

Introduction

The Auditorium Building is an eighteen story, 365,000 square foot building located at the corner of Michigan Avenue and Congress in Chicago. Declared a National Historic Landmark in 1975, the building is owned and operated as a University and academic facility by Roosevelt University. Although grandiose in many respects, this 113 year old facility requires substantial upgrades to infrastructure, classrooms, laboratories and faculty offices. The first phase of an ambitious \$63 million upgrade to the facility was to install a new high efficiency central chilled water and heating plant in the building. The existing plant, with a capacity to serve less than half of the building was 35 years old, inefficient, and prone to numerous service problems, rendering the building with limited air conditioning in recent years.

Phasing a major infrastructure upgrade with the building's use was a significant issue in designing the project. With limited electrical capacity available in the building, and lacking the space and budget to provide greatly enhanced electrical service, an innovative cooling system was required. A detailed analysis was prepared, projecting cooling and power requirements during each phase of future renovation. This analysis identified multiple options for system replacement, including equipment options and pumping/distribution requirements.

The best scheme was determined to be a hybrid central chiller plant, consisting of both gas and electric chillers, primary and variable speed secondary pumping, with a cross connect into the existing chiller system serving the adjacent 18 story Herman Crown Center dormitory building. Because of limited space availability, the ideal location for this chiller plant was determined to be in the basement of the Herman Crown Center, Roosevelt University's adjacent 18 story dormitory building. The basement of the Herman Crown Center was currently occupied by the central steam plant for both the Auditorium Building and Herman Crown Center buildings. Having been identified as an area of infrastructure which would soon be upgraded, a portion of the steam plant was upgraded simultaneously.

A new life safety standby generator was also included in the project, to help consolidate construction costs, since gaining access to the basement steam plant space would require removal of a floor slab and removal of the side of the building in for delivery of the large chillers, boilers, and emergency generator equipment.

Background

Completed in 1889, the Auditorium Building was one of the only multi-use facilities of this type built during the 19th century. Designed and engineered by the team of Dankmar Adler and Louis Sullivan with significant input from Frank Lloyd Wright, the building's innovative design embodied the spirit of a distinctly American architecture – a new, democratic architectural form for a democratic people. Dankmar Adler implemented his

revolutionary infrastructure designs and created the first large-scale building in the world to be electrically lit and partially air-cooled.

Roosevelt University acquired the Auditorium Building following the



Figure 1 - The removal of a non-functional boiler provided space for the new cooling equipment

war in 1946, and converted the office and hotel spaces into university facilities. In the 1950's, a successful large-scale restoration took place, with both Ludwig Mies van der Rohe and Frank Lloyd Wright on the restoration advisory council. The Auditorium Building is listed in the National Register of Historic Places and was declared a National Historic Landmark by the United States Department of the Interior in 1975.

Because the Auditorium Building was built as a hotel more than a century ago, it was not designed for use as a university. When Roosevelt University purchased the building in 1946, space was converted into classrooms and offices throughout the building, concentrating on the east wing, which fronts Michigan Avenue. Many of these spaces have received only minimal improvements since that time, and there has been no complete overhaul of the building's heating and cooling systems.

In order to provide high-quality and safe educational experiences for students and a comfortable environment for visitors, an upgrade of the Auditorium Building's infrastructure and academic facilities, including infrastructure, classrooms, laboratories and faculty and staff offices is critical. In the second quarter of 2000, Roosevelt University commissioned Booth Hansen Architects and Ketchmark & Associates, Inc., Consulting Engineers, to embark on a detailed assessment and master plan for the 365,000 square building. In addition to Programming and Phasing, this assessment evaluated existing mechanical and electrical systems throughout the building, including heating, cooling, ventilation, plumbing, electrical, lighting, and power distribution. Concepts for renovating the building's engineering infrastructure were developed to permit the phased renovation of the building. Priorities were established for each phase of work. Lacking central air conditioning in over 50% of the building, with the remaining portion of the building served by an aging chiller system or window air conditioning units, a new central chilled water plant was identified for one of the first infrastructure renovation phases to occur in the \$63 million master plan. An aging steam boiler system and lack of standby electrical power were also high priority elements to improve safety, comfort and operating efficiencies in the building.



Figure 2- Distribution of chilled water was a difficult process, sometimes requiring pipe trenches

The problem

When the decision was made to substantially upgrade the building's infrastructure, many design challenges were encountered. Innovative solutions would be required. Some of the many challenges included:

1. Over the course of the next 18 years, Roosevelt University was planning on embarking on a massive renovation of the Auditorium Building. The low pressure absorption chiller serving approximately 50% of the Auditorium Building was over 30 years old, had significant maintenance problems, and was no longer a viable source of cooling for the building.
2. An additional 25% of the building is cooled by inefficient window air conditioners. These window units are scattered throughout the entire building, providing no central control or management of temperature. Many of the window units are turned on and operate 24 hours per day, cooling spaces at nights, during weekends, and at other periods when the space is not occupied, wasting tremendous amounts of energy. In addition, the noise generated by window air conditioning units in the classrooms decreases the quality of education in the building. In the winter, engineers and carpenters must install weather covers over each of more than 300 units to prevent cold air from infiltrating to the space. The goal of any new cooling plant would be to ultimately remove all of the window air conditioning units, and provide a cooling source from a central plant.
3. The remaining 25% of the building is not currently air conditioned. As portions of the building are renovated, additional air conditioning loads would be required. Although an estimated of 1700 tons of cooling would ultimately be required from the central plant, approximately 700 tons of this would not be required for approximately 6-10 years, as areas of the building which were not currently air conditioned were added to a central plant. Not wanting to "front load" the cost of a cooling plant with capacity which could not be fully utilized immediately, concepts were needed to phase in additional cooling load in the future, as more load was required.
4. The analysis of available electrical power to support a new cooling plant determined that a new electrical service would

need to be brought into the building if a "conventional" all electric chiller plant were to be installed. The budget, as well as space constraints, did not permit a new electrical service with increased capacity at this time. Compounding this problem was the fact that the existing low pressure absorption chiller was fed from gas, making even a simple replacement of this cooling capacity taxing to the building's electrical system.

5. Economics did not warrant the use of single stage gas fired absorption cooling.
6. Space, economics and the lack of high pressure steam indicated that using two stage absorption chillers was not viable.
7. As window air conditioning units are phased out in renovated areas, some electrical power would become available, since these small window units required substantially more power, per ton, than a central cooling plant required.
8. Although still in service, the 32 year old chillers serving the Herman Crown Center were inefficient, and would need to be replaced in the next 5-10 years. A scheme would need to be developed to permit any new chiller plant to serve the Herman Crown Center, while still keeping those chillers in service to handle standby cooling, as well as to pick up additional cooling requirements as future renovation phases add cooling load.
9. Three large low pressure steam boilers were installed in 1970 and serve both the Auditorium Building and Herman Crown Center. One boiler was already permanently out of service, and scavenged for parts. Although each of the two remaining boilers had the capacity to serve the entire heating and domestic water load in the coldest of winter days, their use during milder weather and during summer to serve domestic hot water loads for the dormitory was extremely inefficient. Furthermore, these boilers occupied the only viable and logical space (*Figure 1*) in the building for the expansion of a central heating and cooling plant.
10. Lacking a source of standby electrical generation for elevators, fire pumps, emergency and egress lighting, a new electric standby generator was deemed to be of utmost importance.



Figure 3 - A new gas engine drive chiller will provide significant operating savings and assisted in minimizing electrical requirements of the new cooling plant

11. Determining the best method for large equipment entry into the basement mechanical rooms needed to be addressed. A portion of the first floor slab and a portion of the building masonry exterior wall would need to be removed for equipment entrance. Since multiple systems, such as chillers, boilers and generators all had similar concerns, dealing with this issue once rather than multiple times was deemed highly desirable. In addition, the generator project would require large exterior louvers for ventilation air, which would also require removal of existing wall elements. Consolidating multiple projects into one project had the potential of saving significant construction costs.
12. Distributing chilled water over a very large building with an unusual "C" shaped floor plan needed to be done in an efficient manner. Detailed projections would need to be developed for future cooling loads of each future phase, in order to put in the piping infrastructure now. In certain locations, the confines of the building's massive foundation required pipe trenches (See Figure 2) for distribution of chilled water to the remainder of the building.

The solution

After detailed analysis of options, it was determined that a hybrid chiller plant would provide the greatest benefits to Roosevelt University. A high efficiency 600 ton electric centrifugal chiller, selected to optimize the System Part Load Value (SPLV) based on projected building loads would be installed to take advantage of what electrical power was available for a cooling plant. An additional 400 tons of cooling were required, which were to be served by a high efficiency natural gas engine driven chiller (Figure 3). Using this multi-source energy plant, the existing electrical service could remain. In addition, detailed operating strategies were developed to minimize operating costs by to minimizing electrical demand of the building during peak conditions, saving significant energy costs from monthly demand. The use of natural gas cooling assists in curtailing the use of peak electrical demand from the utility.



Figure 4 - New primary, secondary chilled water and condenser water pumping

The removal of the non-operational boiler (Figure 1) as well as another of the two older boilers would accommodate these two chillers and associated pumping and peripheral equipment, as well as provide space for two smaller steam boilers. A unique cross connect on the primary chilled water pumping side was made to the penthouse Herman Crown Center chillers, allowing the new chillers to serve the Herman Crown Center building in a more efficient manner than the existing chillers could. In addition, this bi-directional primary cross connect also was designed to permit the Herman Crown Chillers to operate either as standby to the new 1000 tons of hybrid chiller plant installed, or to provide additional capacity over the next 4-6 years, as areas of the building were renovated and window air conditioning units are taken out of service. In 6-10 years, these Herman Crown Chillers will be removed from service, freeing up space for future chiller to handle the remainder of the ultimate 1700 ton cooling load.



Figure 5 - New steam boilers more closely match partial load periods

Making the system even more efficient in the future, the gas engine driven chiller has been designed to include an integral heat exchanger to recover energy in the form of 200°F engine jacket water. A future phase of renovation will use this high grade heat recovery source to pre-heat domestic water heating for the Herman Crown Center, which has a large demand for hot water even in the summer to serve the 200 room dormitory and full service kitchen.

Since peripheral pumping and heat rejection equipment plays a significant role in the overall Kw/ton of delivered cooling capacity, especially at part loads, extreme care was given in the design of the distribution system. A variable speed secondary pumping system (See Figure 4) was installed to circulate water through the thousands of feet of chilled water piping to serve this block long complex. This variable speed pumping system is expected to pay for itself in a relatively short period. A new cooling tower was provided for the new chiller plant. This tower includes variable speed drives on all cells, allowing better control of condenser water temperature while saving significant energy over constant speed or two speed fan operation.

Two new steam boilers (See Figure 5) were provided to replace one of the two existing boilers. The existing boilers, installed in 1970 were each sized to handle the complete heating load of both the Auditorium Building and Herman Crown Center. The new boilers have been sized to handle part load, providing a much more efficient operation in summer time, when only domestic water heating is required.

Life safety to both the Auditorium Building and Herman Crown Center were greatly enhanced with the addition of a 750 KVA diesel generator. This generator provides a reliable standby source for emergency and exit lighting, elevators and fire pumps. Along with chillers and boilers, the large generator required

removal of a portion of the first floor slab as well as a portion of the exterior masonry building wall. By coupling the chiller, boiler and generator projects into a single phase, all equipment was able to share this equipment entry provision. Furthermore, the exterior building wall and floor opening were strategically located so that they could then function to serve the large ventilation loads from the new generator. This innovative and well coordinated approach saved considerable construction costs.



Figure 6 - Coordinating entry of all major equipment through a new masonry opening in the exterior of the building saved considerable construction costs. This new wall opening was

The temperature control system for the building was greatly enhanced with an expanded Direct Digital Control (DDC) Building Automation System (BAS) to efficiently stage and modulate chillers, pumps, cooling towers, and to determine the most efficient operating modes based on load, time of day, utility rates, etc..

Conclusion

The first major infrastructure upgrades to occur in 30+ years at the Auditorium Building posed numerous design and phasing challenges. With major restraining factors such as limited power availability, a unique and highly efficient dual utility source cooling system was designed. This plant minimizes electrical demand during peak periods. This hybrid cooling plant, placed into operation in the summer of 2002, is projected to ultimately save \$189,000/year in utility cooling costs. In addition, an estimated \$70,000/year savings in maintenance costs are projected. Furthermore, a lack of adequate space and the huge cost of dramatically increasing electrical power to the building made the hybrid gas/electric chiller plant the ideal candidate for the renovation. An additional \$10,000/year savings are anticipated under a future phase, when engine jacket heat is recovered from the gas engine chiller to assist in pre-heating the

large domestic water heating load from the Herman Crown Center dormitory and full service cafeteria.

The renovation of 50% of the building's steam capacity with high efficiency boilers sized to better match the building's partial loads and summertime domestic water load will provide additional savings. This savings is projected at nearly \$35,000/year

The new standby generator provides a much higher level of safety to the university, including the Herman Crown Center dormitory. Recognizing the tremendous opportunity in shared construction costs, the generator was included as part of this infrastructure project, providing a cost effective solution for Roosevelt University.

This project received ASHRAE Illinois Chapter's 2002 Excellence in Engineering Award for engineering design demonstrating innovative ideas and solutions to problems.

Building Summary

Gross Sqft – Auditorium Building	365,000 square foot
Number of Floors – Auditorium Building	18
Gross Sqft – Herman Crown Center	135,000 square foot
Number of Floors – Herman Crown Center	18
Cooling Tons	
• New Electric Centrifugal Chiller	600 Tons
• New Gas Engine Chiller	400 Tons
• Existing Herman Crown Center Chillers	450 Tons
New Boiler Capacity	2 @ 125 bhp
Existing Boiler Capacity To Remain	700 bhp
Standby Generator Capacity	750 KVA
Estimated Construction Cost	\$3 Million
Owner	Roosevelt University
Architect	Booth Hansen Architects
Engineer	Ketchmark & Associates, Inc.
General Contractor	AMS Mechanical