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NEW YORK University Medical Center recently completed a unique chiller interconnection project which will save $575,000/year in energy and operating costs and potentially $3.4 million. in avoided future chiller capacity construction.

Using conventional central plant chilled water distribution combined with the technique of connecting individual chiller plants in series flow, a hybrid system was developed for interconnecting the six existing chilled water plants at the New York University Medical Center (NYUMC) in New York City. Motivation for the interconnection was the high utility electric demand charge and the existing mix of steam driven and electric driven chillers at the site. The interconnection, to our knowledge the first of its type, provides both energy dollar savings and an increase in chiller capacity without the construction of new chiller plants.

Design opportunity

Although some large campus type facilities have central distribution of chilled water, many sites were built without them. These latter sites have buildings which were erected over many years with each building housing an individual heating/cooling plant. Typically such plants were designed to meet the individual buildings' maximum calculated cooling load as well as providing spare capacity.

In the case of chilled water plants, especially at hospitals and some university campuses, each building's chilled/condenser water pumps, cooling towers and refrigeration machines often operate 24 hours a day to cool air conditioned spaces. Given load diversity and spare plant capacity, engineers recognized that if these distributed plants were linked together, not all the plants would have to operate. Further, if these plants used different sources of energy, plant operation could be further optimized by time of day to save energy dollars.

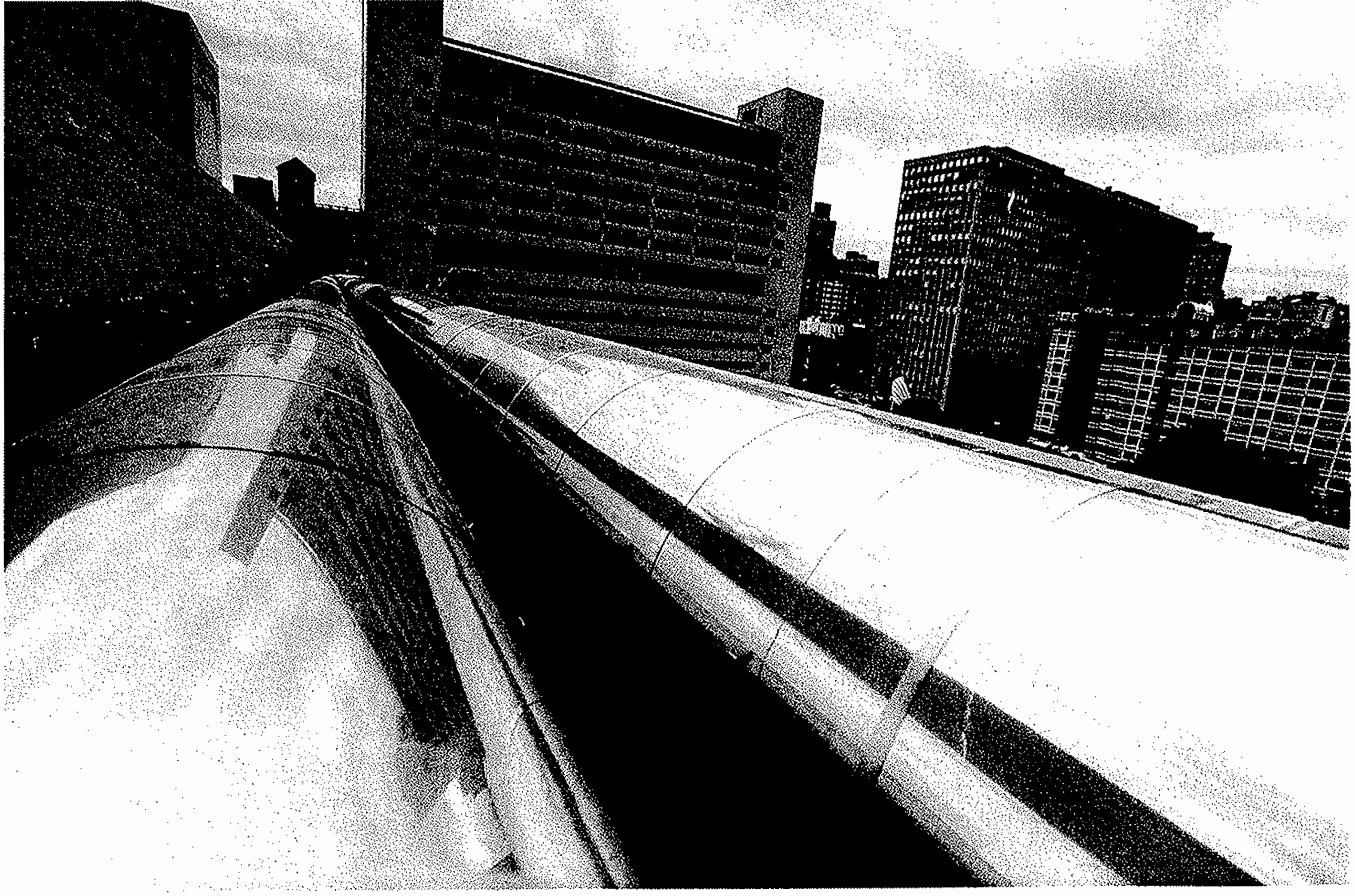
The impetus for the piping interconnection discussed was the need to combat soaring energy costs—some due to basic fuel price increases, others due to utility rate setting policies developed during the mid-1970's. At that time, New York State utility regulators, among others, began to implement electric utility rate schedules which reflected the high cost of on-peak electricity use.

This general electric rate concept is known as "marginal cost pricing" and its most common form is the "time of day" rate which includes a higher demand charge during peak demand hours of the day of the peak season and lower prices for off-peak usage. New York's Consolidated Edison Company established monthly demand costs for large users (3000 kW or over) of as much as $31 to $32 per kW of maximum demand during the peak summer daytime hours (Monday-Friday, 8 a.m.-6 p.m.).

To encourage off peak electrical use, lower night and weekend rates for both consumption and demand were offered. Under such a rate structure it became more and more cost effective to limit the use of peak electrical energy. The conventional methods generally have involved shaving of non-essential loads or switching energy sources during peak periods.

NYUMC obtains both electricity and steam from the local utility company, Consolidated Edison. Due to time of day rates, we recognized that if the center linked its chiller plants together, maximum use of the cheaper energy source was possible. During past cooling seasons, every plant in each building at the center—steam turbine, absorption and electric drive of every vintage and efficiency—ran continuously.

By joining the plants together, steam-turbine driven chillers can operate during the day and electric drive chillers at night.



The interconnection of existing chillers will save an estimated $575,000 in energy and operating costs at the center.

Under this approach it is possible to use only the most efficient chillers of each energy source for any required cooling load.

Engineering approach

Many different options for linking the plants together were considered. It was decided that a combined parallel/series approach with chilled water flow always circulating in the same direction would be the most effective.

Parallel flow is the conventional distribution method whereby chilled water is supplied from and returned to separate pipes (see *Figure 1*). To effectively link the chillers together, the largest steam driven chiller plant, an "anchor plant", was designated to operate as the base plant during the day. At NYUMC, this is the University Hospital plant with over 50 percent of the campus tonnage consisting of three 1350 ton steam turbine driven chillers.

By connecting this anchor plant to all the other plants, during most of the cooling season the University Hospital's chillers can satisfy all the campus *daytime* loads by acting as a central plant utilizing the parallel flow mode. Thus, with the exception of peak weather conditions, all the other pumps, cooling towers, and chillers are deactivated. Whenever the anchor plant cannot meet load, the most efficient outlying individual steam source plant is started up and isolated from the piping loop.

Separating a plant from the loop during parallel flow operation as opposed to feeding the flow from the chiller into the loop is required beause none of the other existing pumps have the pressure capability to operate in parallel with the anchor plant pumps. In addition, possible cumulative pressures might adversely affect the system with this mode of operation. Controls which avoid overpressurization problems are addressed later. As can be seen from *Table 1*, the dollar savings of electric and steam energy are substantial.

In contrast to weekday daytime rates, *nighttime* and *weekend* electric rates are much less costly in terms of both electric demand and consumption; thus electric chillers and auxiliaries can be run as needed at relatively low energy cost. However, no single electric drive plant has the capacity to satisfy all of the night and weekend load.

After examining plant locations around the facility, we recognized that if the plants were connected in series, all of the available electric drive chillers could be utilized. This is accomplished by having each plant draw water from and return water to a constantly circulating loop. In the loop there is no supply or return line. Water is returned to the loop just downstream of where it was withdrawn (see *Figure 2*). A few installations currently exist in the Midwest which uses series flow.[1]

At these sites, as many as half the plants were successfully mothballed after the interconnection was completed at a significant saving in maintenance and personnel costs. As chilled water is circulated through buildings whose chillers are deactivated, the loop chilled water temperature rises as it picks up building heat. Eventually, a chiller (preferably electric) must be activated to lower the loop temperature. The active plants withdraw some of the water, chill it and return it to the loop. The most cost-effective plants are used for this purpose. Throughout much of the cooling season, the cooling load exceeds the total capacity of all the electric drive chillers; thus at least one steam turbine chiller will need to be operating most of the time.

The determination of accurate chilled water load profiles for many of the buildings throughout the cooling season was facilitated by the use of DOE-2 computer models. The models had been previously calibrated against actual building energy use[2] and found to represent an accurate daily and seasonal profile of building consumption. The results of these models were integrated to anticipate the site's daily cooling loads, thereby assisting the operating team during the first year of operation.

Hydraulics

Despite initial appearances, the hydraulic requirements of the combined parallel/series interconnection are straightforward. In parallel, the anchor plant pumps circulate water to satisfy cooling loads in the related buildings and through all the loads connected to the other five plants. Since the anchor plant was originally designed to be a central plant for NYUMC, the pumps were sized for central plant duty (3 pumps, 2650 gpm @ 200 ft. each, 200 hp motors) and are sufficient for use in the interconnection.

In series, the pumps in each plant other than the Health Care Center (HCC) must have the capacity to draw water from the loop through the runout piping and pump it through the loads and local chillers. The additional load on the pumps is just the power required to take water from the loop and return it to the loop. HCC's requirements are slightly different in that it is the plant that circulates the loop.

In the two series loops constructed in Missouri, the loop gpm was set equal to the flow in the largest plant on the loop and a separate pump was installed to circulate the loop. Here, the loop flow was set equal to the flow in the largest electric drive plant (HCC, 2000 gpm) the HCC pumps were used to circulate the loop. All the water in the loop flows around the loop and through the HCC chillers and pumps.

Pressure measurements taken at the pumps during design indicated that all the pumps had enough spare capacity to overcome the additional pumping requirements of the interconnection. To prevent the larger capacity UH pumps from disrupting flow in the loop, a special supply line, used only in series operation, runs from the loop to the suction side of the UH plant chilled water pumps. The line contains a venturi flow measuring device and a throttling valve to prevent the UH plant from extracting more than 2000 gpm from the loop. As a backup measure, connections to UH were made so that the UH pumps can also circulate the loop.

Among the problems that were only resolved satisfactorily during operation were flows and pressure drops within the piping system. Although a great effort was expended to determine accurate pressure drops throughout the existing pipe loop, there always exists the possibility that there may be concealed flow resistances in the existing pipe network. These may take the form of unknown restrictions in the installed piping, partially closed valves or pipes that have been reduced in size in various renovation projects over the years.

System pressures

For this installation, the issue of most concern is the water pressure throughout the system. Two of the major buildings, including the one with the anchor plant, are relatively high rise (18-20 stories). Most of the other structures are lower rise (up to seven stories). None of the building chillers are designed for greater than 125 psi pressures. In general, this does not present a problem for the interconnection loop unless the pumps or new valves are operated in the wrong mode.

For example, if the system is operating in the parallel mode (see *Figure 1*) and a chilled water pump in an individual building is inadvertently started, the pressures become additive because the second pump adds its dynamic head to the system thereby exceeding the 125 psi limits. To protect against this possibility a three tier backup system was developed.

The third and last tier consists of conventional mechanical relief valves that relieve the water pressures to drains, thereby preventing rupture of the chillers, pumps, or piping system. Before that level of safety, two other levels were built into the control and operating system. One of those levels consists of pressure switches in the chilled water pump discharge piping in each plant that stops the pumps if the pressure exceeds a preset limit. The other level consists of control system logic that does not allow pumps in a particular plant to start unless the valves in that plant are in a correct configuration.

Equipment allocation strategy and chilled water temperature setpoints differ greatly between parallel and series operation. In parallel only the UH anchor plant operates and chillers are brought on line and shutdown as required to maintain the desired chilled water setpoint. In turn, the chilled water setpoint is varied to satisfy space temperatures and humidities in NYUMC designated critical areas. The survey of critical areas now includes the entire medical center instead of just the UH complex.

In series, the actual chilled water temperature entering each plant from the loop must be compared to the desired chilled water temperature needed to satisfy space temperatures and humidities associated with that plant. Factors governing the satisfying of six separate, and perhaps different, setpoints include maximizing the use of electric drive chillers while minimizing the number of plants operating and keeping loop operations simple.

Series flow occurs at night and on weekends, which is when the operating staff is at a minimum. In general, series operation will consist of running the HCC chillers hard, running one UH chillers at moderate load, and bringing on the other electric chillers as needed to fine tune temperatures within the loop.

Monitoring and control

Incorporated into this design is an industrial-grade control system intended to be more reliable than conventional HVAC controls. The control system is unique because of its specific application and consists of the following:

A. A command station which allows the operator or facility manager to access all system operating parameters. These include chilled water temperatures throughout loop, status of plant equipment (pumps, chillers, cooling towers), safeties, essential flow rates and system diagrams.

B. Six local plant based microprocessors with related pneumatic interface panels (M/P) capable of executing functions as directed by the command station or unilaterally. These local panels have built in safeties and fail-safe modes.

C. A data bus network linking the above which allows for the transfer of information between plants and the command station.

In general, the system plant operator runs the plant from one location, the command station. The command station displays all real time parameters throughout the system. The most informative screen for operating the interconnection is the one showing status of temperatures in the loop. This temperature information allows the operator to make appropriate decisions on selecting chillers to run during the day. In addition, there are prompt-

About the author

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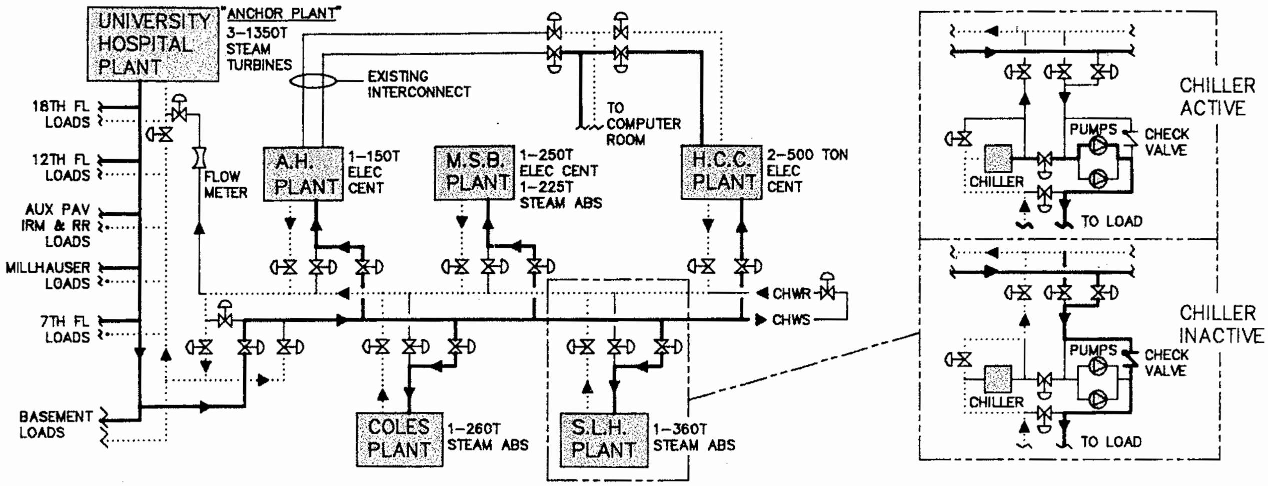

Figure 1—Chilled water interconnect, parallel flow. The heavy solid line indicates supply chilled water while the dotted line indicates return. All chilled water is supplied by the university hospital plant. Each individual plant is supplied by this parallel loop until the load can no longer be met. At that time plants are disconnected from the loop and the local chillers activated. Typical single plant piping is at the right.

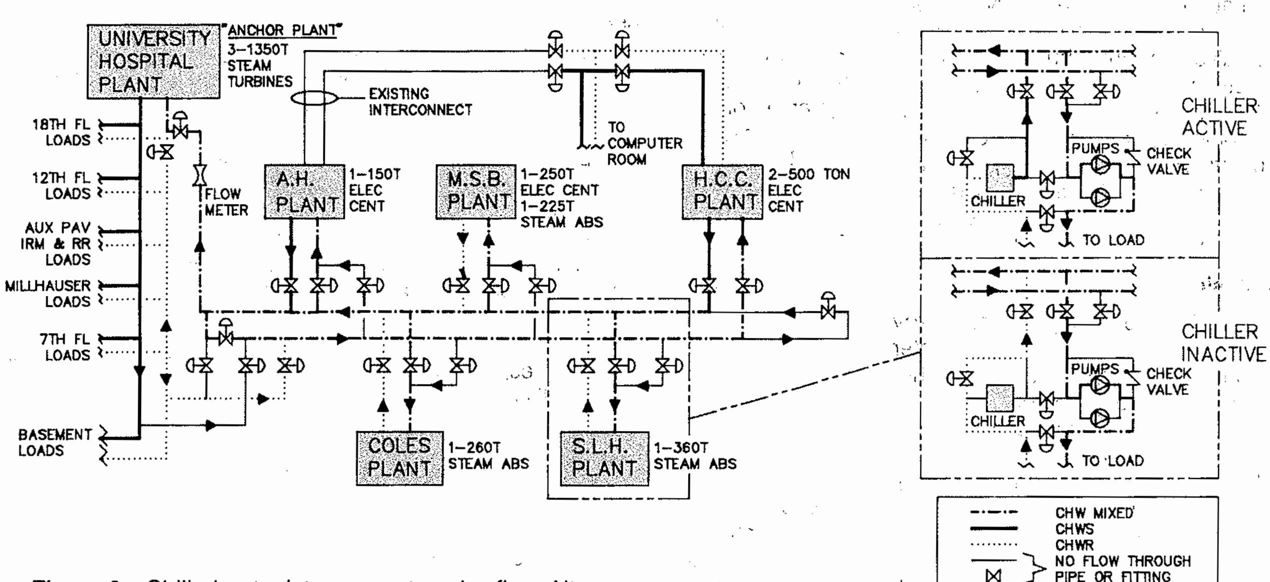

Figure 2—Chilled water interconnect, series flow. Alternating dot-dash line indicates mixed chilled water wherein supply and return flows are combined in the same pipe. In the diagram, the AH and HCC electric drive plants and one UH chiller are operating while the rest of the chillers (mostly steam) are inactive. In order to prevent the large anchor plant, University Hospital (UH) from drawing too much chilled water from the loop, a flow meter controls a valve to limit withdrawal to 2,000 gpm. When mixed water temperature exceeds required supply water temperature, the UH chiller(s) must be operated. Because of the low off-peak electric rates, the active electric drive chillers will be reset to deliver chilled water as cold as possible. Typical single plant piping is at the right.

TABLE 1

Facts about Site and Chilled Water Interconnection

Area (Sq. Ft.)	Total On-Site Cooling Capacity (Tons)	Peak Coincident (Tons) Load	Installation Cost ($)	Annual Energy Savings ($)	Annual Maintenance Savings ($)	Total Savings ($)	Payback (Yrs.)
1,500,000	Total 4890 steam 6290 1400 elect.	4300	2,000,000	500,000	75,000	575,000	3.5

TABLE 2

Existing Chillers

A: Steam	A: Electric	B: Building	B: Chillers
3-1350 ton	2-500 ton	UH (Anchor)	3-1350 ton
1-360 ton	1-250 ton	HCC	2-500 ton
1-260 ton	1-150 ton	MSB	1-150 ton
1-220 ton			1-220 ton
		SLH	1-360 ton
		Coles	1-260 ton
		AH	1-150 ton

ing routines which alert the operator to safety related deficiencies as well as when to switch modes of plant operation.

Each local microprocessor/pneumatic (M/P) panel operates its related plant and valves in accordance with the overall global instructions from the command station. In the event of transmission failure from the command station, the local (M/P) panel continues to control the plant through a pre-determined sequence-of-operation. Local plant variables are continuously transmitted to other local panels in the loop.

Upon failure of a local panel, the pneumatic interface safeties revert to fail-safe positions. These positions consist of fixing valve positions. Thus the two levels of safety backups which come before mechanical backup are microprocessor global or local panel actions and fail-safe pneumatic settings. The local panels are also programmed to disregard unwise operator instructions which could cause adverse system operation.

Conclusions

In addition to the significant energy savings possible from the chilled water interconnection loop operation, the other major benefits are as follows:

1. Future air conditioned buildings or increased cooling loads may be accommodated without additional plants at significant capital savings due to the greater effective capacity of the system. The NYUMC chiller plants now have over 6000 tons of combined capacity of which only 4300 tons currently are necessary during peak operation. If this plant capacity was equated to current capital costs for central plant capacity at $2000 per ton, the additional capacity is worth $3,400,000.

2. Current and future plant improvements are more cost effective since fewer plants have to be upgraded. For example, condenser to chilled water injection in the anchor plant has been installed for off-season operation savings of $60,000/yr. at a cost of $150,000. Without the chilled water loop, each plant would require costly installation of this injection system in order to take full advantage of the savings.

3. Unused chiller plants can be mothballed for periods of time thereby saving significant maintenance and personnel time. Including major overhauls, maintenance and manpower savings are projected to save $75,000 a year for those unneeded plants.

4. The Center now has greater backup capability than previously, especially for those plants which currently have only one chiller.

When installing an interconnect of this type, the following plant operations issues have to be addressed:

1. Process equipment requiring a continuous non-interruptive supply of cooling water cannot conveniently be installed on the loop system because there may be momentary interruptions of flow. Although this will not affect comfort air conditioning units, such equipment as direct water cooled computers and certain electronic equipment (e.g. nuclear magnetic imaging) may be adversely affected. At this site, all this type of process equipment was designed to have separate cooling systems.

2. Due to the increased sophistication of the system, interested and skilled operators are mandatory. The nature of the interaction with plant operation on a daily basis will require an active role on the part of the plant engineers.

We believe this application of a chilled water interconnection utilizing series and parallel flow advances the existing application technology significantly. It will be useful at many larger existing sites with self-contained chiller plants lacking a central plant. ■

Acknowledgments

The author is indebted to the following individuals for helping bring this project to fruition: Manuel X. Patino, Director of Plant, Maintenance & Construction at NYU Medical Center for steadfastly encouraging our design, John Leffler, Project Engineer, Goldman Sokolow Copeland, who carefully worked out the numerous details of the design, and Jon Darcy of Thermo Engineering for helping to develop the control system which orchestrates the operation.

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1. University of Missouri at Rolla and Washington University in St. Louis, Missouri. Both were engineered by William J. Coad of Charles J.R. McClure & Associates.

2. ASHRAE Transactions, Vol. 89, Pt. 1A, No. 2759, 1983, *Retrofit Energy Studies Using the DOE-2 Computer Simulation Program*, by the author.