Case Study: Experiences from the Conversion of an Open Evaporative Cooling Tower System to a Vertical Ground Heat Exchange System

Commercial – CW7
Project Objective:

Replace a failing, outdated and oversized open evaporative cooling tower system with it’s high maintenance and high chemical treatment costs, high energy and water consumption, with a vertical ground heat exchange system to offset the cooling tower’s high capital replacement cost and to reduce long term chemical treatment, maintenance, energy and water costs.
Project Overview:

• Seven buildings with a floor area of 389,555 gross square feet (gsf).
• All buildings constructed in 1936 and later.
• Multiple retrofit projects including window replacements, exterior and interior window shading, lighting and lighting control retrofits, and a DDC system for HVAC control were completed prior to the cooling tower replacement project.
• Starting in 1992, a series of projects converted the HVAC systems (4-pipe fan-coil systems) to 528-536 WAHP’s with a total cooling capacity of 1509-1567 tons (based on Design Bid source information).
Project Time-line:

- Mar. 2011, Request for Proposals, Design-\textit{build}.
- Jan. 2013, Distributed Pumping Design Modification Proposal
- Aug. 2013, System start-up.
- Sep. 2013, Pre-functional Performance Test (Cx).
- Feb. 2017, 500-gal/day of make-up water.
Agenda:

• Design Analyses:
  Design-
  bid Analysis
  Design-
  build Analysis
  GHEX Design Analysis

• Description of Open Evaporative Cooling Tower System.
• Description of WAHP System.
• Description of P&F Heat Exchange System.
• Description of Distributed Condenser Water Pumping System.
• Description of Central Control System Issues.
• Description of Maintenance Issues.
• Commissioning and Retro-commissioning.
• Test and Balancing.
• Measurement and Verification.
Design-*bid* Load Analysis:

• Building loads modeling software: Trace 700.
• 198 building zones modeled: coincidental block loads not calculated.
• Building occupancy scheduled for 10 hours daily, 5 days per week.
• Lights assumed to be 1.0 to 1.5 watts per gsf: model was 1.23 watts per gsf.
• Lights assumed to be on when building occupied: lighting modeled at full connected load, 480 kW, running 8760 hours per year, consuming 4,205,085 kWh/yr.
• Design-bid based on the sum of peak zone loads (200 zones).
Design-\textit{build} Load Analysis:

- Building loads calculated using eQuest.
- 7 building zones modeled: block load analysis.
- Building occupancy schedules same as for Design-bid case.
- Lighting level assumed to be as indicated in the Design-bid model.
- 80\% of lights assumed to be on when buildings are scheduled for occupancy.
- Design-build based on coincident building peak load (block load 7 zones).
GHEX Design Analysis:

• Design-bid: 2-separate borefields with 2 separate central condenser water pumping systems.

• Design-build: 1-borefield with 2-GHEX cells and a distributed pumping system.

• Design-bid based on 873 - 400’ vertical heat exchangers with two 1” PEX heat exchangers in each GHEX.

• Design-build based on 528 - 400’ vertical heat exchangers with one 1-1/4” heat exchanger in each GHEX.

• Use of existing C.I. underground direct return condenser water piping system required for both Design-bid and Design-build.

• Design-build recommended that the underground condenser water piping be replaced with a reverse-return piping system but was declined by the client.
Borefield Schematic:

Piping schematic depicting the two GHEX cells, the NW Borefield and the SE Borefield, and the existing cooling tower interconnecting piping system to each of the buildings.
Section of 3” Header Pipe:

A section of 3” diameter header piping in the SE Borefield was removed to repair a leak in the header piping system. The interior surface was coated with a residue from the cooling tower piping system. This residue has permeated all of the horizontal header piping and the vertical ground heat exchangers with a resultant degradation of the heat transfer capabilities of the system.
Description of Open Evaporative Cooling Tower System:

• Existing cooling tower failing and requires replacement.

• Open sump provides means for oxygen to be introduced into the source condenser water. Existing cooling tower capacity estimated to be in excess of 4,000 tons but was not confirmed.

• The source condenser water system and open tower has NO operational chemical treatment system.

• Existing condenser water underground piping system serving the cooling tower is a cast-iron, direct return piping system with piping from 6” to 14” in diameter.

• Underground piping has been broken and/or damaged by heavy vehicle traffic resulting in multiple leaks, repairs and returned to service without proper system clean, flush and purge.

• The entire underground condenser water piping system is unsuitable for use.
Cooling Tower Equipment Room:

Water treatment equipment for the cooling tower had been abandoned and was partially disconnected.
Cooling Tower:

3” make-up water pipe showing substantial internal corrosion which is typical of the potable system throughout the facility which indicates widespread maintenance issues throughout the facilities.
Condenser Water Pipe:

This section of 14” dia. C.I. Condenser Water pipe was left on the ground behind the chemical cooling tower treatment at the time of the installation of two new central Condenser Water Pumps.
Description of WAHP System:

- Each of (7) buildings has an interior condenser water loop system with heat transfer to the exterior open tower system through a P&F HEX.
- The design-bid documents indicated a WAHP cooling capacity of 260 gsf per ton.
- The design-bid documents indicate a building capacity of 1,350 tons, or 290 gsf per ton with a negligible heating load.
- The design-build proposal provided 400 gsf per ton, or 975 tons of peak coincident cooling load (2.5 ton per heat pump average capacity) with a significant heating load.
- Most of the WAHP’s are located in ceiling cavities and are not extended operating range rated.
- Substantial portions of the building-side condenser water piping systems are not insulated and unsuitable for GCHP application.
- Maintenance service of WAHP’s is unknown but there is a significant probability that filters are not properly serviced and the airside of the coils are not clean resulting in a need for higher building side temperatures in the heating season (WAHP’s were excluded in both the design-bid and design-build contracts).
- All of the 534+ WAHP’s have R-22.
- There are separate ventilation make-up air systems.
Bldg. 671:

WAHP hose kit and uninsulated condenser water supply and return piping. The temperature in the condenser water piping system must be above the dew point temperature of the moisture in the air, typically 55F.

These heat pumps have controls to limit the maximum entering condensing water temperature to about 92F and a minimum entering temperature of 62F.

Service access to the ceiling mounted (approximately 534 WAHP’s was not addressed as part of this project and whether adequate maintenance has been provided is unknown. Statements that the condenser water temperature has to be maintained as high as 80F raises questions as to the maintenance adequacy.
Description of P&F Heat Exchangers:


- Lack of maintenance and chemical treatment in the source side (cooling tower exterior condenser water system resulted in a reduction of up to 75% of the condenser water flow through the Plate & Frame HEX. The Plate and Frame HEX were sized for cooling using an open cooling tower and were not sized for the ground heat exchange application where condenser water was required for heating and cooling.

- The supplemental boilers located on the building side of the Plate and Frame HEX were connected to the building condenser water loop entering the Plate and Frame HEX in heating energy being discharged to the evaporative cooling tower.

- A recent retrofit in the maintenance program in one of the building systems resulted in the boilers operating to heat the water returning from the ground heat exchange system resulting in overheating of the ground heat exchange system.

- “Right Sizing of the Plate and Frame HEX was excluded from the Design-bid and Design-build contract.”
Plate & Frame Heat Exchanger Piping Schematic:

This typical piping schematic was developed at the time of the replacement of a 4-pipe fan-coil system with a WAHP system. The condenser water returning from the building is reheated prior to the condenser water HEX so that the heating energy can be extracted by the cooling tower depending on the control set-point temperatures in the central BMS. The heated water from the boilers should be put into the building condenser water loop on the leaving side of the HEX.
Building 602:

New P&F HEX installation has small purge valves on the Source side with isolation valves properly located. On the building loop side, small purge valves are located on the wrong side of the isolation valves. There is no by-pass pipe on the building loop side to facilitate servicing resulting in the need to shut down all WAHP’s for replacement of the P&F HEX. In mission critical buildings operating 24/7, this is not acceptable.
Bldg. 602:
Disassembled Plate and Frame Heat Exchanger showing metallic debris from the condenser water piping system inside the header (left) and a section of the connecting cooling tower condenser water piping showing internal corrosion and control sensors (right).
Bldg. 602:

A section of pipe removed when a new Plate & Frame heat exchanger was installed illustrates the corrosion and cooling tower loop contamination build-up within the pipe. This distorted surface prevents taking ultra-sonic flow readings.
Description of Distributed Condenser Water Pump System:

- Existing Central Pumps: (2) at 125-hp, no VFD.
- Design-<i>bid</i> Central Pumps ( ):
  - NW Borefield: (2) at
  - SE Borefield: (2) at
- Design-<i>build</i> Distributed Pumps (77.5 hp):
  - Bldg. 602: 2@15-hp w/VFD
  - Bldg. 664: 2@15-hp w/VFD
  - Bldg. 669: 2@7.5-hp w/VFD
  - Bldg. 671: 2@7.5-hp w/VFD
  - Bldg. 681: 2@15-hp w/VFD
  - Bldg. 693: 2@10-hp w/VFD
  - Bldg. 703: 2@7.5-hp w/VFD
Bldg. 693:

Armstrong pumps with integral VFD.
Bldg. 693:

Typical screen on VFD showing the flow, gpm, for the pump. These were not correctly set until March, 2016. In addition, flows could not be obtained due to condition of the heat exchangers.
Description of Central Control Issues:

• Heating Mode: Building Condenser Water Loop temperature control was set at 75F but entering to the WAHP’s.

• Cooling Mode: Building Condenser Water Loop temperature control was set at 75F entering to the WAHP’s.

• Boiler operation was maintained during the winter resulting in excess energy sent to the cooling tower.

• Intensive trend logging capabilities were available but were not provided during the Design-build analysis.
Bldg. 694:

This cooling tower provides a hybrid system capability for the “mission critical” 24-hour requirement of computer operation and communications. Control sequence modifications have not been implemented that would provide for operation during periods of cooling and for the potential of reducing the borefield temperature.
Digital Make-up Water Meter:

A digital water meter was provided to monitor the make-up water use for the purpose of indicating leaks in the borefield or underground piping systems.
Make-up Water Meter:
The digital make-up water meter on 12/8/15, on the left, and on 12/10/15 on the right. The condenser water system in the penthouse was dry. When a recent breach of the old distribution header was repaired, which drained the penthouse level of the condenser water piping and components, a shut-off valve in the make-up water in another part of the building was closed and not turned back on indicating 3-gallons of water was used during the 24-hours after the system was refilled verifying the integrity of the borefield.
System Maintenance: A Requirement

- Source Condenser Water Piping System (flushing and purging, no means of draining the pumping system were identified).
- Plate and Frame Heat Exchangers (did not have purge ports, test ports, backwash piping by-pass and isolation valves).
- Strainers (badly in need of cleaning and screens of the specified size).
- Building side of Plate and Frame Heat Exchanger maintenance, including filter replacement, unknown.
Bldg. 681:

Blow-down valve appears clean but has a minor leak.
Description of Maintenance Issues:

- Underground condenser water piping was not flushed or chemically treated.
- Plate and frame heat exchangers not properly cleaned and flushed since original installation.
- Strainer baskets not cleaned nor replaced.
- BMS incorrectly programmed: maintaining 75F building side condenser water summer and 80F winter.
- Switching to and from cooling tower to GHEX system not performed as instructed.
- Borefield piping contaminated.
Bldg. 602:

(2) New base mounted pumps with VFD controls. This equipment room is at the high point in the system and is the location of the system expansion tanks and make-up water system.
Bldg. 602:

Fouling contaminants from the water in the cooling tower loop as the new condenser water pump was disassembled – note the remaining solids in the muck – the contamination is more than corrosion residue.
Bldg. 602:

Sludge build up within the pump volute showing some of the “slime” build-up from the contaminated cooling tower condenser water loop which appears to have a Biological component likely formed in the open to atmosphere Cooling Tower.
Bldg. 602:

Contaminants from the cooling tower loop removed from the pump.
Bldg. 602:

Taking readings after clearing contaminated cooling tower loop residue from the test ports on a triple duty valve. Probes used in triple duty valve test ports had to be cleaned multiple times before readings could be successfully taken because of test port fouling.
Bldg. 602:

Screens from the condenser water strainers were extremely fouled. This is the suction diffuser screen for one of two new condenser water pumps. Suction diffuser screens are not intended to function as strainers. This picture shows that pre-existing upstream strainers are not performing allowing contaminants to flow throughout the piping system.
Building 664:

In the mechanical room, several empty strainer screen shipping cartons and a new screen were found. The outer layer has approximately 1/8”-3/16” openings with a smaller inner layer.
Bldg. 602:

The condenser water pump’s suction diffuser after the screen removal showing the residue from the cooling tower condenser water loop.
Building 664:
At system start-up in August, 2013, an immediate failure occurred in one of two condenser water pumps for Building 703. Metallic fragments can be seen in the pump impeller. Since then, other system pumps have failed and had to be replaced.
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Bldg. 669:

New condenser water pumps with VFD’s.
Particulate Matter:

Pieces of corroded particulate matter up to 1-1/4” in size capable of causing pump impellers to jam have been found throughout the system causing multiple seized pumps.
Bldg. 671:

New condenser water pumps with VFD’s.
Bldg. 671:
Bldg. 681:

New condenser water pumps with VFD’s.
Bldg. 681:
Fouling contaminants from the water in the cooling tower condenser water loop after the volute was partially cleared – note the remaining solids in the muck and the larger materials in the residue.
Bldg. 703:

Strainer blow down sample after a portion of the water has been drained so solids can be seen. The Cooling Tower (source side) piping is heavily contaminated, plate/frame heat exchangers are badly fouled resulting in the VFD on the condenser water pumps providing a false "throttling valve closed" pressure indication.
Bldg. 664:

The air separator (downstream of strainer) blow down after draining some water off so solids can be seen. This is typical of the source water flow to the plate/frame heat exchanger in all buildings.
Bldg. 681:

Fouling contaminants from the water in the cooling tower condenser water loop after the volute was partially cleared – note the remaining solids in the muck and the larger materials in the residue.
Commissioning and Retro-commissioning:

- Commissioning of the Design-build contract was not completed because of severe system contamination previously shown.
- Pressure drops across strainers and P&F HEX could not be determined because of the lack of purge/test/flush provisions.
- Correcting existing issues was not a part of the contract and queries about addressing these issues were declined.
- Owner notified of severe contamination conditions and accepted the project without commissioning being completed.
- Retro-commissioning was contracted but not completed because of the same installation defects encountered in the original commissioning.
Bldg. 664:

The strainer in the condenser water supply does not have a pressure differential sensor across the strainer. This was typical of the existing strainers throughout the project.
Ultrasonic Flow Measurement:

Flow test was attempted but unsuccessful. Either particulates in the water or heavy contamination inside the pipe would prevented accurate readings. This was the case on all attempts to take measurement on existing system piping – 6” and 12”.
Test and Balancing:

• For a full reverse-return condenser water piping system, the system is “self-balancing”: tests are required to verify that the correct flow is obtained in all parts of the system.

• For the Case Study, a system that is not a full reverse-return piping system, balancing fittings need to be provided and a full Test and Balance procedure performed.

• Balancing of distributed system condenser water pumps not provided.

• Balancing requirements for (2) vaults not provided under the false assumption that they were a reverse return piping system and were self-balancing.
Measurement and Verification:

• BMS data capabilities available but not provided – even after multiple requests as noted below:

• Electrical loads available for each building on user defined time intervals (3-minute preferred);

• Ambient air conditions;

• Selected monitoring of WAHP’s and OSA make-up air units;

• Run-time data for each WAHP and for central condenser water pumps;

• Run-time available for distributed condenser water pumps;

• Make-up water requirements daily.
Critical Conclusions (what was learned):

REPLACING A COOLING TOWER SYSTEM WITH A GROUND HEAT EXCHANGE SYSTEM DOES NOT CONVERT A WAHP SYSTEM TO A GCHP SYSTEM.

Lack of an investment-grade audit +
Incompatibility of system components for a GCHP system +
Building modeling not properly bench-marked +
Deficient system maintenance +
No Test and Balancing performed +
Defective Commissioning and Re-commissioning +
No Measurement and Verification =

COMPLETE PROGRAM FAILURE.
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