Example 7: NR Medium Office, Packaged VAV with Variable-Volume Reheat and Fan-Powered Boxes, Air-to-Water Heat Pump

SYSTEM TAG: T24ACM-PVAVAWHP-PFPB

PROJECT VISION

California Title 24 compliance modeling requires translating mechanical system designs into CBECC 2025 software objects, a process for which little practical guidance exists. Developed as part of the *Addressing Complex HVAC Systems in Code Compliance* project, funded by Southern California Edison through the CalBEM working group, each example walks through how a recognizable HVAC system type translates into CBECC objects, what Title 24 2025 Part 6 requires, and what assumptions were made.

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System Tag: T24ACM-PVAVAWHP-PFPB
Title 24 2025 ACM: System 15d

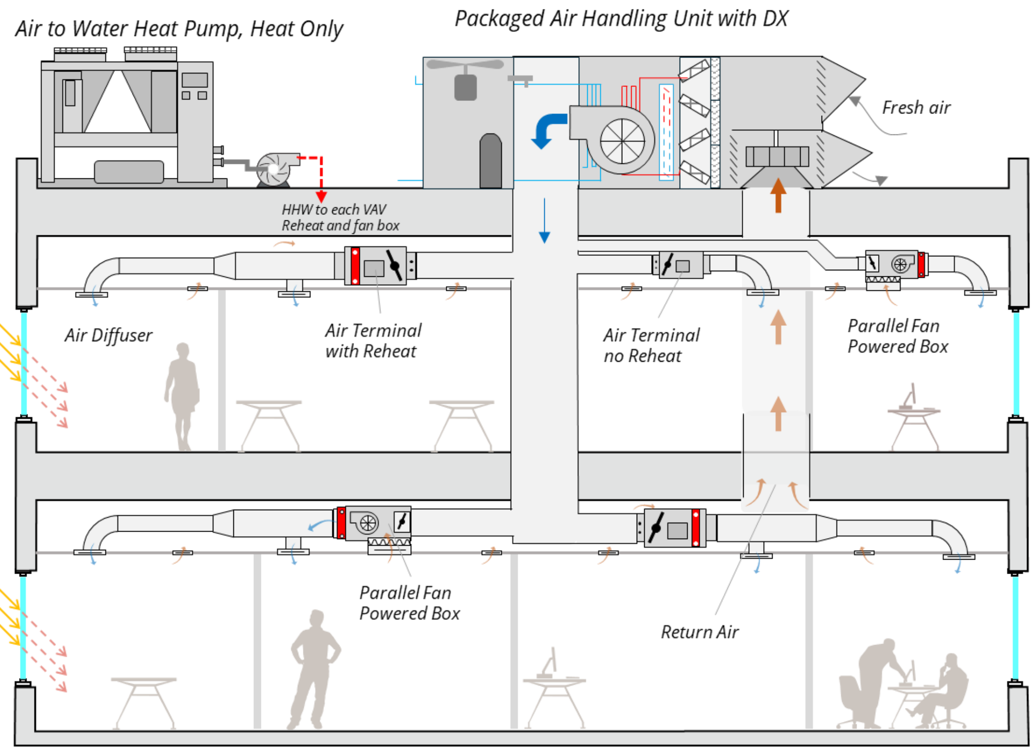
Mechanical Description

This system is a multi-zone heat pump system, with centrally located air handling units providing ventilation and conditioned air to thermal zones through terminal units - a mix of variable air volume reheat boxes and parallel fan-powered boxes. Zone-level terminal units include hot water heating coils supplied by a central air-to-water heat pump plant.

The central air handler systems are referred to as packaged variable air volume air handling units (PVAV), indicating that cooling is provided by a refrigerant system, a direct-expansion (DX) coil, an airside economizer, and modulating airflow and supply air temperature control. This configuration is classically referred to as a PVAV system, however in this setup a subset of thermal zones utilizes terminal units with zone fans, enabling an elevated level of efficiency and reduced level of reheat.

Diagram

The diagram depicts a version of this system with only a single packaged air handler serving two floors, a central air-to-water heat pump on the roof making hot water, and a mix of zone terminal unit types. In the model packaged air handlers are utilized on each floor vs one for the whole building.



Mechanical Details

The system is designed with large floor-by-floor air handlers, each with a cooling coil, delivering fresh air and cold air to each thermal zone through terminal units. Terminal units are variable air volume and more efficient parallel fan powered boxes.

Ventilation: Mixed Air at each air handler, providing ventilation and airflow for cooling

Ventilation control: Fixed ventilation setpoints for all thermal zones (5 per floor)

Cooling: DX cooling delivered with air to variable airflow terminal units

Heating: central air-to-water heat pump and supplemental gas boiler serving hot water to terminal units

Capacity control: variable air flow with fixed air temperatures

Economizing: Yes, upper limit Fixed dry bulb control

Ventilation and cooling are provided by the floor-by-floor PVAV air handling units and modulated at each thermal zone by the terminal units where ventilation controls reside. The system includes the ability to increase the flow of outside air with the airside economizer.

Cooling in the air handlers is produced by a direct-expansion (DX) refrigerant coil, extracting heat to the outside air. This cooling device is indicated in the title of this system by the term 'packaged' in PVAV to indicate this type of cooling element. Zone level variable air volume dampers adjust the airflow requested.

Heating is provided at each terminal unit through a hot water coil. How water is then generated by an air-to-water heat pump, extracting heat from the ambient air. In California, it is typically not common to have a heating coil or pre-heating coil in the air handling unit though in colder climates this can exist.

Mechanical Capacities and Sizing

Equipment is sized based on the peak loads for the building and for this example, sizing matches the compliance standard baseline capacities for the building. This includes the main components of the HVAC, with terminal unit capacity and airflow rates set to autosize. The air handling unit capacities are shown below.

Cooling is provided by three DX units with an integrated economizer. Capacities and efficiency assumptions shown below.

System Name	System Type	Clg Net (kBtu/hr)	Clg Cap (Btu/sf)	IEER	EER	Econo Lockout (°F DB)
Bottom VAV	PVAV	447.1	25	13	9.8	71
Mid VAV	PVAV	469.2	26	13	9.8	71
Top VAV	PVAV	487.7	27	13	9.8	71

Economizer: Fixed Dry Bulb

Each air handling unit is sized for full cooling and modulates air to the ventilation minimum. On average, the air handlers provide 0.68 cfm/sf at peak and 0.15 cfm/sf of ventilation at minimum.

System Name	System Type	Supply (CFM)	Ventilation Min (CFM)	Cooling Density (CFM/SF)	Ventilation Density (CFM/SF)
Bottom VAV	PVAV	11,478	2,681	0.64	0.15
Mid VAV	PVAV	12,116	2,681	0.68	0.15
Top VAV	PVAV	12,788	2,681	0.72	0.15

Fans in each unit are sized based on a prescriptive allowance of fan power in W/cfm. The equivalent static pressure and motor size are shown for reference.

System Name	System Type	Total Static (inH_2O)	Motor Size (BHP)	Fan Eff (W/cfm)
Bottom VAV	PVAV	4.84	13.5	0.946
Mid VAV	PVAV	4.84	14.2	0.946
Top VAV	PVAV	4.87	15.1	0.946

Fan Control: Variable Speed Drive

Code Compliance Software Configuration

Th diagram on the right shows the configuration of the HVAC components based on CBECC architecture.

PVAV Air System

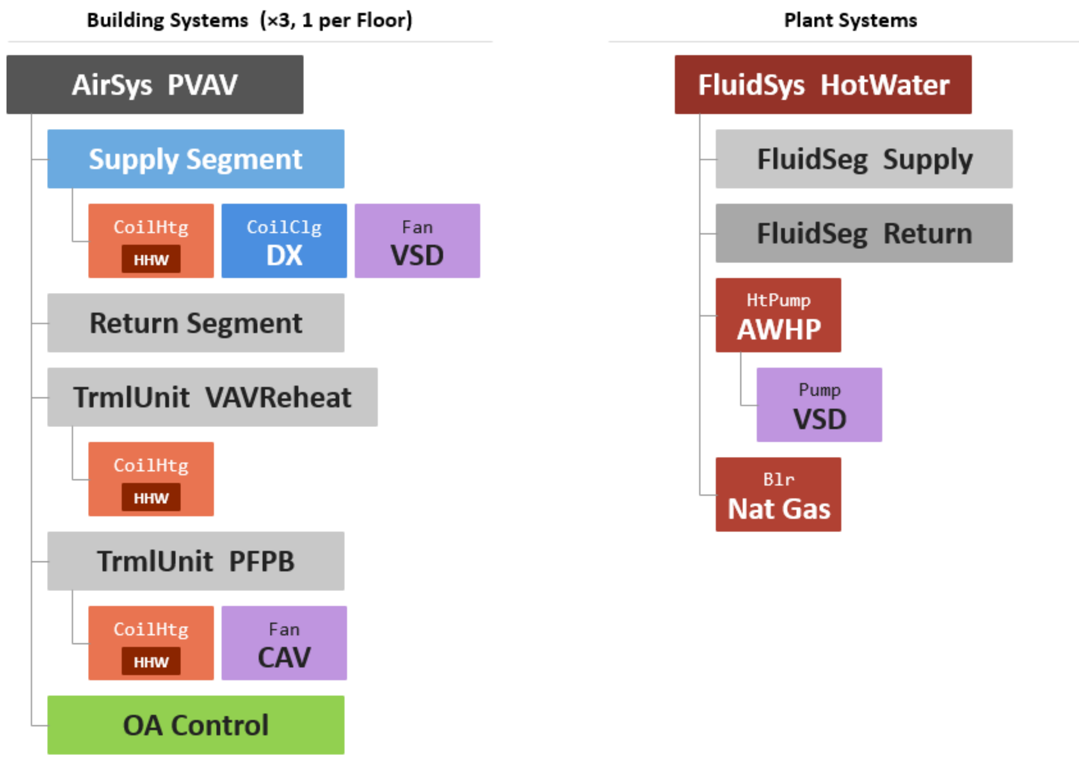
The floor-by-floor air systems are configured with a heating coil, DX cooling coil, outdoor air controller, and a supply fan.

Terminal Units

Two types of terminal units are included, variable air volume boxes with heating or reheat coils from the hot water plant and, parallel-fan-powered-boxes (PFPB) with heating coils and terminal-unit-fans. The PFPB enables lower energy in those zones during reheat instances as well as heating instances by reducing the reliance central fans to increase flow.

Central Hydronic Plant

The hot water plant is modeled with an air-to-water heat pump and backup natural gas boiler. The loop serves the zone terminal units as well as the air system heating coils.



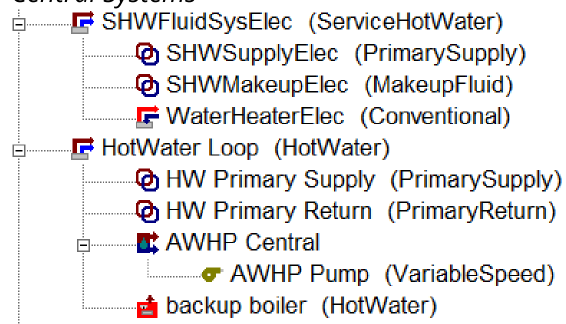
PVAV System

In CBECC, the same systems are depicted in the images shown for the central hot water plant, air handling units and terminal units.

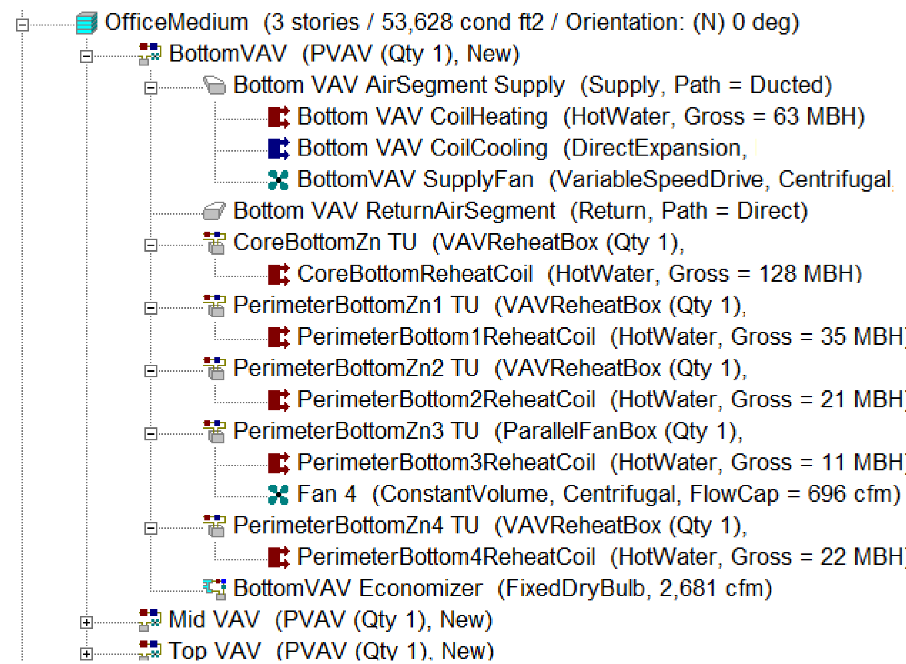
The central systems consist of the hot water loop for heating and the service hot water loop for domestic purposes. The central hot water plant was configured with an air-to-water heat pump and a backup natural gas boiler.

The building systems consist of air systems with terminal units serving each zone. Each air system maintains cooling and ventilation capabilities and with heating provided at the terminal units. Two types of terminal units are used, primarily vav reheat boxes controlling airflow and then PFPB units also controlling local airflow and variable flow from the air system.

Central Systems



Building Systems



CBECC Object Locations

The main component input screens are shown below for the system. Additional information is available by opening the model file.

HHW Plant Loop

The central plant for heating hot water is configured as a hot water loop supplying 130°F and returning 110°F.

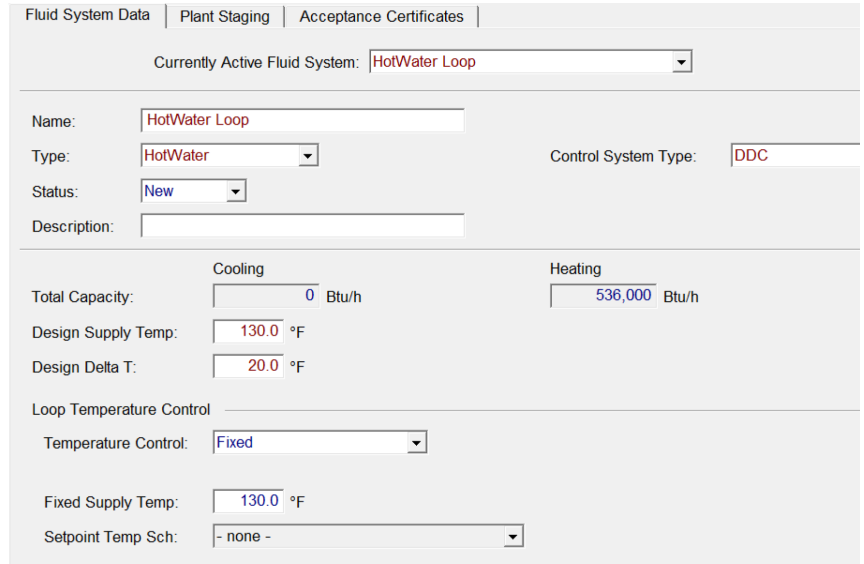
The air-to-water heat pump is configured to operate at the rated cop of 2.92 and a minimum part load ratio of 20%, along with a backup supplemental boiler.

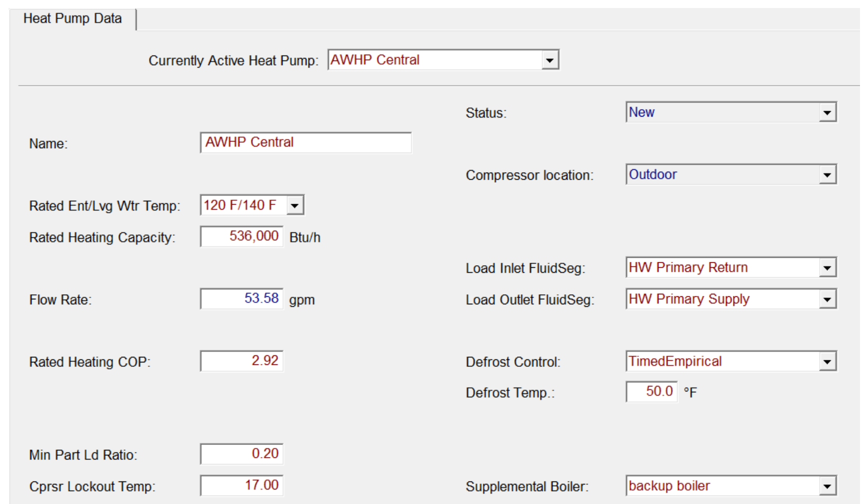
HHW Loop

Design Supply Temp	130°F
Design Delta-T	20°F
Control System	DDC

Air-to-Water HP

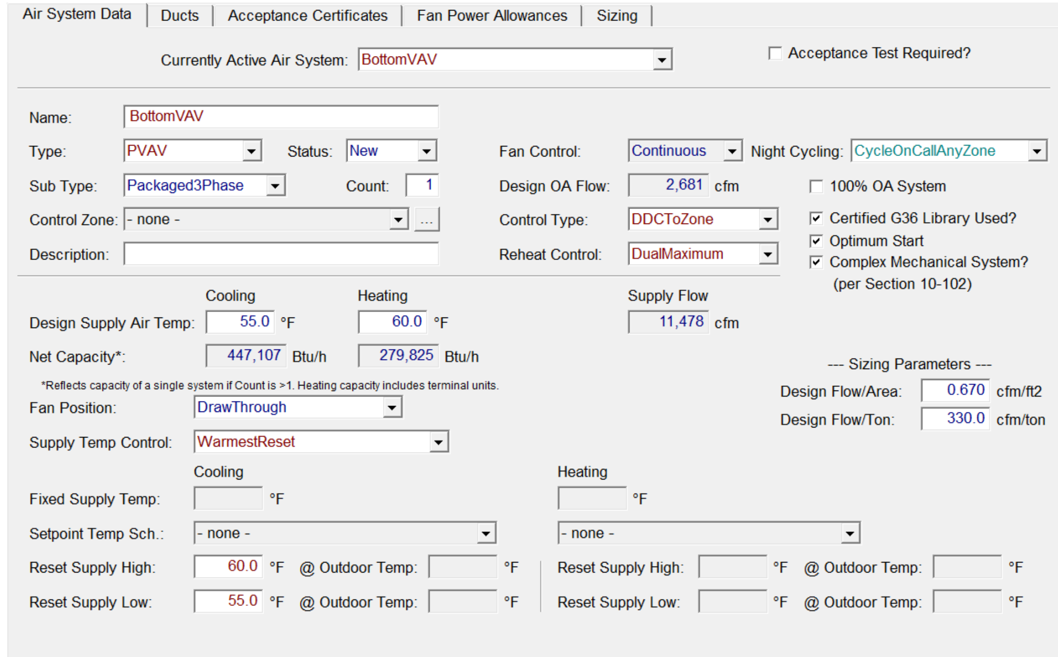
Rated Ent/Lvg	120°F/140°F
Capacity	536,000 Btu/hr (45 tons)
COP	2.92 (heating)
Flow Rate	53.6 gpm
Compressor Lockout	17°F
Backup Boiler	Natural Gas
Boiler Efficiency	84%





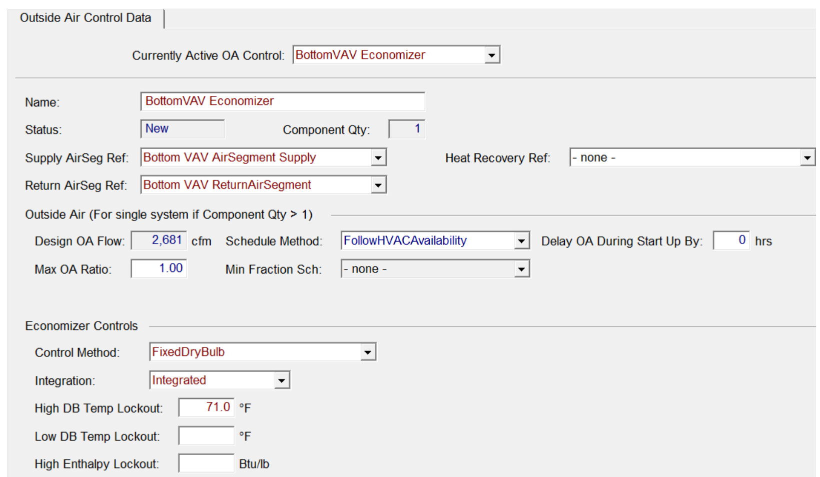
Air Systems

The packaged VAV air handlers are configured with digital controls to the zone (DDCtoZone), Dual Maximum controls, as utilized certified Guideline 36 Libraries. The supply temperature control is set to WarmestReset, which will decrease supply temperature based on the zone that needs the most cooling. Air temperature is able to adjust between 60°F down to 55°F.



Outdoor Air Controller

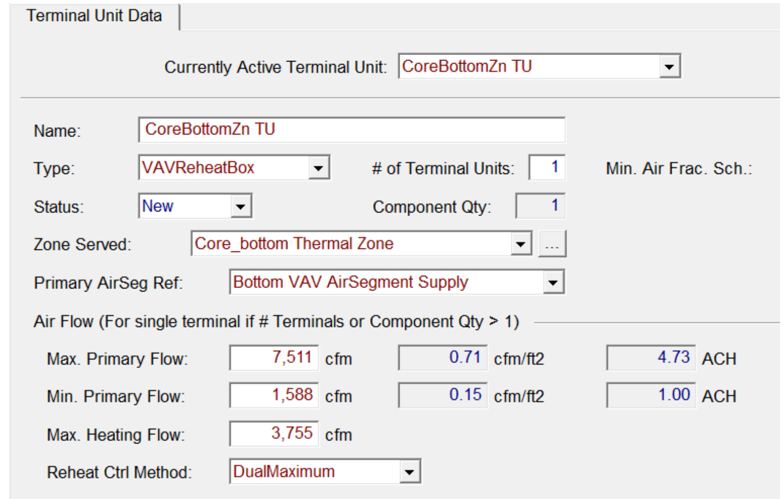
The last object in the air system is outdoor air control. This object controls the economizer if one is configured shown here controlled to Fixed Dry Bulb. The economizer is integrated, which is the most common configuration, meaning the unit will utilize outdoor air up to the return-air room setpoint providing the most energy benefit.



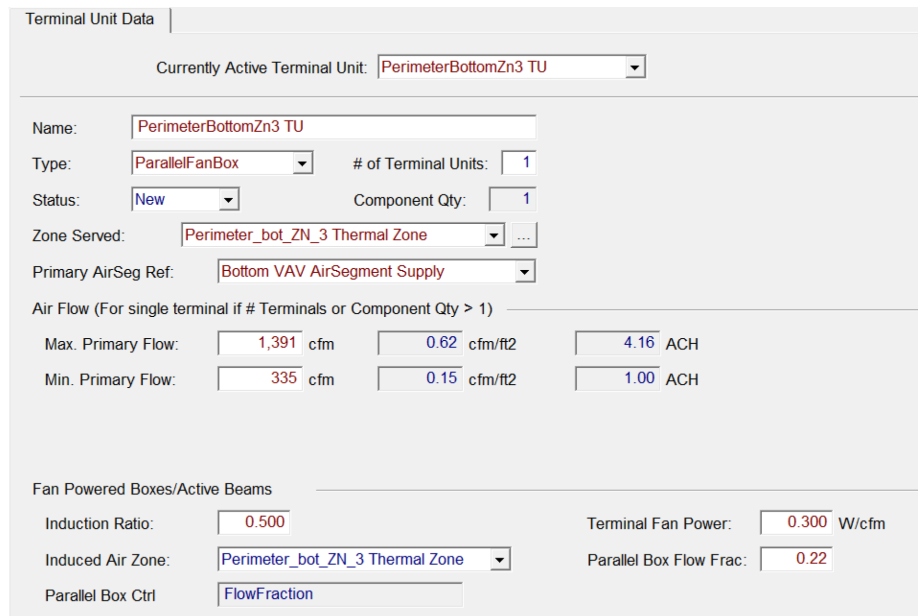
Terminal Units

Each zone is conditioned by a terminal unit, either a VAV Reheat Box or a PFPB.

The VAV reheat box here is shown with defined maximum flow, minimum flow for ventilation and heating maximum for each zone.



The PFPB is shown with both max and min flow. The terminal unit screen also defines the fan power efficiency and airflow induction ratio for the unit. The fan itself however is a separate child component to be defined.



System Efficiency Tables

Category	Proposed (PVAV with VAV, PFPB and AWHP + gas blr)	Standard (PVAV with VAV, PFPB and AWHP + elec blr)
System Type	PVAV | 3 air handlers	PVAV | 3 air handlers
Cooling Efficiency	EER=9.8	EER=9.8
Heating Primary (Central Plant)	Air-to-Water HP at COP 2.92, Backup Gas Boiler| 84% thrml eff	Air-to-Water HP at COP 2.92, Backup Electric | 98% thrml eff
Zone Heating (Reheat)	HW reheat coils at VAV boxes and PFPB units (from central plant)	HW reheat coils at VAV boxes and PFPB units (from central plant)
Fan Type & W/cfm (Supply Fans)	VariableSpeedDrive | (W/cfm), 0.946 W/cfm	VariableSpeedDrive | (W/cfm), 0.946 W/cfm
Economizer	FixedDryBulb (F), 71°F	FixedDryBulb (F), 71°F
DCV Control	Fixed OA	Fixed OA

Relevant Energy Code Citations

Fan Power Budget, Multi-Zone VAV Systems

401.3.3.1 [Section 140.4(a)3A]

Multi-zone VAV air systems shall comply with the prescriptive fan power allowance. The three PVAV supply fans are configured at 0.946 W/cfm with variable speed drive control, within the prescriptive allowance for the system capacity and configuration.

Parallel Fan-Powered Box Fan Power

401.3.3.2 [Section 140.4(a)3B]

Parallel fan-powered terminal units shall not exceed 0.3 W/cfm of unit design airflow. All PFPB terminal fans in this model are configured at 0.3 W/cfm.

Required Air-Side Economizer

401.3.7 [Section 140.4(e)]

All three PVAV cooling units exceed 33,000 Btu/hr and are required to include an air-side economizer. For CZ9, the fixed dry-bulb high-limit shutoff is 71°F per Table 401.3-G [Table 140.4-G]. Economizers are configured as integrated, permitting simultaneous economizer and mechanical cooling operation.

VAV Minimum Airflow Controls

401.3.14 [Section 140.4(m)]

VAV air systems shall include controls that reduce supply air volume to no more than 30% of design airflow at no more than 30% of design fan power. VAV and PFPB terminal units serving each zone include minimum flow setpoints to meet ventilation requirements at reduced load.

Supply Air Temperature Reset

401.3.8 [Section 140.4(f)]

Multi-zone VAV systems shall include supply air temperature reset controls. Supply air temperature resets from 60°F to 55°F based on zone cooling demand using WarmestReset control, reducing reheat energy when full cooling is not required.

Direct Digital Controls to Zone

401.2.2.10 [Section 120.2(j)] and Table 401.2-D [Table 120.2-A]

Each air-handling system and all zones served are required to have DDC to the zone level for new construction where the system supplies more than three zones with a design heating or cooling capacity of 300 kBtu/h or greater. All three PVAV units are configured with DDCtoZone controls and Dual Maximum terminal sequences per ASHRAE Guideline 36 libraries.

Optimum Start/Stop Controls

401.2.2.11 [Section 120.2(k)]

Systems equipped with DDC to the zone level are required to have optimum start/stop controls that calculate pre-conditioning time based on space temperature, occupied setpoint, outdoor air temperature, and time to occupancy.

Air-to-Water Heat Pump Heating Efficiency

Section 400.5 / Table 400.5-A [Section 110.2 / Table 110.2-A]

Air-to-water heat pumps supplying hot water for zone reheat must meet minimum COP requirements for their rated capacity and entering water temperature. The modeled unit is configured at COP 2.92 at rated conditions, meeting the applicable mandatory minimum.

This example is one of eight developed as part of the *Addressing Complex HVAC Systems in Code Compliance* project. The full guide includes additional HVAC system types, alternative configurations, and working CBECC model files. All resources are available through the CalBEM working group and EnergyCodeAce platform.