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Ice Storage Rooftop Retrofit For Rooftop Air Conditioning

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ICE STORAGE ROOFTOP RETROFIT FOR ROOFTOP AIR CONDITIONING

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ABSTRACT

A significant fraction of the floor space in commercial and federal buildings is cooled by single-package rooftop air conditioning units. These units are located on flat roofs and usually operate during the day under hot conditions. They are usually less energy efficient than a chiller system for building cooling. Several U.S. companies are developing systems that employ ice storage in conjunction with chillers to replace older, inefficient rooftop units for improved performance and minimal use of on-peak electricity. Although the low evaporator temperatures needed for ice making tend to reduce the efficiency of the chiller, the overall operating costs of the ice storage system may be lower than that of a packaged, conventional rooftop installation. One version of this concept, the Roofberg® System developed by the Calmac Corporation, was evaluated on a small building at Oak Ridge National Laboratory in Oak Ridge, Tennessee.

The Roofberg system consists of a chiller, an ice storage tank, and one or more rooftop units whose evaporator coils have been adapted to use a glycol solution for cooling. The ice storage component decouples the cooling demand of the building from the operation of the chiller. Therefore, the chiller can operate at night (cooler, more efficient condensing temperatures) to meet a daytime cooling demand. This flexibility permits a smaller chiller to satisfy a larger peak cooling load. Further, the system can be operated to shift the cooling demand to off-peak hours when electricity from the utility is generated more efficiently and at lower cost.

This Roofberg system was successfully installed last year on a small one-story office building in Oak Ridge and is currently being operated to cool the building. The building and system were sufficiently instrumented to allow a determination of the performance and efficiency of the Roofberg system. Although the energy efficiency of a simulated Roofberg storage/chiller concept operating in the full storage mode was about equal to what could be expected through a simple rooftop efficiency upgrade, the operating costs for the Roofberg system could be much more favorable depending on the utility rate structure. The ability of Roofberg to move much of the cooling load to off-peak periods enables it to take advantage of on-peak demand charges and time-of-use electricity rates. The Roofberg system, as installed, was able to reduce the on-peak energy use of the cooling system to 35% of the on-peak energy consumption of the baseline system. A comparative analysis of a rooftop replacement and Roofberg indicated that the Roofberg system on Building 2518 would be the better economic choice over a range of demand charges and on-off peak energy prices which are typical of utility rate tariffs for commercial buildings.

1. INTRODUCTION

A significant fraction of the floor space in commercial and federal buildings is cooled by single-package, rooftop air conditioning units. These units are located on flat roofs and usually operate during the day under hot conditions. Consequently, they are generally less energy efficient than a chiller system for building cooling. Several U.S. companies are developing systems that employ ice storage in conjunction with chillers to replace older, inefficient rooftop units. The advantages are improved performance and minimal use of on-peak electricity. The low evaporator temperatures needed for ice making tend to reduce the efficiency of the chiller, but the overall efficiency of the ice storage system may be higher than the efficiency of a packaged, conventional rooftop installation. One version of this concept, the Roofberg System developed by the Calmac Corporation, was evaluated on a small building in Oak Ridge, Tennessee. This evaluation is being jointly supported through the Federal Energy Management Program, the Calmac Corporation and the Trane Company.

2. ICE STORAGE SYSTEM DESCRIPTION

There are a number of systems for making ice for building cooling, and they are characterized by the heat exchange method used inside the ice storage tank. The Roofberg system consists of one or more insulated, cylindrical tanks containing a spiral-wound plastic tube heat exchanger surrounded by water. At night or during other electrical utility off-peak periods, a glycol solution— nominally a 25% mixture of ethylene glycol and water—is circulated from the evaporator of a chiller through the coil in the storage tank. This cools the water surrounding the coils in the tank. As the water cools, it eventually freezes on the outside of the coils and builds up with the tubing at the center. The freezing process continues to build ice around each tube in the tank. As the freezing process continues to make more ice, the remaining water in the tank can move freely to prevent stress buildup on the inside walls of the storage tank. Since the water in the tank always has a free surface, the tank can be frozen solid without a problem.

The heat exchanger coil in the ice tank is used both to form ice (charge the system) and to melt the ice (discharge). Discharging is accomplished by circulating the glycol solution returning from fan coil units in the building to the plastic coil in the storage tank. Ice melting proceeds outward from the coil surface until most of the ice in the tank is melted. If a subsequent charging process were initiated before all of the ice was melted, heat transfer from the freezing water to the coil surface would not be hindered by ice that might remain from a previous discharge not carried to completion. On the other hand, discharge rates tend to be limited since, as ice melting proceeds, ice that has melted adjacent to the coil tends to insulate the coil surface from the remaining ice. In this type of ice storage system, the water surrounding the heat exchanger in the storage tank remains inside the storage tank. Heat transfer between the chiller or building coils and the storage tank is accomplished during charging and discharging by using the glycol solution heat transfer fluid.

The ice storage system for Building 2518 consisted of one Model 1190 ice storage tank with characteristics indicated in Table 1.

Table 1. Model 1190 ice storage tank specifications

Tank height	101 in.
Tank outside diameter	89 in.
Weight (unfilled)	1550 lb
Weight (filled)	16,750 lb
Volume of water/ice	1,620 gal
Volume of solution in heat exchanger	148 gal
Heat exchanger tube surface area	2280 ft^2
Latent cooling capacity	162 ton-h
Sensible cooling capacity	28 ton-h
Total cooling capacity	190 ton-h

The cooling that can be delivered by a charged tank is a combination of the latent heat of melting of the ice and the sensible heat capacity of the water produced; it may also include the sensible heat capacity of the glycol solution fluid inside the coils in the tank. The manufacturer specifications are based on the latent heat capacity of ice melting at 32°F to produce 1620 gal of water and the sensible heat needed to raise the temperature of 1620 gal of water by 25°F. Whether the specified total cooling capacity of the tank can be realized and used depends on the design of the balance-of-system and the heat transfer rates within the tank necessary to meet the building load.

3. ROOFTOP UNITS

Rooftop units cover a range of configurations depending on the physical relationship between the condensing and evaporating components. They may be (1) single package, air-cooled systems that produce cool air for single or multiple zones, (2) split systems with air-cooled condensers and remote evaporators with no evaporator fan, and (3) split systems with air-cooled condensers and remote fan coil units. In addition, the condenser may be water-cooled, although this is not a common rooftop configuration. If a system produces cold water and routes it to fan coils in a building, it is termed a chiller irrespective of whether it is located on a roof, in a mechanical room or adjacent to a building.

An ice storage system can be integrated into any of the rooftop configurations by decoupling the cooling coil from the system and adapting this coil so that it can accept cool glycol solution from the ice storage tank.

3.1 Integrating Ice Storage and DX Rooftops

In direct-expansion (DX) air-conditioning systems including rooftops, refrigerant is used in the evaporator coil to absorb heat from return air that is blown through the coil by a fan; the exiting, conditioned air is returned to the building. The evaporator fan may be part of the rooftop or it may be a separate component. In either case, when there is a cooling demand, the rooftop is activated and the evaporator fan is used to deliver space cooling. Adapting an ice storage system to a DX rooftop requires that (1) the refrigerant be removed from the unit, (2) the evaporator be either modified (converted) to work with a glycol coolant or be replaced with one suited for glycol, and (3) glycol solution piping from a new chiller/ice storage tank be connected to this coil so that space cooling is provided by a combination of melting ice and/or cooling from the chiller. The space cooling thermostat that controls cooling to the building or zone can be used to turn on the evaporator fan and/or divert glycol solution from the ice storage tank through the coil itself. In cases where the rooftop unit is a single package, the evaporator is located in the same housing as the compressor and condensing section. Here, switching to ice storage requires opening the refrigerant system, recovering the refrigerant, disconnecting the evaporator coil and converting it to work with glycol solution, and reconnecting the coil to glycol solution piping from the storage tank. In addition, electrical power to the original rooftop compressors is disconnected.

The procedure is generally the same for split unitary systems. In cases of multiple compressors and multiple refrigerant circuits, each compressor is disconnected, the refrigerant is reclaimed, and each evaporator coil is converted and connected to a manifold carrying glycol solution from the ice storage tanks. There is no need to remove the old compressors, nor is there any need to change the metal cabinet, curbs, and ductwork of the rooftop. If the condition of the old coils warrants replacement, they could be replaced in lieu of a coil retrofit/conversion.

3.2 Integrated Ice Storage/Rooftop Advantages

Considered as an alternative to rooftop replacement, there are some obvious advantages to integrating ice storage with existing systems. In multistory buildings or large single-story buildings, it requires a crane at the least and a helicopter at most to remove/replace an existing rooftop unit. Depending on the logistics, the number of units to be replaced, and how easily they can be reached, the rigging requirements for replacing rooftops can add appreciably to the cost. Second, it is likely that the original rooftop curbing will not be the right size for the new unit. Replacing old curbing with new will be an added expense that may be compounded by costs associated with new roof penetrations. Third, ice storage permits the building owner to take advantage of time-of-use electric rates and demand cost reductions due to smaller on-peak electric loads. Fourth, there can be savings in operating costs from substituting a chiller system that is more efficient than a replacement rooftop unit. Finally, since ice storage systems effectively decouple the chiller capacity from the load, local but constant cooling loads in one zone of a building can be served by a much larger chiller operating for a shorter period.

4. ICE STORAGE/ROOFTOP FIELD STUDY

Prior to 1995, there were few applications of ice storage to rooftop retrofits, and to our knowledge, none had been installed in federal facilities. In the summer of1995, Oak Ridge National Laboratory (ORNL), with support from the U.S. Department of Energy Federal Energy Management Program's New Technology Demonstration Program, designed, installed, and began operating an experiment to evaluate the performance of an ice storage/rooftop retrofit system on Building 2518 at ORNL. The experiment was supported by the Calmac Corporation, which supplied one ice storage tank (Roofberg®) and on-site assistance in coil conversion, and by the Trane Company, which provided a 20-ton air-cooled chiller. Both organizations were interested in learning how the system would perform and how it would compare with the performance of the existing rooftop units and against several other alternative systems on this building.

4.1 Description of the Test Site (Building 2518)

Building 2518 is a 12,880 ft^2, one-story office building located at ORNL in Oak Ridge, Tennessee. The structure is built on a concrete slab, the exterior walls are concrete block with a brick veneer, the walls are uninsulated, and the windows are single glazed. The north part of the building was constructed in the early 1950s and constitutes 65% of the floor area. The south section was added in the middle 1960s, and its roof is about 4 ft lower than the roof for the north part. This arrangement created a parapet wall along the roof of the building.

A plan view of the building sketched in Fig. 1 indicates that the building is cooled by five packaged rooftop units, labeled AHR1 through AHR5. The evaporators and fans for four of these units are located in the plenum area above the building corridor ceilings. Unit AHR5 is a single package rooftop configuration with conditioned air supply and return ducting penetrating the roof. All of the air handlers are constant volume systems, and the conditioned air is supplied to the building through insulated metal ducting. This building, with a flat, built-up roof, is typical of many single-story buildings found in federal facilities across the country and in the private sector.

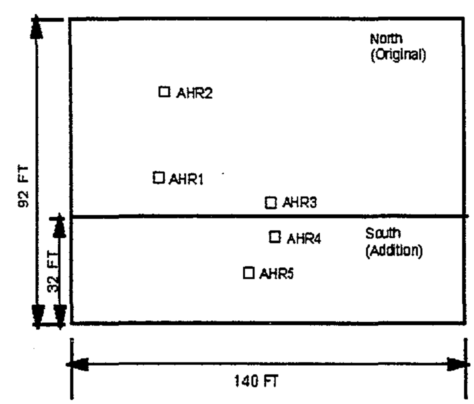

Fig. 1. Location of rooftops.

Nameplate data on each of the units and records maintained at the facility were used to provide installed performance information about the existing units. Table 2 shows the rated cooling capacities of each of the five rooftop units, their approximate age, and details about the function of the area being cooled as well as the operating schedule.

Table 2. Rooftop data for Building 2518 (prior to retrofit)

Rooftop unit (AHR)	Rated capacity (tons)	Original install date	Air distribution system location	Air return	Operating Schedule
1	10	1980	NW Auditorium and conf. Room	Duct	Continuous
2	5	1980	N office suite	Plenum	Continuous
3	22	1964	NE offices	Direct	Off nights/weekends
4	7.5	1964	SE offices	Direct	Off nights/weekends
5	10	1979	SW offices	Direct	Off nights/weekends

The air handlers of rooftop units 3, 4 and 5 are operated from 4:00 A.M. to 6:00 P.M. on Mondays and from 6:00 A.M. to 6:00 P.M.Tuesdays through Fridays. The ice storage system to be described was installed as a retrofit to rooftop units 3, 4, and 5 since they are off for 12 h each day. This provides time for the chiller to charge the ice tank. The air handlers for units 1 and 2 operate in response to thermostats to heat and cool a few offices, the auditorium, and the conference room.

It was anticipated that retrofitting an ice storage system to units 3, 4, and 5, would improve the combined efficiency of these units and reduce the operating costs. This assumption was predicated on the fact that the efficiencies of rooftop and chiller air conditioning systems have improved year by year, and replacement of units as old as 3, 4, and 5 could result in savings in operating maintenance costs. Historical data on the shipment-weighted average of unitary cooling equipment produced from 1976 to 1992 (ref. 1) were used to provide information about the efficiency improvements made in rooftop and other unitary equipment over the last several years. These data indicate that since 1976, the energy efficiency ratios (EERs) of unitary equipment continued to improve over time. Since 1976, EERs have improved by 49%. If this trend were extrapolated to years prior to 1976, the efficiency of unitary equipment installed in the mid 1960s may have had EERs in the range of 5+ Btu/W-h. With EERs between 9 and 10, today's rooftop units are nearly twice as efficient as those early models. Moreover, with age, the efficiency of the original rooftops on the building would be still lower because of compressor wear.

Since the three rooftops on Building 2518 were overdue for replacement, it was determined that this building could serve as a test bed to examine the field performance of a ice storage system/rooftop retrofit. An additional motivation for selecting this building was that it had been extensively monitored 2 years before the Roofberg experiment began. These measurements were performed to characterize the building so that the energy-related effects of lighting and roof-covering retrofits could be evaluated. Further, extensive modeling of the building had been performed using DOE-2.1E. This effort, backed by measurement of building electrical energy consumption, produced close (within 5%) agreement between predicted and actual building energy consumption during the summer (ref. 2). These careful characterizations of Building 2518 would be helpful as baseline starting points to assess the performance of the Roofberg unit and any other simulated alternatives with greater precision and confidence.

5. DESIGN OF THE ICE STORAGE SYSTEM

The ice storage design was based on replacing the function of the 22-, 10- and 7.5-ton rooftop units with an ice storage tank and chiller. The ice tank has a nominal storage capacity of 190 ton-h, and the air-cooled chiller is rated at 20 tons under Air-Conditioning and Refrigeration Institute conditions. An initial design combined these components with the three coils converted to glycol solution operation. A sketch of the design chosen is shown in Fig. 2. A 25% solution of ethylene glycol coolant circulating through the piping shown is used to deliver cooling from the chiller, to the ice tank, to the three coils, or to both at the same time. The system design allows for several modes of operation.

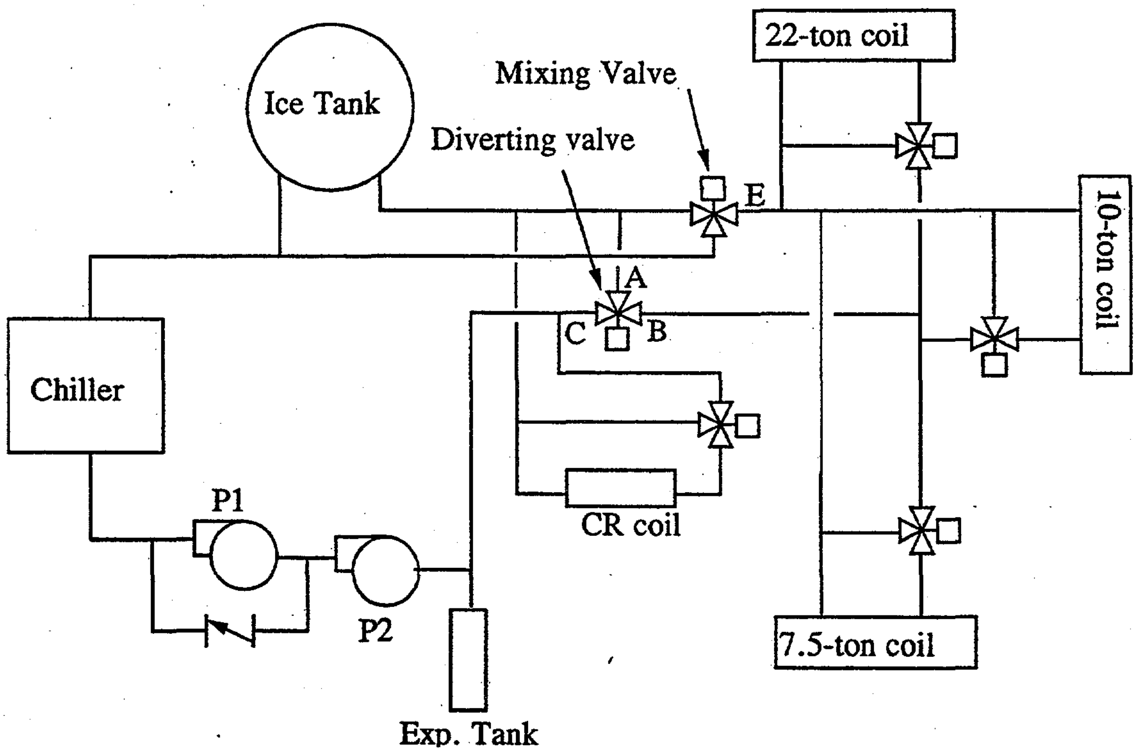

Fig. 2. Design schematic for ice storage/rooftop retrofit.

Mode 1: Ice making (storage charging). In mode 1, the chiller operates during the utility off-peak period to make ice in the storage tank. Since there is no cooling demand during this period, there is no need for the coolant to pass through the three coils shown in the right-hand portion of Fig. 2. This diversion is accomplished by the diverting valve shown. In position A-C, this valve shunts the coolant from the ice storage tank back to the pumps and to the chiller. The CR coil was added to the initial system design to provide up to 1 ton of continuous cooling for a small computer room located in the building.

Mode 2: Ice melting (storage discharging). In mode 2, the ice stored in the tank is used to provide cooling to the three main coils. This is accomplished by changing the position of the diverting valve to B-C so that coolant from the ice tank is circulated through the coils. In this position, port A of the diverting valve is closed. This prevents any short circuiting of coolant from the ice storage tank. In this mode, cooling remains available as needed by the computer room. The three-way mixing valve is a modulating valve that controls the coolant temperature to the coils in the building.

Mode 3: Supplemented ice melting (chiller-assisted storage discharging). This mode is similar to mode 2; however in mode 3, the chiller can operate as needed to supplement cooling from the ice storage tank.

Mode 4: Chiller cooling. If no usable cooling remains in the storage tank, mode 4 allows the chiller to operate as a normal chiller to provide cooling to the building.

Mode 5: System off. In mode 5, the chiller is off and no cooling is being delivered to the rooftop coils. This system enters mode 5 when (A) the storage tank becomes completely charged at night, or (B) there is no cooling load at the main coils during the day. In our design, mode 5 allowed the distribution pumps to continue to run because the computer room generally needed continuous cooling.

5.1 System Control Logic

The operating strategy of the design was to move the daytime cooling demand otherwise served by the chiller to the electrical off-peak periods, generally at night. Consequently, the system can take advantage of favorable time-of-use electric rates at night, and night operation is more efficient because of the cooler, more favorable condensing temperatures. A control system algorithm was designed to require the system to be in specific operating modes at certain times of the day and to allow temperature control within each of these modes. A time clock with battery backup was used to sequence initiation of the ice-building/storage mode and the ice melting/cooling mode. Other parameters were controlled from temperature sensors located in the piping at key points, from thermostats located in the building, and from sensors located in the chiller.

Diverting valve. This valve was controlled by the time clock so that coolant could be diverted from the ice tank back to the pumps during the off-peak period This was done to eliminate pumping energy that otherwise would have been expended in circulating coolant to the 22-, 10- and 7.5-ton coils. Two circulating pumps were installed in series as shown in Fig. 2 so that with P2 operated only during the ice making period (off-peak) and both pumps used for times when cooling is delivered to the coils, a constant coolant flowrate through the chiller could be maintained.

Mixing valve. The mixing valve position is controlled by a temperature sensor located at port E of the valve. During on-peak periods (cooling provided to the coils), the valve modulates as necessary to maintain a setpoint temperature at port E. With a tank full of ice and the system in mode 2 (storage discharging), the mixing valve will allow most of the coolant to bypass the storage tank. However, as storage becomes depleted, the mixing valve control logic diverts more of the coolant through the storage tank to maintain the setpoint temperature. At the end of discharging, all of the coolant passes through the ice storage tank.

Three-way valves at the coils. Each coil in the system was provided with a thermostatically-controlled three-way diverting valve. The existing building thermostats were used to open or close the individual three-way valves at the coils to meet the cooling load in each zone. Prior to the ice storage retrofit, each of the zone thermostats controlled a single rooftop unit. After the retrofit, each thermostat controlled the three-way valve located at one of the coils as shown in Fig. 2. This design allowed the existing zone thermostat to control the glycol solution passing through the coil and to bypass the coil entirely if no space cooling was required. This is an advantage because it allows additional rooftop units to be easily tied into the ice storage system at some future time.

Chiller. The chiller in this study is a Trane Model CGAE-C20 with two scroll compressors and an air-cooled condenser. To meet the needs of this study, the chiller came adapted for ice storage use so that the leaving water temperature (LWT) setpoint could be overridden by a contact closure that would allow the chiller to operate with different setpoints at different times of the day. This contact was controlled by the time clock so that at the initiation of mode 1, the chiller would be fully loaded and would begin to cool the storage tank until a LWT setpoint of about 23°F was reached. This ice-making setpoint is a function of the storage tank design and charging rate.

Ice storage tank. The storage tank is a plastic tank containing a spiral heat exchanger, and the tank is filled with water. In the Calmac design, the working fluid is the glycol solution, and the water in the tank does not circulate. The heat exchanger is used to transfer heat between the water (or ice) surrounding the heat exchanger and the coolant circulating inside the heat exchanger. The Calmac tank used was Model 1190 with a nominal cool storage capacity of 190 ton-h. The system design was based on maintaining a glycol flowrate of 50 gpm during charging and discharging.

5.2 System Design Approach

The design approach was based on a single ice storage tank with fixed heat transfer characteristics and a 20-ton chiller. As a starting point, a relation was developed between chiller capacity, LWT, and the outside dry bulb temperature (ODBT) of the air used for condensing. Chiller manufacturer data at selected temperatures were used through a simple regression analysis tool in EXCEL to develop linear relationships for capacity and EER as functions of LWT and ODBT. This tool was used twice: once to determine the glycol adjustment factor as a function of glycol concentration and a second time to apply the glycol adjustment relation to determine how capacity and EER depend on LWT and ODBT. The coefficients of the linear correlations which were developed had an adjusted R squared of better than 0.99 as expected, and the largest deviation of the predicted capacity from the manufacturers statement of capacity was about 2% over a capacity range from 10 to 20 tons. The greatest deviation of the predicted EER from the stated EER was about 5% over the 10 to 20-ton capacity range. These errors were deemed to be acceptable, and these regression relations were used to design the balance of the system as well as in subsequent experimental data analyses.

Calculations from the relations found for chiller capacity and EER showed that the chiller could provide 13.5 tons of refrigeration during the evening of a design day and at an average ice-making LWT of 26°F. At this point, the design focused on the discharge process to determine the cooling that could be delivered from the ice storage tank at various temperature conditions. From ice storage tank performance information provided by the vendor, it was determined that the tank could deliver no more than 140 ton-h of cooling for a 6-h period if the glycol solution temperature leaving the tank were 42°F or less and the return temperature to the tank were 52°F. Although ice might remain in the tank under these discharging conditions, it could not be put to use without raising the 42°F delivery temperature to the coils from the ice storage tank. Since the tank provides 140 ton-h of cooling during discharge, a subsequent charging process need only provide 140 ton-h of ice storage. This means that as ice is formed at night at a rate of 13.5 tons, it would take 10.4 hours for the system to make and store 140 ton-h of cooling.

If the system discharges 140 ton-h in a 6-h period, the average cooling delivered to the building is 23 tons. Using a 20-ton chiller to provide 23 tons of cooling illustrates a key attribute of a cool storage system—the capability for meeting a large cooling load with a smaller chiller.

The cooling load of the building was modeled to decide if the capacity that could be provided by the storage system would be adequate. A DOE-2.1E model of the building was developed in a separate study (ref. 2) and calibrated using measured data on the total energy consumption of the building and selected components, including the five air handlers in the building, as well as on outdoor conditions on an hourly basis. This data collection effort started in March 1994 and continued for several months. The building model results compared well with experimental data collected at the site and at a near-by weather station. The heating and cooling input parameters were adjusted as needed, and the process was repeated until there was good agreement between the simulation results and data from the building. At the end of this effort, the measured electrical energy consumption and simulated consumption for the building agreed to within 5% for the months June through September — months when the ice storage system provides its best advantage.

Once the model had been calibrated, it was used to predict the hourly loads of each of the rooftop units using typical meteorological year (TMY) data for the test site. From this effort, a data file of the hourly thermal loads at each of the air handlers for the building was produced; this data file was used to determine the peak cooling load needed to complete the design of the system and to provide a basis for Roofberg performance simulations as well as for non-storage alternatives. The DOE-2.1E simulations were also used to determine the efficiency of each of the units. From these simulations and calibration with experimental data, the energy input ratio (EIR) under ARI design conditions of the AC units in the building was determined as shown in Table 3.

Table 3. Performance of existing rooftop units

Rooftop AHR	Nominal cooling capacity (tons)	EIR $\left(\frac{kWh_{(electrical)}}{kWh_{(cooling)}}\right)$	COP	EER $\left(\frac{Btu}{W-h}\right)$
1	10	.35	2.9	9.7
2	5	.53	1.9	6.4
3 (ice retrofit target)	22	.43	2.3	7.9
4 (ice retrofit target)	7.5	.68	1.5	5.0
5 (ice retrofit target)	10	.75	1.3	4.5

In this table, the EIR is a dimensionless performance index employed in the DOE-2 simulation program and is the ratio of the electrical energy consumption to the cooling delivered by a rooftop.

A simple experiment was performed to check the efficiency of the 22-ton unit by determining the heat of rejection of the condenser [$Q_{(condsr)}$] and net electrical power to the unit [$Q_{(elec)}$] and applying the relation

$$COP = \frac{Q_{(condsr)} - Q_{(elec)}}{Q_{(elec)}}.$$

A wattmeter was used to measure the electrical power to the entire unit and to the evaporator fan. The heat of rejection of the unit was determined by measuring the airflow through the condenser and the condenser airflow temperature upstream and downstream of the condenser. Evaporator fan energy was measured and subtracted from the overall power consumption of the unit to obtain $Q_{(condsr)}$. This method for determining the COP (or EER) of the rooftop was straightforward and circumvented the need for conducting the more difficult measurements of cooling capacity at the evaporator coil. This measurement, conducted on a day when the outside air temperature was 92°F and the return air temperature to the indoor coil was 80°F, produced a COP = 2.22 (EER = 7.57). This value was somewhat lower than the EER = 7.93 value found in the DOE-2.1E simulation described.

6. SYSTEM INSTALLATION

The ice storage system was installed on Building 2518 as shown in Fig. 3 and instrumented so that its overall performance could be determined and the individual performance of the major components could be evaluated. The ice storage tank was buried at about 1/3 of its height next to the building. This provided a firm base for the tank in a bermed area next to the building. An existing sidewalk was used as the foundation for the chiller, the two circulating pumps, and the expansion tank. Electrical switchgear for the pumps and chiller, along with system controls and instrumentation/data acquisition hardware, were mounted in weatherproof boxes on the side of the building. Piping between the chillers, the ice tank, pumps and coils for AHRs 3, 4, and 5 was installed on the exterior wall of the building and along the roof as indicated in Fig. 3. All piping was insulated with 1.5-in. of Rubatex, and all insulated piping located outside was covered with aluminum sheathing for protection from weather.

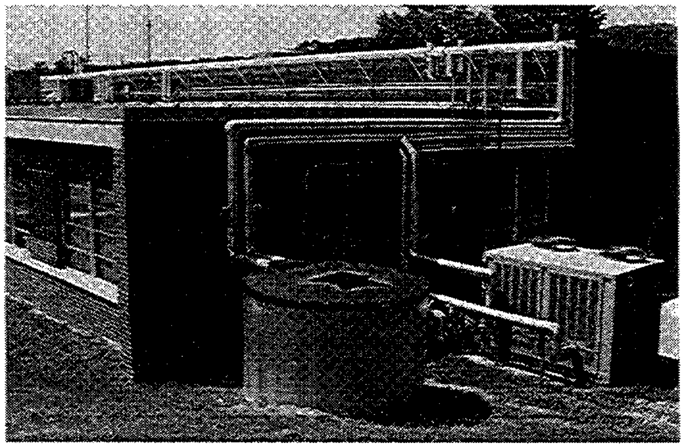

Fig. 3. Roofberg installation.

In the background of Fig. 3 can be seen some of the rooftop units that were part of the retrofit. To mate these units to the Roofberg system, the power and control wiring to the compressors and rooftop units were disconnected; the control wiring from the thermostat was retained to control a three-way coil bypass valve. Finally, refrigerant piping connections to the evaporator coils were removed, and the header assemblies of each of the coils were modified to accept the glycol coolant. A Calmac technician was dispatched to Oak Ridge to perform the coil conversions. It took about a day each to convert, check, and reinstall each of the coils so that glycol could be used. A coil conversion procedure involved disconnecting all of the 180° copper elbows at one end of the coil and installing two header assemblies to provide coolant supply and return. The coil conversion produced two-pass, multi-circuit heat exchanger. Figure 4 shows the final product applied to the 10-ton rooftop system with glycol piping to the unit shown at the lower left.

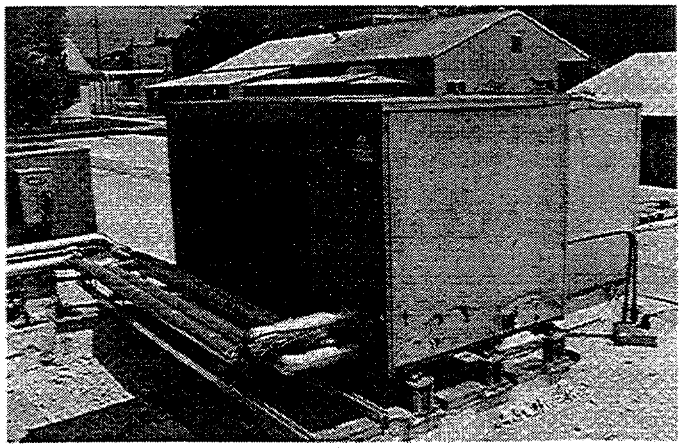

Fig. 4. 10-ton rooftop retrofit.

As part of the installation, the loop was instrumented so that the performance of the ice storage system could be determined. Thermocouples were installed across each loop component that was heated or cooled (e.g., the chiller barrel, the ice storage tank, the three main cooling coils, and a fourth coil added late in the installation phase to maintain cooling to the computer room). Flowmeters (paddle wheel, insertion type) were sized and strategically located so that glycol solution flowrates in each circuit of the loop could be determined. This instrumentation made it possible to determine the cooling demand (or cooling supplied) for each component of the loop. Finally, wattmeters with both analog and pulse output were installed to measure the electrical energy consumption of the chiller and both circulating pumps. All instrumentation sensors were connected to a battery-powered data acquisition system located in an accessible, weatherproof box on an exterior wall of the building.

7. PERFORMANCE RESULTS

Operation of the ice storage system began at the end of July 1995. Startup problems were few; a few leaks at some of the PVC piping fittings were found and corrected and a couple of control wires were reversed so that the stem of the mixing valve actuator moved in the correct direction in response to a coolant temperature increase at the exit of the valve. A bleed valve located at the highest point of the loop had been installed to allow air to be purged from the loop as the piping was filled with a 25% antifreeze (glycol) solution. It took some time and several freeze/melt cycles to completely purge air from the loop because of the long lengths of small diameter tubing in the coils in the ice tank, and in the distribution piping on the roof.

After the instrumentation was debugged, the system was purged, and temperature setpoints in the chiller and the diverting valve were adjusted, the system began unattended operation. Collection began of reliable 30-minute data on system temperatures, flowrates, and energy consumption. From this information and published data on the density and heat capacity of the working fluid, the heat flows to and from the coils, the chiller barrel, and the ice tank were calculated. Pump energy also contributes heat to the cooling load, and although temperature sensors were installed upstream and downstream of the pumps, there was no measurable temperature change across the pumps. Pump heat based on the electrical energy consumption of the pump motor and the motor efficiency was included in the comparative analysis later in this report.

For the period August 14–21, the system delivered 1830 ton-h (21.9 Mbtu) of cooling to the buildings using 2340 kWh of electrical energy. If it is assumed that the tank returned to its original thermodynamic state at the end of this period, then the overall chiller energy consumption would be 1.28 kW/ton, and if pumping energy is included, the performance would be 1.59 kW/ton. During this period, the average ODBT was 81°F. For the period August 21–28, the system delivered 1820 ton-h (21.8 Mbtu) of cooling using 2160 kWh of electrical energy, resulting in an overall chiller energy consumption of 1.19 kW/ton. If the pumping energy is included, this performance drops to 1.50 kW/ton. During the later period, the average ODBT was 78°F. The cooling load of the building remained about the same because in this type of building, the cooling load is primarily the result of internal heat generated within the building. The improvement in efficiency in this second period is in line with the fact that more favorable condensing temperatures existed during the later ice-making period. The energy consumed by the pumps tends to make a large difference in the energy consumption of the system. In this system, a least one pump was on around the clock to meet the continuous cooling load of the computer room. If the computer room had been provided with a separate cooling system, the pumping power could have been reduced and the ice storage system performance improved.

7.1 Storage Tank Performance

Storage tank performance is determined by the temperature of the glycol solution to and from the storage tank during charge and discharge and the amount of stored cooling that is produced. The stored "cool" available for delivery to the building depends on the choice of the initial state of charge of the ice storage tank as illustrated in Fig. 5.

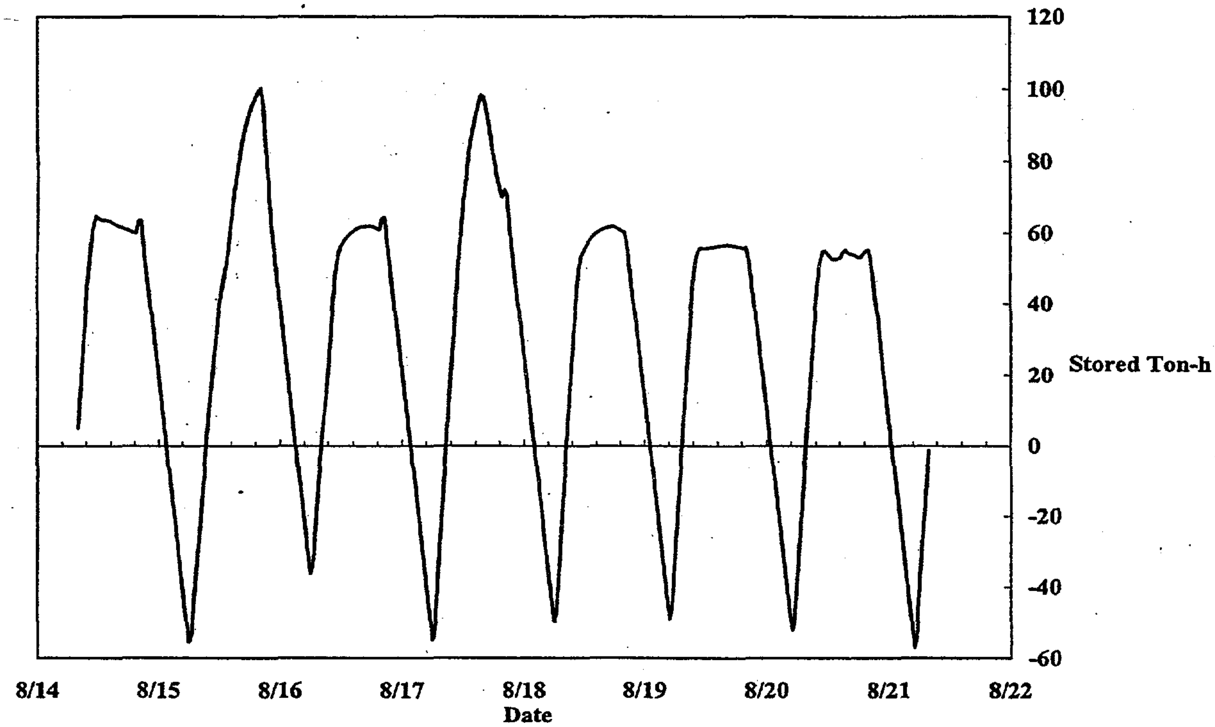

Fig. 5. Profile of cool storage inventory.

Figure 5 shows the cooling that was stored and discharged over a 7-day period. The baseline for zero stored cool was arbitrarily chosen as shown, producing negative storage values. The important component of this curve is the excursion that this curve takes between the end of a discharge cycle and the end of the following charge cycle. For example, on 8/14, the charging process produced 155 ton-h of cooling. The next day, the tank provided about 130 ton-h of cooling to the building before another charging period was started.

The effect of the entering and leaving glycol solution temperatures across the storage tank on the storage capacity is shown in Fig. 6.

The date 8/23–24 was selected for this illustration because there about as much cooling was stored on 8/23 as was discharged on the following day. Tank cooling was initiated at 7:00 P.M. During the charging process, the glycol solution temperature difference across the storage tank was about 8 °F. An interesting detail is the slight dip in the glycol solution temperature curves at about 9:30 P.M., indicating water subcooling and the beginning of ice formation. The charging process continued until about 6:00 A.M., when the temperature of the glycol solution leaving the chiller reached 23 °F and the chiller turned off. At that time, the building

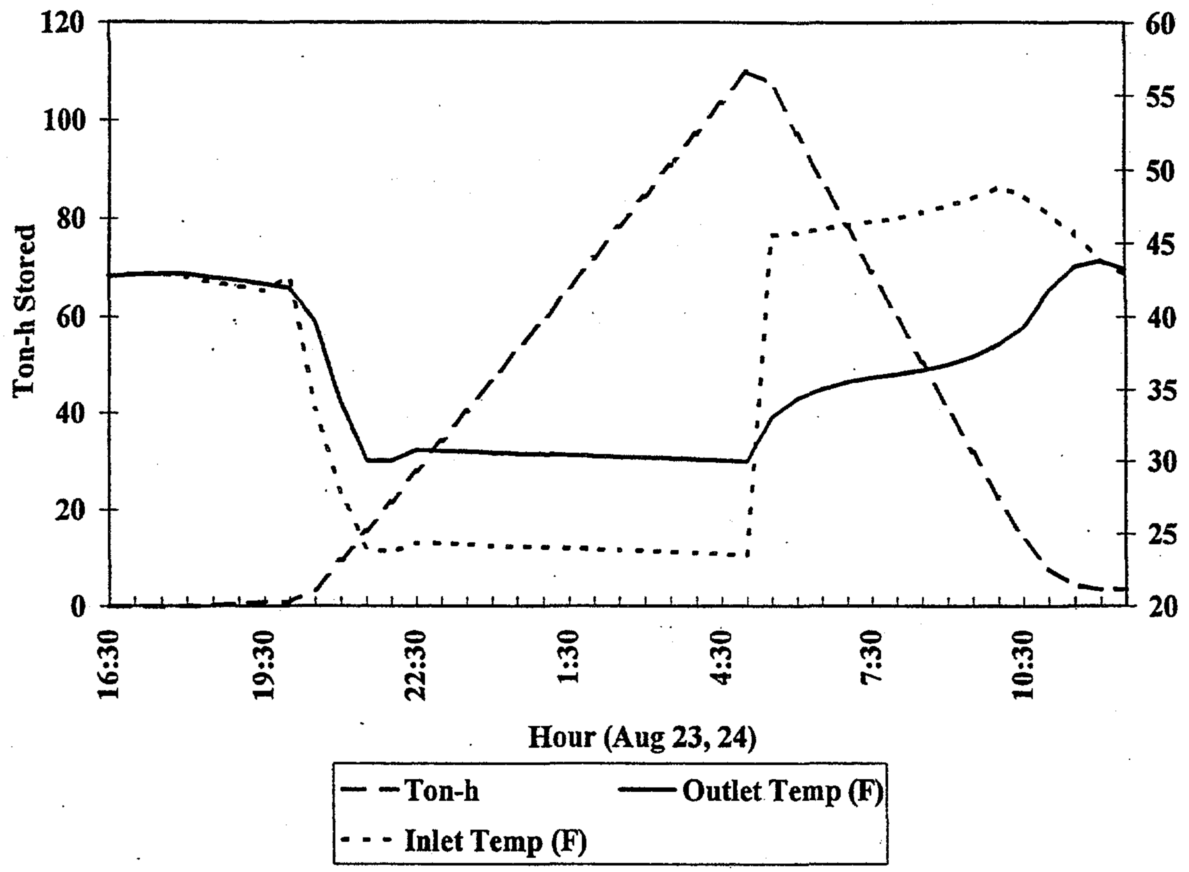

Fig. 6. Single charge/discharge cycle.

began to call for cooling from the storage system. It can be seen that at the initiation of discharge, the temperature difference across the coils was as much as 15 °F, which is 50% more than the design temperature difference. This means that at the initiation of discharge, the system could provide extra cooling capacity that might be useful in certain cases such as pulling the building temperature down quickly after a long weekend. By about noon, storage was depleted and the building reverted to being cooled by the chiller alone. This mode of operation gives cooling priority to storage, with the chiller used to supplement storage as needed. Other control algorithms such as chiller priority where the chiller runs most of the day and storage is used to help meet peak cooling loads could be implemented by raising the chiller setpoint. For the 24-h period shown, the tank was charged with about 110 ton-h of cooling, and most of this was used during the on-peak period.

7.2 Coil Performance

The 2-day period from midnight on 8/24 to midnight on 8/26 was examined to illustrate the cooling performance of each of the main three coils in the building as shown in Fig. 7.

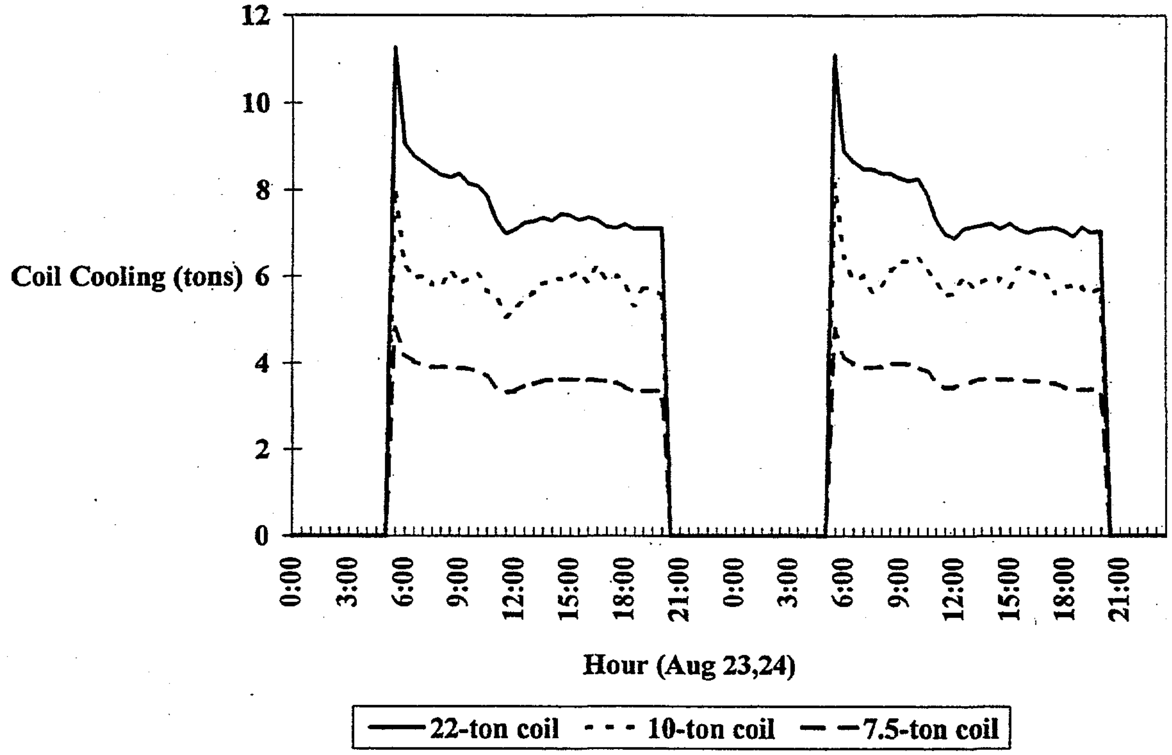

Fig. 7. Cooling performance of main coils.

At 6:00 A.M., ice formed in the storage tank was used to meet the cooling demand of the building; by about noon, storage is depleted and the chiller is activated to meet the load. At 8:00 P.M., the three-way valves at each coil change position so that no cooling is provided to the building, and the system begins to make ice. Cooling provided by the coils for the next day is shown at the right of this figure. These days show that the nominal 22-ton DX coil converted to operate with the glycol solution produces about 8 tons of cooling, the 10-ton coil produces about 6 tons of cooling, and the 7.5-ton coil produces about 4 tons of cooling.

All of the data on system, chiller, ice storage tank, and coil performance parameters used to develop information about the thermal performance for the individual components and combined performance were prepared in spreadsheet format. These data are provided in Appendix A.

8. COMPARISON OF MEASURED AND MODELED PERFORMANCE

One objective of this experiment was to use the data to validate the DOE-2.1E model of Building 2518. Although the DOE-2.1E model had been validated in a prior study of built-up roofing replacements, there was a need to examine how well the model could predict the cooling load of the three main coils used by the Roofberg system. If the model could predict coil cooling loads that agreed with the measured cooling loads from this experiment under similar weather conditions, it could be used with confidence to permit annual simulations of Roofberg as well as other retrofit options.

To accomplish this task, the DOE-2.1E model was used to predict the hourly cooling load of the building based on typical weather data in the region. TMY weather data for Oak Ridge, Tennessee, were used. This analysis produced hourly estimates of the combined total cooling loads (sensible and latent) for the three main coils that had been adapted for the ice storage system. The hourly outside temperature profile from the TMY data was studied and compared with the ODBTs measured in the field during the Roofberg data collection period to find days when the two temperature profiles were a reasonable match. The TMY weather dates of 9/6–7 were found to be a good match of the measured outside temperatures for 8/23–24 of 1995. The maximum temperature for both weather files reached about 93 °F during the day and fell to a minimum of about 70 °F at night. Further, the temperature profiles were very similar, as shown in Fig 8. There is better agreement in these temperatures during the day when the building was being cooled than at night.

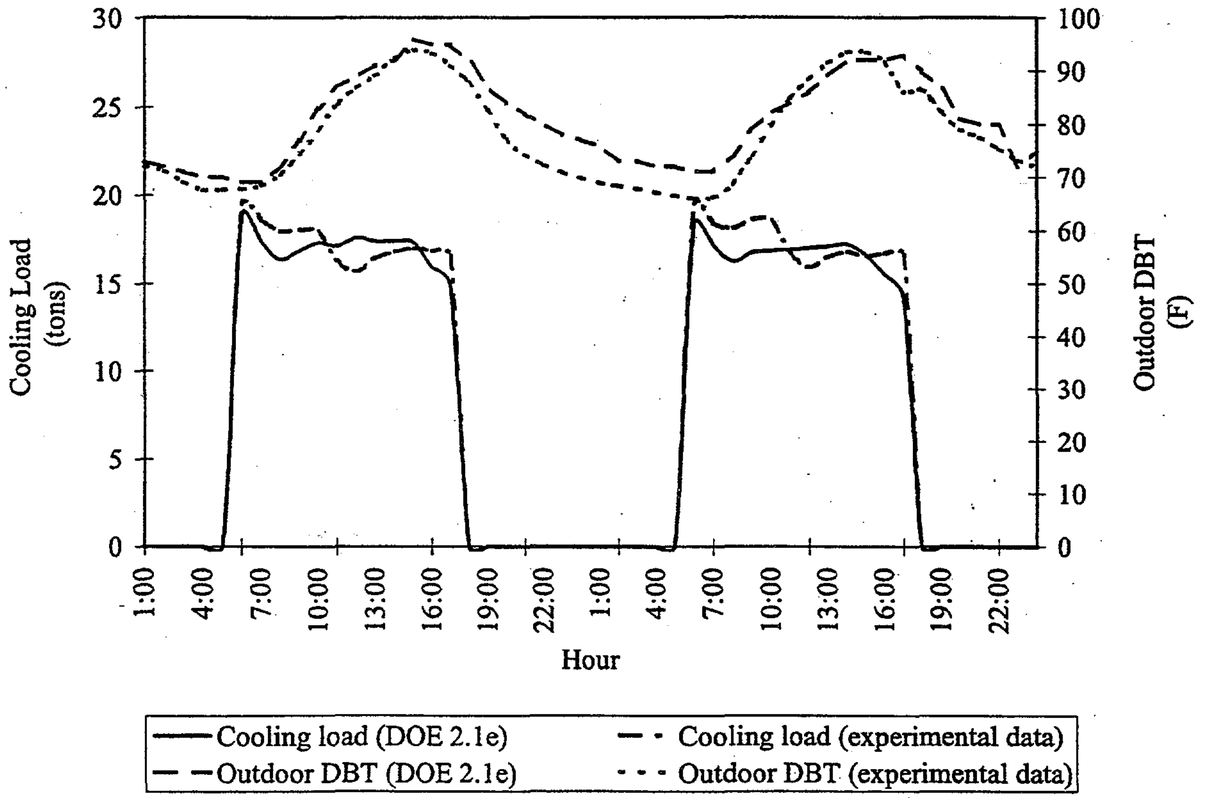

Fig. 8. Comparison of measured and modeled cooling loads.

Figure 8 also includes the measured load at the coils and the coil loads as predicted by DOE-2.1E. These two loads agree reasonably well. Both profiles indicate that the cooling load is larger when the cooling system is turned on each day than during the hottest part of the day. This behavior is typical for buildings where the cooling system is turned off at night and buildings with high internal cooling loads from lights, computers, and occupants. It is interesting to note that the maximum cooling load during this period appears to be about 20 tons, which is less than the capacity of the originally installed rooftops.

The difference in the capacity of the originally-installed rooftops and the significantly smaller cooling loads may be attributed to a combination of factors. First, the cooling load of the building today is less than when it was originally designed. Several retrofits—including a lighting retrofit and a new, insulated roofing membrane—had been installed as part of an overall building performance upgrade and the building had been used as a test bed for energy conservation retrofits. Second, experimental data on the cooling loads were gathered every 30 minutes, and the cooling load shown is an average of the cooling to the coils during this time interval. The peak cooling load (instantaneous) could be higher than what is shown.

9. ANNUAL SIMULATION STUDIES

The value of the Roofberg applied to Building 2518 is determined by the life cycle cost (LCC) of providing cooling to the building compared with the LCC of alternative systems, including a "do nothing" approach in which the existing rooftop units continue to provide the cooling. One input for a LCC analysis is the total annual energy consumed by the system being studied. To provide the input needed for an LCC study, we simulated the performance of several systems that met the annual cooling load of Building 2518. The system to be modeled and studied was a rooftop air conditioner.

9.1 Rooftop Model

The capacity and energy consumption of rooftop units are functions of the operating temperatures, the rated capacity, and the part-load capacity. In this study, the functional relations used by the DOE-2.1E program were used to determine the cooling capacity and EIR of the rooftop each hour of the year. The correlation used for cooling capacity is the relation,

$$\text{C-CAP} = \text{C-CAP}_R \times \text{COOL(EWBT, ODBT)}\,.$$

The factor *COOL(EWBT, ODBT)* results from a bi-quadratic fit of data on entering wet bulb temperature *(EWBT)* and *(ODBT)* to the performance of several rooftop units. It was assumed that the EWBT inside the building was maintained at the rated condition of 67°F; measured data for ODBT and for the rated capacity of the rooftop were input. This yielded a single equation for the capacity of a rooftop based on its rated capacity and on ODBT.

The DOE-2.1E relation for EIR is of the form,

$$\text{C-EIR} = \text{COOLING-EIR} \times \text{COOL-EIR(EWBT, ODBT)} \times \text{COOL-EIR(PLR)/PLR},$$

where the *COOLING-EIR* is the EIR at rated conditions, *COOL-EIR(EWBT, ODBT)* is a factor resulting from a bi-quadratic fit of EIR to the EWBT and ODBT for several rooftops, and *COOL-EIR(PLR)/PLR* is a cubic fit of cooling data to the part-load ratio, *PLR*. The part-load ratio is the fraction of a rooftop's full load necessary to satisfy the hourly cooling load of the building for each hour.

These two relations were used to develop performance profiles of a composite rooftop with a combined capacity and weighted EIR that matched the original rooftops installed on Building 2518. A figure of 39.5 tons was used as the rated capacity (C-CAP_R) of the combined machine and a weighted EIR of 0.52 $kWh_{(electrical)}/kWh_{(cooling)}$ was used.

The same approach was used to consider the performance of new rooftop units for the building. In this case, the total rated cooling capacity was taken to be the same as for the original units; however, the rated EIR was smaller (higher COP) based on rooftop units available today.

9.2 Alternative System Studies

There are several distinctive features of the Roofberg installation on Building 2518 which may or may not be present in other applications. First, the Roofberg system installed on Building 2518 was designed as a full storage system. In this configuration, the chiller was used to produce ice, and during a subsequent on-peak period, the chiller was turned off allowing the ice storage system to meet the cooling load of the building for as long as possible. Full storage operation minimizes on-peak electrical demand and may be the most economic design in cases where there are high demand charges during on-peak periods. With lower demand charges, a partial storage system in which the chiller operates as needed to supplement cooling provided by the tank to the building may be the better option. There is a tradeoff between initial cost savings of a smaller chiller operating as part of a partial storage system, and extra operating costs associated with increased on-peak demand. Second, Roofberg as installed on Building 2518, was designed to provide continuous cooling (nominally 1 ton) to the small computer room. Since the ice tank was functionally located between the chiller and the coil for the computer room, the 1-ton load could be effectively met by the much larger chiller. However, this constant though small load required that at least one of the glycol solution circulation pumps operate continuously, and this increases the overall cooling load because of pump work. The pumps used in the experiment were close-coupled, end suction centrifugal pumps. The pump input power reduced by the motor efficiency becomes thermal energy in the working fluid, which results in an increased load. This not only increases the cooling load which must be met by the Roofberg system, but adds parasitic power to the annual energy consumption of the system.

To examine the impacts of this additional system load and the benefits of full-bore, low-pressure-drop valves on system operation, four system design concepts were developed as indicated in Table 4.

Table 4. Roofberg design options

Case	Roofberg system design
A	Roofberg as designed and installed
B	Case A with low pressure drop valves
C	Case A with no computer room cooling requirement
D	Case B with no computer room cooling requirement

In cases C and D, the computer room load was deleted, and this allowed a control strategy to be used which restricted pump operation to times when there was a cooling load in the building, or when ice was being manufactured at night by the chiller. The impact of these design options on the annual energy consumption of the Roofberg system is shown in Fig. 9. By eliminating the need for continuous pump operation, the total energy consumption of Roofberg is reduced by 33% (comparing design options A and C) and by 20% (comparing design options B and D).

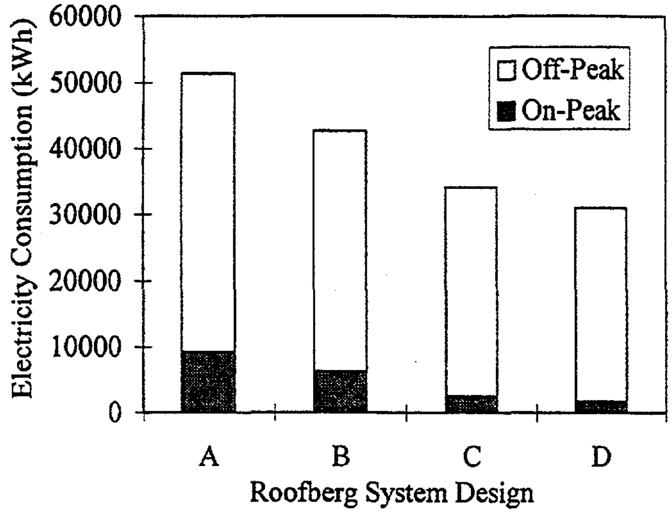

Fig. 9. Impact of Roofberg System Design

This implies that care must be taken in using a storage system to meet a small but constant load such as was present in the computer room of building 2518. Operating the glycol solution pumps to meet this year-round load can exact a heavy energy penalty on the system. In each of the following simulations comparing alternatives to Roofberg, the small continuous cooling load of the computer room is assumed to be met by a separate dedicated cooling unit.

Systems were prepared and examined which would be likely candidates for evaluation by a building or facility manager in making a choice about upgrading a building cooling system. These cases included the baseline (the existing rooftop scenario), the Roofberg application (Roofberg System Design Option D in Fig. 9), a chiller with no ice storage, and replacement of the existing rooftop units with new rooftop units, as indicated in Table 5. The purpose of these studies was to evaluate the Roofberg as one retrofit option for the building.

Table 5. Case studies of cooling alternatives for Building 2518

Case	Cooling system options
1	Original rooftops
2	Roofberg with low pressure drop valves and pump controls (Design D)
3	Chiller with no ice storage
3	New rooftop units—original capacity

Case 1—the base case leaving the original rooftops in place. Although old, these units were continuing to cool zones in the building adequately; however, maintenance requirements for these units had become quite significant and annual maintenance costs high.

Case 2—the Roofberg system with a low-pressure drop mixing valve and pump controls that activate the pump only as needed for ice building or for delivering cooling to the three main coils in the buildings.

Case 3—chiller only operation. The ice storage system was removed, and the chiller operated as needed to provide cooling to the three main coils in the building. In this scenario, the three main coils were converted as for the Roofberg system and coupled together so that the chiller could provide the cooling. This chiller used in this simulation was identical to the one for the Roofberg system.

Case 4—rooftop unit replacement. This case considers replacement of the old rooftop units with new units of the same rated capacity. This scenario represents a typical replacement—ton-for-ton—of rooftops. From manufacturers' literature, we selected three rooftop units with capacities that closely matched the nominal capacities of the old rooftop units originally on the building. We chose a 7.5-ton unit (capacity 88,000 Btu/h, EER 9.0 Btu/W-h under ARI rating conditions), a 10-ton unit (capacity 119,000 Btu/h, EER 9.0 Btu/W-h) and a 20-ton unit (capacity 232,000 Btu/h, EER 8.7 Btu/W-h). All of these performance numbers were generated under ARI rating conditions (95/80/67). The combined cooling performance of these three units is 439,000 Btu/h of cooling with a weighted EER of 8.84 Btu/W-h.

The type of retrofit system can affect the overall annual cooling load (Fig. 10). Although the space-conditioning load of the building is fixed, pumping energy needed to circulate glycol solution contributes more or less to the building load. This changes the overall cooling that must be provided by any one of the systems analyzed. The rooftop replacement option (case 4) and the original rooftop (case 1) had the same impact on the total cooling load as expected. With these rooftops, about 43% of the total cooling load occurred during the off-peak time, which was taken to be 6:00 P.M. to 10:00 A.M. With all of the options using a chiller, including the Roofberg case, the overall cooling load increased because of pump work.

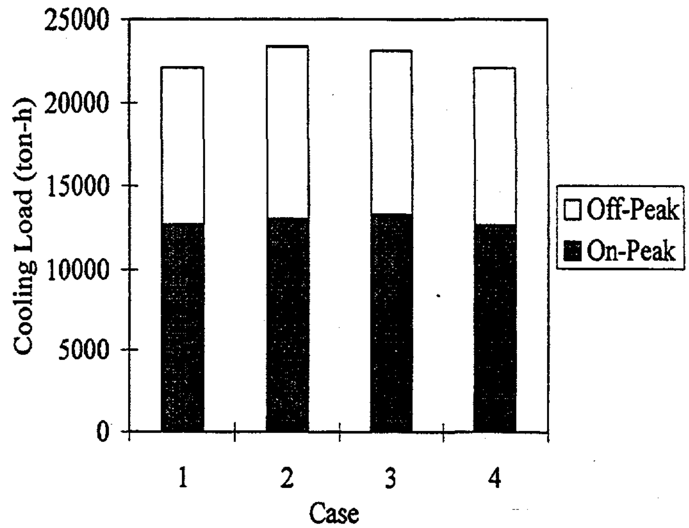

Fig. 10. Cooling loads of rooftop replacement options.

The energy consumption (kWh) of each of the cases varies as shown in Fig. 11. The energy consumption of the original rooftops (case 1) is about 42,000 kWh; 62% of the energy consumption total occurs during on-peak hours. Replacing the original rooftops with new ones (case 4) reduces the overall energy consumption by about 27%. This reduction in energy consumption is due to an improvement in EER with the replacement rooftops. The chiller option (case 3) consumes about 65% of the total amount of energy as the original rooftop units.

When controlled as indicated, the annual energy consumption of the Roofberg system (case 2) in Fig. 11, compares favorably with the energy consumption of a simple rooftop efficiency upgrade (case 4) as shown in Fig. 11. The annual energy consumption in both cases was about 73% of the annual energy consumption of the existing, old rooftops. Better control strategies and moving to a partial storage system may provide still further improvements.

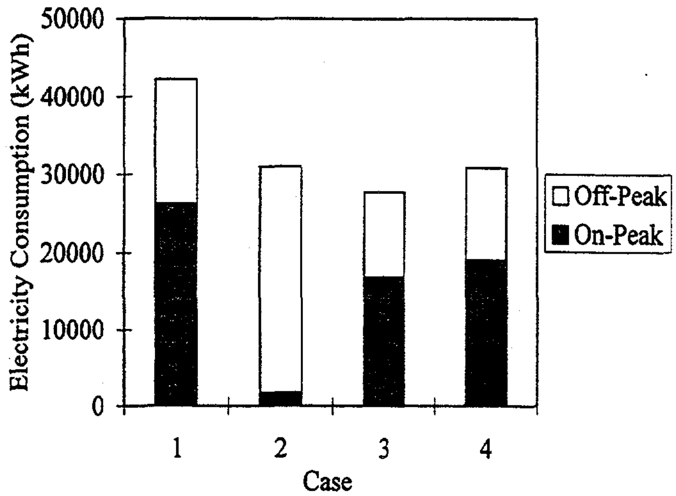

Fig. 11. Electrical energy consumption of rooftop alternatives.

A principal advantage of storage systems such as Roofberg is the ability of shift the electric load from on- to off-peak hours. The analysis presented in Fig. 11 indicates that the Case 2 Roofberg system reduces the on-peak energy use of the cooling system to 16% of the on-peak energy consumption of the baseline system (Case 1). This benefit is realized where there is a spread between on- and off-peak utility tariffs and where demand charges are exacted for on-peak energy consumption.

10. ECONOMIC ANALYSIS

The choice between rooftop unit replacement, retrofit with an ice storage system, or retrofit with one of several alternative systems is determined by economics as well as other factors. One economic measure is simple payback, which is the time that it takes to recover an initial investment in equipment through operating cost savings. This approach, although intuitively attractive, ignores future replacement costs, the true "cost" of money that depends on when investments are made and prevalent economic conditions, as well as other factors.

An economic analysis was performed for case 2 (the Roofberg configuration), for case 3 (the chiller option), and for case 4 (rooftop replacement). For each alternative, a present worth analysis was conducted that considers the time value of money spent or saved over a study period. The economics of each of the alternatives is determined by the installed cost, operating cost, maintenance costs, and replacement costs at the end of the useful life of the equipment.

10.1 Installed Cost

Estimates for the installed cost of each of the alternative systems, including the Roofberg system, are based on a published cost estimating guide for building equipment (ref. 3). Where there was no information on installed cost (e.g., the ice storage tank), the vendor was asked to determine estimates of installed costs based on experience. In cases where the coils of rooftop units were converted to use glycol solution as a coolant, the cost of coil conversion was estimated. Finally, the estimates took into account that alternatives that were more complex than simple rooftop replacement would require a level of design both for the system and for the controls. This was the case for any option which required a chiller.

It is estimated that the installed cost for the Roofberg system applied to Building 2518 would have been $56,600. The highest single cost item is the chiller, which represents about 35% of the total costs; the installed cost of the storage tank is about 20% of the total. The balance of the costs is associated with installation of piping and remaining component plus controls.

Installation costs for the rooftop unit replacements were taken from the referenced cost estimating guide. All installed costs are provided in Appendix B.

10.2 Maintenance Costs

Maintenance costs include, for example, costs for periodic cleaning of the evaporator tube bundle, coil cleaning, periodic attention to the glycol solution fluid concentration and unwanted corrosion products, checking/adjusting the concentration of any biocide added to the water in the ice storage tank, and checking/correcting leaks in the system. Maintenance costs are highly variable because of the attention given in the initial design/installation of the system and the level of attention given to a program of regular maintenance.

10.2.1 Electric Chiller Maintenance Costs.

An early study assumed chiller maintenance to be $0.0075/ton-h, recognizing that maintenance costs are determined by the size of the chiller as well as the number of annual operating hours (ref. 4). If it is assumed that chillers operate for about 2000 h/year, the result is annual chiller maintenance costs of $15/ton. One study that compared the economics of gas versus electric chillers reported electric chiller maintenance costs in the range of $20 to $27/ton (ref. 5). Another current study confirmed the lower estimate (ref. 6). Based on this information, the annual reciprocating chiller maintenance costs were assumed to be $20/ton, which is in line with these estimates. The maintenance costs for chillers were assumed to be about the same as for rooftop units of the same vintage and capacity. Any extra maintenance required for rooftops because of higher ambient operating conditions is offset by any maintenance of circulating pumps and regular checks of the chemical condition of the chilled water (or glycol) distribution fluid in chiller systems.

10.2.2 Ice Storage System Maintenance Costs

Maintenance costs associated with the ice storage tank are primarily due to replacement of the biocide used to prevent algae growth inside the tank. This should be done every 1 to 2 years; material costs are about $40/tank. For a nominal 190-ton-h ice storage system (as used for Building 2518), an annual tank check and topping off with water and a biocide treatment should cost no more than $80 (equivalent to $0.42/ton-h). This value agreed with estimates provided by the ice storage tank manufacturer and was taken to be the annual maintenance cost for the ice storage system (ref. 7).

10.3 Life Cycle Costs of Roofberg and Alternatives

A present worth economic analysis was conducted for the Roofberg system, a chiller system, and a rooftop replacement option, using Federal cost accounting guidelines. Life cycle costing allows the evaluation of proposed capital investments, such as ice storage or new rooftops, expected to reduce the long-term operating costs of buildings and building systems. The Building Life Cycle Cost (BLCC) computer program was used to compute these LCCs for the existing rooftop units as well as for a rooftop replacement, for the chiller option and for the Roofberg ice storage system. Key parameters in this program are the discount rate (the opportunity cost of money) and energy costs. A real discount rate of 4.1% was used in accordance with guidance for economic analyses conducted in 1996. A study period of 20 years was used, which corresponds to the expected life of a chiller and ice storage tank and with what experience has been with rooftop units.

Energy costs were examined parametrically to indicate what energy costs need to be to make the replacement or storage options cost-effective based on their LCCs. Cases 2 and 4 were examined, and energy costs were allowed to vary—on-peak rates from $0.12/kWh to $0.07/kWh, off-peak rates from $0.06 to $0.02/kWh, and monthly demand charges from $5/kW to no demand charge. Our goal was not to determine what the value of the ice storage option is in an application; it was to understand what utility rate structure begins to favor the Roofberg (ice storage) configuration over simple rooftop unit replacement. If a $/kW demand threshold were found where the LCC for the storage option was less than for the non-storage, rooftop replacement option, any demand charge higher than this amount would continue to favor the storage option.

Table 6 presents the results from the LCC analysis for cases 2 and 4 and the baseline. These cases represent the scenarios likely to be considered first as options for upgrading or maintaining the present system. The table is sectioned into segments of uniform demand and energy costs, and the system with the lowest LCC can be determined in each section. For example, if the monthly demand charge is $5/kW and energy costs are \$0.12/kWh on-peak and \$0.06/kWh off-peak (the first four entries in the table), case 2 has the lowest LCC. For this analysis, demand charges were chosen that were \$5/kW or less, which capture the demand charges exacted by a large number of electric utilities in the United States. The energy costs in Table 6 reflect commercial electricity rates that are higher than the average \$0.08/kWh for the United States as well as those that are lower.

A review of the entries in Table 6 shows that under some utility rate structures, the ice storage system has the lowest LCC of the options studied, while under others a rooftop replacement option appeared more economical. The plot in Fig. 12 represents a further exploration of this In this figure, we assumed that there was a \$5/kW demand charge. Figure 12 shows ranges in on-peak rates and rate differentials where the Roofberg system is more economical and other regions where a simple rooftop replacement is the better economic option. Since the Roofberg system is capable of significant load shifting, it becomes a more valuable choice as the difference in time-of-use rates increases.

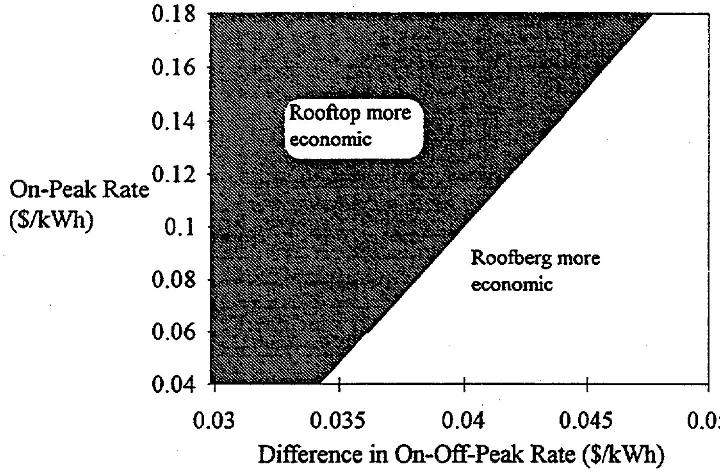

Fig. 12. Region of lowest life-cycle cost for rooftop and Roofberg.

Although it is not shown in Fig. 12, if the demand charge is higher than \$5/kW, any additional advantage of off-peak rates becomes less. If there is no demand charge and the time-of-use electricity rates are limited as shown in Table 6, rooftop systems appear to have the lowest LCC.

Interestingly, within the parameters of demand and time-of-use rates evaluated, this study failed to find any region where the chiller option (case 3) had the lowest LCC of the systems examined.

Table 6. Life-cycle cost analysis results

Case	Installed cost ($)	Maint. cost ($/y)	Demand charge ($/kW)	On-peak Rate ($/kWh)	Off-peak Rate ($/kWh)	On-peak Energy (kWh/y)	Off-peak Energy (kWh/y)	Sum of monthly peaks (kW)	LCC ($)
1	0	1580	5	0.12	0.06	26149	16172	260.09	114703
2	53623	480	5	0.12	0.06	3386.9	29092	64.56	99054
4	35796	400	5	0.12	0.06	19818	10845	168.96	106900
1	0	1580	5	0.12	0.04	26149	16172	260.09	110199
2	53623	480	5	0.12	0.04	3386.9	29092	64.56	90951
4	35796	400	5	0.12	0.04	19818	10845	168.96	103879
1	0	1580	5	0.12	0.02	26149	16172	260.09	105695
2	53623	480	5	0.12	0.02	3386.9	29092	64.56	82848
4	35796	400	5	0.12	0.02	19818	10845	168.96	100859
1	0	1580	5	0.1	0.06	26149	16172	260.09	107420
2	53623	480	5	0.1	0.06	3386.9	29092	64.56	98111
4	35796	400	5	0.1	0.06	19818	10845	168.96	101380
1	0	1580	5	0.1	0.04	26149	16172	260.09	102916
2	53623	480	5	0.1	0.04	3386.9	29092	64.56	90008
4	35796	400	5	0.1	0.04	19818	10845	168.96	98360
1	0	1580	5	0.1	0.02	26149	16172	260.09	98412
2	53623	480	5	0.1	0.02	3386.9	29092	64.56	81905
4	35796	400	5	0.1	0.02	19818	10845	168.96	95339
1	0	1580	5	0.08	0.06	26149	16172	260.09	100137
2	53623	480	5	0.08	0.06	3386.9	29092	64.56	97167
4	35796	400	5	0.08	0.06	19818	10845	168.96	95860
1	0	1580	5	0.08	0.04	26149	16172	260.09	95633
2	53623	480	5	0.08	0.04	3386.9	29092	64.56	89064
4	35796	400	5	0.08	0.04	19818	10845	168.96	92840
1	0	1580	5	0.08	0.02	26149	16172	260.09	91129
2	53623	480	5	0.08	0.02	3386.9	29092	64.56	80962
4	35796	400	5	0.08	0.02	19818	10845	168.96	89819

Table 6 (continued)

Case	Installed cost ($)	Maint. cost ($/y)	Demand charge ($/kW)	On-peak Rate ($/kWh)	Off-peak Rate ($/kWh)	On-peak Energy (kWh/y)	Off-peak Energy (kWh/y)	Sum of monthly peaks (kW)	LCC ($)
1	0	1580	5	0.07	0.06	26149	16172	260.09	96496
2	53623	480	5	0.07	0.06	3386.9	29092	64.56	96695
4	35796	400	5	0.07	0.06	19818	10845	168.96	93101
1	0	1580	5	0.07	0.04	26149	16172	260.09	91991
2	53623	480	5	0.07	0.04	3386.9	29092	64.56	88593
4	35796	400	5	0.07	0.04	19818	10845	168.96	90080
1	0	1580	5	0.07	0.02	26149	16172	260.09	87487
2	53623	480	5	0.07	0.02	3386.9	29092	64.56	80490
4	35796	400	5	0.07	0.02	19818	10845	168.96	87059
1	0	1580	0	0.12	0.06	26149	16172	260.09	78495
2	53623	480	0	0.12	0.06	3386.9	29092	64.56	90058
4	35796	400	0	0.12	0.06	19818	10845	168.96	83365
1	0	1580	0	0.12	0.04	26149	16172	260.09	73991
2	53623	480	0	0.12	0.04	3386.9	29092	64.56	81955
4	35796	400	0	0.12	0.04	19818	10845	168.96	80344
1	0	1580	0	0.12	0.02	26149	16172	260.09	69487
2	53623	480	0	0.12	0.02	3386.9	29092	64.56	73852
4	35796	400	0	0.12	0.02	19818	10845	168.96	77324
1	0	1580	0	0.1	0.02	26149	16172	260.09	62204
2	53623	480	0	0.1	0.02	3386.9	29092	64.56	72909
4	35796	400	0	0.1	0.02	19818	10845	168.96	71804
1	0	1580	0	0.12	0.12	26149	16172	260.09	92008
2	53623	480	0	0.12	0.12	3386.9	29092	64.56	114316
4	35796	400	0	0.12	0.12	19818	10845	168.96	92427

11. CONCLUSIONS

Packaged air conditioning units cool a large fraction of commercial buildings in the United States. More than half of commercial floorspace is cooled by these units, and most are located on rooftops. Based on tons of cooling, the market share for rooftops has risen from about 45% in the early 1960's to about 65% in the early 1990's. These systems are popular due to their low cost, flexibility and simplicity in providing building cooling. There is a large stock of old rooftops with relatively poor efficiency (6 EER or less) which are candidates for either replacement with a new model, or conversion to an alternative cooling system such as Roofberg.

The process for retrofitting existing rooftops to the Roofberg requires that the coils in the existing rooftops be either converted to accept a glycol solution by modifying the manifolds to each individual coil circuit, or that they be replaced by new chilled water (glycol solution) coils. In either case, the existing rooftop cabinet can be used and little or no modifications to the roofing are needed - an advantage. In the demonstration on ORNL's Building 2518, coils were converted rather than replaced. Heat transfer data from this experiment showed the coil capacity after conversion to be lower than the nominal coil rating would suggest. This implies that electing the option of converting the existing DX coils to operate with glycol rather than coil replacement needs to be considered carefully. The better choice may have been to replace the old coils with ones designed to work with the glycol solution.

It is important to address the energy needed to circulate the glycol solution in the Roofberg system. In the demonstration, the circulation pumps were operated continuously to charge and discharge the ice storage tank and to meet the cooling needs of the computer room in Building 2518. This pumping energy adds to the cooling load of the building during the on-peak periods and to the cooling load during the off-peak (ice-making) period which lowers the energy efficiency of the design. Alternatives for meeting small, continuous cooling loads should be used.

From simulations, the energy efficiency of the Roofberg storage/chiller concept was approximately equal to what could be expected through a simple rooftop efficiency upgrade, and the operating costs for the Roofberg system could be much more favorable depending on the utility rate structure. The ability of Roofberg to move much of the cooling load to off-peak periods enables it to take advantage of on-peak demand charges and time-of-use electricity rates. A comparative analysis of a rooftop replacement and Roofberg indicated that the Roofberg system would be the better economic choice over a range of demand charges and on-off peak energy prices which are typical of utility rate tariffs for commercial buildings.

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APPENDIX A. SYSTEM PERFORMANCE DATA

Roofberg Performance
August 14-21, 1995

Day & time	outdoor	Chiller In	Chiller Out	Chiller	Cool from chiller	Ton-h from chiller	Cool from Tank	Ton-h from tank	Cool to 22-ton coil	Cool to 10-ton coil	Cool to 7.5-ton coil	Cool to CR coil	Cooling by chiller & tank	Total cooling at coils
0:30	(F)	(F)	(F)	(W)	(Ton)	(cum.)	(tons)	(cum.)	(tons)	(tons)	(tons)	(tons)	(tons)	(tons)
8/14/95 8:00	73.9	46.2	45.6	3690	1.38	0.34	20.10	5.03	13.94	12.02	5.17	0.05	21.48	31.17
8/14/95 8:30	76.4	48.3	48.4	0	-0.16	0.65	23.16	15.84	9.56	7.00	4.24	0.04	23.01	20.86
8/14/95 9:00	78.8	48.9	48.8	600	0.33	0.69	22.63	27.29	9.33	7.17	4.26	0.04	22.96	20.79
8/14/95 9:30	83.8	49.3	48.0	2802	2.54	1.41	20.90	38.17	9.36	7.39	4.30	0.03	23.44	21.08
8/14/95 10:00	88.9	50.3	48.1	5202	4.35	3.14	17.53	47.78	9.06	7.29	4.16	0.03	21.89	20.54
8/14/95 10:30	90.7	51.9	50.9	2400	2.09	4.75	15.61	56.06	13.41	6.84	3.74	0.37	17.70	24.36
8/14/95 11:00	92.5	57.2	53.4	8202	7.43	7.13	10.23	62.52	6.56	5.62	3.13	0.46	17.65	15.77
8/14/95 11:30	94.1	56.9	47.1	22002	19.04	13.74	-1.29	64.76	7.10	5.84	3.39	0.31	17.75	16.64
8/14/95 12:00	95.7	56.7	47.1	22200	18.72	23.18	-0.88	64.22	7.16	6.34	3.42	0.25	17.84	17.17
8/14/95 12:30	96.6	56.7	47.2	22800	18.38	32.46	-0.43	63.89	7.14	6.51	3.44	0.27	17.95	17.35
8/14/95 13:00	97.5	56.6	47.2	22998	18.36	41.64	-0.37	63.69	7.16	6.40	3.43	0.35	17.99	17.34
8/14/95 13:30	97.7	56.8	47.4	23202	18.25	50.80	-0.14	63.56	7.11	6.61	3.43	0.37	18.12	17.51
8/14/95 14:00	97.9	56.7	47.3	23202	18.35	59.95	-0.23	63.47	7.03	6.50	3.44	0.29	18.11	17.26
8/14/95 14:30	98.0	55.3	46.3	23202	17.61	68.93	-1.38	63.07	13.30	6.15	3.44	0.28	16.22	23.17
8/14/95 15:00	98.1	56.2	46.9	23598	18.21	77.89	-0.18	62.68	7.17	6.09	3.40	0.30	18.03	16.96
8/14/95 15:30	98.1	54.8	45.8	23400	17.56	86.83	-1.13	62.35	12.99	6.25	3.50	0.44	16.43	23.18
8/14/95 16:00	98.1	55.8	46.6	23598	17.96	95.71	-0.25	62.00	8.79	6.28	3.46	0.39	17.71	18.92
8/14/95 16:30	95.8	55.1	45.9	23400	17.88	104.67	-0.62	61.78	10.55	6.18	3.48	0.30	17.25	20.51
8/14/95 17:00	93.6	54.6	45.5	23202	17.76	113.58	-1.50	61.25	11.08	6.21	3.44	0.24	16.26	20.97
8/14/95 17:30	89.7	55.6	46.3	23400	18.16	122.57	0.39	60.97	7.46	5.98	3.46	0.24	18.55	17.14
8/14/95 18:00	85.8	54.0	45.1	23202	17.51	131.48	-1.23	60.76	11.74	6.12	3.30	0.33	16.28	21.48
8/14/95 18:30	84.6	54.8	45.6	22998	18.10	140.39	-0.31	60.38	7.39	5.79	3.14	0.19	17.79	16.51
8/14/95 19:00	83.3	54.7	45.4	22800	18.08	149.43	-0.41	60.20	7.20	6.11	3.12	0.24	17.67	16.67
8/14/95 19:30	81.8	54.5	45.2	22200	18.13	158.48	-0.53	59.96	7.27	6.02	3.17	0.26	17.61	16.72
8/14/95 20:00	80.2	57.0	56.8	600	0.33	163.10	14.62	63.49	5.87	5.08	2.63	0.20	14.95	13.78
8/14/95 20:30	79.4	48.4	39.5	19998	15.63	167.09	-14.00	63.64	0.00	0.00	0.00	0.39	1.62	0.39
8/14/95 21:00	78.6	42.2	33.6	19602	14.93	174.73	-14.08	56.62	0.00	0.00	0.00	0.62	0.85	0.62
8/14/95 21:30	78.0	37.3	29.4	19200	13.64	181.87	-12.62	49.94	0.00	0.00	0.00	0.72	1.02	0.72
8/14/95 22:00	77.4	33.1	25.6	18600	12.82	188.49	-11.93	43.81	0.00	0.00	0.00	0.66	0.90	0.66
8/14/95 22:30	76.9	30.1	22.8	18402	12.51	194.82	-11.68	37.91	0.00	0.00	0.00	0.71	0.82	0.71
8/14/95 23:00	76.5	31.2	23.6	18198	12.90	201.17	-12.32	31.90	0.00	0.00	0.00	0.69	0.58	0.69
8/14/95 23:30	76.0	31.3	23.7	18198	13.04	207.66	-12.42	25.72	0.00	0.00	0.00	0.69	0.62	0.69
8/15/95 0:00	75.6	31.2	23.6	18198	13.04	214.18	-12.44	19.50	0.00	0.00	0.00	0.70	0.60	0.70
8/15/95 0:30	75.5	31.2	23.6	17802	13.11	220.72	-12.50	13.27	0.00	0.00	0.00	0.70	0.62	0.70
8/15/95 1:00	75.4	31.1	23.5	18000	13.11	227.27	-12.49	7.02	0.00	0.00	0.00	0.71	0.62	0.71
8/15/95 1:30	75.1	31.1	23.4	17802	13.19	233.85	-12.47	0.78	0.00	0.00	0.00	0.70	0.72	0.70
8/15/95 2:00	74.8	31.0	23.4	17802	13.08	240.42	-12.43	-5.44	0.00	0.00	0.00	0.75	0.65	0.75
8/15/95 2:30	74.6	31.0	23.4	17598	13.03	246.95	-12.42	-11.66	0.00	0.00	0.00	0.78	0.62	0.78
8/15/95 3:00	74.3	30.9	23.2	17802	13.15	253.49	-12.48	-17.88	0.00	0.00	0.00	0.74	0.67	0.74
8/15/95 3:30	74.0	30.8	23.3	17598	12.97	260.02	-12.45	-24.11	0.00	0.00	0.00	0.73	0.51	0.73
8/15/95 4:00	73.8	30.8	23.1	17400	13.17	266.55	-12.55	-30.36	0.00	0.00	0.00	0.72	0.62	0.72

Roofberg Performance
August 14-21, 1995

Day & time	outdoor	Chiller In	Chiller Out	Chiller	Cool from chiller	Ton-h from chiller	Cool from Tank	Ton-h from tank	Cool to 22-ton coil	Cool to 10-ton coil	Cool to 7.5-ton coil	Cool to CR coil	Cooling by chiller & tank	Total cooling at coils
0:30	(F)	(F)	(F)	(W)	(Ton)	(cum.)	(tons)	(cum.)	(tons)	(tons)	(tons)	(tons)	(tons)	(tons)
8/15/95 4:30	73.5	30.8	23.1	17400	13.23	273.15	-12.58	-36.65	0.00	0.00	0.00	0.72	0.65	0.72
8/15/95 5:00	73.2	30.7	23.0	17400	13.06	279.73	-12.51	-42.92	0.00	0.00	0.00	0.71	0.55	0.71
8/15/95 5:30	73.0	30.6	22.9	17400	13.25	286.30	-12.60	-49.20	0.00	0.00	0.00	0.71	0.65	0.71
8/15/95 6:00	72.9	30.6	22.9	17202	13.16	292.91	-12.55	-55.48	0.00	0.00	0.00	0.71	0.62	0.71
8/15/95 6:30	72.9	49.4	48.6	798	0.96	296.44	20.07	-53.60	9.19	7.95	3.94	0.46	21.03	21.55
8/15/95 7:00	72.9	47.9	47.9	0	-0.01	296.67	18.72	-43.90	7.47	6.71	3.48	0.29	18.71	17.96
8/15/95 7:30	73.7	48.0	48.0	0	0.01	296.67	18.18	-34.68	7.32	6.42	3.40	0.25	18.19	17.39
8/15/95 8:00	74.5	48.3	48.5	0	-0.28	296.61	18.28	-25.56	7.38	6.66	3.48	0.26	18.01	17.78
8/15/95 8:30	76.4	48.8	48.7	600	0.24	296.60	18.42	-16.39	7.30	7.00	3.59	0.34	18.65	18.23
8/15/95 9:00	78.3	49.1	48.6	1002	0.60	296.81	18.01	-7.28	7.38	7.03	3.63	0.30	18.62	18.33
8/15/95 9:30	82.4	49.4	48.0	2202	1.82	297.41	17.12	1.50	7.34	7.35	3.70	0.27	18.94	18.66
8/15/95 10:00	86.5	49.6	47.8	3402	2.26	298.43	16.64	9.94	7.34	7.43	3.71	0.32	18.89	18.80
8/15/95 10:30	89.3	50.1	47.2	4602	3.53	299.88	15.72	18.03	7.23	7.64	3.70	0.36	19.25	18.94
8/15/95 11:00	92.1	50.5	47.2	5598	4.23	301.82	14.87	25.68	7.20	7.42	3.71	0.39	19.11	18.72
8/15/95 11:30	93.7	51.1	46.9	6600	5.17	304.17	13.94	32.88	7.12	7.70	3.71	0.37	19.11	18.90
8/15/95 12:00	95.2	51.0	44.3	9798	8.37	307.56	10.38	38.96	7.23	7.24	3.72	0.31	18.75	18.50
8/15/95 12:30	96.4	51.5	43.9	10602	9.43	312.01	9.03	43.81	6.95	7.42	3.67	0.31	18.46	18.34
8/15/95 13:00	97.7	52.4	44.0	13002	10.56	317.00	7.04	47.83	6.78	6.81	3.50	0.32	17.60	17.40
8/15/95 13:30	98.3	54.0	48.3	9798	7.24	321.45	9.33	51.92	6.32	6.67	3.35	0.46	16.57	16.79
8/15/95 14:00	99.0	58.0	57.9	198	0.13	323.29	15.07	58.02	5.53	5.72	2.90	0.48	15.20	14.63
8/15/95 14:30	98.9	61.4	61.5	0	-0.01	323.32	13.16	65.08	4.87	4.78	2.46	0.45	13.15	12.57
8/15/95 15:00	98.8	64.5	64.5	198	0.01	323.32	11.38	71.22	4.09	4.17	2.10	0.49	11.40	10.85
8/15/95 15:30	98.7	67.2	67.2	198	0.03	323.33	9.84	76.53	3.42	3.78	1.82	0.38	9.87	9.40
8/15/95 16:00	98.6	69.4	69.4	198	0.00	323.34	8.54	81.12	2.87	3.11	1.60	0.29	8.54	7.88
8/15/95 16:30	97.5	71.5	71.3	198	0.26	323.40	7.33	85.09	2.22	2.68	1.37	0.22	7.59	6.49
8/15/95 17:00	96.4	73.1	73.1	0	0.00	323.47	6.32	88.50	1.86	2.33	1.19	0.16	6.32	5.54
8/15/95 17:30	93.4	74.6	74.4	198	0.26	323.53	5.34	91.42	1.46	1.91	1.02	0.15	5.60	4.54
8/15/95 18:00	90.3	75.7	75.5	198	0.26	323.66	4.30	93.83	1.02	1.72	0.75	0.15	4.57	3.63
8/15/95 18:30	87.9	76.4	76.4	0	0.00	323.73	3.66	95.82	0.78	1.63	0.57	0.13	3.66	3.11
8/15/95 19:00	85.5	77.2	77.2	198	0.00	323.73	3.14	97.52	0.63	1.19	0.50	0.10	3.14	2.42
8/15/95 19:30	83.4	77.8	77.9	0	-0.13	323.70	2.62	98.96	0.44	1.06	0.41	0.10	2.49	2.00
8/15/95 20:00	81.3	78.3	78.2	0	0.13	323.70	1.97	100.11	0.34	0.62	0.36	0.10	2.10	1.42
8/15/95 20:30	80.2	72.2	59.5	22002	22.63	329.39	-21.78	95.15	0.00	0.00	0.00	0.18	0.85	0.18
8/15/95 21:00	79.0	63.5	51.6	21600	21.32	340.38	-20.85	84.49	0.00	0.00	0.00	0.31	0.46	0.31
8/15/95 21:30	78.3	56.3	45.4	20802	19.28	350.53	-18.68	74.61	0.00	0.00	0.00	0.44	0.60	0.44
8/15/95 22:00	77.5	50.0	40.2	19998	17.17	359.64	-16.38	65.85	0.00	0.00	0.00	0.58	0.79	0.58
8/15/95 22:30	76.7	44.3	35.4	19398	15.60	367.83	-14.72	58.07	0.00	0.00	0.00	0.70	0.88	0.70
8/15/95 23:00	75.9	39.2	30.8	18798	14.53	375.36	-13.34	51.06	0.00	0.00	0.00	0.80	1.18	0.80
8/15/95 23:30	75.4	34.8	27.1	18198	13.28	382.31	-12.23	44.66	0.00	0.00	0.00	0.89	1.06	0.89
8/16/95 0:00	74.8	30.8	23.4	17802	12.82	388.84	-11.77	38.66	0.00	0.00	0.00	0.97	1.05	0.97
8/16/95 0:30	74.6	30.9	23.3	17598	13.12	395.32	-12.41	32.62	0.00	0.00	0.00	0.96	0.71	0.96

Day & time	outdoor	Chiller In	Chiller Out	Chiller	Cool from chiller	Ton-h from chiller	Cool from Tank	Ton-h from tank	Cool to 22-ton coil	Cool to 10-ton coil	Cool to 7.5-ton coil	Cool to CR coil	Cooling by chiller & tank	Total cooling at coils
0:30	(F)	(F)	(F)	(W)	(Ton)	(cum.)	(tons)	(cum.)	(tons)	(tons)	(tons)	(tons)	(tons)	(tons)
8/16/95 1:00	74.3	31.4	23.7	17598	13.21	401.91	-12.47	26.40	0.00	0.00	0.00	0.94	0.74	0.94
8/16/95 1:30	73.9	31.4	23.7	17598	13.26	408.52	-12.49	20.16	0.00	0.00	0.00	0.94	0.78	0.94
8/16/95 2:00	73.6	31.3	23.6	17400	13.35	415.18	-12.53	13.90	0.00	0.00	0.00	0.94	0.83	0.94
8/16/95 2:30	73.4	31.3	23.6	17400	13.26	421.83	-12.50	7.65	0.00	0.00	0.00	0.93	0.76	0.93
8/16/95 3:00	73.2	31.2	23.6	17598	13.02	428.40	-12.42	1.42	0.00	0.00	0.00	0.94	0.60	0.94
8/16/95 3:30	73.0	31.2	23.5	17400	13.23	434.97	-12.48	-4.81	0.00	0.00	0.00	0.93	0.76	0.93
8/16/95 4:00	72.7	31.1	23.4	17400	13.23	441.58	-12.49	-11.05	0.00	0.00	0.00	0.93	0.74	0.93
8/16/95 4:30	72.4	31.0	23.3	17400	13.27	448.21	-12.53	-17.30	0.00	0.00	0.00	0.93	0.74	0.93
8/16/95 5:00	72.1	31.0	23.3	17202	13.26	454.84	-12.53	-23.57	0.00	0.00	0.00	0.93	0.72	0.93
8/16/95 5:30	72.0	30.9	23.2	17400	13.30	461.48	-12.56	-29.84	0.00	0.00	0.00	0.93	0.74	0.93
8/16/95 6:00	71.8	30.9	23.2	16998	13.25	468.11	-12.54	-36.12	0.00	0.00	0.00	0.93	0.71	0.93
8/16/95 6:30	71.9	50.6	50.2	402	0.53	471.56	21.84	-33.79	9.69	8.38	4.14	0.65	22.37	22.86
8/16/95 7:00	72.0	49.1	49.0	0	0.09	471.71	19.89	-23.36	7.97	6.76	3.70	0.52	19.98	18.94
8/16/95 7:30	73.5	48.9	48.9	0	-0.04	471.73	19.11	-13.61	7.68	6.63	3.58	0.32	19.07	18.21
8/16/95 8:00	75.0	49.0	48.7	600	0.41	471.82	18.87	-4.12	7.68	6.62	3.63	0.29	19.29	18.21
8/16/95 8:30	77.9	47.2	45.6	4002	2.05	472.43	15.18	4.40	12.96	11.67	4.40	0.66	17.22	29.69
8/16/95 9:00	80.8	45.2	40.8	7602	5.98	474.44	11.38	11.03	16.00	13.76	4.68	0.79	17.36	35.23
8/16/95 9:30	84.1	49.6	48.1	3402	2.54	476.57	21.37	19.22	10.00	8.35	4.39	0.27	23.91	23.01
8/16/95 10:00	87.4	49.7	48.2	4002	3.06	477.97	21.54	29.95	10.07	7.79	4.61	0.21	24.60	22.67
8/16/95 10:30	90.0	50.3	47.5	6402	5.34	480.07	18.97	40.07	9.67	7.88	4.51	0.20	24.31	22.26
8/16/95 11:00	92.5	51.4	47.5	8202	7.45	483.27	15.49	48.69	9.31	7.47	4.27	0.18	22.94	21.23
8/16/95 11:30	94.5	53.4	45.6	17598	15.01	488.89	6.31	54.14	8.61	6.90	4.00	0.27	21.33	19.78
8/16/95 12:00	96.4	54.0	44.7	22398	18.00	497.14	2.79	56.41	8.30	7.26	3.97	0.24	20.79	19.77
8/16/95 12:30	95.8	54.6	45.3	22602	17.96	506.13	2.29	57.68	8.21	6.70	3.89	0.24	20.25	19.03
8/16/95 13:00	95.2	55.2	45.9	22800	17.95	515.11	1.88	58.72	7.86	6.81	3.77	0.27	19.83	18.70
8/16/95 13:30	96.9	55.6	46.2	22998	18.26	524.16	1.34	59.53	7.67	6.45	3.76	0.27	19.60	18.15
8/16/95 14:00	98.6	56.0	46.6	23202	18.10	533.25	1.22	60.17	7.74	6.40	3.68	0.29	19.33	18.11
8/16/95 14:30	98.7	56.3	47.0	23598	18.02	542.28	1.05	60.74	7.61	6.61	3.59	0.33	19.07	18.14
8/16/95 15:00	98.8	56.6	47.3	23598	18.02	551.29	0.84	61.21	7.49	6.28	3.54	0.40	18.86	17.71
8/16/95 15:30	98.1	56.8	47.4	23598	18.17	560.34	0.58	61.56	7.39	6.25	3.48	0.42	18.76	17.54
8/16/95 16:00	97.3	56.8	47.4	23802	18.19	569.43	0.23	61.76	7.38	5.95	3.44	0.27	18.43	17.04
8/16/95 16:30	95.9	57.0	47.5	23598	18.28	578.55	0.19	61.87	7.20	6.39	3.46	0.28	18.48	17.32
8/16/95 17:00	94.5	57.2	47.7	23400	18.44	587.73	0.19	61.97	7.24	6.31	3.46	0.43	18.64	17.44
8/16/95 17:30	93.1	57.1	47.7	23598	18.38	596.94	0.08	62.04	7.30	6.17	3.45	0.38	18.46	17.30
8/16/95 18:00	91.8	56.8	47.4	23400	18.22	606.09	-0.33	61.97	7.31	6.04	3.30	0.27	17.89	16.93
8/16/95 18:30	91.1	56.5	47.0	23202	18.46	615.26	-0.78	61.70	7.17	5.77	3.16	0.26	17.68	16.35
8/16/95 19:00	90.5	56.2	46.7	22998	18.47	624.49	-0.78	61.31	7.16	5.81	3.15	0.26	17.69	16.38
8/16/95 19:30	88.1	55.9	46.5	22998	18.35	633.70	-0.86	60.90	7.27	5.65	3.16	0.26	17.49	16.33
8/16/95 20:00	85.6	58.2	58.0	402	0.51	638.41	14.41	64.29	5.92	4.70	2.64	0.27	14.91	13.52
8/16/95 20:30	82.5	49.8	40.9	21000	15.55	642.42	-14.02	64.38	0.00	0.00	0.00	0.46	1.52	0.46
8/16/95 21:00	79.3	43.5	35.1	20598	14.75	650.00	-13.93	57.39	0.00	0.00	0.00	0.62	0.82	0.62

					Cool from	Ton-h from	Cool from	Ton-h from	Cool to	Cool to	Cool to	Cool to	Cooling by	Total cooling
Day & time	outdoor	Chiller In	Chiller Out	Chiller	chiller	chiller	Tank	tank	22-ton coil	10-ton coil	7.5-ton coil	CR coil	chiller & tank	at coils
0:30	(F)	(F)	(F)	(W)	(Ton)	(cum.)	(tons)	(cum.)	(tons)	(tons)	(tons)	(tons)	(tons)	(tons)
8/16/95 21:30	77.9	38.6	30.6	19602	13.74	657.12	-12.68	50.74	0.00	0.00	0.00	0.73	1.06	0.73
8/16/95 22:00	76.5	34.4	26.9	19200	13.01	663.81	-11.95	44.58	0.00	0.00	0.00	0.82	1.05	0.82
8/16/95 22:30	75.5	30.6	23.4	18402	12.40	670.16	-11.38	38.75	0.00	0.00	0.00	0.81	1.01	0.81
8/16/95 23:00	74.5	30.9	23.4	18000	12.88	676.48	-12.26	32.84	0.00	0.00	0.00	0.84	0.62	0.84
8/16/95 23:30	73.7	31.3	23.7	18000	13.12	682.98	-12.40	26.67	0.00	0.00	0.00	0.88	0.72	0.88
8/17/95 0:00	72.9	31.3	23.7	17598	13.21	689.56	-12.46	20.46	0.00	0.00	0.00	0.88	0.76	0.88
8/17/95 0:30	72.4	31.3	23.6	17598	13.26	696.18	-12.50	14.22	0.00	0.00	0.00	0.88	0.76	0.88
8/17/95 1:00	72.0	31.1	23.5	17400	13.06	702.76	-12.48	7.97	0.00	0.00	0.00	0.88	0.58	0.88
8/17/95 1:30	71.7	31.1	23.5	17400	13.15	709.31	-12.48	1.73	0.00	0.00	0.00	0.89	0.67	0.89
8/17/95 2:00	71.4	31.0	23.3	17202	13.25	715.91	-12.67	-4.56	0.00	0.00	0.00	0.75	0.58	0.75
8/17/95 2:30	71.2	31.1	23.4	17202	13.22	722.53	-12.55	-10.86	0.00	0.00	0.00	0.89	0.67	0.89
8/17/95 3:00	70.9	31.0	23.3	17202	13.23	729.14	-12.55	-17.13	0.00	0.00	0.00	0.89	0.69	0.89
8/17/95 3:30	70.7	31.0	23.2	16998	13.34	735.79	-12.59	-23.42	0.00	0.00	0.00	0.90	0.76	0.90
8/17/95 4:00	70.5	30.9	23.1	17202	13.29	742.45	-12.67	-29.73	0.00	0.00	0.00	0.76	0.62	0.76
8/17/95 4:30	70.3	30.8	23.1	16998	13.31	749.09	-12.60	-36.05	0.00	0.00	0.00	0.91	0.70	0.91
8/17/95 5:00	70.2	30.8	23.1	16800	13.24	755.73	-12.55	-42.34	0.00	0.00	0.00	0.90	0.69	0.90
8/17/95 5:30	70.1	30.7	23.0	16998	13.27	762.36	-12.60	-48.63	0.00	0.00	0.00	0.90	0.67	0.90
8/17/95 6:00	70.0	30.7	22.9	16800	13.36	769.01	-12.59	-54.92	0.00	0.00	0.00	0.90	0.77	0.90
8/17/95 6:30	70.0	47.7	46.8	1998	1.77	772.80	26.00	-51.57	12.48	9.60	5.04	0.37	27.76	27.49
8/17/95 7:00	70.0	47.5	47.5	0	-0.17	773.19	24.46	-38.96	10.31	7.23	4.43	0.05	24.28	22.01
8/17/95 7:30	71.2	47.8	47.8	0	0.04	773.16	23.30	-27.02	9.60	7.05	4.21	0.04	23.34	20.90
8/17/95 8:00	72.5	48.1	48.1	0	0.00	773.17	23.03	-15.44	9.48	6.81	4.20	0.04	23.03	20.52
8/17/95 8:30	75.3	48.4	48.6	0	-0.23	773.11	23.34	-3.85	9.48	7.14	4.24	0.03	23.10	20.89
8/17/95 9:00	78.1	48.7	48.7	0	-0.14	773.02	23.32	7.81	9.45	7.10	4.27	0.04	23.18	20.86
8/17/95 9:30	81.7	49.1	48.9	1002	0.48	773.11	22.43	19.25	9.38	7.28	4.25	0.03	22.91	20.95
8/17/95 10:00	85.3	49.4	47.7	3600	3.21	774.03	19.88	29.83	9.23	7.47	4.29	0.01	23.09	21.01
8/17/95 10:30	88.0	50.7	50.7	0	0.06	774.85	22.46	40.41	8.86	7.20	4.13	0.00	22.52	20.18
8/17/95 11:00	90.7	53.2	53.2	0	0.04	774.87	20.65	51.19	7.91	7.07	3.80	0.01	20.69	18.80
8/17/95 11:30	92.5	57.2	57.2	0	0.10	774.91	17.56	60.74	6.46	5.89	3.18	0.26	17.66	15.78
8/17/95 12:00	94.3	61.2	61.1	0	0.12	774.96	14.64	68.79	5.18	4.88	2.61	0.38	14.76	13.05
8/17/95 12:30	95.7	64.5	64.5	0	0.06	775.01	12.14	75.49	4.20	4.08	2.12	0.25	12.20	10.65
8/17/95 13:00	97.2	67.4	67.3	0	0.16	775.06	10.07	81.04	3.30	3.15	1.73	0.30	10.23	8.47
8/17/95 13:30	97.8	69.7	69.7	198	0.04	775.11	8.38	85.66	2.73	2.55	1.47	0.23	8.42	6.97
8/17/95 14:00	98.4	71.8	71.6	0	0.40	775.22	7.07	89.52	2.17	2.08	1.29	0.16	7.47	5.70
8/17/95 14:30	98.1	73.7	73.5	0	0.40	775.42	6.15	92.83	1.59	1.92	1.11	0.14	6.55	4.76
8/17/95 15:00	97.7	75.4	75.3	198	0.20	775.57	5.37	95.71	1.16	2.06	0.97	0.11	5.57	4.30
8/17/95 15:30	97.6	76.7	76.9	198	-0.40	775.52	4.77	98.24	0.94	2.13	0.84	0.11	4.38	4.02
8/17/95 16:00	97.5	76.4	70.4	10002	11.91	778.39	-6.55	97.80	1.30	1.99	0.97	0.16	5.36	4.42
8/17/95 16:30	96.4	74.1	67.0	11598	14.07	784.89	-7.24	94.35	2.16	2.18	1.24	0.23	6.83	5.81
8/17/95 17:00	95.4	72.2	63.9	15402	16.32	792.49	-8.30	90.46	2.73	2.41	1.47	0.27	8.02	6.89
8/17/95 17:30	93.1	68.9	58.0	24402	21.50	801.94	-11.63	85.48	3.83	3.30	1.89	0.35	9.86	9.37

					Cool from	Ton-h from	Cool from	Ton-h from	Cool to	Cool to	Cool to	Cool to	Cooling by	Total cooling
Day & time	outdoor	Chiller In	Chiller Out	Chiller	chiller	chiller	Tank	tank	22-ton coil	10-ton coil	7.5-ton coil	CR coil	chiller & tank	at coils
0:30	(F)	(F)	(F)	(W)	(Ton)	(cum.)	(tons)	(cum.)	(tons)	(tons)	(tons)	(tons)	(tons)	(tons)
8/17/95 18:00	90.9	66.3	55.6	24000	21.02	812.57	-9.27	80.25	4.64	3.75	2.07	0.45	11.75	10.91
8/17/95 18:30	89.4	64.1	53.6	24000	20.64	822.99	-7.47	76.07	5.07	4.37	2.30	0.52	13.17	12.26
8/17/95 19:00	88.0	62.5	52.1	23202	20.37	833.24	-5.93	72.72	5.53	4.91	2.51	0.58	14.44	13.53
8/17/95 19:30	85.0	61.3	50.9	22998	20.23	843.39	-4.78	70.04	6.00	4.90	2.64	0.59	15.45	14.13
8/17/95 20:00	82.0	62.8	62.5	402	0.59	848.60	12.28	71.91	4.92	4.14	2.21	0.37	12.87	11.64
8/17/95 20:30	80.4	54.8	45.1	20598	17.17	853.04	-15.78	71.04	0.00	0.00	0.00	0.43	1.39	0.43
8/17/95 21:00	78.8	48.0	38.7	19998	16.38	861.43	-15.59	63.19	0.00	0.00	0.00	0.57	0.79	0.57
8/17/95 21:30	77.8	42.5	34.0	19398	14.92	869.25	-14.03	55.79	0.00	0.00	0.00	0.69	0.89	0.69
8/17/95 22:00	76.8	37.6	29.7	18600	13.72	876.41	-12.74	49.10	0.00	0.00	0.00	0.79	0.99	0.79
8/17/95 22:30	76.0	33.5	26.0	18402	13.00	883.09	-11.82	42.96	0.00	0.00	0.00	0.88	1.17	0.88
8/17/95 23:00	75.2	30.2	22.9	18000	12.50	889.47	-11.59	37.10	0.00	0.00	0.00	0.95	0.91	0.95
8/17/95 23:30	74.6	31.2	23.6	17802	13.10	895.87	-12.32	31.13	0.00	0.00	0.00	0.92	0.77	0.92
8/18/95 0:00	73.9	31.4	23.7	17802	13.27	902.46	-12.42	24.94	0.00	0.00	0.00	0.92	0.84	0.92
8/18/95 0:30	73.6	31.3	23.7	17598	13.09	909.05	-12.40	18.73	0.00	0.00	0.00	0.92	0.69	0.92
8/18/95 1:00	73.2	31.3	23.7	17598	13.16	915.61	-12.42	12.52	0.00	0.00	0.00	0.92	0.74	0.92
8/18/95 1:30	73.0	31.2	23.6	17598	13.18	922.20	-12.42	6.31	0.00	0.00	0.00	0.92	0.76	0.92
8/18/95 2:00	72.7	31.2	23.4	17400	13.30	928.82	-12.50	0.08	0.00	0.00	0.00	0.92	0.81	0.92
8/18/95 2:30	72.4	31.1	23.5	17400	13.18	935.44	-12.45	-6.15	0.00	0.00	0.00	0.92	0.72	0.92
8/18/95 3:00	72.1	31.1	23.4	17400	13.21	942.03	-12.49	-12.39	0.00	0.00	0.00	0.92	0.72	0.92
8/18/95 3:30	72.0	31.0	23.3	17202	13.30	948.66	-12.53	-18.64	0.00	0.00	0.00	0.92	0.77	0.92
8/18/95 4:00	71.8	31.0	23.3	17202	13.25	955.30	-12.51	-24.90	0.00	0.00	0.00	0.92	0.74	0.92
8/18/95 4:30	71.5	30.9	23.2	17202	13.14	961.90	-12.49	-31.15	0.00	0.00	0.00	0.92	0.65	0.92
8/18/95 5:00	71.2	30.9	23.1	16998	13.30	968.51	-12.51	-37.41	0.00	0.00	0.00	0.92	0.79	0.92
8/18/95 5:30	71.2	30.8	23.1	17202	13.23	975.14	-12.49	-43.66	0.00	0.00	0.00	0.92	0.74	0.92
8/18/95 6:00	71.1	30.7	23.1	16800	13.11	981.73	-12.46	-49.89	0.00	0.00	0.00	0.92	0.65	0.92
8/18/95 6:30	71.2	48.1	46.4	3000	3.21	985.81	25.54	-46.62	12.52	9.94	5.19	0.43	28.74	28.09
8/18/95 7:00	71.4	47.8	47.8	0	-0.04	986.60	25.01	-33.99	10.30	7.69	4.49	0.04	24.97	22.53
8/18/95 7:30	72.3	48.1	48.1	0	0.08	986.61	23.86	-21.77	9.81	7.02	4.33	0.07	23.94	21.23
8/18/95 8:00	73.2	48.6	48.7	0	-0.21	986.58	23.82	-9.85	9.85	7.13	4.34	0.04	23.61	21.36
8/18/95 8:30	75.7	48.9	48.9	0	-0.14	986.49	23.81	2.06	9.64	7.52	4.18	0.04	23.67	21.37
8/18/95 9:00	78.1	49.3	48.7	1398	1.03	986.71	22.90	13.73	9.62	7.48	4.44	0.03	23.93	21.58
8/18/95 9:30	82.0	49.7	47.9	3402	3.35	987.81	20.62	24.61	9.45	7.93	4.51	0.27	23.96	22.16
8/18/95 10:00	86.0	50.0	47.8	5400	4.39	989.74	19.28	34.59	9.55	7.78	4.51	0.00	23.68	21.84
8/18/95 10:30	88.9	50.8	47.7	6600	6.03	992.35	17.15	43.70	9.41	7.73	4.46	0.02	23.17	21.62
8/18/95 11:00	91.8	52.3	45.6	14400	12.98	997.10	8.97	50.23	8.76	7.78	4.27	0.00	21.94	20.81
8/18/95 11:30	93.7	53.2	43.9	21798	17.88	1004.81	3.62	53.37	8.69	7.51	4.26	0.14	21.50	20.60
8/18/95 12:00	95.5	54.1	44.9	22200	17.87	1013.75	3.06	55.04	8.35	7.35	4.12	0.17	20.93	20.00
8/18/95 12:30	96.4	54.9	45.6	22602	17.94	1022.70	2.72	56.49	8.25	7.10	4.03	0.31	20.66	19.69
8/18/95 13:00	97.3	55.5	46.3	22800	17.97	1031.68	2.20	57.72	7.94	7.17	3.97	0.30	20.17	19.39
8/18/95 13:30	97.5	56.0	46.7	22998	18.12	1040.70	1.73	58.70	7.83	6.79	3.89	0.29	19.85	18.80
8/18/95 14:00	97.7	56.5	47.0	23202	18.31	1049.81	1.44	59.49	7.59	6.83	5.11	0.41	19.74	19.93

Roofberg Performance
August 14-21, 1995

					Cool from	Ton-h from	Cool from	Ton-h from	Cool to	Cool to	Cool to	Cool to	Cooling by	Total cooling
Day & time	outdoor	Chiller In	Chiller Out	Chiller	chiller	chiller	Tank	tank	22-ton coil	10-ton coil	7.5-ton coil	CR coil	chiller & tank	at coils
0:30	(F)	(F)	(F)	(W)	(Ton)	(cum.)	(tons)	(cum.)	(tons)	(tons)	(tons)	(tons)	(tons)	(tons)
8/18/95 14:30	97.9	56.9	47.3	23400	18.61	1059.04	1.03	60.11	7.47	6.39	3.79	0.45	19.64	18.10
8/18/95 15:00	98.1	57.0	47.7	23400	18.16	1068.23	0.88	60.58	7.38	6.81	3.72	0.32	19.03	18.24
8/18/95 15:30	98.2	57.3	47.9	23598	18.20	1077.32	0.78	61.00	7.39	6.71	3.73	0.31	18.98	18.13
8/18/95 16:00	98.4	57.5	48.1	23802	18.30	1086.44	0.60	61.34	7.32	6.59	3.67	0.41	18.90	17.99
8/18/95 16:30	94.9	57.6	48.1	23598	18.52	1095.65	0.37	61.59	7.21	6.29	3.62	0.41	18.89	17.53
8/18/95 17:00	91.4	57.6	48.2	23802	18.39	1104.87	0.27	61.75	7.18	6.26	3.61	0.36	18.66	17.41
8/18/95 17:30	88.9	57.7	48.2	23598	18.48	1114.09	0.12	61.84	7.06	6.61	3.61	0.30	18.60	17.58
8/18/95 18:00	86.4	57.5	48.0	23598	18.59	1123.36	-0.39	61.78	6.98	6.43	3.41	0.27	18.20	17.10
8/18/95 18:30	85.7	56.9	47.4	22998	18.47	1132.62	-0.80	61.48	7.11	5.90	3.25	0.27	17.67	16.53
8/18/95 19:00	85.1	56.6	47.0	22800	18.72	1141.92	-0.99	61.03	7.02	5.95	3.28	0.29	17.73	16.54
8/18/95 19:30	83.2	56.1	46.4	22200	18.84	1151.31	-1.36	60.44	7.02	5.83	3.21	0.31	17.48	16.37
8/18/95 20:00	81.3	55.4	47.1	18402	16.23	1160.08	0.72	60.28	7.18	5.36	3.21	0.28	16.95	16.03
8/18/95 20:30	79.4	45.2	36.8	19800	14.70	1167.81	-13.16	57.17	0.00	0.00	0.00	0.50	1.54	0.50
8/18/95 21:00	77.5	39.2	31.2	19602	13.99	1174.99	-13.17	50.59	0.00	0.00	0.00	0.69	0.82	0.69
8/18/95 21:30	77.7	34.8	27.1	18798	13.22	1181.79	-12.16	44.26	0.00	0.00	0.00	0.78	1.06	0.78
8/18/95 22:00	77.9	30.8	23.6	18198	12.48	1188.21	-11.67	38.30	0.00	0.00	0.00	0.71	0.81	0.71
8/18/95 22:30	77.5	30.6	23.3	18402	12.56	1194.47	-11.96	32.40	0.00	0.00	0.00	0.70	0.60	0.70
8/18/95 23:00	77.0	31.3	23.8	18198	13.00	1200.86	-12.31	26.33	0.00	0.00	0.00	0.86	0.69	0.86
8/18/95 23:30	76.1	31.3	23.6	18000	13.14	1207.40	-12.52	20.12	0.00	0.00	0.00	0.71	0.62	0.71
8/19/95 0:00	75.2	31.3	23.7	17802	13.14	1213.97	-12.45	13.88	0.00	0.00	0.00	0.87	0.69	0.87
8/19/95 0:30	74.6	31.1	23.4	17802	13.25	1220.56	-12.62	7.61	0.00	0.00	0.00	0.71	0.64	0.71
8/19/95 1:00	73.9	31.1	23.5	17598	13.11	1227.16	-12.49	1.33	0.00	0.00	0.00	0.87	0.62	0.87
8/19/95 1:30	73.2	31.0	23.4	17598	13.06	1233.70	-12.58	-4.94	0.00	0.00	0.00	0.72	0.48	0.72
8/19/95 2:00	72.5	31.0	23.3	17400	13.16	1240.26	-12.61	-11.23	0.00	0.00	0.00	0.71	0.55	0.71
8/19/95 2:30	72.1	31.0	23.3	17598	13.25	1246.86	-12.54	-17.52	0.00	0.00	0.00	0.88	0.71	0.88
8/19/95 3:00	71.6	30.9	23.3	17400	13.08	1253.44	-12.50	-23.78	0.00	0.00	0.00	0.81	0.59	0.81
8/19/95 3:30	71.3	30.8	23.1	17400	13.24	1260.02	-12.64	-30.07	0.00	0.00	0.00	0.80	0.60	0.80
8/19/95 4:00	71.1	30.8	23.1	17202	13.29	1266.66	-12.57	-36.37	0.00	0.00	0.00	0.88	0.72	0.88
8/19/95 4:30	70.9	30.7	23.0	17202	13.39	1273.33	-12.73	-42.69	0.00	0.00	0.00	0.74	0.65	0.74
8/19/95 5:00	70.7	30.7	23.0	17202	13.25	1279.99	-12.59	-49.02	0.00	0.00	0.00	0.88	0.65	0.88
8/19/95 5:30	70.4	47.6	47.5	402	0.19	1283.35	27.17	-45.38	12.25	9.88	5.03	0.35	27.36	27.51
8/19/95 6:00	70.2	47.4	47.4	0	0.04	1283.41	24.21	-32.54	9.99	7.22	4.38	0.05	24.24	21.65
8/19/95 6:30	70.3	47.6	47.7	0	-0.15	1283.38	23.22	-20.68	9.63	6.94	4.17	0.04	23.07	20.78
8/19/95 7:00	70.3	47.8	47.8	0	0.02	1283.34	22.52	-9.24	9.31	6.61	4.09	0.04	22.54	20.03
8/19/95 7:30	71.4	47.8	47.9	0	-0.19	1283.30	22.27	1.95	9.21	6.68	4.02	0.06	22.08	19.97
8/19/95 8:00	72.5	47.9	48.0	0	-0.25	1283.19	21.99	13.02	9.10	6.61	3.95	0.04	21.74	19.70
8/19/95 8:30	75.4	48.3	48.4	0	-0.17	1283.08	21.54	23.90	8.89	6.40	3.88	0.02	21.36	19.19
8/19/95 9:00	78.3	48.7	48.9	0	-0.37	1282.95	21.09	34.56	8.71	6.47	3.79	0.02	20.73	18.98
8/19/95 9:30	81.5	49.5	48.3	3000	2.49	1283.47	17.50	44.21	8.41	6.07	3.61	0.01	19.99	18.11
8/19/95 10:00	84.7	51.0	46.0	9198	9.68	1286.52	9.21	50.88	7.72	6.43	3.50	0.02	18.89	17.66
8/19/95 10:30	87.4	52.6	46.1	13002	12.58	1292.08	5.18	54.48	7.34	5.89	3.28	0.00	17.75	16.51

Roofberg Performance
August 14-21, 1995

Day & time	outdoor	Chiller In	Chiller Out	Chiller	Cool from chiller	Ton-h from chiller	Cool from Tank	Ton-h from tank	Cool to 22-ton coil	Cool to 10-ton coil	Cool to 7.5-ton coil	Cool to CR coil	Cooling by chiller & tank	Total cooling at coils
0:30	(F)	(F)	(F)	(W)	(Ton)	(cum.)	(tons)	(cum.)	(tons)	(tons)	(tons)	(tons)	(tons)	(tons)
8/19/95 11:00	90.0	52.6	43.3	21000	18.08	1299.74	-0.29	55.70	7.46	6.15	3.36	-0.02	17.78	16.96
8/19/95 11:30	91.8	52.6	43.4	21198	18.01	1308.76	-0.08	55.61	7.37	6.28	3.36	0.01	17.93	17.02
8/19/95 12:00	93.6	52.7	43.6	21600	17.75	1317.70	0.10	55.61	7.51	6.27	3.34	0.01	17.85	17.14
8/19/95 12:30	94.7	52.9	43.7	21798	17.85	1326.61	0.12	55.67	7.35	6.41	3.30	0.03	17.97	17.09
8/19/95 13:00	95.9	53.0	43.9	22002	17.54	1335.45	0.31	55.78	7.31	6.40	3.30	0.05	17.85	17.06
8/19/95 13:30	95.5	53.0	44.1	22602	17.33	1344.17	0.37	55.95	7.26	6.49	3.28	0.02	17.70	17.06
8/19/95 14:00	95.0	53.2	44.2	22998	17.52	1352.88	0.27	56.11	7.11	6.16	3.25	0.03	17.79	16.55
8/19/95 14:30	95.0	53.2	44.3	23400	17.20	1361.56	0.25	56.24	7.10	6.15	3.24	0.02	17.45	16.52
8/19/95 15:00	95.0	53.2	44.4	22800	17.08	1370.13	0.23	56.36	7.20	6.11	3.22	0.02	17.31	16.55
8/19/95 15:30	96.0	53.3	44.5	23598	17.20	1378.70	0.19	56.46	7.08	5.89	3.19	0.03	17.40	16.19
8/19/95 16:00	97.0	53.4	44.7	23598	16.90	1387.23	0.23	56.57	6.96	6.37	3.17	0.03	17.14	16.53
8/19/95 16:30	96.4	53.4	44.5	23400	17.29	1395.78	-0.08	56.61	6.88	6.07	3.12	0.02	17.21	16.10
8/19/95 17:00	95.9	53.4	44.4	23202	17.54	1404.48	-0.25	56.53	6.81	6.12	3.14	0.03	17.29	16.11
8/19/95 17:30	92.6	53.4	44.4	23202	17.40	1413.22	-0.19	56.42	6.98	5.99	3.12	0.02	17.20	16.11
8/19/95 18:00	89.2	53.4	44.4	22998	17.55	1421.95	-0.23	56.31	6.99	5.85	3.13	0.03	17.32	16.00
8/19/95 18:30	87.5	53.4	44.3	22800	17.69	1430.76	-0.33	56.17	6.93	5.91	3.15	0.04	17.36	16.05
8/19/95 19:00	85.8	53.2	44.2	22800	17.56	1439.58	-0.41	55.98	6.94	6.02	3.16	0.04	17.15	16.15
8/19/95 19:30	83.8	53.0	43.9	22200	17.78	1448.41	-0.58	55.74	6.95	5.80	3.18	0.05	17.20	15.98
8/19/95 20:00	81.9	52.8	44.9	18798	15.42	1456.71	1.50	55.96	6.95	5.88	3.16	0.05	16.92	16.04
8/19/95 20:30	80.6	42.9	34.9	19800	14.03	1464.08	-12.32	53.26	0.00	0.00	0.00	0.52	1.71	0.52
8/19/95 21:00	79.3	36.9	29.3	19800	13.35	1470.92	-12.53	47.04	0.00	0.00	0.00	0.55	0.82	0.55
8/19/95 21:30	79.0	32.9	25.7	19398	12.51	1477.39	-11.61	41.01	0.00	0.00	0.00	0.61	0.90	0.61
8/19/95 22:00	78.6	30.2	23.1	18402	12.22	1483.57	-11.47	35.24	0.00	0.00	0.00	0.67	0.76	0.67
8/19/95 22:30	77.8	31.1	23.6	18402	12.94	1489.86	-12.39	29.28	0.00	0.00	0.00	0.64	0.55	0.64
8/19/95 23:00	77.0	31.2	23.7	18402	12.96	1496.33	-12.43	23.07	0.00	0.00	0.00	0.59	0.53	0.59
8/19/95 23:30	76.6	31.1	23.6	18198	13.04	1502.83	-12.52	16.84	0.00	0.00	0.00	0.59	0.52	0.59
8/20/95 0:00	76.1	31.1	23.6	18198	12.94	1509.33	-12.44	10.59	0.00	0.00	0.00	0.67	0.50	0.67
8/20/95 0:30	75.5	31.1	23.5	18000	13.10	1515.84	-12.53	4.35	0.00	0.00	0.00	0.68	0.57	0.68
8/20/95 1:00	74.8	31.0	23.4	18000	13.08	1522.39	-12.52	-1.91	0.00	0.00	0.00	0.68	0.57	0.68
8/20/95 1:30	74.2	30.9	23.5	18000	12.85	1528.87	-12.45	-8.16	0.00	0.00	0.00	0.69	0.40	0.69
8/20/95 2:00	73.6	30.9	23.4	17802	13.01	1535.34	-12.48	-14.39	0.00	0.00	0.00	0.67	0.53	0.67
8/20/95 2:30	72.9	30.8	23.3	17802	12.99	1541.84	-12.48	-20.63	0.00	0.00	0.00	0.67	0.52	0.67
8/20/95 3:00	72.1	30.8	23.2	17598	13.20	1548.39	-12.62	-26.90	0.00	0.00	0.00	0.68	0.59	0.68
8/20/95 3:30	71.9	30.7	23.1	17598	13.12	1554.97	-12.59	-33.20	0.00	0.00	0.00	0.69	0.53	0.69
8/20/95 4:00	71.6	30.7	23.1	17400	13.06	1561.52	-12.60	-39.50	0.00	0.00	0.00	0.69	0.47	0.69
8/20/95 4:30	72.1	30.7	22.9	17400	13.33	1568.11	-12.69	-45.82	0.00	0.00	0.00	0.70	0.64	0.70
8/20/95 5:00	72.5	30.6	22.9	17400	13.21	1574.75	-12.66	-52.15	0.00	0.00	0.00	0.65	0.55	0.65
8/20/95 5:30	72.9	47.0	46.7	402	0.49	1578.17	25.94	-48.83	11.47	9.35	4.72	0.30	26.43	25.84
8/20/95 6:00	73.2	46.7	46.7	0	-0.02	1578.29	23.26	-36.53	9.56	7.01	4.18	0.04	23.24	20.79
8/20/95 6:30	73.3	47.0	47.0	0	0.06	1578.30	22.44	-25.11	9.22	6.55	4.01	0.06	22.50	19.84
8/20/95 7:00	73.4	47.2	47.3	0	-0.12	1578.28	22.00	-14.00	8.95	6.59	3.88	0.03	21.89	19.45

Day & time 0:30	outdoor (F)	Chiller In (F)	Chiller Out (F)	Chiller (W)	Cool from chiller (Ton)	Ton-h from chiller (cum.)	Cool from Tank (tons)	Ton-h from tank (cum.)	Cool to 22-ton coil (tons)	Cool to 10-ton coil (tons)	Cool to 7.5-ton coil (tons)	Cool to CR coil (tons)	Cooling by chiller & tank (tons)	Total cooling at coils (tons)
8/20/95 7:30	73.5	47.3	47.4	0	-0.23	1578.19	21.78	-3.05	8.83	6.66	3.84	0.05	21.55	19.38
8/20/95 8:00	73.6	47.4	47.4	0	0.00	1578.14	21.43	7.75	8.58	6.51	3.81	0.05	21.43	18.94
8/20/95 8:30	74.0	47.7	47.8	0	-0.16	1578.10	20.99	18.35	8.42	6.54	3.74	0.06	20.83	18.76
8/20/95 9:00	74.5	48.1	48.1	0	0.00	1578.06	20.49	28.72	8.17	6.18	3.63	0.04	20.49	18.03
8/20/95 9:30	74.8	48.8	48.8	0	0.02	1578.06	19.78	38.79	7.88	6.04	3.55	0.06	19.80	17.54
8/20/95 10:00	75.2	49.9	47.3	5598	5.15	1579.36	13.31	47.06	7.44	6.04	3.35	0.05	18.45	16.88
8/20/95 10:30	74.8	51.1	45.8	9000	10.33	1583.23	6.64	52.04	7.10	5.44	3.16	0.02	16.97	15.71
8/20/95 11:00	74.3	52.2	45.9	11202	12.19	1588.86	3.89	54.68	6.63	5.30	3.02	0.03	16.08	14.99
8/20/95 11:30	74.5	51.7	42.1	19200	18.80	1596.60	-2.27	55.08	6.95	5.33	3.09	0.03	16.52	15.40
8/20/95 12:00	74.7	51.2	41.6	18798	18.68	1605.97	-1.79	54.07	7.07	5.73	3.19	0.05	16.90	16.05
8/20/95 12:30	75.7	50.7	41.1	18798	18.66	1615.31	-1.57	53.23	7.26	5.64	3.24	0.03	17.09	16.18
8/20/95 13:00	76.8	50.3	40.8	18798	18.50	1624.60	-1.32	52.50	7.22	6.08	3.28	0.06	17.19	16.64
8/20/95 13:30	78.8	49.4	42.8	12402	12.82	1632.43	1.87	52.64	12.15	5.99	3.16	0.03	14.69	21.33
8/20/95 14:00	80.8	50.5	41.0	18600	18.44	1640.25	-1.53	52.72	7.35	5.42	3.20	0.03	16.90	15.99
8/20/95 14:30	82.5	49.4	43.0	12000	12.46	1647.97	2.29	52.91	11.95	5.66	3.20	0.01	14.75	20.81
8/20/95 15:00	84.2	52.2	46.0	10998	12.05	1654.10	3.99	54.48	6.56	5.35	2.96	0.04	16.05	14.91
8/20/95 15:30	83.9	50.9	43.0	15600	15.38	1660.96	-1.07	55.21	12.32	5.46	3.02	0.04	14.31	20.84
8/20/95 16:00	83.7	51.0	42.0	18798	17.43	1669.16	-1.81	54.50	10.20	5.82	3.08	0.04	15.63	19.14
8/20/95 16:30	82.3	51.2	43.2	16602	15.67	1677.44	0.31	54.12	9.43	5.77	3.09	0.25	15.98	18.54
8/20/95 17:00	81.0	50.1	42.4	15798	15.06	1685.12	-0.66	54.03	12.55	5.62	3.10	0.04	14.40	21.31
8/20/95 17:30	80.3	49.8	41.9	16200	15.34	1692.72	-0.72	53.69	12.80	5.75	3.10	0.23	14.62	21.89
8/20/95 18:00	79.7	49.7	41.3	17400	16.17	1700.60	-1.46	53.14	12.37	5.77	3.14	0.03	14.71	21.31
8/20/95 18:30	78.5	51.0	43.8	14400	14.04	1708.15	1.67	53.20	9.77	5.59	3.05	0.03	15.71	18.44
8/20/95 19:00	77.4	51.1	45.0	11202	11.76	1714.60	3.02	54.37	10.67	5.63	2.98	0.21	14.78	19.49
8/20/95 19:30	76.0	51.1	44.0	13998	13.78	1720.99	-0.16	55.09	12.60	5.43	2.95	0.03	13.62	21.01
8/20/95 20:00	74.7	50.5	44.0	13200	12.77	1727.62	1.07	55.32	12.92	5.44	3.01	0.24	13.84	21.60
8/20/95 20:30	73.9	42.0	33.7	17802	14.50	1734.44	-12.94	52.35	0.00	0.00	0.00	0.34	1.56	0.34
8/20/95 21:00	73.0	35.8	28.0	17802	13.66	1741.48	-13.06	45.85	0.00	0.00	0.00	0.36	0.59	0.36
8/20/95 21:30	72.8	31.7	24.2	17400	13.06	1748.16	-12.29	39.51	0.00	0.00	0.00	0.53	0.76	0.53
8/20/95 22:00	72.5	30.2	22.8	17202	12.81	1754.63	-12.39	33.34	0.00	0.00	0.00	0.47	0.42	0.47
8/20/95 22:30	72.3	31.1	23.4	17400	13.36	1761.17	-12.96	27.00	0.00	0.00	0.00	0.50	0.40	0.50
8/20/95 23:00	72.1	31.2	23.5	17202	13.38	1767.85	-12.89	20.54	0.00	0.00	0.00	0.54	0.49	0.54
8/20/95 23:30	71.9	31.1	23.4	17202	13.30	1774.52	-13.01	14.06	0.00	0.00	0.00	0.46	0.29	0.46
8/21/95 0:00	71.6	31.1	23.4	17202	13.33	1781.18	-12.87	7.60	0.00	0.00	0.00	0.60	0.47	0.60
8/21/95 0:30	71.5	30.9	23.3	17202	13.31	1787.84	-13.00	1.13	0.00	0.00	0.00	0.43	0.31	0.43
8/21/95 1:00	71.4	31.0	23.2	17202	13.38	1794.52	-12.88	-5.34	0.00	0.00	0.00	0.62	0.50	0.62
8/21/95 1:30	71.2	30.8	23.1	16998	13.40	1801.21	-13.00	-11.81	0.00	0.00	0.00	0.42	0.40	0.42
8/21/95 2:00	71.1	30.9	23.1	17202	13.51	1807.94	-12.93	-18.30	0.00	0.00	0.00	0.63	0.57	0.63
8/21/95 2:30	70.9	30.8	23.1	16998	13.37	1814.66	-12.95	-24.77	0.00	0.00	0.00	0.46	0.42	0.46
8/21/95 3:00	70.7	30.7	23.1	16998	13.28	1821.32	-12.86	-31.22	0.00	0.00	0.00	0.60	0.42	0.60
8/21/95 3:30	70.8	30.7	23.0	17202	13.34	1827.97	-12.89	-37.66	0.00	0.00	0.00	0.48	0.45	0.48

Roofberg Performance
August 14-21, 1995

Day & time 0:30	outdoor (F)	Chiller In (F)	Chiller Out (F)	Chiller (W)	Cool from chiller (Ton)	Ton-h from chiller (cum.)	Cool from Tank (tons)	Ton-h from tank (cum.)	Cool to 22-ton coil (tons)	Cool to 10-ton coil (tons)	Cool to 7.5-ton coil (tons)	Cool to CR coil (tons)	Cooling by chiller & tank (tons)	Total cooling at coils (tons)
8/21/95 4:00	70.9	30.6	22.9	16998	13.32	1834.64	-12.84	-44.09	0.00	0.00	0.00	0.60	0.48	0.60
8/21/95 4:30	70.8	30.6	22.8	16998	13.34	1841.30	-12.81	-50.50	0.00	0.00	0.00	0.53	0.54	0.53
8/21/95 5:00	70.7	30.4	22.8	16800	13.10	1847.92	-12.79	-56.90	0.00	0.00	0.00	0.53	0.31	0.53
8/21/95 5:30	70.7	46.3	46.0	402	0.58	1851.34	24.86	-53.88	11.11	9.35	4.62	0.27	25.44	25.36
8/21/95 6:00	70.7	46.1	46.1	0	0.04	1851.49	22.44	-42.06	9.09	6.74	4.03	0.04	22.48	19.91
8/21/95 6:30	71.0	46.4	46.4	0	-0.12	1851.47	21.64	-31.04	8.76	6.48	3.86	0.05	21.53	19.15
8/21/95 7:00	71.2	46.7	46.8	0	-0.27	1851.38	21.30	-20.30	8.54	6.59	3.79	0.04	21.03	18.96
8/21/95 7:30	71.6	44.9	44.8	0	0.06	1851.32	18.09	-10.45	14.60	6.65	3.83	0.04	18.14	25.11
8/21/95 8:00	72.0	45.0	45.1	0	-0.10	1851.31	18.40	-1.33	14.84	6.72	3.96	0.04	18.31	25.57

Day & time	outdoor	Chiller In	Chiller Ou	Chiller	Cool fm chille	Ton-h from chiller	Cool from Tank	Ton-h from tank	Cool to 22-ton coil	Cool to 10-ton coil	Cool to 7.5 ton coil	Cool to CR coil	Cooling by chiller & tank	Total coolin at coils
0:30	(F)	(F)	(F)	(W)	(tons)	(cum.)	(tons)	(cum)	(tons)	(tons)	(tons)	(tons)	(tons)	(tons)
8/21/95 8:30	72.41	45.73	45.71	0	0.04	0.01	18.73	4.68	15.50	6.85	4.05	0.04	18.77	26.43
8/21/95 9:00	72.86	46.18	46.27	0	-0.17	-0.02	18.92	14.09	14.95	6.95	4.04	0.23	18.74	26.17
8/21/95 9:30	73.94	46.79	46.86	0	-0.14	-0.10	18.81	23.52	14.63	6.73	3.99	0.03	18.67	25.38
8/21/95 10:00	75.02	47.63	47.77	198	-0.27	-0.20	19.05	32.99	14.67	6.83	3.97	0.24	18.78	25.71
8/21/95 10:30	77.99	48.61	47.59	2400	1.98	0.22	16.16	41.79	14.89	6.50	3.93	0.22	18.14	25.54
8/21/95 11:00	80.96	51.41	46.94	7800	8.69	2.89	10.02	48.33	9.69	6.27	3.73	0.03	18.71	19.72
8/21/95 11:30	83.39	52.17	45.63	12798	12.74	8.25	4.11	51.87	10.93	6.08	3.57	0.20	16.85	20.78
8/21/95 12:00	85.82	51.62	43.19	17802	16.40	15.54	0.02	52.90	13.15	6.39	3.74	0.21	16.42	23.50
8/21/95 12:30	87.35	51.69	42.96	19398	16.98	23.88	-0.47	52.79	12.74	6.42	3.77	0.16	16.51	23.09
8/21/95 13:00	88.88	52.22	43.06	20598	17.80	32.58	-0.33	52.59	10.63	6.58	3.72	0.03	17.47	20.96
8/21/95 13:30	90.5	52.36	43.61	19998	17.00	41.28	0.95	52.74	10.27	6.54	3.81	0.23	17.96	20.84
8/21/95 14:00	92.12	52	43.71	18798	16.11	49.56	0.51	53.11	15.80	6.33	3.75	0.03	16.62	25.92
8/21/95 14:30	91.67	53.42	44.03	21402	18.25	58.15	0.51	53.36	7.59	6.32	3.71	0.03	18.75	17.65
8/21/95 15:00	91.22	53.48	44.13	21600	18.18	67.25	0.39	53.58	7.47	6.24	3.70	0.03	18.57	17.45
8/21/95 15:30	91.04	52.42	43.87	19602	16.64	75.96	-0.06	53.67	6.81	6.34	3.72	0.04	16.58	16.91
8/21/95 16:00	90.86	53.78	44.44	21798	18.17	84.66	0.39	53.75	7.49	6.29	3.71	0.04	18.56	17.54
8/21/95 16:30	91.13	53.77	44.46	22002	18.11	93.73	0.25	53.91	7.36	6.23	3.65	0.03	18.37	17.27
8/21/95 17:00	91.4	48.06	44.12	9798	4.77	99.45	0.06	53.99	0.53	1.83	3.02	0.08	4.83	5.45
8/21/95 17:30	87.44	49.57	48.33	0	0.00	100.64	0.00	54.00	0.00	0.00	0.06	0.00	0.00	0.06
8/21/95 18:00	83.48	55.88	52.72	0	0.00	100.64	0.00	54.00	0.00	0.00	0.00	0.00	0.00	0.00
8/21/95 18:30	82.04	60.11	55.78	0	0.00	100.64	0.00	54.00	0.00	0.00	0.00	0.00	0.00	0.00
8/21/95 19:00	80.6	62.56	57.93	0	0.00	100.64	0.00	54.00	0.00	0.00	0.00	0.00	0.00	0.00
8/21/95 19:30	79.34	64.23	59.83	0	0.00	100.64	0.00	54.00	0.00	0.00	0.00	0.00	0.00	0.00
8/21/95 20:00	78.08	65.57	61.43	0	0.00	100.64	0.00	54.00	0.00	0.00	0.00	0.00	0.00	0.00
8/21/95 20:30	77.54	66.49	62.7	0	0.00	100.64	0.00	54.00	0.00	0.00	0.00	0.00	0.00	0.00
8/21/95 21:00	77	66.94	63.57	0	0.00	100.64	0.00	54.00	0.00	0.00	0.00	0.00	0.00	0.00
8/21/95 21:30	76.37	67.26	64.27	0	0.00	100.64	0.00	54.00	0.00	0.00	0.00	0.00	0.00	0.00
8/21/95 22:00	75.74	67.64	64.92	0	0.00	100.64	0.00	54.00	0.00	0.00	0.00	0.00	0.00	0.00
8/21/95 22:30	75.11	68.24	65.63	0	0.00	100.64	0.00	54.00	0.00	0.00	0.00	0.00	0.00	0.00
8/21/95 23:00	74.48	68.54	66.23	0	0.00	100.64	0.00	54.00	0.00	0.00	0.00	0.00	0.00	0.00
8/21/95 23:30	73.94	68.7	66.55	0	0.00	100.64	0.00	54.00	0.00	0.00	0.00	0.00	0.00	0.00
8/22/95 0:00	73.4	68.67	66.74	0	0.00	100.64	0.00	54.00	0.00	0.00	0.00	0.00	0.00	0.00
8/22/95 0:30	73.22	68.58	66.94	0	0.00	100.64	0.00	54.00	0.00	0.00	0.00	0.00	0.00	0.00
8/22/95 1:00	73.04	68.56	67.18	0	0.00	100.64	0.00	54.00	0.00	0.00	0.00	0.00	0.00	0.00
8/22/95 1:30	72.95	68.79	67.62	0	0.00	100.64	0.00	54.00	0.00	0.00	0.00	0.00	0.00	0.00
8/22/95 2:00	72.86	69.21	68.17	0	0.00	100.64	0.00	54.00	0.00	0.00	0.00	0.00	0.00	0.00
8/22/95 2:30	72.41	69.27	68.35	0	0.00	100.64	0.00	54.00	0.00	0.00	0.00	0.00	0.00	0.00
8/22/95 3:00	71.96	69.23	68.4	0	0.00	100.64	0.00	54.00	0.00	0.00	0.00	0.00	0.00	0.00
8/22/95 3:30	71.69	69.24	68.5	0	0.00	100.64	0.00	54.00	0.00	0.00	0.00	0.00	0.00	0.00
8/22/95 4:00	71.42	69.21	68.57	0	0.00	100.64	0.00	54.00	0.00	0.00	0.00	0.00	0.00	0.00
8/22/95 4:30	71.15	69.16	68.61	0	0.00	100.64	0.00	54.00	0.00	0.00	0.00	0.00	0.00	0.00
8/22/95 5:00	70.88	69.14	68.66	0	0.00	100.64	0.00	54.00	0.00	0.00	0.00	0.00	0.00	0.00
8/22/95 5:30	70.61	69.1	68.68	0	0.00	100.64	0.00	54.00	0.00	0.00	0.00	0.00	0.00	0.00
8/22/95 6:00	70.34	69.07	68.74	0	0.00	100.64	0.00	54.00	0.00	0.00	0.00	0.00	0.00	0.00
8/22/95 6:30	70.25	69.04	68.78	0	0.00	100.64	0.00	54.00	0.00	0.00	0.00	0.00	0.00	0.00
8/22/95 7:00	70.16	68.99	68.79	0	0.00	100.64	0.00	54.00	0.00	0.00	0.00	0.00	0.00	0.00
8/22/95 7:30	70.88	69.03	68.86	0	0.00	100.64	0.00	54.00	0.00	0.00	0.00	0.00	0.00	0.00
8/22/95 8:00	71.6	70	68.59	1398	0.60	100.80	2.78	54.70	-0.02	0.03	0.01	0.00	3.38	0.03

8/22/95 8:30	73.49	58.35	47.14	19002	20.42	106.05	3.90	56.37	8.54	6.51	3.86	0.05	24.32	18.96
8/22/95 9:00	75.38	56.04	44.63	19002	19.60	116.06	-0.79	57.14	7.98	6.29	3.68	0.02	18.81	17.97
8/22/95 9:30	78.71	55.61	44.35	19200	19.36	125.80	-0.70	56.77	7.83	6.37	3.68	0.02	18.65	17.90
8/22/95 10:00	82.04	55.35	44.22	19800	19.07	135.40	-0.55	56.46	7.78	6.29	3.71	0.02	18.52	17.80
8/22/95 10:30	84.38	55.36	44.32	20202	18.90	144.89	-0.31	56.24	7.64	6.33	3.71	0.04	18.59	17.72
8/22/95 11:00	86.72	55.72	44.84	20802	19.06	154.38	0.32	56.24	7.64	6.35	3.75	0.63	19.37	18.37
8/22/95 11:30	87.98	55.77	45.07	20802	18.90	163.87	0.37	56.42	7.66	6.24	3.71	0.58	19.27	18.20
8/22/95 12:00	89.24	55.89	45.21	21198	18.84	173.31	0.19	56.56	7.58	6.30	3.71	0.35	19.03	17.95
8/22/95 12:30	89.78	56.09	45.29	21198	19.04	182.78	0.18	56.65	7.40	6.16	3.68	0.47	19.22	17.70
8/22/95 13:00	90.32	56.08	45.43	21600	18.76	192.23	0.09	56.72	7.38	6.35	3.67	0.28	18.85	17.68
8/22/95 13:30	91.67	55.99	45.38	21600	18.65	201.58	-0.14	56.70	7.29	6.35	3.67	0.26	18.51	17.57
8/22/95 14:00	93.02	55.81	45.25	21798	18.52	210.88	-0.19	56.62	7.37	6.15	3.64	0.39	18.32	17.56
8/22/95 14:30	93.38	55.65	45.11	21798	18.48	220.12	-0.37	56.48	7.23	6.28	3.63	0.28	18.11	17.42
8/22/95 15:00	93.74	55.44	45.02	22200	18.26	229.31	-0.33	56.30	7.26	6.23	3.59	0.23	17.92	17.30
8/22/95 15:30	92.57	55.79	46.63	19602	16.08	237.89	1.40	56.57	7.22	5.77	3.50	0.35	17.48	16.84
8/22/95 16:00	91.4	55.61	45.23	22200	18.19	246.46	-0.67	56.76	7.28	5.56	3.49	0.25	17.53	16.58
8/22/95 16:30	91.67	55.41	45.02	22002	18.22	255.56	-0.74	56.41	7.16	5.91	3.51	0.23	17.48	16.81
8/22/95 17:00	91.94	55.12	44.61	21798	18.41	264.72	-0.88	56.00	7.21	5.49	3.49	0.28	17.53	16.46
8/22/95 17:30	90.05	54.91	44.54	22002	18.17	273.86	-0.67	55.62	7.31	5.59	3.49	0.32	17.50	16.72
8/22/95 18:00	88.16	54.25	43.88	22002	18.16	282.94	-1.16	55.16	7.24	5.33	3.37	0.19	17.00	16.13
8/22/95 18:30	86.99	53.82	43.48	21798	18.08	292.00	-1.19	54.58	7.18	5.48	3.32	0.19	16.90	16.17
8/22/95 19:00	85.82	53.76	43.46	21600	18.02	301.03	-0.79	54.08	7.25	5.88	3.34	0.18	17.23	16.64
8/22/95 19:30	82.67	53.54	43.11	21402	18.23	310.09	-0.91	53.66	7.13	5.77	3.34	0.19	17.32	16.43
8/22/95 20:00	79.52	52.8	43.92	18000	15.53	318.53	1.03	53.69	7.27	5.35	3.31	0.18	16.56	16.10
8/22/95 20:30	76.64	41.69	34.6	19002	14.12	325.94	-12.29	50.87	0.00	0.00	0.00	0.49	1.83	0.49
8/22/95 21:00	73.76	35.7	28.81	18402	13.71	332.90	-12.58	44.66	0.00	0.00	0.00	0.58	1.13	0.58
8/22/95 21:30	73.04	31.49	24.82	17598	13.15	339.62	-11.91	38.54	0.00	0.00	0.00	0.70	1.24	0.70
8/22/95 22:00	72.32	30.2	23.4	17202	13.35	346.24	-12.37	32.47	0.00	0.00	0.00	0.58	0.98	0.58
8/22/95 22:30	73.04	31.32	24.39	17202	13.64	352.99	-12.63	26.22	0.00	0.00	0.00	0.75	1.00	0.75
8/22/95 23:00	73.76	31.22	24.25	16998	13.71	359.83	-12.79	19.86	0.00	0.00	0.00	0.59	0.92	0.59
8/22/95 23:30	73.67	31.25	24.21	16998	13.84	366.71	-12.70	13.49	0.00	0.00	0.00	0.76	1.14	0.76
8/23/95 0:00	73.58	31.11	24.15	16800	13.69	373.60	-12.82	7.11	0.00	0.00	0.00	0.58	0.87	0.58
8/23/95 0:30	73.22	31.11	24.09	16602	13.81	380.47	-12.74	0.72	0.00	0.00	0.00	0.75	1.06	0.75
8/23/95 1:00	72.86	30.99	24.04	16800	13.66	387.34	-12.84	-5.68	0.00	0.00	0.00	0.62	0.83	0.62
8/23/95 1:30	72.05	30.92	24.01	16602	13.58	394.15	-12.73	-12.07	0.00	0.00	0.00	0.62	0.84	0.62
8/23/95 2:00	71.24	30.88	23.99	16998	13.54	400.93	-12.67	-18.42	0.00	0.00	0.00	0.74	0.86	0.74
8/23/95 2:30	70.16	30.79	23.83	16602	13.67	407.73	-12.80	-24.79	0.00	0.00	0.00	0.58	0.86	0.58
8/23/95 3:00	69.08	30.83	23.83	16398	13.74	414.58	-12.68	-31.16	0.00	0.00	0.00	0.76	1.06	0.76
8/23/95 3:30	68.36	30.71	23.73	16602	13.70	421.44	-12.80	-37.53	0.00	0.00	0.00	0.59	0.90	0.59
8/23/95 4:00	67.64	30.72	23.83	16800	13.53	428.25	-12.59	-43.88	0.00	0.00	0.00	0.70	0.94	0.70
8/23/95 4:30	67.64	30.53	23.7	16800	13.40	434.98	-12.61	-50.18	0.00	0.00	0.00	0.64	0.78	0.64
8/23/95 5:00	67.64	30.46	23.62	16998	13.42	441.68	-12.60	-56.48	0.00	0.00	0.00	0.59	0.82	0.59
8/23/95 5:30	67.73	46.23	45.64	402	1.02	445.30	21.68	-54.21	11.27	8.02	4.82	0.32	22.70	24.42
8/23/95 6:00	67.82	45.75	45.68	0	0.12	445.58	19.66	-43.88	9.05	6.24	4.21	0.03	19.79	19.53
8/23/95 6:30	68.09	45.95	45.96	0	-0.02	445.61	18.93	-34.23	8.79	5.95	4.04	0.03	18.92	18.81
8/23/95 7:00	68.36	46.25	46.34	0	-0.16	445.57	18.65	-24.83	8.64	6.01	3.96	0.03	18.50	18.65
8/23/95 7:30	69.44	46.37	46.42	0	-0.09	445.51	18.39	-15.57	8.48	5.82	3.92	0.03	18.31	18.25
8/23/95 8:00	70.52	46.48	46.5	0	-0.03	445.47	18.29	-6.40	8.36	5.75	3.91	0.03	18.26	18.04
8/23/95 8:30	72.5	46.74	46.82	0	-0.14	445.43	18.38	2.77	8.30	6.11	3.90	0.02	18.25	18.33
8/23/95 9:00	74.48	47.03	47.12	0	-0.16	445.36	18.34	11.95	8.37	5.82	3.89	0.02	18.18	18.11
8/23/95 9:30	76.73	47.51	47.58	0	-0.12	445.29	18.16	21.08	8.16	5.94	3.87	0.01	18.04	17.97
8/23/95 10:00	78.98	48.13	48.28	0	-0.26	445.19	18.11	30.14	8.10	6.03	3.83	0.01	17.85	17.97

8/23/95 10:30	81.41	49.11	48.59	1200	0.90	445.35	16.32	38.75	7.87	5.69	3.70	0.01	17.22	17.27
8/23/95 11:00	83.84	51.03	47.12	7002	6.82	447.29	9.39	45.18	7.30	5.52	3.47	0.01	16.21	16.30
8/23/95 11:30	85.37	52.5	45.79	10800	11.71	451.92	4.05	48.54	6.98	5.07	3.32	0.01	15.76	15.38
8/23/95 12:00	86.9	52.84	43.17	18600	16.85	459.06	-0.61	49.40	7.08	5.27	3.35	0.02	16.24	15.71
8/23/95 12:30	87.98	52.45	42.07	20202	18.07	467.79	-1.29	48.92	7.25	5.48	3.48	0.02	16.78	16.21
8/23/95 13:00	89.06	52.35	42	20598	18.00	476.81	-0.87	48.38	7.28	5.64	3.52	0.02	17.13	16.46
8/23/95 13:30	90.68	52.32	42.04	20802	17.87	485.77	-0.54	48.03	7.35	5.82	3.58	0.02	17.33	16.78
8/23/95 14:00	92.3	52.38	42.08	21198	17.91	494.72	-0.30	47.82	7.29	5.91	3.61	0.02	17.61	16.83
8/23/95 14:30	93.11	52.41	42.24	21402	17.68	503.62	-0.07	47.73	7.45	5.94	3.62	0.02	17.61	17.03
8/23/95 15:00	93.92	52.59	42.41	21600	17.70	512.46	0.09	47.74	7.42	5.98	3.62	0.02	17.78	17.04
8/23/95 15:30	93.65	52.71	42.55	21798	17.68	521.30	0.10	47.78	7.31	6.10	3.62	0.03	17.78	17.06
8/23/95 16:00	93.38	52.79	42.69	22002	17.58	530.12	0.17	47.85	7.37	5.87	3.61	0.02	17.75	16.87
8/23/95 16:30	92.21	52.81	42.8	22002	17.42	538.87	0.07	47.91	7.30	6.23	3.59	0.05	17.49	17.17
8/23/95 17:00	91.04	53.12	42.91	22200	17.78	547.67	0.16	47.97	7.14	5.90	3.57	0.46	17.94	17.08
8/23/95 17:30	89.42	53.05	42.89	22002	17.71	556.54	0.00	48.01	7.12	5.99	3.55	0.29	17.71	16.96
8/23/95 18:00	87.8	52.8	42.76	22002	17.50	565.34	-0.28	47.94	7.21	5.78	3.44	0.25	17.22	16.68
8/23/95 18:30	85.19	52.49	42.29	21798	17.76	574.15	-0.61	47.72	7.09	5.31	3.34	0.34	17.15	16.08
8/23/95 19:00	82.58	52.23	42.16	21600	17.54	582.98	-0.63	47.41	7.11	5.71	3.35	0.18	16.91	16.36
8/23/95 19:30	79.88	52	41.83	21000	17.69	591.78	-0.82	47.05	7.10	5.71	3.36	0.19	16.87	16.36
8/23/95 20:00	77.18	51.68	42.75	17598	15.53	600.09	1.30	47.17	7.11	5.55	3.38	0.19	16.83	16.22
8/23/95 20:30	75.74	40.57	33.6	18402	13.83	607.43	-11.87	44.53	0.00	0.00	0.00	0.44	1.96	0.44
8/23/95 21:00	74.3	34.75	27.92	18198	13.54	614.27	-12.35	38.48	0.00	0.00	0.00	0.60	1.19	0.60
8/23/95 21:30	73.31	30.72	24.07	18000	13.08	620.92	-11.86	32.42	0.00	0.00	0.00	0.72	1.22	0.72
8/23/95 22:00	72.32	30.6	23.72	17598	13.53	627.57	-12.47	26.34	0.00	0.00	0.00	0.65	1.06	0.65
8/23/95 22:30	71.6	31.26	24.37	17598	13.56	634.35	-12.61	20.07	0.00	0.00	0.00	0.63	0.94	0.63
8/23/95 23:00	70.88	31.24	24.35	17400	13.56	641.13	-12.54	13.78	0.00	0.00	0.00	0.73	1.02	0.73
8/23/95 23:30	70.34	31.21	24.3	17400	13.59	647.91	-12.57	7.51	0.00	0.00	0.00	0.72	1.02	0.72
8/24/95 0:00	69.8	31.1	24.19	17400	13.60	654.71	-12.66	1.20	0.00	0.00	0.00	0.58	0.94	0.58
8/24/95 0:30	69.35	31.03	24.1	17202	13.63	661.52	-12.63	-5.12	0.00	0.00	0.00	0.69	1.00	0.69
8/24/95 1:00	68.9	31.01	24.16	16998	13.46	668.30	-12.54	-11.41	0.00	0.00	0.00	0.74	0.92	0.74
8/24/95 1:30	68.63	30.97	23.99	17202	13.72	675.09	-12.62	-17.70	0.00	0.00	0.00	0.74	1.10	0.74
8/24/95 2:00	68.36	30.81	23.94	16998	13.51	681.90	-12.64	-24.02	0.00	0.00	0.00	0.58	0.86	0.58
8/24/95 2:30	68.09	30.83	23.88	16800	13.65	688.69	-12.63	-30.34	0.00	0.00	0.00	0.73	1.02	0.73
8/24/95 3:00	67.82	30.8	23.85	16800	13.66	695.52	-12.62	-36.65	0.00	0.00	0.00	0.72	1.04	0.72
8/24/95 3:30	67.46	30.69	23.71	16998	13.71	702.36	-12.73	-42.99	0.00	0.00	0.00	0.61	0.98	0.61
8/24/95 4:00	67.1	30.71	23.67	16602	13.83	709.25	-12.67	-49.34	0.00	0.00	0.00	0.73	1.16	0.73
8/24/95 4:30	66.83	30.64	23.6	16602	13.83	716.16	-12.69	-55.67	0.00	0.00	0.00	0.67	1.14	0.67
8/24/95 5:00	66.56	30.47	23.53	16602	13.63	723.02	-12.70	-62.02	0.00	0.00	0.00	0.66	0.92	0.66
8/24/95 5:30	66.29	46.16	45.62	402	0.94	726.67	21.68	-59.78	11.10	8.15	4.80	0.41	22.62	24.46
8/24/95 6:00	66.02	45.64	45.66	0	-0.03	726.89	19.66	-49.44	8.91	6.43	4.16	0.03	19.63	19.53
8/24/95 6:30	66.11	45.85	45.9	0	-0.09	726.86	18.87	-39.81	8.66	5.90	3.99	0.04	18.78	18.59
8/24/95 7:00	66.2	46.18	46.28	0	-0.17	726.80	18.58	-30.45	8.50	6.01	3.93	0.03	18.41	18.47
8/24/95 7:30	67.46	46.36	46.44	0	-0.14	726.72	18.45	-21.19	8.49	5.66	3.89	0.03	18.31	18.08
8/24/95 8:00	68.72	46.6	46.65	0	-0.09	726.66	18.47	-11.96	8.40	5.82	3.93	0.03	18.39	18.18
8/24/95 8:30	71.42	46.95	47.06	0	-0.19	726.59	18.74	-2.65	8.40	6.14	3.98	0.02	18.55	18.55
8/24/95 9:00	74.12	47.34	47.41	0	-0.12	726.51	18.79	6.73	8.29	6.36	4.00	0.01	18.67	18.66
8/24/95 9:30	76.91	47.83	47.91	0	-0.14	726.45	18.76	16.11	8.22	6.35	3.97	0.01	18.62	18.55
8/24/95 10:00	79.7	48.53	48.73	0	-0.35	726.33	18.65	25.46	8.27	6.40	3.89	0.00	18.30	18.57
8/24/95 10:30	82.31	49.51	48.12	2400	2.42	726.85	15.74	34.06	7.89	6.11	3.81	0.01	18.16	17.82
8/24/95 11:00	84.92	51.38	46.85	7800	7.90	729.42	9.12	40.28	7.32	5.87	3.57	0.00	17.02	16.76
8/24/95 11:30	86.63	52.84	45.55	12600	12.72	734.58	4.05	43.57	6.98	5.56	3.42	0.18	16.77	16.14
8/24/95 12:00	88.34	53.39	43.87	18198	16.59	741.91	0.19	44.63	6.88	5.61	3.44	0.20	16.79	16.14

8/24/95 12:30	89.87	53.18	42.87	20802	17.95	750.54	-0.75	44.49	7.10	5.99	3.52	0.19	17.20	16.80
8/24/95 13:00	91.4	53.16	42.83	21000	17.97	759.52	-0.50	44.17	7.15	5.78	3.58	0.20	17.47	16.71
8/24/95 13:30	92.48	53.1	42.83	21198	17.87	768.48	-0.30	43.97	7.18	5.86	3.63	0.20	17.57	16.87
8/24/95 14:00	93.56	53.1	42.95	21798	17.67	777.36	-0.12	43.87	7.23	5.97	3.62	0.20	17.55	17.02
8/24/95 14:30	93.56	53.16	42.97	21798	17.74	786.22	-0.03	43.83	7.10	5.94	3.61	0.19	17.70	16.85
8/24/95 15:00	93.56	53.07	43	22002	17.53	795.03	-0.09	43.80	7.22	5.74	3.61	0.15	17.44	16.72
8/24/95 15:30	92.57	53.19	43.13	22200	17.52	803.79	0.02	43.78	7.09	6.19	3.62	0.16	17.54	17.06
8/24/95 16:00	91.58	53.17	43.02	22002	17.69	812.60	-0.19	43.74	7.00	6.15	3.57	0.15	17.50	16.87
8/24/95 16:30	88.88	53.16	43.06	22398	17.60	821.42	-0.14	43.66	7.08	6.05	3.57	0.14	17.46	16.84
8/24/95 17:00	86.18	53.12	43.11	22002	17.44	830.18	-0.10	43.60	7.10	6.01	3.56	0.20	17.34	16.87
8/24/95 17:30	86.36	52.88	42.84	22200	17.49	838.91	-0.35	43.48	7.13	5.63	3.53	0.18	17.14	16.47
8/24/95 18:00	86.54	52.74	42.65	22002	17.58	847.68	-0.49	43.27	7.04	5.75	3.43	0.16	17.09	16.39
8/24/95 18:30	84.47	52.46	42.32	21600	17.65	856.48	-0.68	42.98	6.92	5.79	3.38	0.17	16.98	16.26
8/24/95 19:00	82.4	52.22	42.2	21600	17.46	865.26	-0.57	42.67	7.14	5.75	3.38	0.18	16.88	16.45
8/24/95 19:30	80.69	51.95	41.77	21798	17.71	874.05	-0.78	42.33	7.01	5.60	3.39	0.12	16.93	16.11
8/24/95 20:00	78.98	51.76	43.05	18402	15.17	882.27	1.53	42.52	7.05	5.74	3.38	0.09	16.70	16.26
8/24/95 20:30	78.26	40.71	33.8	19002	13.72	889.49	-11.77	39.96	0.00	0.00	0.00	0.50	1.95	0.50
8/24/95 21:00	77.54	34.99	28.29	18798	13.28	896.24	-12.13	33.98	0.00	0.00	0.00	0.64	1.15	0.64
8/24/95 21:30	76.46	30.88	24.42	18600	12.70	902.74	-11.56	28.06	0.00	0.00	0.00	0.55	1.14	0.55
8/24/95 22:00	75.38	30.44	23.88	18402	12.89	909.13	-11.98	22.17	0.00	0.00	0.00	0.72	0.90	0.72
8/24/95 22:30	74.3	31.21	24.55	18198	13.09	915.63	-12.23	16.12	0.00	0.00	0.00	0.54	0.86	0.54
8/24/95 23:00	73.22	31.29	24.47	18000	13.41	922.26	-12.35	9.98	0.00	0.00	0.00	0.71	1.06	0.71
8/24/95 23:30	72.59	31.18	24.33	17802	13.47	928.98	-12.41	3.79	0.00	0.00	0.00	0.72	1.06	0.72
8/25/95 0:00	71.96	31.05	24.23	17598	13.41	935.70	-12.49	-2.44	0.00	0.00	0.00	0.58	0.92	0.58
8/25/95 0:30	71.42	31.05	24.2	17400	13.46	942.42	-12.44	-8.67	0.00	0.00	0.00	0.73	1.02	0.73
8/25/95 1:00	70.88	31.04	24.03	17400	13.76	949.22	-12.52	-14.91	0.00	0.00	0.00	0.72	1.24	0.72
8/25/95 1:30	70.52	30.9	24.1	17400	13.36	956.00	-12.42	-21.15	0.00	0.00	0.00	0.69	0.94	0.69
8/25/95 2:00	70.16	30.81	23.96	17202	13.46	962.71	-12.56	-27.39	0.00	0.00	0.00	0.61	0.90	0.61
8/25/95 2:30	69.98	30.83	23.9	16998	13.62	969.48	-12.52	-33.66	0.00	0.00	0.00	0.73	1.10	0.73
8/25/95 3:00	69.8	30.77	23.81	17202	13.67	976.30	-12.55	-39.92	0.00	0.00	0.00	0.73	1.12	0.73
8/25/95 3:30	69.53	30.69	23.79	16998	13.55	983.10	-12.55	-46.20	0.00	0.00	0.00	0.60	1.00	0.60
8/25/95 4:00	69.26	30.66	23.74	16998	13.58	989.89	-12.52	-52.47	0.00	0.00	0.00	0.71	1.06	0.71
8/25/95 4:30	69.08	30.59	23.77	16998	13.39	996.63	-12.43	-58.71	0.00	0.00	0.00	0.74	0.96	0.74
8/25/95 5:00	68.9	30.52	23.65	16998	13.49	1003.35	-12.43	-64.92	0.00	0.00	0.00	0.71	1.06	0.71
8/25/95 5:30	68.81	46.59	46.04	402	0.96	1006.96	22.41	-62.43	11.28	8.61	4.98	0.27	23.37	25.14
8/25/95 6:00	68.72	46.06	46.08	0	-0.03	1007.19	20.21	-51.77	8.91	6.82	4.31	0.03	20.18	20.08
8/25/95 6:30	68.81	46.31	46.38	0	-0.12	1007.15	19.46	-41.85	8.60	6.69	4.12	0.03	19.34	19.45
8/25/95 7:00	68.9	46.5	46.44	0	0.10	1007.15	18.95	-32.25	8.38	6.10	4.01	0.03	19.06	18.51
8/25/95 7:30	69.98	46.67	46.68	0	-0.02	1007.17	18.74	-22.83	8.33	6.16	3.99	0.03	18.72	18.50
8/25/95 8:00	71.06	46.79	46.82	0	-0.05	1007.15	18.72	-13.46	8.40	5.95	3.99	0.03	18.67	18.37
8/25/95 8:30	73.67	47.17	47.31	0	-0.24	1007.08	19.06	-4.02	8.44	6.57	4.03	0.01	18.82	19.05
8/25/95 9:00	76.28	47.54	47.72	0	-0.31	1006.94	19.12	5.53	8.41	6.61	4.02	0.01	18.80	19.06
8/25/95 9:30	79.43	48.3	48.48	0	-0.31	1006.79	19.23	15.11	8.41	6.58	4.09	0.00	18.92	19.09
8/25/95 10:00	82.58	49.24	48.48	1800	1.32	1007.04	17.93	24.40	8.09	6.85	4.06	0.00	19.25	19.00
8/25/95 10:30	85.55	50.35	47.98	4602	4.12	1008.40	14.09	32.41	7.80	6.34	3.88	0.00	18.21	18.02
8/25/95 11:00	88.52	52.58	46.05	11802	11.40	1012.28	5.76	37.37	7.03	6.37	3.62	0.18	17.16	17.21
8/25/95 11:30	90.14	53.07	43.17	20400	17.26	1019.44	0.47	38.93	7.15	5.98	3.62	0.17	17.73	16.92
8/25/95 12:00	91.76	53	42.81	21000	17.75	1028.20	-0.07	39.03	7.16	6.17	3.65	0.01	17.68	16.99
8/25/95 12:30	93.2	53.2	43.02	21600	17.74	1037.07	0.10	39.04	7.16	6.21	3.64	0.19	17.84	17.21
8/25/95 13:00	94.64	53.34	43.29	21798	17.52	1045.89	0.30	39.14	7.22	5.94	3.66	0.20	17.81	17.03
8/25/95 13:30	94.46	53.62	43.5	22002	17.64	1054.67	0.24	39.27	7.04	6.22	3.64	0.22	17.88	17.12
8/25/95 14:00	94.28	53.6	43.54	22398	17.53	1063.47	0.19	39.38	7.16	5.98	3.62	0.20	17.73	16.96

8/25/95 14:30	95.63	53.67	43.67	22398	17.42	1072.21	0.24	39.49	7.11	5.97	3.63	0.19	17.67	16.90
8/25/95 15:00	96.98	53.87	43.87	22998	17.43	1080.92	0.26	39.61	7.08	5.99	3.61	0.24	17.69	16.93
8/25/95 15:30	96.35	53.89	43.86	22602	17.49	1089.65	0.16	39.72	7.16	5.73	3.59	0.29	17.65	16.77
8/25/95 16:00	95.72	53.8	43.72	22602	17.56	1098.41	-0.17	39.72	6.92	6.07	3.55	0.18	17.39	16.72
8/25/95 16:30	95.45	53.84	43.79	22602	17.52	1107.18	-0.14	39.64	6.87	6.47	3.54	0.17	17.38	17.05
8/25/95 17:00	95.18	53.81	43.74	22602	17.56	1115.95	-0.14	39.57	7.00	5.96	3.53	0.19	17.42	16.69
8/25/95 17:30	93.65	53.56	43.46	22398	17.61	1124.75	-0.42	39.43	7.00	5.54	3.51	0.23	17.19	16.28
8/25/95 18:00	92.12	53.3	43.18	22398	17.64	1133.56	-0.68	39.15	6.85	5.62	3.37	0.23	16.96	16.07
8/25/95 18:30	90.32	52.78	42.84	22602	17.33	1142.30	-0.84	38.77	6.87	5.66	3.28	0.11	16.50	15.93
8/25/95 19:00	88.52	52.48	42.5	22200	17.38	1150.98	-0.89	38.34	6.82	5.60	3.28	0.14	16.49	15.84
8/25/95 19:30	85.01	52.22	42.19	21798	17.47	1159.69	-0.82	37.92	6.98	5.40	3.32	0.17	16.65	15.87
8/25/95 20:00	81.5	52.01	43.29	18402	15.18	1167.86	1.38	38.05	6.93	5.66	3.33	0.17	16.56	16.09
8/25/95 20:30	81.14	41.11	34.31	19398	13.49	1175.02	-11.62	35.49	0.00	0.00	0.00	0.35	1.86	0.35
8/25/95 21:00	80.78	35.41	28.62	19002	13.44	1181.76	-12.14	29.55	0.00	0.00	0.00	0.64	1.31	0.64
8/25/95 21:30	79.16	31.26	24.77	18600	12.75	1188.30	-11.53	23.64	0.00	0.00	0.00	0.52	1.22	0.52
8/25/95 22:00	77.54	30.33	23.79	18402	12.84	1194.70	-11.80	17.80	0.00	0.00	0.00	0.73	1.04	0.73
8/25/95 22:30	76.73	31.25	24.56	18402	13.15	1201.20	-12.21	11.80	0.00	0.00	0.00	0.55	0.94	0.55
8/25/95 23:00	75.92	31.18	24.5	18000	13.13	1207.77	-12.18	5.70	0.00	0.00	0.00	0.71	0.94	0.71
8/25/95 23:30	75.29	31.19	24.38	18198	13.38	1214.40	-12.24	-0.41	0.00	0.00	0.00	0.71	1.14	0.71
8/26/95 0:00	74.66	31.1	24.21	17802	13.54	1221.13	-12.46	-6.58	0.00	0.00	0.00	0.58	1.08	0.58
8/26/95 0:30	74.12	31.02	24.28	17802	13.22	1227.82	-12.24	-12.75	0.00	0.00	0.00	0.73	0.98	0.73
8/26/95 1:00	73.58	30.98	24.2	17598	13.30	1234.45	-12.26	-18.88	0.00	0.00	0.00	0.73	1.04	0.73
8/26/95 1:30	73.13	30.88	24.03	17598	13.44	1241.13	-12.38	-25.04	0.00	0.00	0.00	0.57	1.06	0.57
8/26/95 2:00	72.68	30.86	24.01	17400	13.45	1247.85	-12.37	-31.23	0.00	0.00	0.00	0.75	1.08	0.75
8/26/95 2:30	72.59	30.82	24.03	17400	13.33	1254.55	-12.33	-37.40	0.00	0.00	0.00	0.75	1.00	0.75
8/26/95 3:00	72.5	30.78	23.88	17400	13.55	1261.27	-12.43	-43.59	0.00	0.00	0.00	0.68	1.12	0.68
8/26/95 3:30	72.59	30.7	23.8	17400	13.55	1268.04	-12.49	-49.82	0.00	0.00	0.00	0.67	1.06	0.67
8/26/95 4:00	72.68	30.65	23.87	17202	13.30	1274.75	-12.32	-56.02	0.00	0.00	0.00	0.75	0.98	0.75
8/26/95 4:30	73.22	30.62	23.78	17202	13.42	1281.43	-12.36	-62.19	0.00	0.00	0.00	0.76	1.06	0.76
8/26/95 5:00	73.76	30.5	23.62	17202	13.50	1288.16	-12.44	-68.39	0.00	0.00	0.00	0.62	1.06	0.62
8/26/95 5:30	74.21	46.94	46.24	402	1.22	1291.84	22.87	-65.78	11.15	8.94	4.99	0.48	24.09	25.56
8/26/95 6:00	74.66	46.31	46.36	0	-0.09	1292.12	20.60	-54.92	8.96	7.40	4.26	0.03	20.51	20.65
8/26/95 6:30	74.66	46.48	46.45	0	0.05	1292.12	19.65	-44.85	8.55	6.84	4.08	0.03	19.71	19.50
8/26/95 7:00	74.66	46.6	46.66	0	-0.10	1292.10	19.17	-35.15	8.47	6.48	3.96	0.03	19.06	18.94
8/26/95 7:30	75.38	46.71	46.74	0	-0.05	1292.06	18.93	-25.62	8.31	6.42	3.90	0.03	18.88	18.66
8/26/95 8:00	76.1	46.77	46.81	0	-0.07	1292.03	18.78	-16.19	8.22	6.43	3.85	0.03	18.71	18.54
8/26/95 8:30	76.55	46.88	46.96	0	-0.14	1291.98	18.49	-6.88	8.11	6.32	3.80	0.03	18.35	18.26
8/26/95 9:00	77	47.16	47.22	0	-0.10	1291.92	18.21	2.30	7.96	6.32	3.72	0.02	18.11	18.02
8/26/95 9:30	77.18	47.59	47.58	0	0.02	1291.90	17.81	11.30	7.75	6.01	3.62	0.02	17.83	17.40
8/26/95 10:00	77.36	48.09	48.21	0	-0.21	1291.85	17.43	20.11	7.56	6.11	3.53	0.02	17.22	17.22
8/26/95 10:30	77.27	49.61	48.52	2202	1.90	1292.27	14.10	28.00	7.01	5.62	3.27	0.02	16.00	15.93
8/26/95 11:00	77.18	51.39	45.94	8400	9.52	1295.13	5.61	32.92	6.57	5.03	3.04	0.02	15.13	14.65
8/26/95 11:30	76.91	52.16	44.81	11802	12.85	1300.72	2.10	34.85	6.27	5.08	2.95	0.02	14.94	14.32
8/26/95 12:00	76.64	52.36	44.08	14598	14.47	1307.55	0.40	35.47	6.26	5.02	2.94	0.02	14.87	14.25
8/26/95 12:30	76.73	52.41	44.11	14598	14.51	1314.79	0.31	35.65	6.20	4.91	2.92	0.02	14.83	14.05
8/26/95 13:00	76.82	52.06	42.05	18000	17.48	1322.79	-2.29	35.16	6.36	5.36	2.99	0.02	15.19	14.74
8/26/95 13:30	77.99	51.21	40.74	19200	18.24	1331.72	-2.47	33.97	6.76	5.30	3.11	0.02	15.76	15.20
8/26/95 14:00	79.16	50.62	40.26	19200	18.02	1340.78	-1.90	32.88	6.82	5.65	3.20	0.02	16.12	15.69
8/26/95 14:30	79.25	50.27	39.84	19398	18.12	1349.82	-1.55	32.02	6.75	5.82	3.23	0.02	16.58	15.82
8/26/95 15:00	79.34	49.89	39.73	19602	17.66	1358.76	-1.11	31.35	7.00	5.88	3.28	0.02	16.54	16.18
8/26/95 15:30	78.53	49.68	39.88	19002	17.01	1367.43	-0.57	30.93	6.91	5.93	3.26	0.03	16.44	16.13
8/26/95 16:00	77.72	49.54	39.65	19602	17.17	1375.97	-0.64	30.63	6.96	5.90	3.27	0.02	16.53	16.16

8/26/95 16:30	76.46	49.83	42.91	12402	12.04	1383.28	3.55	31.35	6.74	5.35	3.14	0.02	15.59	15.24
8/26/95 17:00	75.2	51.58	46.03	8598	9.71	1388.72	4.69	33.41	6.09	4.96	2.86	0.02	14.40	13.93
8/26/95 17:30	74.66	52.22	44.06	13998	14.26	1394.71	0.10	34.61	5.90	4.94	2.80	0.02	14.37	13.66
8/26/95 18:00	74.12	51.19	40.68	19002	18.31	1402.85	-3.26	33.82	6.25	5.37	2.96	0.02	15.05	14.61
8/26/95 18:30	73.67	50.36	39.86	19002	18.26	1411.99	-2.71	32.33	6.58	5.28	3.08	0.03	15.54	14.97
8/26/95 19:00	73.22	49.16	42.4	11598	11.80	1419.51	1.55	32.04	11.82	5.22	3.06	0.18	13.35	20.29
8/26/95 19:30	72.77	51.46	45.25	9402	10.86	1425.17	3.43	33.29	6.06	5.04	2.85	0.02	14.28	13.98
8/26/95 20:00	72.32	51.18	46.6	7002	8.03	1429.89	4.02	35.15	9.91	4.67	2.71	0.18	12.05	17.47
8/26/95 20:30	72.23	42.43	34.95	17400	14.89	1435.62	-13.09	32.88	0.00	0.00	0.00	0.29	1.79	0.29
8/26/95 21:00	72.14	36.27	29.11	17598	14.22	1442.90	-12.93	26.37	0.00	0.00	0.00	0.48	1.29	0.48
8/26/95 21:30	72.05	31.87	25.12	17400	13.28	1449.77	-12.10	20.12	0.00	0.00	0.00	0.51	1.18	0.51
8/26/95 22:00	71.96	30.08	23.31	17202	13.28	1456.41	-12.47	13.97	0.00	0.00	0.00	0.44	0.80	0.44
8/26/95 22:30	71.87	31.26	24.46	17400	13.37	1463.07	-12.50	7.73	0.00	0.00	0.00	0.42	0.86	0.42
8/26/95 23:00	71.78	31.24	24.41	17400	13.42	1469.76	-12.55	1.47	0.00	0.00	0.00	0.50	0.86	0.50
8/26/95 23:30	71.69	31.17	24.26	17400	13.56	1476.51	-12.60	-4.82	0.00	0.00	0.00	0.56	0.96	0.56
8/27/95 0:00	71.6	31.07	24.18	17400	13.53	1483.28	-12.62	-11.13	0.00	0.00	0.00	0.49	0.90	0.49
8/27/95 0:30	71.51	30.96	24.14	17400	13.39	1490.01	-12.60	-17.43	0.00	0.00	0.00	0.46	0.79	0.46
8/27/95 1:00	71.42	30.96	24.16	17400	13.35	1496.69	-12.49	-23.70	0.00	0.00	0.00	0.52	0.86	0.52
8/27/95 1:30	71.33	30.88	24.01	17202	13.47	1503.40	-12.53	-29.96	0.00	0.00	0.00	0.58	0.94	0.58
8/27/95 2:00	71.24	30.83	23.93	17400	13.54	1510.15	-12.62	-36.24	0.00	0.00	0.00	0.50	0.92	0.50
8/27/95 2:30	70.97	30.75	23.91	17202	13.41	1516.89	-12.57	-42.54	0.00	0.00	0.00	0.48	0.84	0.48
8/27/95 3:00	70.7	30.73	23.83	17202	13.53	1523.62	-12.55	-48.82	0.00	0.00	0.00	0.53	0.98	0.53
8/27/95 3:30	70.7	30.69	23.83	17202	13.46	1530.37	-12.49	-55.08	0.00	0.00	0.00	0.62	0.96	0.62
8/27/95 4:00	70.7	30.61	23.7	17400	13.55	1537.12	-12.57	-61.35	0.00	0.00	0.00	0.48	0.98	0.48
8/27/95 4:30	70.61	30.51	23.74	17202	13.28	1543.83	-12.47	-67.61	0.00	0.00	0.00	0.48	0.80	0.48
8/27/95 5:00	70.52	30.45	23.69	17202	13.25	1550.46	-12.38	-73.82	0.00	0.00	0.00	0.60	0.86	0.60
8/27/95 5:30	70.61	45.43	44.86	600	0.99	1554.02	20.72	-71.74	10.38	7.91	4.58	0.23	21.71	23.10
8/27/95 6:00	70.7	45.08	45.15	0	-0.12	1554.23	19.03	-61.80	8.37	6.51	3.92	0.03	18.91	18.84
8/27/95 6:30	71.15	45.39	45.42	0	-0.05	1554.19	18.38	-52.45	8.07	6.35	3.77	0.03	18.33	18.23
8/27/95 7:00	71.6	45.59	45.65	0	-0.10	1554.15	17.94	-43.37	7.90	6.11	3.66	0.03	17.84	17.70
8/27/95 7:30	72.23	45.74	45.78	0	-0.07	1554.11	17.69	-34.46	7.69	6.22	3.62	0.03	17.62	17.55
8/27/95 8:00	72.86	45.79	45.88	0	-0.16	1554.05	17.59	-25.64	7.59	6.29	3.58	0.02	17.44	17.48
8/27/95 8:30	74.39	45.83	45.95	0	-0.21	1553.96	17.43	-16.88	7.65	6.01	3.53	0.03	17.22	17.22
8/27/95 9:00	75.92	44.4	44.48	0	-0.14	1553.87	15.28	-8.70	13.67	6.26	3.53	0.03	15.14	23.49
8/27/95 9:30	76.91	44.88	44.99	0	-0.19	1553.79	15.20	-1.09	13.97	6.02	3.48	0.16	15.01	23.63
8/27/95 10:00	77.9	46.11	46.1	0	0.02	1553.75	15.96	6.70	10.18	5.80	3.39	0.02	15.98	19.40
8/27/95 10:30	78.53	45.95	46.08	0	-0.23	1553.70	15.65	14.61	10.96	5.97	3.37	0.17	15.42	20.46
8/27/95 11:00	79.16	46.48	46.41	0	0.12	1553.67	13.65	21.93	13.32	5.35	3.19	0.15	13.77	22.01
8/27/95 11:30	80.6	49.06	47.59	2400	2.57	1554.34	9.94	27.83	11.27	4.93	2.83	0.14	12.51	19.16
8/27/95 12:00	82.04	50.41	46	7800	7.71	1556.91	3.90	31.29	10.92	4.73	2.67	0.14	11.61	18.46
8/27/95 12:30	84.2	51.45	45.6	10398	10.24	1561.40	1.44	32.62	10.83	5.01	2.60	0.14	11.67	18.58
8/27/95 13:00	86.36	51.23	44.65	12402	11.51	1566.84	0.31	33.06	10.44	4.67	2.65	0.12	11.82	17.88
8/27/95 13:30	87.53	51.59	45.37	12000	10.89	1572.44	1.12	33.42	11.05	4.71	2.61	0.14	12.01	18.52
8/27/95 14:00	88.7	52.17	44.52	14802	13.39	1578.51	-1.00	33.45	9.43	4.93	2.60	0.11	12.39	17.08
8/27/95 14:30	87.26	51.9	45.04	13398	12.00	1584.85	0.61	33.35	10.02	4.71	2.63	0.11	12.62	17.47
8/27/95 15:00	85.82	51.69	43.37	16800	14.53	1591.49	-1.96	33.02	10.41	4.82	2.65	0.11	12.57	17.99
8/27/95 15:30	86.36	51.25	42.18	18198	15.82	1599.07	-2.41	31.92	9.51	5.51	2.77	0.11	13.42	17.91
8/27/95 16:00	86.9	50.42	41.63	17400	15.31	1606.86	-1.90	30.85	10.57	5.17	2.84	0.17	13.41	18.75
8/27/95 16:30	85.64	49.95	42.83	14400	12.42	1613.79	0.30	30.45	12.18	5.23	2.87	0.16	12.72	20.44
8/27/95 17:00	84.38	50.55	45.01	10200	9.69	1619.32	2.54	31.16	11.20	4.82	2.70	0.15	12.22	18.85
8/27/95 17:30	84.29	51.45	46.09	8802	9.39	1624.08	2.19	32.34	11.00	4.94	2.60	0.16	11.58	18.70
8/27/95 18:00	84.2	51.95	45.31	11802	11.64	1629.34	0.12	32.92	10.89	4.59	2.52	0.16	11.76	18.16

8/27/95 18:30	82.94	51.52	43.34	15798	14.31	1635.83	-2.01	32.44	11.10	5.15	2.62	0.16	12.30	19.04
8/27/95 19:00	81.68	50.7	41.55	18600	15.98	1643.40	-3.07	31.17	10.75	5.07	2.75	0.18	12.91	18.76
8/27/95 19:30	80.24	49.82	41.45	16200	14.60	1651.05	-1.60	30.00	11.19	5.13	2.84	0.16	12.99	19.31
8/27/95 20:00	78.8	49.61	41.95	15198	13.36	1658.04	-0.30	29.53	11.81	5.27	2.88	0.18	13.06	20.14
8/27/95 20:30	77.36	40.27	33.32	18402	13.77	1664.82	-11.91	26.48	0.00	0.00	0.00	0.30	1.86	0.30
8/27/95 21:00	75.92	34.59	27.69	18402	13.65	1671.67	-12.46	20.38	0.00	0.00	0.00	0.39	1.19	0.39
8/27/95 21:30	75.02	30.49	24	18198	12.73	1678.27	-11.63	14.36	0.00	0.00	0.00	0.50	1.10	0.50
8/27/95 22:00	74.12	30.62	23.95	18000	13.10	1684.72	-12.27	8.39	0.00	0.00	0.00	0.52	0.82	0.52
8/27/95 22:30	73.22	31.15	24.29	18000	13.48	1691.37	-12.62	2.16	0.00	0.00	0.00	0.44	0.86	0.44
8/27/95 23:00	72.32	31.15	24.26	17598	13.54	1698.12	-12.66	-4.15	0.00	0.00	0.00	0.45	0.88	0.45
8/27/95 23:30	71.51	31.08	24.26	17598	13.40	1704.86	-12.59	-10.46	0.00	0.00	0.00	0.47	0.81	0.47
8/28/95 0:00	70.7	31.04	24.17	17400	13.50	1711.58	-12.62	-16.77	0.00	0.00	0.00	0.54	0.88	0.54
8/28/95 0:30	70.16	30.92	24.04	17202	13.50	1718.33	-12.68	-23.09	0.00	0.00	0.00	0.55	0.82	0.55
8/28/95 1:00	69.62	30.87	23.85	16998	13.79	1725.15	-12.84	-29.47	0.00	0.00	0.00	0.45	0.94	0.45
8/28/95 1:30	69.08	30.81	23.92	16998	13.52	1731.98	-12.74	-35.87	0.00	0.00	0.00	0.46	0.79	0.46
8/28/95 2:00	68.54	30.82	23.82	17202	13.74	1738.80	-12.68	-42.22	0.00	0.00	0.00	0.56	1.06	0.56
8/28/95 2:30	68.18	30.73	23.77	16800	13.66	1745.65	-12.76	-48.58	0.00	0.00	0.00	0.54	0.90	0.54
8/28/95 3:00	67.82	30.63	23.66	16800	13.67	1752.48	-12.85	-54.98	0.00	0.00	0.00	0.45	0.82	0.45
8/28/95 3:30	67.73	30.59	23.61	16602	13.70	1759.32	-12.84	-61.40	0.00	0.00	0.00	0.46	0.86	0.46
8/28/95 4:00	67.64	30.59	23.64	16800	13.62	1766.16	-12.74	-67.80	0.00	0.00	0.00	0.54	0.88	0.54
8/28/95 4:30	67.91	30.49	23.55	16602	13.62	1772.97	-12.77	-74.18	0.00	0.00	0.00	0.57	0.84	0.57
8/28/95 5:00	68.18	30.34	23.51	16602	13.39	1779.72	-12.73	-80.55	0.00	0.00	0.00	0.50	0.67	0.50
8/28/95 5:30	68.99	44.8	44.36	600	0.76	1783.26	19.79	-78.79	10.04	7.70	4.38	0.11	20.56	22.23
8/28/95 6:00	69.8	44.59	44.58	0	0.02	1783.45	18.21	-69.28	8.22	6.14	3.78	0.03	18.23	18.16
8/28/95 6:30	69.89	44.85	44.88	0	-0.05	1783.44	17.60	-60.33	7.91	5.99	3.64	0.03	17.55	17.57
8/28/95 7:00	69.98	44.57	44.47	0	0.17	1783.47	16.27	-51.87	10.60	5.71	3.59	0.04	16.44	19.93
8/28/95 7:30	71.06	43.9	44.11	0	-0.36	1783.43	15.60	-43.90	13.64	5.86	3.60	0.18	15.23	23.28
8/28/95 8:00	72.14	43.28	43.37	0	-0.16	1783.30	14.27	-36.43	16.31	5.88	3.66	0.21	14.11	26.06

Appendix B. Installed System Costs

Roofberg System Cost

Item	Crew	Daily output	Man-hours	Unit	Bare Costs Material ($)	Bare Costs Labor ($)	Bare Costs Equipment ($)	Unit total ($)	No. of units	Total ($)
20-ton liquid chiller	Q-7	0.35	91.429	ea.	14450	2300		19345	1	19345
Conc. pad	C-17a	26.7	3.03	cu. yd.	94	72	5.55	211	1	211
3 cu. ft. expansion tank with bladder	Q-5			ea.	945	32		1088	1	1088
1.5 hp pump	Q-1	3	5.333		835	125		1106	1	1106
1.5 hp pump	Q-1	3	5.333		835	125		1106	1	1106
Combination motor starter for chiller	1-ele	1	8	ea.	715	210		1102	1	1102
Combo motor starter for P1	Q-1	1.8	4.44	ea.	480	115	835	701	1	701
Combo motor starter for P2	Q-1	1.8	4.44	ea.	480	115	835	701	1	701
Piping, PVC Sch 40, 2-in. dia.	Q-1	59	0.271	lin.ft.	1.44	6.45		11	300	3378
Coil conversion (1-da. each, $100 mat. est.)	Q-5	1.06	15	ea.	100	360		650	3	1950
Valve, 2-in., 3-way, mixing/diverting	1-6	14	0.86	ea	460	23		541	3	1622
Pipe Insulation, 2-in. (300 lin. ft.)	1-abs.	105	0.76	lin.ft.	0.82	1.94		4	300	1144
Pipe Insulation finish (Al)	Q-14	120	0.133	sq. ft.	0.54	3.06		5	470	2436
Valve, 1-in, at coils, elec. actuated	I-6	28	0.43	ea.	201	11.3		238	3	714
Proportional/2 pos. valve controllers	1-stpi	6	1.33	ea.	214	35		288	5	1440
Cutting and drilling - brick wall	1 ele	4.4	1.818			47		71	3	212
Automatic air vent, 2"	Q-5	12	1.33	ea.	575	32		681	1	681
Separator, entrainment	1 stpi.	11	0.73	ea.	205	19.25		254	1	254
Strainer	1 stpi	10	0.8	ea.	365	21		433	1	433
Antifreeze (30% conc.)				gal.	6.74			7	35	259
Ice storage tank (including installation)				ton-h	60			60	190	11400
Pipe Insulation - Rubber tubing- 2"	1 abs	105	0.076	lin.ft.	0.82	1.94		4	200	762
Misc. (valves, gauges, thermometers, etc.)										500
System Design (24 h @ $45/h)	Egr.		24							1080
									Total:	53623

Note: Crew Stpi is a pipefitter

Rooftop Replacement Cost

Item	Crew	Daily output	Man-hours	Unit	Bare Cost Material ($)	Bare Cost Labor ($)	Bare Cost Equipment ($)	Unit total ($)	No. of units	Total ($)
20-ton, air-cooled condensing unit	Q-6	0.4	60	ea.	7250	1475		10188	1	10188
7.5-ton, air-cooled condensing unit	Q-5	0.55	29.1	ea.	3110	690		4456	1	4456
10-ton rooftop, single package	Q-6		52.2	ea.	7220	1300		9892	1	9892
Misc. (new disconnects, crane operator, etc.)									1	500
									Total:	25036

Notes:
1. 20-ton and 7.5-ton units are air-cooled condensing type; uses existing evaporator/fan coil unit
2. 10-ton is single package with self-contained evaporator

Chiller System Cost (No Ice Storage)

Item	Crew	Daily output	Man-hours	Unit	Bare Costs Material ($)	Bare Costs Labor ($)	Bare Costs Equipment ($)	Unit total ($)	No. of units	Total ($)
20-ton liquid chiller	Q-7	0.35	91.429	ea.	14450	2300		19345	1	19345
Conc. pad	C-17a	26.7	3.03	cu. yd.	94	72	5.55	211	1	211
3 cu. ft. expansion tank with bladder	Q-5			ea.	945	32		1088	1	1088
1.5 hp pump	Q-1	3	5.333		835	125		1106	1	1106
1.5 hp pump	Q-1	3	5.333		835	125		1106	1	1106
Combination motor starter for chiller	1-ele	1	8	ea.	715	210		1102	1	1102
Combo motor starter for P1	Q-1	1.8	4.44	ea.	480	115	835	701	1	701
Combo motor starter for P2	Q-1	1.8	4.44	ea.	480	115	835	701	1	701
Piping, PVC Sch 40, 2-in. dia.	Q-1	59	0.271	lin.ft.	1.44	6.45		11	200	2252
Coil conversion (1-da. each, $100 mat. est.)	Q-5	1.06	15	ea.	100	360		650	3	1950
Pipe Insulation, 2-in. (200 lf)	1-abs.	105	0.76	lin.ft.	0.82	1.94		4	200	762
Pipe Insulation finish (Al)	Q-14	120	0.133	sq. ft.	0.54	3.06		5	315	1633
Valve, 1-in, at coils, elec. actuated	I-6	28	0.43	ea.	201	11.3		238	3	714
Cutting and drilling - brick wall	1 ele	4.4	1.818			47		71	3	212
Automatic air vent, 2"	Q-5	12	1.33	ea.	575	32		681	1	681
Separator, entrainment	1 Stpi.	11	0.73	ea.	205	19.25		254	1	254
Strainer	1 Stpi	10	0.8	ea.	365	21		433	1	433
Antifreeze (30% conc.)				gal.	6.74			7	10	74
Pipe Insulation - Rubber tubing- 2"	1 abs	105	0.076	lin.ft.	0.82	1.94		4	200	762
Misc. (valves, gauges, thermometers, etc.)										350
System Design (8 h @ $45/h)	Egr.		8							360
									Total:	35796

Note: Crew Stpi is a pipefitter

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