



## Fair City Plaza

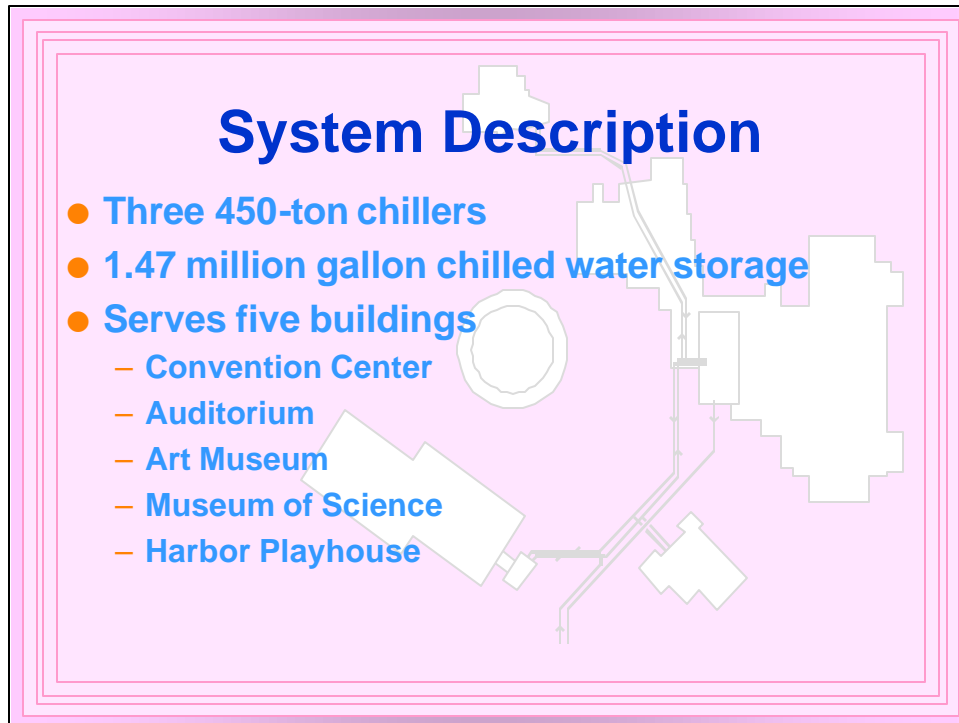


**Task: Diagnose problems, recommend improvements for small municipal district cooling system**

The Fair City Plaza district cooling system provides chilled water to five buildings in a downtown museum district. In 1996, the system's three chillers were converted to use refrigerant R-134a, and a chilled water storage tank was installed to allow a large part of the system's cooling loads to be met using relatively inexpensive off-peak electricity.

Following these modifications, cooling costs have decreased significantly. However, a number of operation and maintenance problems have arisen. The most serious of these is that the chillers have been experiencing major breakdowns. There are also questions about the ability of the system to meet its cooling loads.

The HVAC&R Center at the University of Wisconsin was engaged to evaluate the design and operation of the district cooling system, and to review the heating, ventilating and air-conditioning (HVAC) systems in the individual buildings. Our report, which was produced with the support and assistance of Central Power and Light Company and EPRI, summarizes our analysis and conclusions and provides our recommendations for addressing the problems.



The district cooling plant consists of three centrifugal chillers each rated at 450 tons cooling capacity, a 1.47-million-gallon chilled water storage tank, and associated pumps, cooling towers and piping. The chillers are rated at 450 tons capacity and 0.80 kW/ton when chilling 900 gpm of chilled water from 54°F to 42°F.

The chillers are piped in parallel, each with its own 50 hp pump, with common supply and return headers. Two 200-hp variable-speed secondary pumps, one of which is a backup, circulate water to the five buildings served by the system. The storage tank is piped between the connection of the chiller supply to the secondary pumps, and the chilled water return from the buildings.

The chilled water storage tank is designed to store 13,800 ton-hours of cooling, with a 15°F temperature differential (40-55°F).

The chillers and pumps are located in a mechanical room in a lower level of the Convention Center. The storage tank is located about 500 feet to the west of the mechanical room. The five buildings are located at distances of 150 to 350 feet from the mechanical room.

The current operating strategy eliminates all chiller operation during the electric utility's on-peak hours of 1:00 pm to 7:00 pm, dramatically reducing electric demand charges.

## Major Complaints

- Chillers breaking down
- Difficulty meeting loads
- Hard to control the system
- Equipment deteriorating

The most serious problem facing the system at this time is chiller failures. Chiller 1 failed in July 1998, Chiller 2 failed in January and Chiller 3 failed in March of this year, and the repair costs were about \$20,000 for each chiller.

There has been some question as to whether the chillers and thermal storage tank have sufficient capacity to meet the cooling loads currently existing in the five buildings served by the district cooling system.

Currently, the Museum of Science, as well as some of the other buildings, are not receiving sufficient cooling capacity from the central plant.

Control valves nearest the plant are sometimes forced open by the high pressure differential. This makes proper temperature control difficult, and also bypasses cold water to the return.

Rooftop air-handling units on several buildings have deteriorated from exposure to the weather and are in poor condition. Control valves corrode quickly and some have had to be replaced within three years of being installed.



Operators often have to bleed large amounts of air from the system.

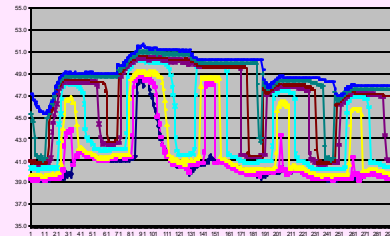
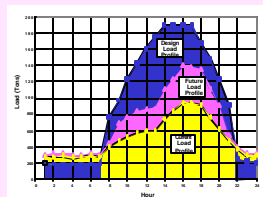
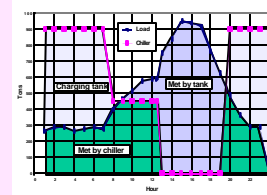
The EMS logs show many instances when the EMS was commanding a chiller to restart, at one-minute intervals, sometimes for hours at a time. While the logs do not indicate how often the chiller actually started in response to these commands, the operating staff indicated that the chillers often underwent repeated starts and stops.

The design of the distribution system has no provision for controlling the chilled water flow to each building at its desired level. The maintenance staff have attempted to adjust flows by setting manual valves but these manual settings cannot respond to changing conditions, and they often have unintended consequences.

Operating data show that the storage tank rarely operates with a thermocline layer separating warm and cold regions of the tank, as it should.

# System Analysis

- Interviewed operators
- Observed system operation
- Reviewed trend logs
- Calculated load profiles



HVAC&R Center staff visited the site, met with plant operating personnel and staff from the buildings served by the system, and observed the condition and operation of the system and its components. With the assistance of CP&L/CSW staff and the plant operators, we gathered data under various normal and simulated operating conditions.

We used this information, along with design documentation and historical trend data collected from the automatic control system, to analyze the performance and the capabilities of the system. We developed estimates of the original design load profile, the current load profile, and the near-term future load profile. We evaluated the operation of the chilled-water storage tank, and estimated its capacity under various conditions.

Using this information, we developed diagnoses of the problems facing the system, and recommendations to resolve them.

## Diagnosis - System

- No documentation of design intent
- Limited training for operators
- Some features "value-engineered" out
  - Return pipe from tank
  - Temperature sensors

There is very little documentation on the design intent for this system. The O&M manual supplied by the storage tank manufacturer provides information on the design operating conditions and maintenance requirements for the tank itself. However, the operating staff has received no information on operating modes and control sequences for other parts of the system or for the system as a whole.

The distribution system was originally designed with a primary-secondary configuration, but the return pipe from the storage tank to the central plant was deleted to save cost. Hydraulically, the storage tank is located at one end of a common return header, and the chillers are located at the other end. As currently configured, it is not possible to control the return temperature to the storage tank.

Much of the instrumentation needed for plant operation was also deleted from the original design to save costs. Without load measurements for each of the buildings, and return temperatures for loads, storage tanks, and chillers, it is difficult for operators to know how well the loads are being met. Without measurements of chiller power draw, there is no way to gauge the efficiency of the system. With no tank level sensor, operators measure the level manually by dropping a line into a hatch on top of the tank.

## Diagnosis - Chillers

- **Water leaking from the system**
  - Tank level drops below upper diffuser
  - Air enters the piping
  - Pumps become air bound
  - Flow to chillers stops
- **Chiller safeties wired incorrectly**
  - flow switch not working properly
  - excessive cycling leads to overheating
- **Incorrect bearings**

The system has been losing water at an average rate of 525 gallons per day. When the water level falls below the upper tank diffuser, air is drawn into the system. When air collects at the chilled water pumps, the pumps become air bound, flow through the chillers stops, and the chiller shuts down.

The flow switches should prevent any compressor operation when there is no flow, but a service technician observed Chiller 1 starting when both its chilled water pump and its condenser water pump were off.

It appears that the anti-short-cycling controls are not operating correctly. Frequent starts and stops cause excessive wear and tear on a chiller's motor, gears, and bearings. Even if the 20-minute delay is functioning correctly, repeated starting and stopping causes undue stress on the machine. The breakdowns of Chillers 1 and 2 are linked to mechanical wear and stress on the gears and bearings. Chiller 3 failed because of an overheated motor, which can also be due to excessive starting and stopping.

When Chiller 1 was rebuilt in 1998, it was found that one of the impeller bearings was not the correct size, which could have increased the stress on rotating components. This bearing was presumably installed when the chillers were converted to R-134a refrigerant in 1996. The other two chillers may also have had incorrect bearings installed.

## Diagnosis - Capacity

- **Low return temperature**
  - reduces chiller capacity
  - reduces storage capacity
  - prevents tank from stratifying
- **Flow control disabled**
  - low flow reduces capacity
- **Design has no provision for maintaining return temperatures**
- **System is capable of meeting future loads**

A chiller will provide only enough capacity to cool the return water to the setpoint temperature. If the return temperature is low, less capacity is needed to cool it to the setpoint, so less capacity is available. The return temperature to the chillers is nearly always 48°F or less. With the current chilled water supply temperature of 38°F, this limits the chillers to 83% or less of their full capacity.

There are no provisions in the design of the system to maintain the required 55°F return temperature to the storage tank. The return temperature to the tank is usually below 47°F, and is almost never above 50°F. This reduces the usable storage capacity of the tank to less than two-thirds of its nominal value. It also limits the ability of the tank to properly stratify.

The chiller flow rates change depending on how many chillers are running. The system has automatic control valves to maintain the correct flow rate to each chiller. However, the control valves have been set to a fixed position and do not modulate to control the flow rate. When the flow rate is below its design value, the chiller output is reduced proportionally.

Our analysis shows that with appropriate operational changes, the system is capable of meeting current and near-term future loads, with some capacity to spare.

## Recommendations

- Find and repair leak(s)
- Monitor tank level remotely
- Correct the chiller controls
- Install flow control for tank and loads
- Revise the central plant operating strategy

**Management-level** recommendations include:

- Create a System Manual with the information needed to understand, operate, and maintain the system. The System Manual should document the design intent, control sequences, equipment capacities, operating procedures, and other pertinent information.
- Provide training to upgrade the capabilities of the staff. Operators should understand stratified chilled water storage concepts, the design intent for the central plant and associated building systems, and system operating modes and control sequences. Operators should also be familiar with HVAC fundamentals, troubleshooting, and interactions.

**Operations-level** recommendations include:

- Find and fix the leak(s) in the system
- Install a level sensor on the storage tank and don't ever let the water level fall below the minimum level.
- Correct the flow switches and anti-recycle controls on the chillers
- Restore chiller flow control valves to automatic operation, and provide flow control for storage tank and loads.
- Revise the operating sequences for the chillers, the thermal storage tank, and the variable-speed secondary pump in order to properly charge the storage tank, operate the chillers more effectively, and better control the chilled water flow.