The National Institutes of Health | Division of Technical Resources | Office of Research Facilities

Design Requirements Manual **News to Use**

November 2024

Vol. 02, No. 86

The formulae $\frac{\partial \rho U_i}{\partial t}+\frac{\partial}{\partial x_j}(\rho U_i U_j)=-\frac{\partial P}{\partial x_i}+\frac{\partial}{\partial x_j}\left(\mu\frac{\partial U_i}{\partial x_j}\right)+g_i(\rho-\rho_0)$ *for building* $\frac{\partial}{\partial x_j}(\rho \bar{U}_i \bar{U}_j)=-\frac{\partial P}{\partial x_i}+\frac{\partial}{\partial x_j}\left(\mu\frac{\partial \bar{U}_i}{\partial x_j}-\rho\overline{u_i' u_j'}\right)+g_i(\rho-\rho_0)$ *state of the art* $\frac{\partial}{\partial x_i}(\rho \bar{U}_i \bar{H})=\frac{\partial}{\partial x_i}\left(\lambda\frac{\partial \bar{T}}{\partial x_i}-\rho\overline{u_i' h'}\right)$ *biomedical research facilities.*

Design Considerations for Active Chilled Beam System Control

Chilled beams are commonly used in HVAC design for BSL-2 laboratories at NIH. This creates a "hybrid" design that uses smaller primary air handlers (to provide ventilation and manage latent loads) and a water-side chilled beams system (to manage sensible cooling and heating loads). The heat transfer capacity of the water allows reductions of the overall fan, cooling, and heating energy and total capital cost as compared to a traditional all-air VAV reheat system. The four-pipe active chilled beam terminal units (with both a reheat water valve and a chilled water valve) are typically used in lab spaces to provide accurate temperature control. The two-pipe active chilled beam units (for cooling only) can be used for supplemental cooling spaces. Chilled beam terminal units require process cooling chilled water (not campus chilled water). Below are typical design considerations for active chilled beam system control.

Process Cooling Water System

1. **Heat Exchangers:** Chilled beam process cooling water is typically generated utilizing campus chilled water through N+1 water-to-water heat exchangers. Each heat exchanger is provided with a two-way modulating temperature control valve on the chilled water side and a two-way automatic isolation valve on the process cooling side. The two-way modulating valve on the primary side of each heat exchanger controls the leaving process cooling water. A low-limit temperature switch located on the discharge piping of each heat exchanger closes the respective chilled water control valve when the leaving process cooling water drops below 14.4°C (58°F).
2. **Pump and Flow Control:** The chilled beam process cooling water distribution system uses N+1 pumps. The system is designed as a variable flow with a VFD for each pump, modulating pump speeds at various flow conditions to maintain system differential pressure setpoint. A minimum flow bypass valve located near the end of the system allows pump operation at low load conditions.
3. **Temperature Control:** The process cooling system supplies chilled water to chilled beams. The chilled beam supply water shall be reset based on the highest space dewpoint temperatures from multiple locations in areas served by chilled beams. The chilled beam supply water temperature shall be not less than 14.4°C (58°F) and at least 1.1°C (2°F) higher than space dewpoint temperature. During startup, the chilled beam supply water temperature is initially set higher and gradually reduced to set point while maintaining a minimum 1.1°C (2°F) differential higher than the highest space dewpoint temperature.

Active Chilled Beam Terminal Units

1. **Four-Pipe Chilled Beam Control:** The following control requirements are used for a four-pipe active chilled beam unit in the lab:
   - Each pressure zone is provided with a pressure-independent supply air terminal unit and a pressure-independent exhaust air terminal unit. For negative pressure labs, the supply terminal unit tracks airflow offset with the exhaust terminal.
   - Each pressure zone is provided with one or more four-pipe chilled beam units.
   - Each active, four-pipe chilled beam unit shall be provided with an induction air connection, a cooling coil section, and a reheat coil section. Temperature control for each space will be provided by modulating the two-way control valves in the chilled beam cooling coils and reheat coils in sequence.
2. **Humidity/Condensation Control:** Because a chilled beam cannot remove latent load, provide the following instrumentation and control strategy to avoid condensation:
   - Provide a relative humidity sensor in select rooms served by chilled beams. The BAS shall then calculate the space dewpoint temperature based on the measured space temperature and relative humidity and send a signal to the process cooling water system to reset chilled beam supply water temperature as described in this article.
   - Provide a pipeline condensation sensor in the chilled beam supply pipe upstream of the control valve at each temperature control zone. Upon sensing condensation, the BAS shall close the chilled water control valve to chilled beams in the room and generate a critical alarm. The alarm must be manually reset when condensation clears.

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