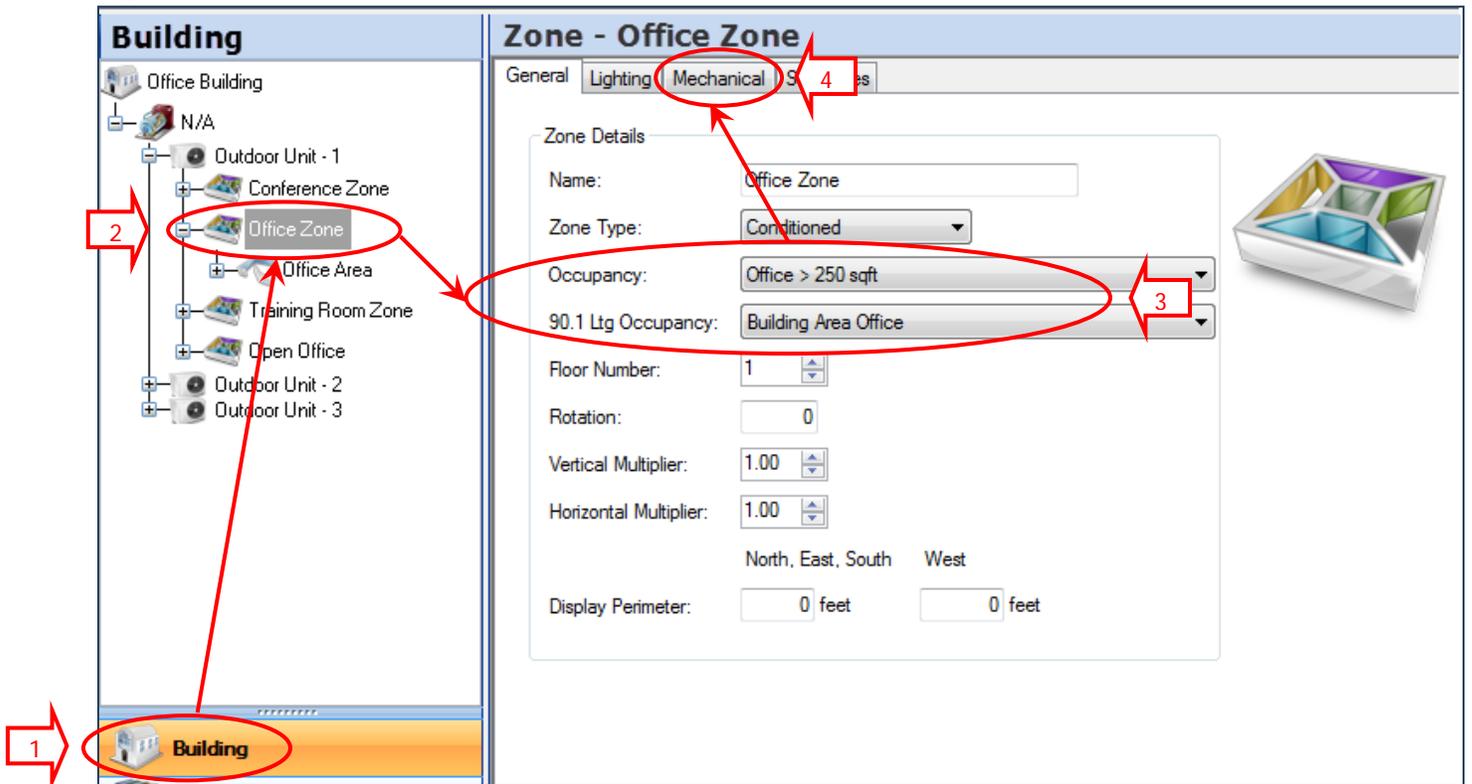
Once the Zonal System general characteristics are completed, specify the fan features as indicated in [Figure 5](#) above.

1. Select the Fan Tab.
 

NOTE: For most occupancy types, do not check the Fan Cycles On with Load (when heating or cooling is required) box. This input applies only to residential units of high-rise residential buildings and hotel/motel guest rooms. EnergyPro models fan operation as continuous during occupied hours for all other occupancy types.
2. Check the ECM Motor box if the fan motor is an electronically commutated motor (ECM).
  - a. Enter the fan Flow Rate in cfm at design conditions.
  - b. Enter the fan Design Power (brake horsepower) at design conditions. If the fan power is expressed in kilowatts, divide kilowatts by 0.746 to convert to horsepower. EnergyPro uses this input and the Drive Efficiency to calculate input fan power.
  - c. Enter the Drive Efficiency of the zonal fan expressed as a percentage (%). This value is 100% if the fan is direct drive. Indirect drive fans (with fan belts) are characterized by drive efficiencies less than 100%, usually around 97%. The efficiency of variable speed drives (VSDs) vary with the load on the motor. At full and near-full load, efficiencies typically range from 95-97%.

## Modeling the Ventilation System (General Tab)

Figure 6: Zone General Information



(See Figure 6)

To model the ventilation system, define the zone characteristics using the Building Tree.

1. Select Building in the lower-left window pane. EnergyPro displays the project Building Tree in the top-left window.
2. Select the appropriate Zone Element in the Building Tree (the Office Zone in this case). EnergyPro displays the Zone Editing Window on the right. Select Expand Tree from the View Menu to view all the tree elements.
3. In the General Tab, select the occupancy type from the drop-down list. For CA Title 24 projects, select from the "Occupancy" field. For LEED or ASHRAE 90.1 calculations, use the "90.1 Lighting Occupancy" field.
4. Next, select the Mechanical tab.

## Modeling the Ventilation System (Mechanical Tab)

Figure 7: Zone Mechanical Information

**Zone - Office Zone**

General | Lighting | **Mechanical** | Schedules

Zone Level Mechanical System Data

Zonal System: FXMQ48PVJU

Zonal Multiplier: 1

Demand Control Ventilation:

Pipe Length: 25 feet

Supply AC per Hour: 0

Supply Air Flowrate: 0 cfm

Supply Air Flowrate only required for VAV systems which will comply under the Prescriptive Approach (see MECH-3)

**Ventilation**

Use Standard (Area Basis) 0.15 cfm/ft<sup>2</sup>

Use Occupancy 0.5 cfm/ft<sup>2</sup>

Use Air Change 0 AC/hr 0 cfm/ft<sup>2</sup>

Exhaust Fan: 0 cfm/ft<sup>2</sup>

(See Figure 7)

1. If the Zonal System isn't already specified, click on the Zonal System field to open the Zonal Library and select the Indoor Unit (Zonal System).
2. Check the Demand Control Ventilation box if the zone has DCV. Enter the refrigerant pipe length from the outdoor to the indoor unit in the Pipe Length field, in feet.
3. In the Ventilation section, select Use Standard (Area Basis), Use Occupancy, or Use Air Change. For most occupancy types, it's sufficient to allow EnergyPro to automatically model the ventilation system energy usage based on CA standard ventilation requirements for each occupancy type. EnergyPro automatically uses the data from the CA Building Code (Table 1004.1.1), which specifies the maximum occupant loads for various occupancy types and building uses upon which the minimum ventilation rate is calculated. Note that if you select Use Occupancy or Use Air Change, you must manually enter the data which the software uses to calculate the ventilation rate, as described below.
  - a. Use Standard: EnergyPro automatically sets the ventilation rate based on the occupancy type.
  - b. Use Occupancy: EnergyPro calculates the ventilation rate based on the Occupant Density and Ventilation rates specified in the Occupant Tab of the Room Element in the Building Tree.
  - c. Use Air Change: EnergyPro calculates the ventilation rate based on the user input AC/hr field to the right.

## Results

The NR Performance results will include data for heating, cooling and fan energy for an air-cooled system. Water-cooled system results will also include pumping energy.

## Optimizing Energy Efficiency

There are several ways to optimize the energy efficiency of a VRF system, including:

- **Equipment Efficiency:** High EER and IEER (part-load efficiency) systems use less energy than standard efficiency equipment.
- **Heat Recovery:** Heat recovery allows the system to use the heat removed from one zone in cooling mode to heat a zone requiring heat.
- **Variable Speed Compressors:** Variable speed compressors allow the system to operate at optimal efficiency at part-load by providing only the exact amount of cooling required at any given time.
- **Properly sized indoor units:** By selecting indoor units matched to the load, fan energy consumption will be reduced.
- **Properly sized outdoor units:** In selecting the outdoor unit, look at the peak coincident load for all the indoor units.
- **Load Diversity:** When selecting units consider the fact that some loads inside a building will move; thus people using conference rooms and lunch rooms, are not using their offices and systems can be sized accordingly.