DESIGN GUIDELINE 230050
CHILLED WATER SYSTEMS

Scope

Chilled water systems including system configuration, chiller sizing and redundancy, chillers, cooling towers, refrigerant monitoring, control requirements, and utility metering.

Related Sections

U-M Design Guideline Sections:
220010 – Plumbing Specialties
230040 – Hydronic Systems and Specialties
230060 – Mechanical Sound and Vibration Control

U-M Master Specification Sections:
230930 – Refrigeration Detection and Alarm
232116 – Hydronic Piping Specialties
232513 – Chemical Water Treatment – Closed Loop
232516 – Chemical Water Treatment – Open Loop Systems
236416 – Centrifugal Water Chillers
236500 – Cooling Towers

U-M Master Details:

MD 230930 001 – Refrigerant Monitor Control Diagram
MD 232116 002 – Coalescing Separator & Floor Mounted Expansion Tank Detail
MD 232513 001 – Glycol Feed System Detail
MD 232513 002 – Closed System Makeup Detail
MD 232513 003 – Closed System Shot Feeder Detail
MD 236416 001 – Electric Drive Water Cooled Chiller Piping Schematic
MS 236416 001 – Electric Water Cooled Centrifugal/Screw/Scroll Chiller Schedule
MS 236500 001 – Cooling Tower Schedule
MD 236500 002 – Seasonal Tower Piping Detail
MD 236500 003 – Condenser Water Treatment Equipment Diagram
Future: Tertiary Control Diagram

General Requirements

This guideline describes typical requirements which may not be appropriate for all sizes and types of chilled water systems. After reviewing this guideline, the Designer shall consult with the U-M Design Manager and propose the chilled water system type and configuration for approval.

Normally projects shall utilize the U-M master specifications and master details listed under Related Sections since they express U-M requirements. The A/E shall edit the specifications and details to make them project specific, being careful not to remove U-M requirements. Turn on hidden text and read all editor's notes when editing specifications.

System Configuration

Chiller Plant Chilled Water Arrangement: Design new CHW systems with Variable Primary chilled water pumping with a controlled bypass to maintain minimum chilled water flow at the chiller evaporator. Normally a magnetic type flow meter shall be provided to measure primary flow for minimum flow control. Avoid over-sizing the bypass control valve and carefully select to provide stable control. Multiple chillers shall be used in any installation of greater than ~ 400 tons.

Chiller Plant Condenser Water Arrangement: Provide constant volume condenser water pumping and variable speed cooling tower fans.

Arrange pumps to directly pump to a chiller. Pump discharge header arrangements using auto-flow balance valves or similar methods to maintain the required flow rate through the chiller condenser shall not be used. This is due to reliability problems experienced with such designs at U-M.

For large plants (~ > 500 tons) analyze the energy savings benefit of variable flow condenser water.

Chiller Plant Pumps: In all cases provide a single redundant condenser water pump and a single redundant chilled water pump that can be manually valved into service for the other pumps of the same service.

- Example 1: System Peak Diversified Load = 1000 tons. It is determined a fully redundant chiller **is not** required. 500 ton chillers are determined to be the best chiller selection. Provide (2) 500 ton chillers, (3) primary chilled water pumps, and (3) condenser water pumps.
- Example 2: System Peak Diversified Load = 1000 tons. It is determined a fully redundant chiller **is** required. 500 ton chillers are determined to be the best chiller selection. Provide (3) 500 ton chillers, (4) primary chilled water pumps, and (4) condenser water pumps.

Provide selector switches at the pumps to allow the operator to select which pump operates with a chiller. See “System Controls” section for more information.

Chiller Plant Delta T: For chilled water plants that serve new buildings, design for a distribution temperature differential (“delta T”) of at least 14° F (e.g. 44F CHWS/ 58F CHWR). For plants serving existing buildings, the existing coil performance must be considered when establishing system temperatures and delta T.

Pumps in Buildings Connected to the Chiller Plant: When connecting to chilled water plants serving multiple buildings, the building served should normally be arranged as a decoupled pumping arrangement (bridge) with a modulating valve in the secondary return leg, controlled to maintain the building loop CHWS temperature at +1°F above the distribution temperature.

The building pumping system shall include pump redundancy appropriate to the mission of the connected building. Provide no less than two identical capacity units, sized for somewhere between 50% and 100% of required building load.

Control Valves in Buildings Connected to the Chiller Plant : When connecting chiller plants to existing buildings, convert the building to variable flow by replacing existing 3-way chilled water control valves with 2-way control valves.

System Sizing and Chiller Redundancy

Calculations, criteria and assumptions regarding rationale for chiller sizing must be clearly defined in the Owner Project Requirements and Basis of Design. Indicate in the Basis of Design document the connected load and the peak diversified load (PDL) and any accommodation provided for future capacity needs.

Typically the chillers should consist of a minimum of two identical capacity units, each sized for somewhere between 50% and 100% (see rationale below) of the peak diversified load (adjusted to account for heat recovery and future capacity as described below). The engineer of record is responsible for determining PDL.

Calculate the connected load (total of scheduled load at design condition) and peak diversified load (anticipated or measured actual peak load within a building or system that reflects diversity between loads). Base system sizing on PDL, adjusted for future capacity and heat recovery. PDL is defined as the maximum load expected on a diversified cooling system on a design cooling day. Sanity check the PDL against the connected load.

Determine minimum load and verify that the chillers are capable of stable control at this load.

For existing systems, PDL shall be derived by consulting measured loads from the BAS system data historian. If unavailable, use computerized building energy simulation modeling.

For new systems PDL shall be established using a computerized building energy simulation model (Trane Trace, Carrier E20-II HAP, etc.) that complies with the requirements for simulation programs in ASHRAE 90.1 Appendix G.

To avoid oversizing central cooling equipment the model shall credit energy recovery systems. When determining the energy recovery system *credit*, if there is a significant chance of energy recovery failure, assume the largest discrete energy recovery system is not operational.

- Example: The building has two air handlers with energy recovery wheels. One unit can recover 100 tons on a design day, the other can recover 50 tons on a design day. The load should be reduced by 50 tons (because the 100 ton heat recovery system should be assumed to have failed).
- Example: A glycol run-around energy recovery system with redundant pumps and serving multiple coils: Such a system may be deemed to have very low probability of any failure, allowing full credit to be assumed for energy recovery.

Finally, in consultation with the U-M Design Manager, determine the need for future capacity and add it to the PDL to determine the required CHW system capacity. Normally assume no additional capacity. In cases where there is a significant potential for incremental increases in loads due to future renovations, a modest allowance of +/-10% future growth may be included. In some cases allowing space for future *additional* or *larger replacement* chillers may be appropriate.

After CHW system capacity is determined, consider the implications of losing one chiller. (Redundant pumping shall be considered normal for all installations.) If the loss of up to 50% of the CHW system capacity in an emergency is manageable through load shedding or shifting to other cooling sources, chillers may be sized for as little as 50% of the required CHW system capacity, though careful analysis may imply sizing at 60-70% to be more appropriate. Examples of these ***non-critical CHW applications***:

- Buildings where ventilation air can be temporarily reduced.
- Buildings were outside air can be reduced in an emergency by temporarily limiting use of non-critical exhaust systems.
- Buildings or portions of buildings where space temperature can be compromised above normal set-points in an emergency.

When sizing chillers and considering the above load reduction strategies, it shall not be assumed that ventilation air can be reduced by more than 50% or that space temperature can rise above 78°F.

Non-critical CHW applications

- Typically would include offices, classrooms, outpatient facilities, buildings with return air systems, child care facilities, and housing. For single building chiller plants, the design shall provide at least sufficient redundancy for the critical portion of the facility.

Critical CHW applications

- Typically would include in-patient care facilities, animal vivaria, ambulatory outpatient surgical facilities, data centers and 100% outdoor air wet lab buildings. A system is considered to be a critical CHW application if loss of any cooling capacity is intolerable for the application due to stringent criteria and operational constraints. In this case capacity should be 100% of the required CHW system capacity for each of two units or three units at 50% , etc. For critical applications, the need for emergency power to provide un-interrupted chilled water capacity shall be evaluated. For building areas such as vivaria, data centers or certain hospital areas requiring cooling operation during a power outage, consider providing a smaller chiller connected to emergency power along with its ancillary equipment.

- Also refer to U-M Design Guideline 230010-H Supplemental HVAC Design for in-patient and ambulatory facilities. UMHHC has rigorous requirements for N+1 chiller plant requirements; consult Hospital Facilities Planning & Design for direction.

Chillers

Obtain approval of the U-M Project Design Manager before making decisions on chiller type. The following are general criteria:

- Air cooled screw or scroll chillers: 100 tons or less
- Water cooled scroll chillers: 100 to 200 tons
- Water cooled screw chillers: 150 to 250 tons.
- Centrifugal chillers: 250 tons and larger.

The type of chiller refrigerant as of the date of this Design Guideline has not been resolved. Therefore a review of refrigerant options will be required for each project.

Multiple chillers shall be used in any installation greater than ~ 400 tons. Chillers shall be sized to operate efficiently over the full range of system load profile. Special caution shall be exercised to avoid sizing that results in short cycling in low load ranges. Multiple/additional chillers shall be used if the load profile indicates that short cycling will occur.

For chillers above 100 tons, develop a pre-purchase or bid package with bid alternates that allows the AE and the University to evaluate the chiller bids from a total (life cycle) cost perspective. Provide a life cycle cost analysis to evaluate chiller options for the base design and for bid alternates. Contact the Project Design Manager for maintenance and utilities costs. Determine the project specific system load profile and require per specification that the manufacturer provide as a part of their bid the annual energy usage based upon the load profile.

Investigate and document energy-saving opportunities where additional initial investment produces an acceptable simple or life cycle payback in accordance with U-M Design Guideline 3.2 Energy and Water Conservation. Analyze high efficiency chillers with magnetic bearings or variable speed drives (VSDs) where the load profile exhibits an opportunity for acceptable payback. For air cooled chillers with significant winter loads, analyze chillers with water-side economizers. Chillers exposed to the outside air shall be designed with 30% ethylene glycol. To avoid glycol inefficiency and glycol makeup systems, consider providing an indoor chiller with remote condenser or dry-cooler in lieu of roof top chillers.

Where there is a significant winter chilled water load, analyze the benefit of making winter chilled water utilizing a cooling tower and a plate-frame (P/F) heat exchanger, typically referred to as free cooling.

- When possible, arrange piping so that the cooling tower water entering the P/F heat exchanger is connected **from** the tower cold water supply piping located upstream of the warm-up bypass pipe, instead of from piping located downstream of the warm-up bypass. This allows the P/F exchanger to continue to receive the coldest tower water during transitions to pay (chiller) cooling.
- Pipe the P/F heat exchanger counter flow with the entering condenser water connected to the bottom of the heat exchanger so that solids deposit in the heat exchanger bottom region. For large plants, provide tees and valves to allow P/F heat exchanger back-flushing.

In buildings connected to central plants with free cooling, the sizing and/or type of "year round" terminal equipment connected to the chilled water system must consider the elevated chilled water temperature provided by the central plant in winter. Options include additional coil rows/fins, heat pumps, and DX with water cooled condensers. If the building has separate chilled beam and/or process cooling loops (operating at higher supply temp.s) and chilled water pump loops (operating at lower ~ 45ºF supply temp.), such terminal equipment should be connected to the higher temperature loop to allow the chilled water pump loop to be shut down during winter free cooling.

For centrifugal and screw machines, marine water boxes shall be specified for both condenser and evaporator (both ends), at minimum for the condenser if not available on the evaporator. Marine water box end plates shall be hinged type when available; when not available provide a means of suspending the end plates when removed such as (when available from the chiller mfr.) gantry crane mounting plates and a removable gantry crane, or structural steel above for a chain-fall. Where marine boxes are not feasible, design shall indicate removable spool pieces between isolation valves and chiller heads, at both the evaporator and condenser, which when removed allow tubes to be pulled or cleaned.

Design piping and chiller placement so that complete chiller overhaul, including motor replacement, may be performed without the removal of permanent piping or electrical conduit.

- Provide permanent steel rail (beam) hoistways located over the centerline of centrifugal chillers and extending a minimum of 5 feet beyond the end of the chiller for removal of the motor and compressor. Provide a rail hoistway design that is capable of suspending the heaviest chiller component. Require the bean to be labeled with its maximum weight capacity. For large chillers or where the beam will be high above the chiller, provide a permanent hoist on the beam.
- On the design drawings, indicate "no-fly" zones *above and at the ends* of the chiller where pipe, electrical conduit, etc. shall not trespass, to allow unobstructed service work on the chiller including removal of motors, compressors, evaporator and condenser heads, and pipe spool pieces.
- Require spool pieces/flanges on refrigerant relief piping where its removal is necessary to permit removal of the chiller motor, compressor or other components.

Provide adequate maintenance aisles and room door widths or removable panels to allow chiller tube and chiller replacement. For chillers located in penthouses or other high locations, provide means for future replacement with a crane if other routes are not available. Dash-out/indicate equipment clearances and access pathways on the drawings

Cooling Towers

Due to lower energy consumption and ease of maintenance, cross-flow induced draft towers shall normally be used, not forced-draft type. If a project requires a forced draft tower, provide adequate space for fan shaft removal.

Cooling tower fans shall be driven by a variable speed drive with bypass.

Account for de-rating factors associated with screen walls and re-entrainment.

Evaluate the need for low sound fans and/or tower sound attenuators.

Fan drive should be through a drive shaft and gear reducer, with motor mounted outside of the air stream. Include external oil lines and dip stick. The University discourages the use of V-belt drive cooling towers. If V-Belt drives are used, provide non-ferrous sheaves.

Cooling towers located on roofs shall be supported on galvanized steel frame-work with a minimum of 5 feet clearance between the bottom of the steel and the roof, to enable roof maintenance and replacement. Provide vibration isolators on cooling towers located on the roofs of normally occupied buildings. Provide galvanized or aluminum platforms, platform handrails and ladders for large multi cell installations, designed to permit access to all interior and exterior components requiring routine maintenance. Provide sufficient ladders to tower tops to allow safe access to motors and to all hot water basins for inspection. Provide galvanized or aluminum tower top handrails where hot water basin access requires walking on the top of the tower cells. Internal walkways shall be provided when access to cold water basins requires passing through adjacent cells.

Provide switched exterior lighting for the cooling tower to allow safe night-time access. Illuminate the top area of the tower including basins, fans, and motors; and the bottom area of the tower, e.g. access platforms, steps, and ladders. Avoid over-lighting.

Provide mechanical floats for tower make-up as opposed to electronic level controls.

Do not use flume boxes to equalize the water level in cold water basins across cells. Rather, provide an equalizer pipe, with shut-off valves to allow isolation of each tower basin.

Where cooling towers are used for winter operation with wet outdoor sumps, provide electric basin heaters and heat trace all outdoor piping. Heat-trace systems shall be DDC controlled and monitored; separate programmable controllers are not permitted.

Pipe cooling tower overflow and drain piping to the condenser water system blowdown magmeter, and then to sanitary waste. Do not discharge to roof or storm drains. Assure that the sanitary drain size is capable of handling a failed open fill valve overflow situation.

Provide blind flanges at both ends of cooling tower hot and cold manifold pipes and on equalizer lines. Equip the blind flanges with an eccentric reducer at the blind flange bottom, terminated with 2-1/2" blind flange "clean-outs". Clean-outs allows fire hoses to be connected for flushing and draining purposes.

Whenever possible, butterfly valves shall be mounted in vertical pipe sections. This reduces the deposition of solids at the disc seat, making tight closure more likely. In horizontal pipe sections, butterfly valves shall be mounted with the stem horizontal and the disc seating against the flow direction at the bottom of the disc seat.

Strainers, Filtration and Air Removal

Condenser Side: Provide floor mounted basket strainers for all condenser water pumps. In addition, provide a coalescing type solids separator upstream of the chiller for single chiller systems or on the common condenser water return piping on multiple chiller systems.

CHW Side: Provide combination coalescing solids separator/air separators. A side stream separator and pump shall be considered for larger chilled water systems, sized nominally for 20% of system flow.

Water Treatment

Refer to U-M master specification and details under Related Sections. For hospital projects a shot feeder may not be required, consult with the U-M Design Manager.

Condenser Water Piping

To eliminate corrosion resulting from drained empty pipe, require non-ferrous piping (stainless steel schedule 10 or other) where the condenser water piping is intended to be drained during off-season. Strategically locate drain valves to keep indoor ferrous piping full of water year round.

For critical plants, or where replacing piping in the future would be extremely difficult, or where there is minimal interior piping, consider specifying non-ferrous pipe for all condenser water piping.

Cooling Tower and Chiller Room Noise and Vibration

Acoustic testing and analysis is typically required for cooling tower installations. Consult the U-M Design Manager and U-M Design Guideline 230060 Mechanical Sound and Vibration Control.

Consider noise and vibration criteria in chiller mechanical rooms and adjacent areas. Specify machine noise and vibration limits, and specify testing procedures. Evaluate the need for noise and vibration abatement to achieve acceptable noise levels.

Refrigeration Monitoring and Ventilation

For refrigeration systems located indoors, determine if a refrigerant monitoring system is required per the calculation methods detailed in the Michigan Mechanical code and ASHRAE Standard 15. If so, provide a refrigerant monitoring and ventilation system in accordance with the most current edition of the code and standard.

Utilize the U-M Standard Detail for the refrigerant monitor control requirements and comply with the designer notes included with that detail.

The U-M refrigerant detection and alarm master specification and detail reflect U-M's basic requirements for refrigerant monitoring of low toxicity, low flammability refrigerants (ASHRAE Standard 34 safety group A1 and B1). They do not express requirements for higher toxicity/higher flammability refrigerants such as ammonia systems. In the rare circumstances such systems are being considered, notify the U-M Design Manager and meet with U-M EHS and other U-M parties to determine specific requirements.

Provide a system of fans and dampers to sweep the room with fresh air and exhaust to clear the room of refrigerant. Typical designs shall include one exhaust fan (and possibly one supply fan) powered with a variable frequency drive to provide normal mechanical room ventilation at one speed and emergency refrigerant evacuation at another speed. The supply and exhaust fans and related dampers of the refrigerant ventilation system shall be activated through hard wiring from the refrigerant monitor control panel, not through DDC controls, unless it results in complicated multi-relay controls.

If possible, locate the refrigerant monitor control panel outside the mechanical room in a location not normally accessible to the general public, preferably a vestibule requiring a mechanical room key for access. As an alternative, in consultation with the U-M Design Manager, include a remote external display of the refrigerant level outside of the mechanical room, depending on the situation. Where mounted inside the machine room, mount the monitor as close as possible to the primary room entrance. Installation of self-contained breathing apparatus is not required since U-M has a 24/7 emergency response team with trained personnel properly fitted for SCBA.

System Controls

Use of U-M standard control diagrams and sequences when available. The description below is an overview of features required by U-M and as such does not list all the controls required for a chiller plant.

Chiller sequencing shall be via a combination of calculated load and CHW supply temperature.

Chiller start/stop functions, sequencing, cooling tower operation etc. shall be controlled by the U-M Building Automation System (BAS). Use of proprietary chiller or pump control packages is not permitted.

U-M BAS shall start and stop chillers and monitor chiller status, refrigerant head (for condenser water reset, see below) and a common chiller trouble alarm, via analog and digital DDC points (not BacNet or similar communications) connected to the chiller’s control panel.

In addition, for Hospital projects only, provide the chiller with a BACnet integration card, integrated into the BMS front-end, to allow additional monitoring.

For systems with no backup/redundant pumps, the primary chilled water pumps and condenser water pumps are to be started and stopped by hard wiring to the associated chiller control panel (as opposed to the U-M BAS starting and stopping the pumps).

When redundant condenser and chilled water pumps are used, the U-M BAS system shall start the pumps. Provide a multi-contact selector switch for each pump to allow field selection of the assignment of each pump to a chiller. Label the switch similar to the following:

Chiller 1, Chiller 2, Chiller X…., Off Line

with a BAS digital input connected to each chiller selection contact. In this manner the selector switch position will signal the BAS to operate, for example, primary CHWP-3 with Chiller 1.

Provide a sequence of operation for the pump selector switches that generates a warning alarm whenever pump assignments are conflicting, i.e. when selector switches assign the same pump to multiple chillers. (Note: Typically manual valves shall be used to route pump flow through the appropriate chiller.)

Similarly, provide a multi-contact selector switch for each chiller to allow field selection of the chiller lead and lag sequence. Label the switch similar to: Lead, Lag, Off Line.

Include a temperature transmitter in the cooling tower cold water basin alarmed on temperature, for freeze protection.

Cooling tower vibration switches shall be hard wired to the tower's variable speed drive (or motor starter) safety circuit, not indirectly connected through BAS.

Cooling tower filter or separator blow down valves shall be controlled as the first stage of tower blowdown via the water treatment control panel. Refer to the U-M standard detail.

Condenser water temperature reset shall be included for centrifugal chiller plants and for plants with other chiller types that will use less energy if condenser water reset is implemented. The BAS will reset the condenser water setpoint, indexed against outside air wet bulb temperature. The chiller control panel shall generate a 4-20ma output signal to BAS to limit the amount of condenser water setpoint reset to safe reductions. Generally absorption chiller systems shall provide a fixed condenser water temperature setpoint.

Water cooled chiller plants shall have a motorized two-way condenser water bypass valve arranged to allow more rapid condenser water warm-up when the plant/towers are started "cold". For combination absorption and centrifugal chiller plants, separate bypasses shall be designed to provide a higher fixed temperature to the absorption chillers and re-settable lower temperature to the centrifugal chillers.

Utility Metering

Metering Required:

- Cooling tower make-up water and cooling tower blow-down, metered separate from the building water service. Refer to design guideline 220010 Plumbing Specialties for details.
- For a central chilled water plant serving multiple buildings, all utilities involved in the generation of chilled water (i.e. water, electric, steam (absorbers)) shall be metered separately from the building in which it resides.
- Each separate building connected to a central chilled water plant shall include chilled water BTU load metering consisting of a magnetic flow meter, high precision temperature transmitters on supply and return, and a BTU meter/computer. These devices are described in U-M Master Specification section 230900 - Mechanical Systems Controls.
    - The high precision temperature transmitters must be labeled as such on the control drawings.
    - The high precision temperature transmitters and magnetic flow meter must be shown connected to the BTU meter and to a DDC panel.
    - The BTU meter must be shown connected to a Utility Data Acquisition Panel.
    - The Utility Data Acquisition Panel must be shown with an Ethernet connection to the nearest data closet.

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