CHILLED WATER SYSTEM MASTER PLAN
GEORGIA INSTITUTE OF TECHNOLOGY

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ABSTRACT

Hosting the 1996 Olympic Village resulted in accelerated dormitory construction and several building renovation projects at the Georgia Institute of Technology in an unusually short time period. Campus planners evaluated individual building cooling systems, expansion of the existing central chilled water system, and construction of a satellite chilled water system. Timing of construction and budget constraints were major concerns.

A decision was made to develop a satellite system primarily serving a new dormitory complex. RDA Engineering, Inc. evaluated the existing chilled water system, new construction, and plans for future growth throughout the Georgia Tech campus. A chilled water master plan was developed to provide planners with direction for future integration of the satellite system with the main campus system and guidelines for budgeting requests, and to identify problem areas resulting from campus expansion. The planning process and development of a chilled water system model are presented in this paper.

INTRODUCTION

Between July 19 and August 4, 1996, the Atlanta Committee for the Olympic Games (ACOG) brought together more than 10,000 athletes representing nearly 200 nations. In all, the event drew 2 million visitors to the Atlanta metropolitan area. Over 3,000 hours of television coverage allowed two-thirds of the world's population — 3.5 billion people — to watch the competition and spectacle. Yet, of the thousands of athletes, coaches, organizers, sportscasters, and billions of television viewers, only a handful were aware of the district heating and cooling (DHC) systems laboring behind the scenes to provide indoor comfort, hot water, and process cooling.

The lack of recognition for District Energy is not intentional; it is a fact of life for the DHC industry. In our modern society, we do not notice much of the technology that provides the reliable services we have grown accustomed to. Building engineers know the best heating and cooling systems are the ones we do not notice. They are the ones that operate efficiently, do not break down, and maintain temperatures which are "just right."

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The focal point for Olympic activity was the Olympic Village at Georgia Tech, home for 15,000 athletes, coaches, and officials. Georgia Tech was also the site of the Olympic natatorium for swimming and diving events and the Alexander Memorial Coliseum, the venue for boxing. The 330-acre Tech campus normally accommodates a student enrollment of 13,000.

Major construction programs undertaken for the Olympics included more than $150 million in new campus housing facilities, an $11 million renovation of the Coliseum, construction of a $28 million Aquatic Center, and more than $1.7 million in grounds upgrades. Numerous temporary facilities were also constructed to accommodate the athletes.

From the time of initial Olympic bid submission, Georgia Tech was the center of Atlanta's Olympic plan. The main reason was the substantial housing and athletic facilities located in a campus setting near Atlanta's urban center. Duplicating these facilities from scratch would have cost several hundred million dollars. Once notice to proceed was received, Tech planners moved to accelerate nearly 10 years of projected dormitory construction into a 4½-year time span. This was in addition to an ongoing campus growth rate of five to seven percent per year needed to meet academic and research expansion.

CAMPUS DESCRIPTION

Georgia Tech is located on a 30-acre campus within the City of Atlanta, close to the City's central business district. The design of the early campus exhibits the traditional urban pattern of a campus quadrangle surrounded by academic buildings. Over the years, the campus has grown to its present size primarily in a northwesterly direction.

The Georgia Tech campus has been served by a central steam system since 1923. Currently, steam is distributed throughout the south, central, and east portions of the campus to 80 buildings. A central chilled water plant was constructed in 1965 and has been expanded to serve approximately three million square feet of buildings from a single location. The steam system operates year-round to serve classrooms, administration, dormitories, and research facilities, while the chilled water system is only operated during summer months.

In preparing a master plan for central systems infrastructure, RDA Engineering relied on a campus master plan completed in 1991 by Sasaki Associates, Inc. Minor changes to that plan which occurred during the study period were also incorporated.

For analysis purposes, RDA divided the campus into four quadrants as shown in Figure No. 1. The southeast quadrant contains the original campus with administration buildings, student housing, etc. The central chiller plant and boiler plant are located near the center of this quadrant. The southeast quadrant is the oldest section of the campus. It contains academic buildings, dormitories, and administration buildings. The central steam and chilled water plant are located in the center of the quadrant.

The southwest quadrant contains academic buildings and student activity facilities constructed primarily during the 1960s and 1970s.

The northwest quadrant contains the majority of the construction associated with hosting the 1996 Olympics, as well as numerous housing facilities and contract research facilities. This quadrant will be the site for most new building development over the next 10 to 15 years. A satellite chilled water plant was recently constructed in the northern area of this quadrant in support of dormitory facilities in this area.

The northeast quadrant contains contract research facilities, the coliseum, and several student housing buildings. This area also contains a number of athletic fields. Building activity to support contract research activities will likely occur in the northern region of this quadrant.

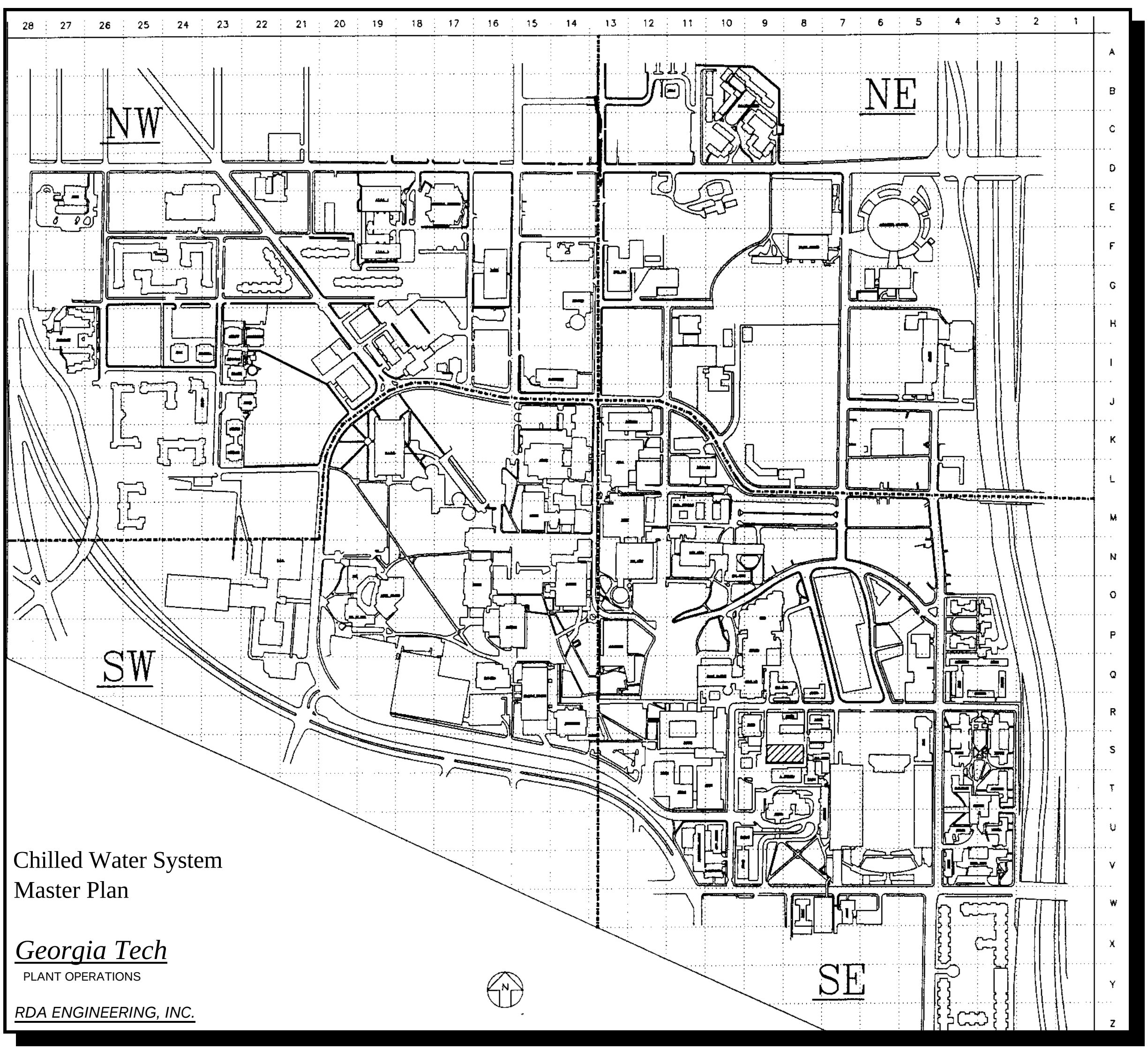


Figure No. 1: Georgia Tech Campus

CENTRAL SYSTEM DESCRIPTIONS

Steam System

The central boiler plant consists of four boilers with a combined capacity of 160,000 pounds per hour. The boilers were originally designed to fire coal, but have been converted to fire heavy oil and natural gas. Steam is generated at a pressure of 150 pounds per square inch and throttled through pressure reducing valves to approximately 40 pounds per square inch for distribution to the campus. Almost all condensate from the campus is returned and used as makeup water to the boiler system.
The boiler plant sees a load varying from a peak of 120,000 pounds per hour during the coldest winter conditions to 20,000 pounds per hour minimum load in summer. The steam loads consist of energy required for building heating, humidification, and service water heating requirements. No significant process load other than minor steam used for cooking facilities is encountered.

Central Cooling System

In 1965, a chilled water plant was established for the purpose of providing cooling for the Georgia Tech campus. The plant, as configured today, consists of six electric drive centrifugal water chillers with a total installed capacity of 8,000 tons. The water chillers are piped in a parallel arrangement to produce a leaving chilled water temperature of 45° F. Return chilled water temperatures of 55° to 60°F are typical.

The chilled water load serviced by the central plant consists entirely of space temperature conditioning and dehumidification requirements. The plant is not operated during the coldest winter months.

The present central campus chiller plant has 8,000 tons of installed refrigeration capacity; however, it is operated at 6,000 tons or less on a design day due to evaporative cooling tower limitations. At peak outside design conditions, the plant supplies 47° outgoing water and the return from the campus is 56°. The existing system is augmented by three chillers located in campus buildings totaling 900 tons which are operated only on peak days.

The majority of the campus buildings served by the chilled water distribution piping are connected to the system in a primary/secondary pumping loop. The buildings utilize a building pump and three-way valve which varies from 100 percent chilled water from the distribution system to none, depending upon the building load requirements.

Chilled Water Distribution System

The central chiller plant was constructed adjacent to the existing central steam plant. This location is in the southeast quadrant of the campus now, but was central to the campus at the time of its inception. Chilled water lines were extended in an eastern direction to the primary dormitory area of the day and 24-inch chilled water mains were extended west toward existing classroom buildings, the library, and the student center building. Reportedly, the plant was designed to serve approximately two million square feet of building area with a planned capacity of 4,000 tons. Buildings constructed in the late 1960s and early 1970s in the southern portion of the northwest quadrant were constructed with individual building chiller plants due to their distance from the central chilled water source. However, as campus expansion continued to move in a northwesterly direction in the mid-1970s, chilled water distribution lines were added and these buildings were connected to the central system. Lines continued to be added in a radial fashion toward the northwest quadrant of the campus.

In most buildings, supplemental chilled water pumps are required in order to boost or assist the central distribution pumps in delivering sufficient water volume. Since pump additions to serve specific buildings are required, the use of multiple pumps in series can produce complex effects in a distribution system of this size. Pump and valve operation in one building can significantly effect pressures available to other buildings. This problem is transient over changing load patterns and produces problems which are difficult to identify and correct.

The Georgia Tech staff indicate that there are variety of problems with the central distribution system. First, piping sizes may be inadequate for buildings connected due to the incremental development of the central chilled water system. As lines have been stretched into the northwest quadrant of the campus, pressure available for chilled water delivery has been dissipated and the effects of individual building pumps become even more disruptive.

A condition that makes this situation worse is the inability of building control systems to achieve a high temperature differential. Differentials of 15° to 18°F should be achieved with supply water temperatures of 40° to 42°F. Unfortunately, the building systems at Georgia Tech operate at much lower differentials. This requires more water to be circulated for the same amount of cooling load and uses available pump horsepower rapidly as peak load conditions approach.

In addition to general pressure and flow problems throughout the distribution system, certain campus buildings experience specific problems. This may include reverse flow or unusually low supply water pressures. Causes of these problems may include incorrect supply and return connections from the distribution system, cross-connections between supply and return piping, or pressure transients caused by building distribution pumps.

NEED FOR MASTER PLANNING

The chilled water system has been expanded over the last 20 years in a non-standardized fashion. Problems include low pressure in some areas, high pressure in others, and reverse flow. It is thought that some underground lines may be cross-connected. Uncertainty over load growth and timing of building connections has contributed to uncoordinated growth.

Tech's central system problems are common to many universities. First, growth of the campus has been away from the central plant. This means that chilled water and steam lines sized 30 to 40 years ago are too small for new buildings located across campus. The situation is aggravated by numerous building additions which have used different pumping connection schemes to assist chilled water pressure or "draw" water out of the existing chilled water mains. Second, buildings are usually funded one at a time, located some distance from existing district system lines, and budgeted without provisions for utility infrastructure development. Additionally, low electricity prices and the high cost of district line extensions have resulted in building designs based on individual heating and cooling systems in order to get the "most" building from limited construction budgets.

In the late 1980s and early 1990s, most new buildings were being designed with self-contained air conditioning plants because of the limited capacity of the central plant and problems previously described. This was not the most efficient design since the life cycle costs of individual building chiller plants are higher than using central plant utilities. In 1992, it was determined that there was a need to add chiller capacity to the central plant and that an overall study of system hydraulics should be undertaken.

For Georgia Tech, Olympic-related construction allowed consideration of a satellite chilled water plant in the western part of the campus. A 3,000-ton plant was designed and constructed to serve new Olympic dorms and nearby research facilities. The new plant can be expanded to 4,500 tons with future chiller additions. Underground lines are routed to a connection point with the main campus chilled water system. Without the Olympic rush, these dorms would probably have been built one at a time with individual HVAC systems.

The Department of Energy provided funding to assist Georgia Tech's Facilities Department in planning and analyzing the central chilled water system expansion and future operation as a result of the Olympic Games. RDA Engineering worked with Georgia Tech engineers to evaluate the hydraulics of the chilled water system, plan additional piping interconnections, and evaluate chilled water storage as a means to provide for future load growth.

DEVELOPING THE MASTER PLAN

The master planning process consists of collecting information about existing conditions, projecting future requirements, and proposing solutions which will provide for the future. The process sounds deceptively simple, however, it can be complex when future requirements are uncertain.

In Georgia Tech's case, a significant amount of effort was expended in determining existing conditions. This involved identifying buildings served by the central chilled water system, estimating loads required at the various buildings, and identifying existing piping conditions. While most information was available, compiling the information on more than 80 campus buildings of various ages, including renovations, and identifying the locations and sizes of underground piping installed over a period of 30 years became a substantial task for consultants unfamiliar with the day-to-day aspects of facilities operations.

Projecting future requirements is also extremely difficult for a college campus dependent upon state funding for academic construction and outside research contracts to support construction of laboratory and independent research facilities. A campus master plan prepared in 1991-1992 provided the basis for probable locations and gross square footage of buildings which could be built within the next 10 to 15 years. Pinpointing when buildings would be constructed and in what location was an entirely different matter. To obtain future building estimates, RDA worked closely with Georgia Tech planners and the engineering staff to arrive at a "best guess" scenario. Unlike some planning projects, past growth is not a certain indicator of future requirements.

In addition to new construction, a substantial number of individually cooled buildings throughout the campus are in relatively close proximity to central chilled water lines. An estimate was made of the remaining useful life of existing systems and the cooling loads of those buildings were added to future requirements.

With a load-growth scenario developed, the study team evaluated existing piping systems and potential piping system additions in order to model distribution system growth. A computer model was used to evaluate pressure and flow throughout the campus for existing conditions as well as to test the performance of the system as it was modified to serve projected load growth. Additional refrigeration capacity was assumed to be added at the satellite plant which could be interconnected with the main campus distribution piping.

In addition to proposing specifics for chilled water infrastructure expansion, the master plan document provided an excellent guide for campus administration and financial planners to use in their budgeting process. A clear direction was established with regard to underground piping and large refrigeration machine additions so that planners could look beyond the individual building costs in their budgeting process. Additionally, a methodology is in place for updating the plan and periodic reassessment based on actual growth conditions.

LONG-TERM LOAD GROWTH

RDA Engineering used the campus master plan provided by Sasaki Associates, Inc. to predict long-term campus growth. Using the near-term projects identified in the master plan, approximately 730,000 square feet of building additions were identified for near-term campus growth. The master plan space needs analysis also identified approximately 1.4 million square feet of facilities required over the next 10 to 15 years. Table I presents both the near- and long-term projected building programs which were used as the basis for this study.

In addition to new construction, there are numerous buildings throughout the campus which have not been connected to the central chilled water system. These buildings represent additional load which can be added over time as installed refrigeration systems are phased out or need to be replaced. Figure No. 2 illustrates the campus chilled water demand.

Table I
Projected Annual Load Growth

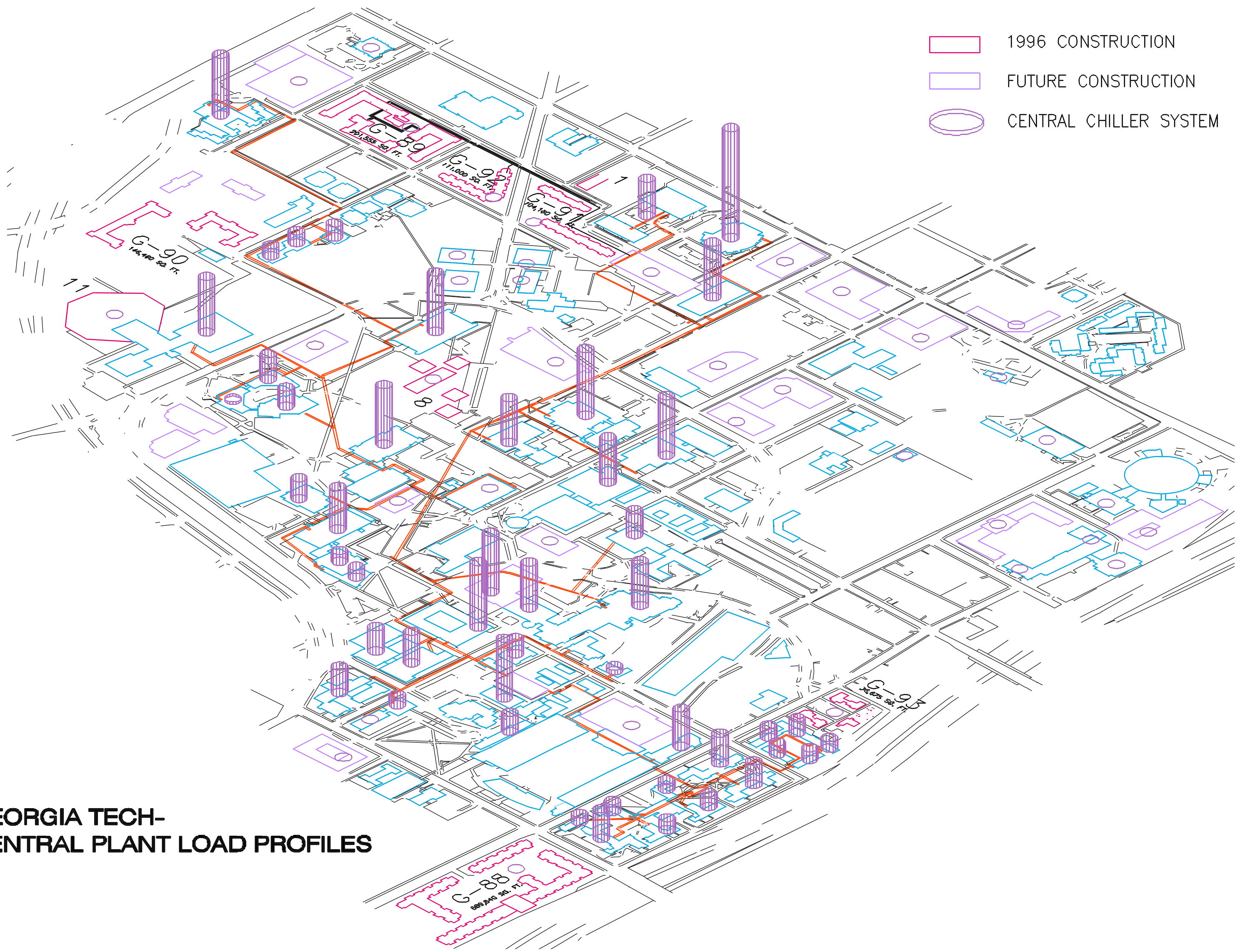
	1997	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
New Construction	350	365	140	420	0	400	160	400	0	400
Existing Buildings	0	200	210	120	530	140	20	280	200	0
Additional Tons/Year	350	565	350	540	530	540	180	680	200	400
Cumulative Tons	350	915	1,265	1,805	2,335	2,875	3,055	3,735	3,935	4,335

CHILLED WATER STORAGE

An alternate method of meeting peak refrigeration requirements is to combine new refrigeration machine capacity with chilled water storage. RDA explored this concept applied to the satellite chilled plant site and found the application offers an excellent opportunity to reduce costs and conserve energy as the campus grows.

The concept of thermal storage for air conditioning systems has been used since the earliest days of air conditioning. Early systems made ice which could be melted during peak cooling load periods to produce chilled water. Today, ice storage is used in both campus systems and individual building air conditioning systems where economics are favorable. In the past 10 years, storage of chilled water has been applied in numerous campus situations by using a large insulated water storage tanks with water distribution headers which promote stratification of cold water.

Consideration of chilled water storage for the Georgia Tech campus in the past has been unfavorable due to the type of electric rate structure from the Georgia Power Company. Recently, however, a new rate structure based on real time pricing has been offered to Georgia Tech. The new electric rate structure allows the University to purchase electric energy at very low rates during off-peak hours. Prices may be as low as .2¢/kilowatt hour during off-peak times. During summer hours, prices rise to as much .45¢/kilowatt hour during peak load times. No demand charge is imposed on real time pricing. As a result, it is possible to use electricity during off-peak times to produce chilled water



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CENTRAL PLANT LOAD PROFILES

and store it with the intent of using the refrigeration effect to displace expensive electricity during peak times.

A unique condition of this utility rate is that it is applied to electric load growth beyond a specific base load profile. In Georgia Tech's case, the base load was established prior to Olympic construction and provides excellent opportunities for future electric load management and chilled water storage in response to on-peak and off-peak pricing.

To evaluate a chilled water thermal storage application, RDA assumed that a chilled water storage tank would be constructed adjacent to the satellite chiller plant. An addition 2,000 to 2,500-ton chiller would be installed in the spare bay of the satellite plant and be piped in a way such that it can feed the distribution system and can separately charge the thermal storage tank. A tank volume of approximately 1.7 million gallons was chosen to provide up to 20,000 ton hours at a 20 degree temperature differential.

Using an hour-by-hour simulation and actual real-time energy prices provided by the Georgia Power Company, RDA estimated that the operation of the chilled water storage tank would produce savings in the order of $52,000 per year at 1995 prices. Capital costs of the tank are estimated at approximately $140 per peak ton less than installation of a new electric drive chiller.

CONCLUSIONS

Development of a campus-wide District Cooling System provides benefits to the Georgia Institute of Technology through organization of refrigeration services, reduction of maintenance and operating costs, enhancing ability to optimize refrigeration sources, and providing opportunities to apply thermal storage technology. In the future, cogeneration and electrical demand limiting may also be considered.

This opportunity exists at Georgia Tech due to the diversity of the numerous buildings which can benefit from a central cooling system. The campus district cooling system optimizes the use of available refrigeration sources and reduces overall electrical requirements from the local electric utility.

Other benefits which can be derived through central district cooling include a comprehensive approach to multiple refrigeration unit dispatch, a long-term chlorofluorocarbon (CFC) refrigerant phase-out plan, and the potential to reduce capital costs through utilization of central chiller systems rather than individual building systems.

Projected growth for the next 15 years estimates total refrigeration requirements for Georgia Tech buildings will increase by approximately 35 percent. This growth will take place primarily in the northern area of the campus through construction of office and research facilities. Existing buildings located throughout the campus which currently have individual refrigeration machines will also require replacement or upgrading in this time period due to the age of machinery and CFC refrigerant phase-out. The central chilled water piping infrastructure available throughout the campus and the two central plants are available to meet existing refrigeration needs and can be expanded in a logical fashion to provide reliable and efficient air conditioning service to new buildings.

Recommendations included in the master plan include integration of the satellite chiller facility located at 10th Street with the main campus chilled water system, a plan to address modifications to piping connections which will make the entire system work more efficiently, suggestions to utilize existing refrigeration systems as backup for the central plant chillers, and to segment the chilled water system into central campus versus east campus residential areas. Additionally, it is recommended that chilled water storage be considered in combination with additional refrigeration machine additions at the satellite chiller plant location. Initial feasibility studies indicate chilled water storage is less expensive that a refrigeration machine addition and will save operating costs due to the new Georgia Power real-time pricing rate schedule.