Modeling Chilled Beams
in HAP v4.8

This e-Help provides a high-level overview of chilled beams, how they work and how to model them in HAP v4.8 (and later versions). The first half of this article explains the how chilled beam systems work. The second half explains HAP modeling. Please consult specific manufacturers' application and product literature for application and design information.

Europe has successfully applied chilled beam systems for a decade even though it is a relatively new technology in North America. The inherent design and operational advantages have influenced the popularity of chilled beam systems in North America. We will discuss these advantages later in this e-Help.

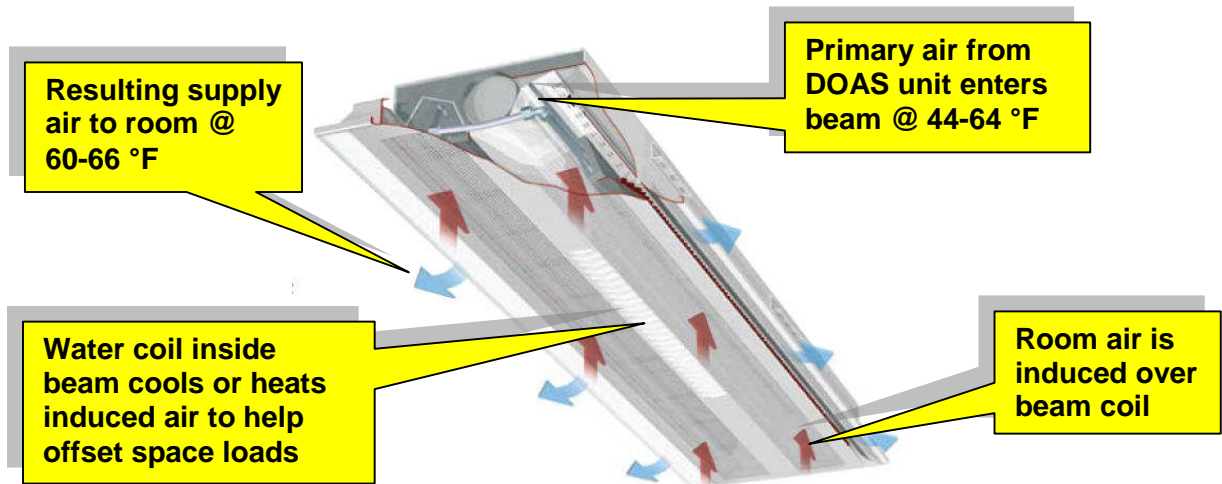There are two types of chilled beam systems: active and passive.

Resulting supply air to room @ 60-66 °F

Primary air from DOAS unit enters beam @ 44-64 °F

Water coil inside beam cools or heats induced air to help offset space loads

Room air is induced over beam coil

Figure 1 – Active Chilled Beam

Active chilled beams (ACB) use pre-conditioned primary ventilation air in a quantity necessary to meet the room latent load and ensure good air quality for the occupied area. The conditioned primary air absorbs the space latent load; resulting in the chilled beam coil operating without condensation. The ACB then cools or heats the induced air to meet the room sensible load and respond to the room thermostat requirements. High latent loads in the space require the dew point of the primary air to be low, which can result in primary air temperatures at the lower end of the range shown above. At low load conditions, this may result in little if any of the cooling load being handled by the cooling coil within the chilled beam. A serious problem occurs when the primary air over-cools the space.
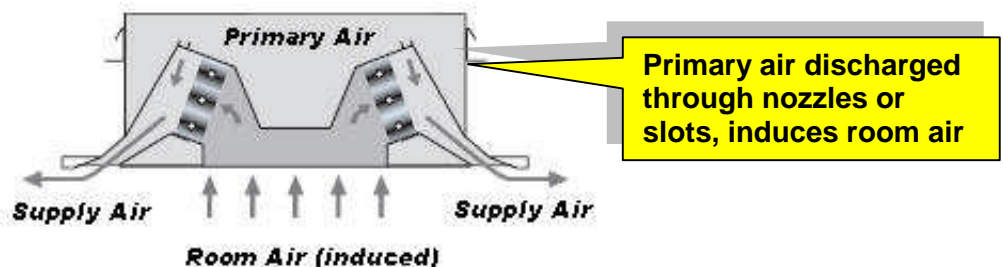

Primary air discharged through nozzles or slots, induces room air

Figure 2 – Active Chilled Beam Cut Away

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Active chilled beams operate using the induction process. During induction, the primary air discharges at high velocity through nozzles located within the device as illustrated in Figure 2. These high velocity primary air jets create a negative pressure in the room inlet portion of the beam thereby inducing room air through the beam coil where it mixes with the primary air. This mixed air is then discharged through the outlet slot of the beam into the room, resulting in a total supply airflow quantity 3 to 4 times greater than the primary airflow. We refer to this ratio of supply air to primary air as the induction ratio.

Passive chilled beams (PCB) work using natural convection. Air cooled by the coil inside the beam becomes denser than the surrounding room air and therefore flows downward into the room. The difference in density combined with the height of the beam induces room air down through the beam coil. Thus passive beams mainly provide a downward airflow in the room, as shown in Figure 3. This downward flow induces air from the room upward into the ceiling plenum and then back through the beam coil. Unlike an active chilled beam, the passive chilled beam system delivers treated primary ventilation air directly to the space and not through the chilled beam. Nevertheless, like the active chilled beam, this ventilation air must be sufficiently dehumidified to meet the entire room latent load.
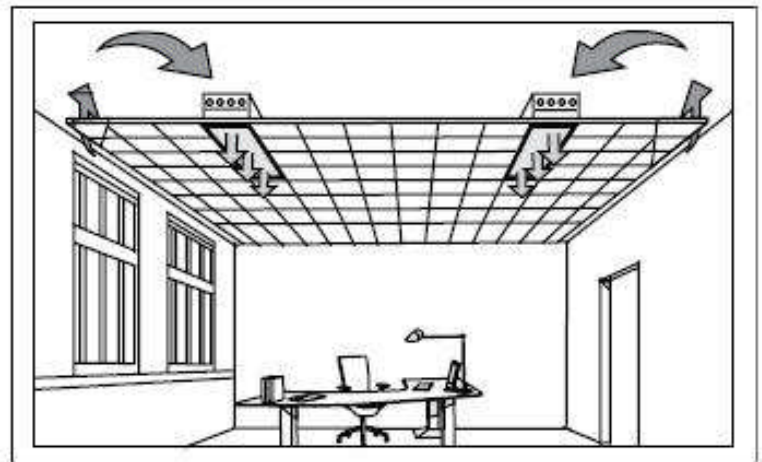

Figure 3 – Passive Chilled Beam Airflow Pattern

To avoid drafts in spaces with low ceilings do not locate PCB above workstations with sedentary occupants. Both remixing and displacement terminal devices provide good comfort in the room when used in combination with PCB.

What are the advantages of chilled beam systems over conventional system designs? Chilled beam systems are suitable for use in high sensible cooling load applications or where individual temperature control is required. Compared with a system where the cooling duty is supplied entirely by air (all-air systems), a chilled beam system reduces the fan power requirements and space needed for air-handling plant equipment and ducting. Chilled beam systems have the following advantages:

- High sensible load capacity (offices, computer rooms)
- Decouples ventilation load from room sensible and latent loads resulting in better temperature control and fan energy savings
- Typical supply air temperature is 60-66 °F exiting the chilled beam maximizing occupant comfort. Conventional systems deliver cold air at 55 °F with the potential of creating drafts if poor mixing occurs
- Constant volume supply airflow eliminates potential air dumping as compared to varying airflows in VAV systems.
- Reduced fan power requirements (100-250 CFM/ton)
- Increased space ventilation effectiveness (1.0) due to the good mixing (high induction ratio) of room air and supply air
- Reduced plenum space required (units are ~12" tall); good for retrofit applications
- Easily integrates with T-bar dropped ceiling grids
- Some units incorporate fluorescent lighting fixtures and fire sprinkler heads
- Some units offer directional air flow pattern control, optimizing comfort and preventing drafts

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What are the typical design conditions used for the chilled water and primary air for a chilled beam system and how are they controlled?

Assuming applications with normal ceiling heights (9-10 ft), apply chilled beams in applications with cooling loads of 25-30 Btuh/ft² of floor area. This capacity limitation is primarily due to the maximum possible air velocity in the space. Chilled beams use warmer chilled water from the secondary side of the cooling plant (or from mixing of primary and secondary water) at an inlet temperature from 57-61 °F to prevent condensation from occurring on the beam coil, install special humidity (condensation) sensors on the chilled beam coil that close the water control valve if the RH gets to 90% on the incoming chilled water pipe. Alternatively, use an atmospheric RH sensor in combination with an air temperature sensor to reset the supply water temperature upward closer to 60 °F during conditions when condensation might occur.

That is why it is important for the DOAS (dedicated outdoor air system) to adequately dehumidify the primary ventilation air such that it can absorb all of the latent loads in the zone. Higher outdoor humidity levels result in greater indoor latent loads due to infiltration, door openings and permeance. When considering chilled beam technologies, it is critical that the internal latent loads be calculated correctly and that they accurately reflect the properties of the building envelope. An excellent resource for determining internal latent loads is the ASHRAE Humidity Control Design Guide. The DOAS leaving air temperature (LAT) should be in the 44-64 °F dry bulb range with approximately 44-45 °F dew point (DP) to ensure there is no condensation on the beam coil. The lower end of the ranges should be used when the zone latent loads are higher, such as conference rooms, school classrooms, etc. while the higher end of the range may be used in applications with low zone latent loads.

How do you model a chilled beam system in HAP v4.8 (and later versions)?

HAP v4.8 (and later versions) have the ability to directly model active chilled beam (ACB) systems. Construction of a model for an example ACB system in HAP will be described in the following paragraphs to explain the basic modeling procedure.
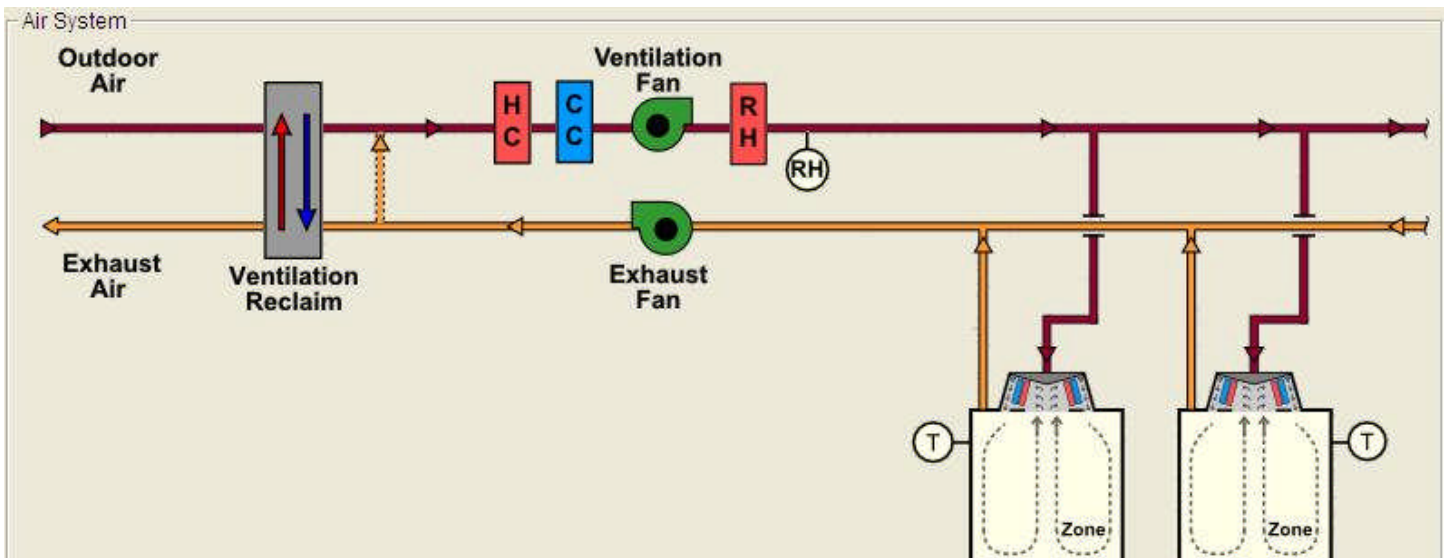

Figure 2. Simplified Active Chilled Beam System Diagram

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For our modeling example, assume the active chilled beam system is a 4-pipe system with cooling and heating provided in the beam terminals. The system serves four separate office zones. A Dedicated Outdoor Air System (DOAS) preconditions outdoor ventilation air and supplies the treated air to the active chilled beam terminals. The DOAS will also use an air-to-air energy recovery device to increase system energy efficiency.

To begin construction of the system model specify the following on the *General* tab of the HAP air system properties window (Figure 3):

- Equipment Type = Terminal Units
- System Type = Active Chilled Beam
- Ventilation = Common Ventilation System

"Common ventilation system" is HAP's term for the DOAS unit. Note that the selection of a common ventilation system is defaulted and locked because it is mandatory. It is what drives the operation of the active chilled beam terminals.

Next, on the *Vent System Components* tab select the components in the left-hand panel as shown in Figure 4. Then, working from top to bottom, review and revise data for each of the components:

1. **Ventilation Air Data** – Sample inputs are shown in Figure 4. Note that outdoor air dampers are marked as closed for the unoccupied period. Because the ventilation fan needs to run to power the ACB terminals 24 hours a day, there can be value in closing the outdoor air dampers during the unoccupied period to reduce the loads on the DOAS cooling and heating coils. In cold climates this can result in substantial savings for heating energy.

2. **Ventilation Reclaim** – In this example our system includes an Energy Recovery Ventilator (ERV) wheel. As shown in Figure 5, this device has the ability for both sensible and latent heat reclaim. The thermal efficiency and motor input power are sample values. Be sure to obtain this data from manufacturer's product data if you are modeling specific equipment in your system.
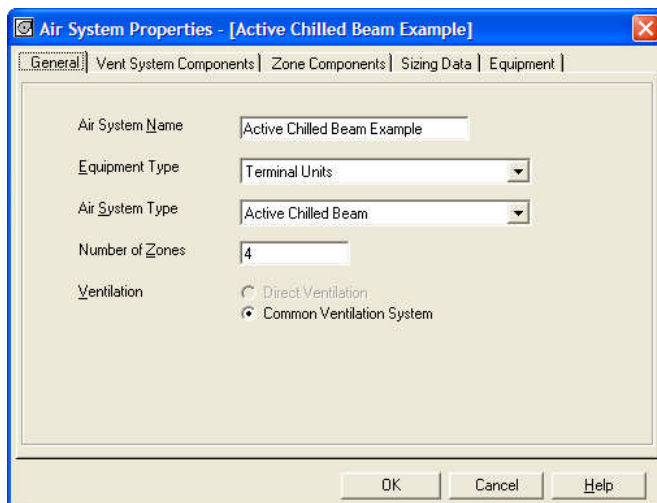

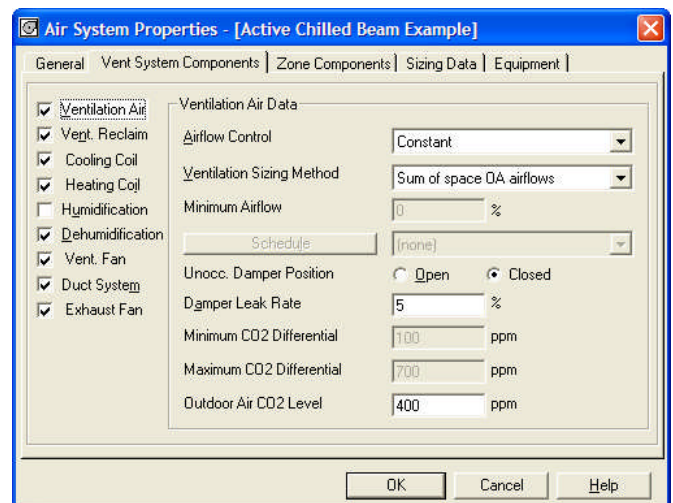**Figure 3. Air System Properties, General Tab**

Figure 4. Vent System Components Tab, Ventilation Air Data

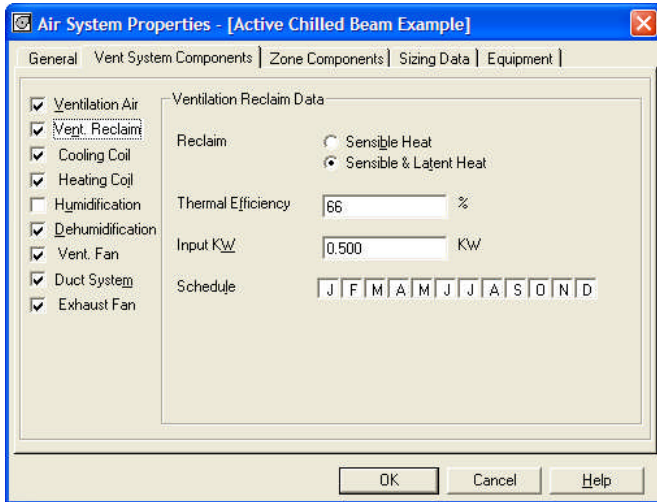## Modeling Chilled Beams
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**Figure 5. Vent System Components Tab,
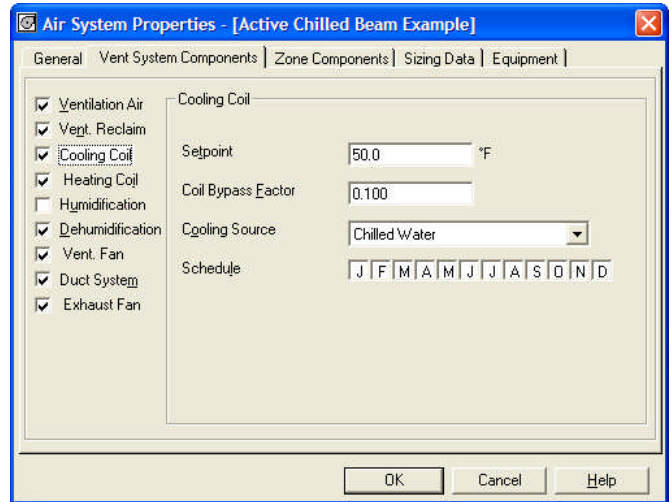Ventilation Reclaim Data**

**Figure 6. Vent System Components Tab
Ventilation Cooling Coil Data**

3. **Ventilation Cooling Coil** – As mentioned previously, active chilled beam terminals operate as sensible-only devices (no latent). Therefore, the DOAS must supply air to the chilled beams at conditions capable of absorbing all the zone latent load thereby preventing condensation on the beam coil. This means the DOAS unit leaving air temperature (LAT) must be selected at a dry bulb temperature and dew point less than zone-neutral conditions. Let's assume a room design conditions of 75 F and 50% relative humidity (RH). At sea level this represents a dew point (DP) temperature of about 55 F Therefore, we will use a DOAS LAT slightly less than this – 50 F (see Figure 6)
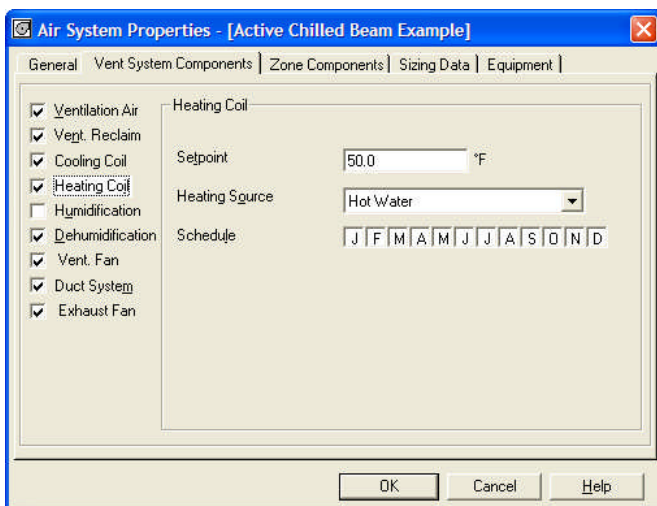
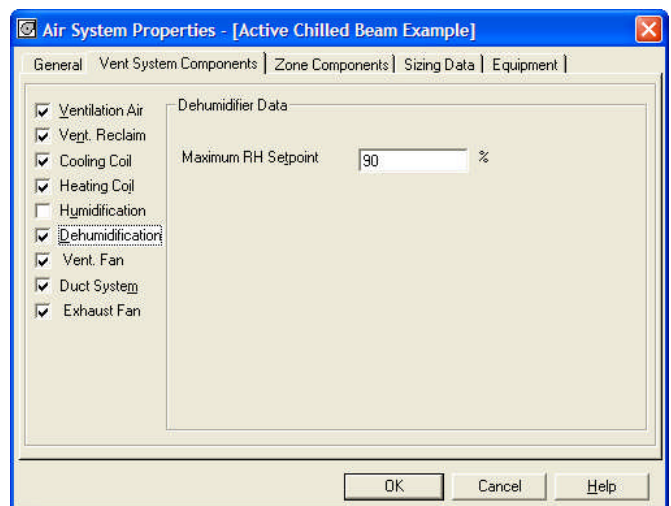**Figure 7. Vent System Components Tab,
Ventilation Heating Coil Data**

**Figure 8. Vent System Components Tab
Dehumidification Control Data**

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4. **Ventilation Heating Coil** – We will use the same DOAS supply air discharge setpoint for heating as for cooling (see Figure 7). Therefore when discharge air from the ERV is below 50 F it will be heated to maintain a 50 F discharge temperature from the DOAS unit. When it is above 50 F it will be cooled to maintain a 50 F discharge temperature.

5. **Dehumidification Control** – Our sample system will use a humidistat at the DOAS unit discharge to control the humidity of the primary supply air. A maximum relative humidity (RH) setpoint of 90% will be used (Figure 8). When the discharge RH rises above 90% the ventilation cooling coil will sub-cool the air to condense additional moisture and bring the humidity down to 90%. If necessary, the heating coil will provide dehumidification reheat to bring the DOAS discharge temperature back up to the 50 F setpoint temperature.

It is sometimes necessary to use a trial-and-error approach to determine the DOAS dehumidification setpoint appropriate for your application. As a general rule, use the highest LAT and RH% that maintains the zone at 40-50% RH, which ensures no condensation and minimizes energy usage.

The Hourly Zone Loads Report shown (selection option shown in Figure 9, report contents shown in Figure 10) displays hourly values of resulting zone relative humidity and zone dry bulb temperatures for design cooling days. This report should be used to check the zone relative humidity to determine if the DOAS dehumidification RH setpoint should be adjusted.

For our example 4-zone building, we generated the Hourly Zone Loads report for the peak design month of July. Also consider checking the zone RH% during off-design times like September or October. This report can be generated for any off-design month. If the Hourly Zone reports indicate a maintained zone 40-50% RH, then the DOAS unit leaving air temperature and relative humidity setpoint are acceptable.
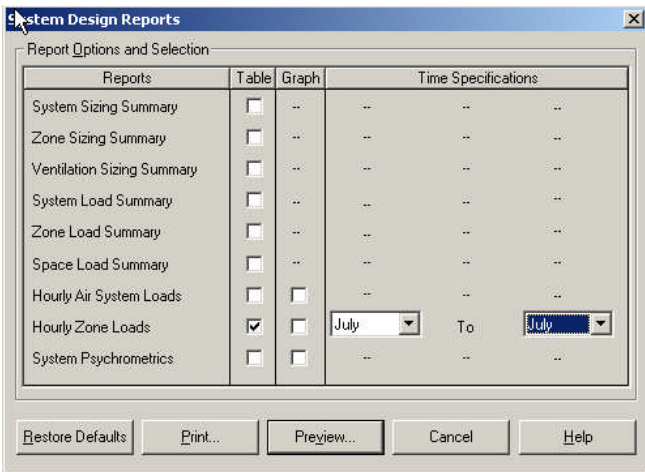

Figure 9. System Design Reports Selection,
Hourly Zone Loads Report

Figure 10. Hourly Zone Loads Report

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6. **Ventilation Fan** – Sample fan inputs are shown in Figure 11. A forward curved fan will be used. The total static pressure of 5 in wg represents static needed to overcome the pressure drops of the ERV, filters, coils, and ductwork, and to supply the required static pressure at the active chilled beam terminal nozzles. The efficiency is representative for this type of fan.

   The ventilation fan will run continuously at design flow for both occupied and unoccupied operating hours. In an ACB system this is necessary to control zone humidity levels, prevent condensation on the ACB terminal cooling coils and to power the ACB terminals.

7. **Duct System** – The example system will use a ducted return. For the sake of simplicity we did not specify duct leakage or duct heat gain. (Screen image of duct system inputs not shown).

8. **Exhaust Fan** – Finally, the exhaust fan will be the same type as the ventilation fan (forward curved, variable frequency drive). The total static pressure of 1.5 in wg represents the pressure drops of the ERV and the ductwork. (Screen image of exhaust fan inputs not shown).
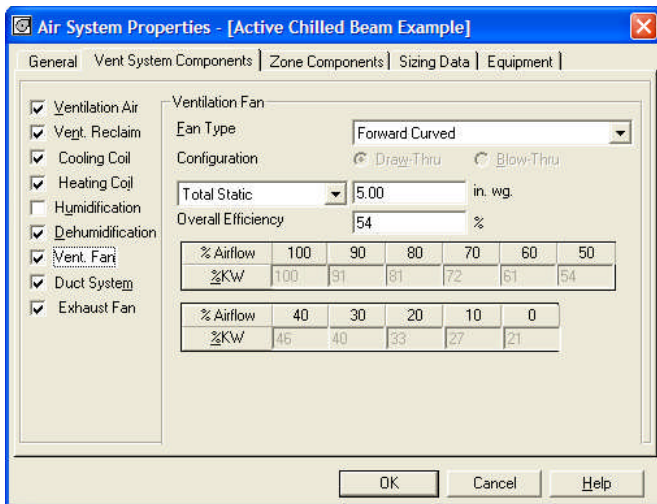

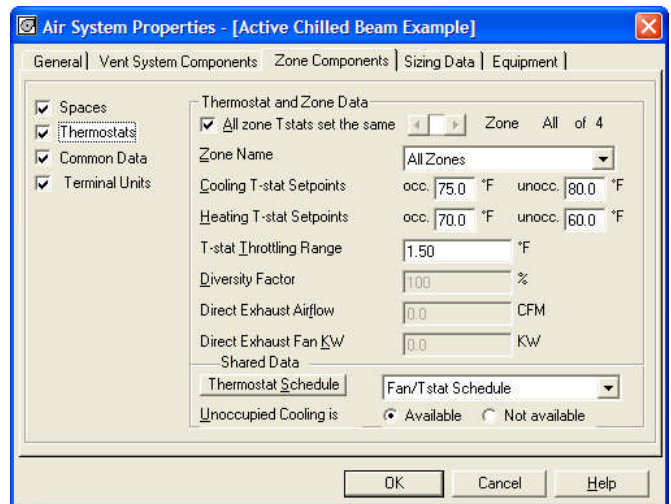**Figure 11. Vent System Components Tab, Ventilation Fan Data**

Figure 12. Zone Components Tab Thermostats Data

Next we move to the ***Zone Components*** tab shown in Figure 12. Working from top to bottom through the categories of data shown in the left panel of this tab, review and revise the following data:

1. **Spaces** – Assign spaces to the zones in the system. Our example system has four zones, each with one space. (Screen image of this data not shown).

2. **Thermostats** – Assign the thermostat setpoints and thermostat schedule. Sample values are shown in Figure 10. Note that unoccupied cooling is specified as "available". This is important because it is critical for the system to control humidity at all times to prevent condensation of moisture on ACB terminal cooling coils.

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3. **Common Data** – This data category is used to specify the capability of the ACB terminals. As shown in Figure 13, the terminals in our example have both cooling and heating capability.

4. **Terminal Units Data** – In this final category of data you can define one set of values applying to all ACB terminals, or can specify individual data for each zone's terminal equipment. This is done via the "All zones the same" check box in the upper left (Figure 14). In our example, we'll specify one set of data applying to all zones.

The terminal type will always be "active chilled beam". The "induction ratio" is the ratio of total supply airflow produced by the terminal to primary airflow entering the terminal. Typical values range from 2.7 to 4.0. If you have specific ACB equipment in mind, consult manufacturer's data to determine the appropriate value. A representative value of 3.0 is used in our example. Finally, specify the bypass factor that is representative for the terminal cooling coil. A value of 0.090 is used in our example.
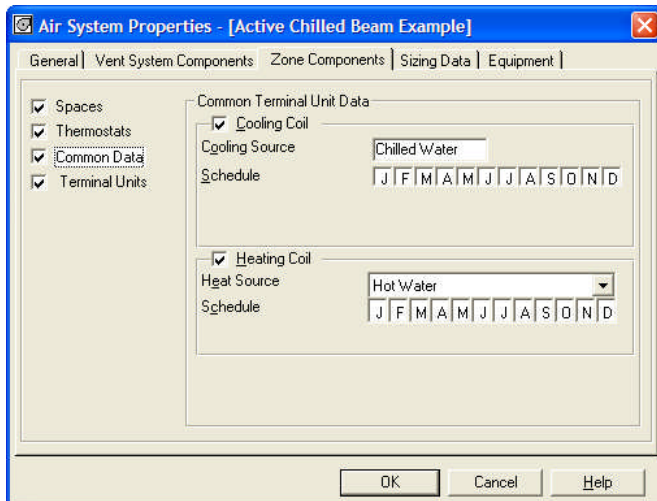

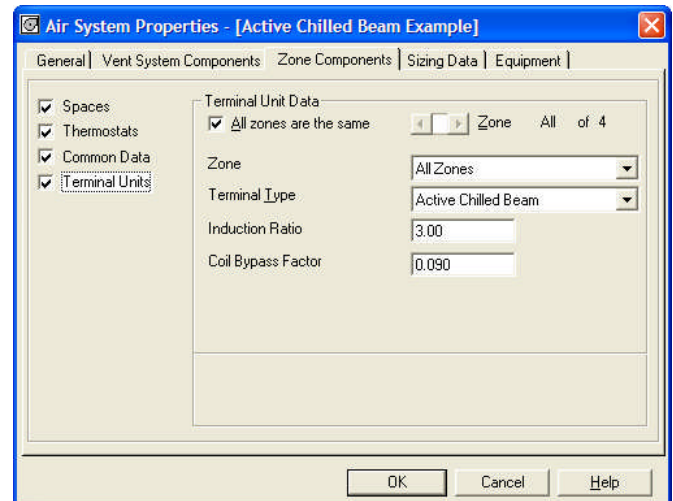**Figure 13. Zone Components Tab,
Common Data**

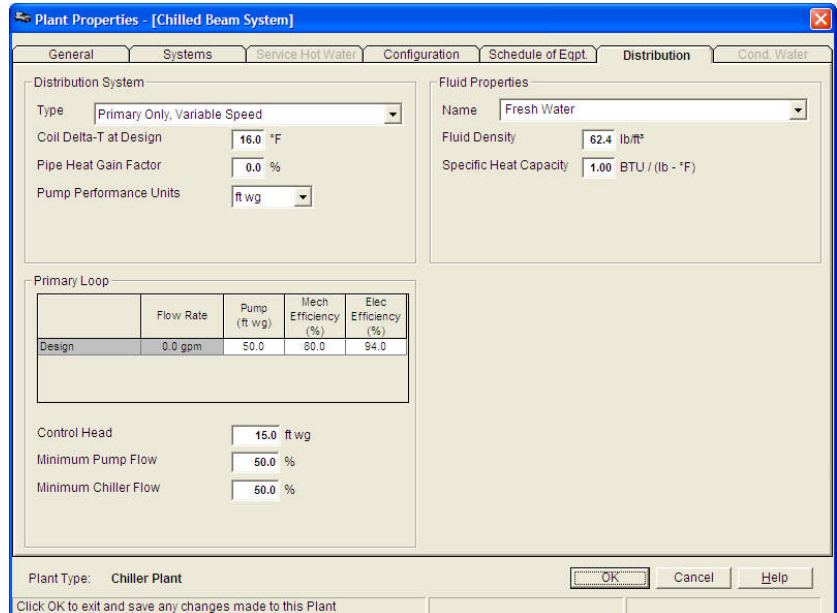**Figure 14. Zone Components Tab
Terminal Unit Data**

At this point the active chilled beam air-side system is fully defined and can be saved and then used in system design and energy analysis calculations.

What about the Chilled Water Plant Model?

The chilled water plant for chilled beam systems needs to operate at two supply water temperatures. The DOAS needs to receive cold water at a supply temperature like 44 °F in order to condense sufficient moisture out of the outdoor air flow to handle the space latent load. The chilled beam units need to receive warmer water, typically in the 57 to 61 °F range. This is achieved by producing cold chilled water at 44 °F LCHWT and supplying it first to the DOAS coil. Outlet water from the DOAS unit is then typically blended with water from the return side of the plant to reach the desired 57 to 61 °F temperature for supply to the chilled beam units.

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To develop an equivalent plant model for this configuration in HAP, first define the chillers according to actual system specifications. That is, supplying 44 °F LCHWT and with waterflow rates appropriate for the actual delta-T. This delta-T is often in the range 16 to 20 °F. Connect the chillers to a chilled water plant. Specify the plant design LCHWT as 44 °F. On the Distribution Tab (Figure 15) the best results are obtained by specifying "Primary Only/Constant Speed" or "Primary Only/Variable Speed" as the system type. Specify the Coil Delta-T at design as your overall system design delta-T - such as the 16 to 20 °F value.

Figure 15 – Chilled Water Plant Modeling For Chilled Beam

Conclusion

Chilled beams provide many advantages, as discussed. By decoupling the ventilation loads from the zone sensible and latent loads, the terminals are designed to handle lower total airflow quantities, thereby using smaller equipment.

It is important to account for the zone latent loads in your design considerations and to ensure proper sizing of the DOAS including the ventilation air loads plus the zone latent loads, while the chilled beams are sized to handle the zone sensible loads only.

As mentioned previously, you should consult manufacturer's specific design application literature when attempting to design a chilled beam system.

Resources:

1) *Design Considerations For Active Chilled Beams*; Alexander, Darren, P.E. & O'Rourke, Mike; ASHRAE Journal, Sept. 2008; pp. 50-58
2) *DOAS & Humidity Control*; Larranaga, Michael D., Beruvides, Mario G., Ph.D., P.E., Holder, H.W., Karunasena, Enusha, Ph.D. & Straus, David C, Ph.D.; ASHRAE Journal, May 2008; pp. 34-39.
3) *Chilled Beams & Pinnacle Application Guide*; Semco, March 2011.
4) *Humidity Control Design Guide*; Harriman L., Brundrett G. and Kittler R., ASHRAE 2001, Atlanta GA.