Central plant upgrades take off at Denver International Airport

Since its opening day Feb. 28, 1995, Denver International Airport (DEN) has continued to grow and evolve. Today, in fact, the facility operates on the scale of a city in terms of the amount of people moving through and working across the 50-plus-sq-mile property. In 2018, DEN served 64.5 million passengers – up 4.8 percent over the prior year – and 2019 was on track to be another record-breaking year. The passenger traffic forecasts for 2025 are now expected to be reached by 2020.

The central utility plant (CUP) serving DEN has continually evolved as well. With cooling and heating systems tied to fundamental airport operations like passenger bridges, aircraft preconditioned-air systems, food services and information technology infrastructure, the CUP is a critical component that must expand and upgrade as the airport grows.

The 10 cooling tower cells at DEN, visible between the terminal and Concourse A, are the tip of the iceberg – topping a huge complex of chillers, boilers, pumps and a vast array of pipes and other equipment residing far below the airport surface. This critical system supplies heating hot water and chilled water to 7.72 million sq feet of space across seven buildings: the terminal, three concourses, an airport office building, a hotel and transit center as well as the CUP itself.

At present, the CUP is undergoing a major upgrade that will enable it to keep pace with the ongoing $1.5 billion airport expansion project that is adding 39 gates. Upon completion of its upgrades in 2021, the plant will have 20,000 tons of chilled-water capacity and 214 MMBtu/hr of hot water capacity; and it will serve an increased airport service area of 8.97 million sq ft.

The history of improvements and renewal at the CUP tells a story of progress – one of responding to new requirements and technologies as well as changing utility rate structures and steady airport growth.

GOING ELECTRIC

When DEN opened in 1995, cooling was provided by three new 4,150-ton chillers and one 3,300-ton unit (relocated from the Stapleton airport), all relying on R-22 refrigerant and natural gas engines to drive the compressors. At the time, there were financial incentives to invest in gas-fired equipment over electric motors. For example, gas-fired engines offset utility demand charges that would have been levied against large electric motors. However, these advantages were short-lived.

By the early 2000s, technology and the airport’s utility rate structure had also evolved, making the original design assumptions that drove selection of natural gas engines obsolete. Moreover, the gas engines were prone to breakdowns, and finding qualified professionals to perform maintenance and repairs was...
OPTIMIZING THE HYDRONIC SYSTEM

The solution was a series of hydronic optimization projects that started in 2010 with an initial effort to hydraulically model the thermal distribution systems. The result of the analysis was the removal of more than 200 pumps that were in series or local coil booster pumps, as well as the addition of variable-frequency drives at optimal locations to better control the system. Completed in 2014, this project provided relief to the maintenance staff and also improved system operations in several ways. For instance, coil flow rates were stabilized against the dynamic pumping conditions through installation of pressure independent control valves.

While an improvement to system operations, this first step in optimization did not address several issues that continued to plague the system. (See fig. 1 for progression of the pump system improvements.)

By 2016, another chronic issue, uncontrolled heating coils, had emerged as a problem needing resolution. Because several separate entities were responsible for finishing out the majority of DEN’s interior spaces, the airport’s Design Standards Manual was not always strictly followed. One unfortunate result was a lack of control valves on smaller unit heaters, perimeter radiant heaters and other small heating coils. Free flow through equipment without control valves resulted in significant excess flow within the system as well as pumps running out on their curves and operating far from their best efficiency point.

This led to increased energy usage and accelerated failure of the secondary pump components. Commonly referred to as “wild flow,” this lack of control can be managed on a small scale. However, given the sheer size of DEN and the quantity of those small coils, the uncontrolled coils aggregated to account for a significant amount of the total system flow.

These open paths in the system prevented the secondary pumps from building pressure needed for optimal performance. Like blowing into a leaky balloon harder and harder, the uncontrolled units simply bypassed more water as the pumps ramped up. In the most extreme case, one concourse was forced to run all its secondary pumps at 100 percent, including the redundant pump, and the system was still unable to maintain its end-of-line differential pressure setpoint.

In addition to contributing to a poor system delta T, low pressure problems and excess pumping energy across the system, these isolated issues propagated where the pump sets were fighting one another; and the system was difficult to control without constant adjustments to balancing valves up and down the line.

Located next to the main terminal, the CUP is linked to the rest of the airport via a main spine of chilled-water...
and heating water distribution headers located beneath the train tunnel. The hydronic system was installed in a series of loops off the main spine. However, since the secondary pumps were local to each building/concourse and a large decoupler separated the plant from the main spine, each pumping system pulled its suction flow from the decoupler node – leading to each of the pumping systems impacting one another as loads increased and decreased. The operations personnel, organized by individual concourse, each attempted to regulate their own swings via manual adjustments to balance valves within the pump rooms. The distribution spine pressure was in constant fluctuation as each concourse pump system fought for the right to draw flow from the decoupler and return its water back to the CUP. As local system balance valves were closed and more of the excess secondary flow was forced back to the CUP, it became unavoidable that the decoupler line would commonly run backward. This led to the CUP primary pumps tripping off due to the excess return pressure and, more concerning, colder return water being sent directly back to the fleet of noncondensing boilers.

To address the main issues at the CUP, the design team proposed closing the decoupler to pressurize the main spine and fully opening all the individual balancing valves, which encourages the wild flow to stay within its individual concourse loop. This improvement was completed in 2018.

The decoupler is the point where all the loops interacted together. By closing this node and pressurizing the main spine all the way up to the far end of the airport complex, each concourse can draw just what it needs from the centralized loop to meet its individual heating load. The increased differential pressure from the main loop also provides more suction pressure to the secondary pumps and helps them satisfy the excess flows. For example, with the decoupler closed, the worst-case concourse was able to meet its differential pressure setpoint and shut down the redundant pump at lower loads.

While these adjustments and new sets of secondary pumps will greatly improve system operation, one of the root causes has yet to be addressed: Only through a long and diligent process of adding individual control valves will DEN regain complete control of the heating system flows and realize those benefits. This retrofitting project is on DEN’s capital planning list to address as soon as possible.

**REDUCING RISK**

Over time, it was clear that the originally installed large-capacity chillers and boilers represented a challenging operational situation. With the CUP’s entire capacity wrapped up in a small number of large R-22 units, the operations profile represented an unacceptable level of risk if one or more of these units were to go out of service. For instance, elective maintenance could not occur at certain times of the year since taking down that piece of equipment would severely limit overall system capacity. Limited turndown also created difficulties in maintaining stability

**FIGURE 1.** Hydronic optimization: Progression of the Denver International Airport heating water pump system.

<table>
<thead>
<tr>
<th>Year</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995 – Original construction</td>
<td>The original airport system featured an open decoupler with multiple blending loops and series booster pumps.</td>
</tr>
<tr>
<td>2014 – After initial optimization projects</td>
<td>Initial optimization efforts eliminated over 200 pumps across the airport, however unstable header pressures and wild flow pushing back to the CUP contributed to continued system challenges.</td>
</tr>
<tr>
<td>2018 – After closing main decoupler</td>
<td>Closing the main decoupler provides more uniform header pressures and balanced operation across the entire system.</td>
</tr>
</tbody>
</table>

CCC – Concourse C | CCB – Concourse B | CCA – Concourse A | AOB – Airport office building | CUP – Central utility plant

Source: Burns & McDonnell.
at certain load points. To begin addressing the overall operational challenges and start the R-22 phaseout process, the aging 3,300-ton chiller was replaced with two 2,500-ton variable-speed machines in 2012.

In 2016, a new plant modernization plan was being developed to prepare for a wave of airport growth and to address some of these concerns. The plan forecasted future load profiles, projected future utility rates, considered updates in available equipment technology and recommended the next generation of changes to the CUP. In addition, the project provided recommendations that would improve resilience, achieve more flexibility for expansion in reaction to future loads and increase overall system efficiency.

The plan encompassed both the chiller and boiler sides of the CUP as well as the supporting ancillary systems. The plant had not been originally designed to accommodate standalone power generation, and that option was still considered unfeasible. The initial basic concept of highly reliable hot and chilled water distributed to all concourses, buildings and support areas remained a central element of the plan.

A key recommendation of the modernization plan was to continue the precedent of installing smaller units that could provide more flexibility and realize energy savings through variable-speed drives. Through a lifecycle cost analysis, the variable-speed machines proved a better long-term value since they could provide superior efficiency by utilizing the colder condenser-water temperatures that Denver’s dry climate allows for the majority of the year. Converting to smaller variable-speed chillers would also improve turndown, provide more flexible response to load changes and create the potential for significant cost savings. However, the stakes are high when it means potential disruption of one of the nation’s largest aviation hubs. Successful transition would mean continuous operation of the system amid removal of the original, large chillers and boilers in a carefully staged sequence as the smaller, more efficient units replaced them.

Two new chillers begin operations as the large original unit awaits demolition in the background.

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System snapshot: Denver International Airport*

<table>
<thead>
<tr>
<th></th>
<th>Hot water system</th>
<th>Chilled-water system</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Startup year</strong></td>
<td>1994</td>
<td>1994</td>
</tr>
<tr>
<td><strong>Number of buildings served</strong></td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td><strong>Total square footage served</strong></td>
<td>7.72 million sq ft</td>
<td>7.72 million sq ft</td>
</tr>
<tr>
<td><strong>Number boilers/chillers</strong></td>
<td>4 boilers</td>
<td>3 chillers</td>
</tr>
<tr>
<td><strong>Plant capacity</strong></td>
<td>200 MMBtu/hr</td>
<td>12,450 tons</td>
</tr>
<tr>
<td><strong>Fuel types</strong></td>
<td>Natural gas, Jet-A fuel</td>
<td>Electric</td>
</tr>
<tr>
<td><strong>Distribution network length</strong></td>
<td>10 miles</td>
<td>12.5 miles</td>
</tr>
<tr>
<td><strong>Piping type</strong></td>
<td>Insulated carbon steel in tunnels</td>
<td>Insulated carbon steel in tunnels</td>
</tr>
<tr>
<td><strong>Piping diameter range</strong></td>
<td>4 to 24 inches</td>
<td>4 to 36 inches</td>
</tr>
<tr>
<td><strong>System pressure</strong></td>
<td>160 psig max</td>
<td>160 psig max</td>
</tr>
<tr>
<td><strong>System temperatures</strong></td>
<td>160-230 F plant, 150-190 F buildings</td>
<td>42 F supply/56 F return</td>
</tr>
<tr>
<td><strong>System water volume</strong></td>
<td>180,000 gal</td>
<td>380,000 gal</td>
</tr>
</tbody>
</table>

* This reflects system data as of Jan. 1, 2020. At completion of current concourse expansion and plant upgrade projects in 2021, the DEN central utility plant will
  • serve an airport area of 8.97 million sq ft,
  • operate a total of nine boilers and eight chillers, and
  • produce up to 216 MMBtu/hr of heating hot water and 20,000 tons of chilled water.

Source: Burns & McDonnell.
On the heating side, one of the four large original 60-MMBtu/hr high-temperature heating water boilers failed prematurely as the modernization plan was nearing completion. Following the plan’s recommendations, the failed boiler was replaced with three smaller units contributing 20 MMBtu/hr each. However, due to this failure and delay in getting new permanent capacity on line, the airport was forced to install a rental boiler at the time. The rental unit was ultimately purchased and put into permanent operation because of the continued issues with the system and persistent load growth. The remaining original boilers are scheduled for replacement over the next two years to bolster the system capacity ahead of the looming airport growth.

MOVING IN LOCKSTEP

Denver International Airport is currently in the middle of its $1.5 billion gate expansion project. The 39 new gates are being added to the ends of the concourses, providing opportunities for DEN’s airlines to grow and for the airport to accommodate new airlines, including international carriers. All new gates are slated to be operational by 2021 and will represent a 30 percent increase in DEN’s current gate capacity. The project is just one of several in DEN’s current $3.5 billion five-year capital improvement program.

WITH EXPANSIONS TO ALL THREE CONCOURSES NOW UNDERWAY, UPGRADES AND IMPROVEMENTS TO THE CUP ARE MOVING IN LOCKSTEP.

With expansions to all three concourses now underway, upgrades and improvements to the CUP are moving in lockstep. The CUP chiller project was funded as part of a larger effort to remove all R-22 refrigerant across the entire airport ahead of U.S. Environmental Protection Agency mandates. Based on the recommendations from the modernization report, the approach of replacing one large chiller with two smaller VFD chillers is now being duplicated across the plant. By publication of this article, the second set of new 2,500-ton chillers (3A/3B) will be operational, and the final two remaining R-22 chillers will have been demolished.

The number of chillers will ultimately double from four to eight, each with 2,500 tons of capacity and dual VFD compressors installed. With independent refrigerant circuits specified into the dual-compressor machines, the plant will be armed with ample redundancy to survive a number of failure modes. Similarly, the number of heating hot water boilers will double at the end of the upgrade project from four to eight, each with 20 MMBtu/hr of capacity.

Bringing new chillers and boilers on line while taking others off line is a crucial and delicate procedure: The chiller system, especially, is challenged to absorb an outage at any time of the year because of its importance in maintaining critical cooling loads. Successful replacement has required impeccable coordination as valves, bypasses, hot taps and pipe cuts must be executed under live operation. The project has been somewhat like a juggling act, as water must continue flowing, pressures must be kept within acceptable ranges, and sufficient capacity must be maintained— while major pieces of key equipment are removed and new equipment is installed.

The project hit a critical period during summer 2019, when cooling loads began to peak beyond projections and the construction project was in full swing. Amid the initial demolition work, CUP operators became concerned as they realized the N+1 equipment they would be depending on was one of their least reliable units. Fortunately, the CUP staff voiced the concern in time, and the airport elected to invest its own contingency budget to temporarily repower and maintain one of the other chillers that was imminently scheduled for demolition. This foresight preserved crucial redundancy in the system and saved the airport from a major incident in late summer 2019 when the unreliable unit failed unexpectedly.

POSITIONED TO MEET DEMAND

Thanks to effective master planning and timely project implementation, airport executives are well-positioned to provide efficiency and reliable capacity to the upgraded concourses. While the CUP evolution and modernization process will enable DEN to meet demand for a few years, the airport is not done growing. Astonishingly, the original airport planners built in the ability to double the current runway quantity from six to 12— after which point the need to construct entirely new concourse structures would be triggered. Inevitably, the cycle of renewal and improvement will begin all over again with the next wave of growth.