HEAT RECOVERY AND THERMAL STORAGE -

A STUDY OF THE MASSACHUSETTS STATE TRANSPORTATION BUILDING

VOL. 1

by

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B. S. Mechanical Engineering
University of Massachusetts
Amherst, Massachusetts
1983

SUBMITTED TO THE DEPARTMENT OF ARCHITECTURE
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREES OF
MASTER OF SCIENCE IN ARCHITECTURE STUDIES
and
MASTER OF SCIENCE IN MECHANICAL ENGINEERING
at the
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
June, 1986

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Submitted to the Department of Architecture
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ABSTRACT

A study of the energy system at the Massachusetts State Transportation Building was conducted. This innovative energy system utilizes internal-source heat pumps and a water thermal storage system to provide building heating and cooling. The potential benefits of this type of system include both energy savings and operating and equipment cost savings when compared to more conventional building heating and cooling systems.

The study involved monitoring of equipment performance, computer simulation of the building energy system dynamics, and analysis of actual and modelled system efficiency.

It was found that the building is presently operating as a 'low energy' building, despite a number of factors which have limited the heat pump system's capability to entirely meet winter heating requirements. Significant additional operation efficiency and cost savings are potentially available if a variety of measures are undertaken, including: stratification of the thermal storage system, utilization of demand management controls, and increased lighting system efficiency.

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This work is dedicated

to the memory of my little sister, Liisa

whose fine spirit still lives

in the hearts of those of us who loved her

Acknowlegments

The generous financial support of Massport Building Management and the ASHRAE Research Division Grant-in-Aid Fellowship are gratefully acknowledged.

A special thank-you to Laszlo Fleischer, Chief Engineer of the Massachusetts State Transportation Building, whose unfaltering encouragement, enthusiasm, and guidance have made this project possible.

Many thanks to my advisors, Harvey Bryan and Dr. Leon Glicksman, and reader, Bill Wright; who have each offered invaluable support, suggestions and ideas that have shaped this work from its inception.

Thanks to all of the State Transportation Building staff:

- Massport Building Management for generously letting me use their PC's and other office equipment and supplies, providing me with countless cups of coffee, and creating a pleasant work environment;

- Tony Bonanno, Mechanical Supervisor, and Ray Anderson, Electrical Supervisor, for providing valuable information and support;

- the Delta Operators for sharing their work space, keeping me company, teaching me about the Delta 1000, and letting me read their newspapers;

- the Maintenance Staff for teaching me 'hands on' about how the equipment and mechanical systems work, and providing comic relief;

- Art O'Brien, Lead HVAC Mechanic, for answering my endless questions, and respectfully listening to my ideas.

Acknowlegments, continued

I gratefully acknowledge the contributions of information and ideas from the following individuals:

Howard McKew, Energy System Industries, Inc. (formerly of Shooshanian Engineering)
Hank Eggert, Shooshanian Engineering, Inc.
John Clancy and Linda Skinkle, Goody Clancy and Associates, Inc.
Tunney Lee, Gordon King, and Hope Davis, Massachusetts Division of Capital Planning and Operations (DCPO)
Bob Tamblyn and Gary Johnson, Engineering Interface Limited
Charles Seaver, QED Seaver
India Hoeshen-stein and John Intorcio, Syska and Hennessey, Inc.
Roger Dennison, Helene Ferm, and Joe Donohue, Energy Planning, Inc.
James Russell and Jack Ellis, Boston Edison
Randy Truman and Bud Wildin, University of New Mexico Department of Mechanical Engineering
Louie Gunther, Albuquerque Publishing Co.
Mark Wallin, Synergic Resources Corporation
Jorgen Boldt, Technical University of Denmark
Rebecca Thatcher, MIT Department of Mechanical Engineering
Don Aucoin, Air Flow Associates
Technical Services Division, Honeywell, Inc.
Lawrence Spielvogel, Lawrence G. Spielvogel, Inc.
Doug Riches, Chief Engineer, Bell Canada Building, Toronto
Lloyd Algie, Associated Energy Technologies

Acknowdegments, continued

Last, but definately not least, I thank the following individuals who generously offered their time to help with the production of this work:

- my sister, Jan Bjorklund, who devoted countless hours to data entry, editing, paste-up, organizing, bringing me dinner, and keeping me company through several late nights;

- my brother-in-law, Patrick Flaherty, who did most of the typing, provided expert advice on editing, footnotes, bibliographies, and other such details, and was always enthusiastic about getting the job done;

- my sister, Lynn Bjorklund, who devoted many late nights and weekends to doing a very professional job on the graphics;

- my husband, Brian Flaherty, who did hundreds of paste-ups, more than his share of the housework, and most importantly provided the emotional support to see me through several months of being a 'work-widow';

- Johnny Moore and Joe Mueller of Sir Speedy Printing and Copying for doing an excellent job on very short notice;

- my friends Ruth Barton, Karen Smith, Joanna Rosenblatt, Brian Molloy, and Virginia Michead for contributing their time and companionship.

Finally, I thank my parents, Doris and Truman Bjorklund, for always giving me the love and confidence I needed.

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Terminology

Btu - British Thermal Unit

cfm - cubic feet per minute

c_p - specific heat per unit mass (Btu/lb·degF)

C_p - specific heat (Btu/degF)

degF - degrees Farenheit

gpm - gallons per minute

h - enthalpy (Btu/hr)

kW - kilowatt

kWh - kilowatt-hour

lb - pounds (mass)

m - mass flow rate (lb/hr)

Q - heat (Btu)

q - rate of heat flow (Btu/hr)

sq.ft. - square feet

T - temperature

t - time

Introduction

The Massachusetts State Transportation Building is one of several new large office buildings in North America which employ the emerging energy system design concept of using internal source heat pumps coupled with water thermal storage tanks for heating and cooling. The potential benefits of this type of system include both energy savings and operating and equipment cost savings when compared to more conventional building heating and cooling systems.

Large office buildings tend to be internal-load dominated, meaning that the heat generated inside the buildings by lights, people, appliances and equipment influences the heating and cooling requirements of the building more than ambient weather conditions. In the heating season, internal-source heat pumps are designed to recover the excess heat generated in the core of the building and use it to heat the perimeter of the building which is more subject to the influences of outdoor conditions. Coupled with a thermal storage system, excess heat can be stored for future needs when sufficient internal heat gains are not available. This sort of "bootstrap heating" concept can significantly conserve energy and equipment costs when compared with the costs of providing conventional heating and cooling plants and operating them simultaneously.[1]

Thermal storage systems can also offer significant cost benefits during summer cooling operation. The thermal storge tanks can be used as load management devices, saving both electricty costs and equipment

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[1]R.T. Tamblyn, "Bootstrap heating for Commercial Office Buildings" ASHRAE Journal, (April 1963), pp.53-64.

costs. The storage tanks are cooled by refrigeration equipment during night-time periods of lower building electric demand. The thermal storage system is then used during building occupied hours for cooling, reducing or eliminating day-time cooling equipment operation. In this way both day-time electricity demand and cooling equipment peak capacity are reduced.

In locations where electric rates incorporate demand penalties, and day-time electric rates are higher than night-time off-peak rates, this sort of operation can yield significant electric cost savings. Because of their load management capability, thermal storage systems can provide benefits not only to the building owners but also to the electric utilities by helping to reduce demand peaks and even out electric consumption during the day. This reduces the rate of growth of electric power demand and therefore the rate at which electric utilities must provide new electric generating facilities to meet that demand. Some electric utilities have chosen to promote the installation of chilled water and ice thermal storage systems through economic incentives as part of their load management strategies.[2]

Since thermal storage systems allow the cooling operation to be spread out over the day rather than operating to meet instantaneous cooling loads, the first cost savings of decreased cooling equipment peak capacity requirements can prove significant, depending upon the thermal storage capacity. The cost savings in the case of the Transportation Building was almost sufficient to offset the additional

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[2]In addition to high demand charges and time-of-use rates, some electric utilities such as Southern California Edison and Pacific Gas and Electric rebate customers for the additional design costs of thermal storage systems or provide other rebates based upon the amount of kW of demand which are shifted from the peak.

first cost of the thermal storage tanks.[3]

Night-time cooling operations with thermal storage tanks can also increase cooling system efficiency by providing more favorable cooling tower operating conditions and the option of controlling the load on the heat pumps to operate at their optimal design conditions.

The major objective of this thesis is to document and analyze the performance of the energy system at the Massachusetts State Transportation Building. Its findings should benefit both the operators of this specific energy system and the designers and operators of similar systems. The research conducted for this work has included both energy system data collection and several months of 'hands on' observations of how the system is operated.

This thesis demonstrates that the energy system design has contributed to making the State Transportation Building a relatively 'low energy' building. It also documents the potential for further energy and cost savings. The influence of dynamic changes such as weather and occupancy conditions upon the performance and operation of the building energy system are assessed relative to energy efficiency and cost efficiency. Questions concerning optimal thermal storage management from season to season and electric load management are addressed.

It is hoped that this work will help to fill the existing void of actual system performance information on internal-source heat pump and thermal storage systems.

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[3]The designers anticipated a 2000 ton peak cooling requirement but installed equipment with a capacity of only 1200 tons. The equipment cost reduction roughly balances the $237,000 installed cost of the storage system according to H. Eggart, Shooshanian Engineering (Interview on October 11, 1985).

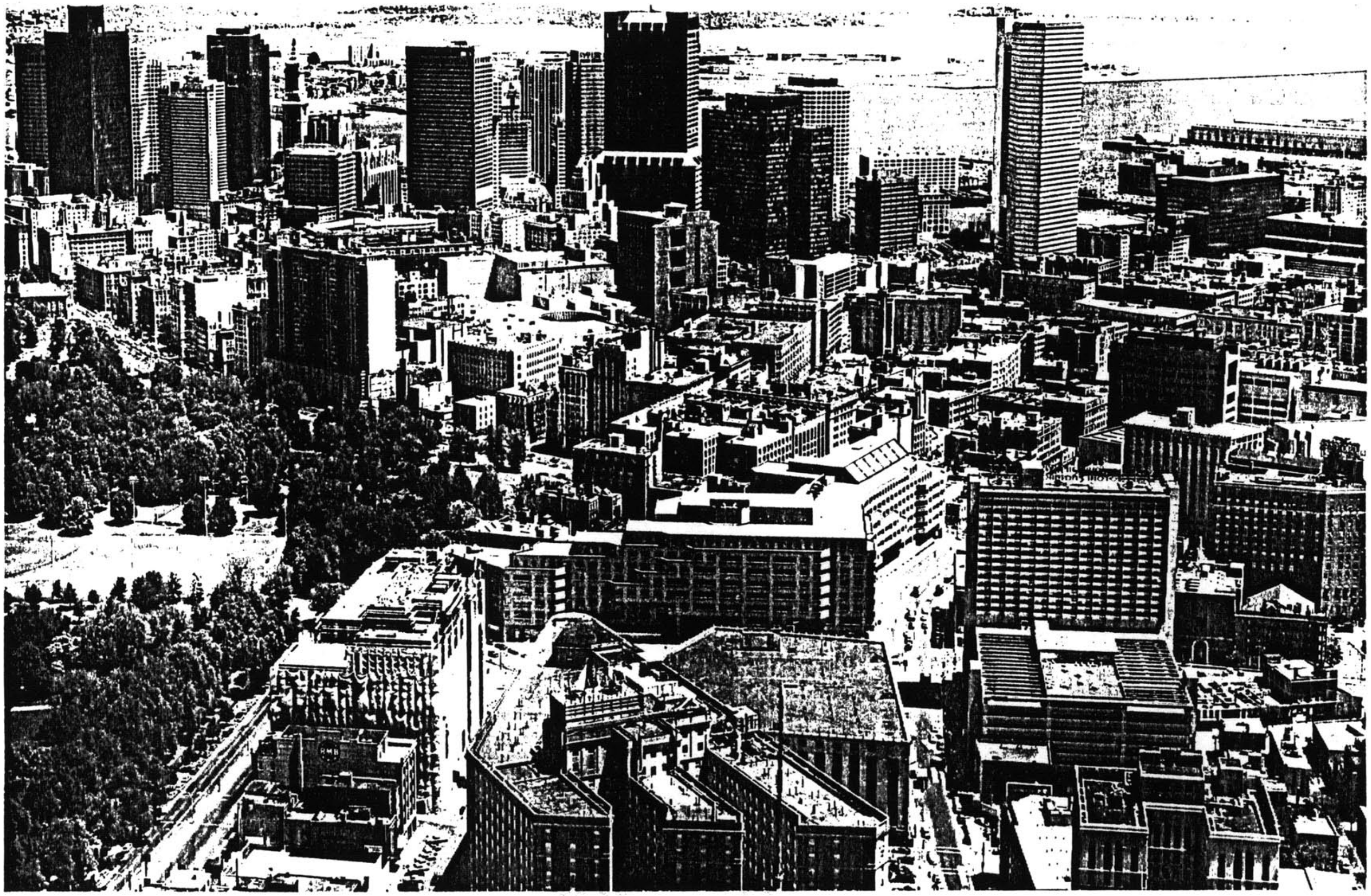

Figure 1-1: Aerial View of the State Transportation Building, Boston

Chapter I: General Description of the Building

The Program

The Massachusetts State Transportation Building is owned and operated by the Commonwealth of Massachusetts. The building is located in Park Square, in the heart of Boston (see Figure 1-1), and was completed in December of 1983. The 901,000 sq.ft. building (83,700 m^2) was commissioned, programmed, and built by the Commonwealth to provide quality office space to eight state transportation agencies, a two-level underground parking area, and street-level retail space. This mixed-use program was conceived in an attempt to revitalize a deteriorated urban site in close proximity to Boston's theatre district, State House, other state offices, business district, and the Boston Common (see Figure 1-2).

By providing one building to house eight agencies which were previously scattered throughout the city, the Commonwealth hoped to allow the agencies to share services, and to facilitate more communication and cooperation between them. Shared services include a transportation library, copy center, conference center, childcare, cafeteria, and health services.

The design criteria for the building evolved from collaboration between the State, local neighborhood and business organizations, and the building's architects, Goody Clancy and Associates, Inc. of Boston. Unlike many office buildings which are built on speculation, representatives of the transportation agencies which now occupy the building were able to participate in the programming of the building through regular meetings with the architects.

c. Goody, Clancy & Associates, Inc.

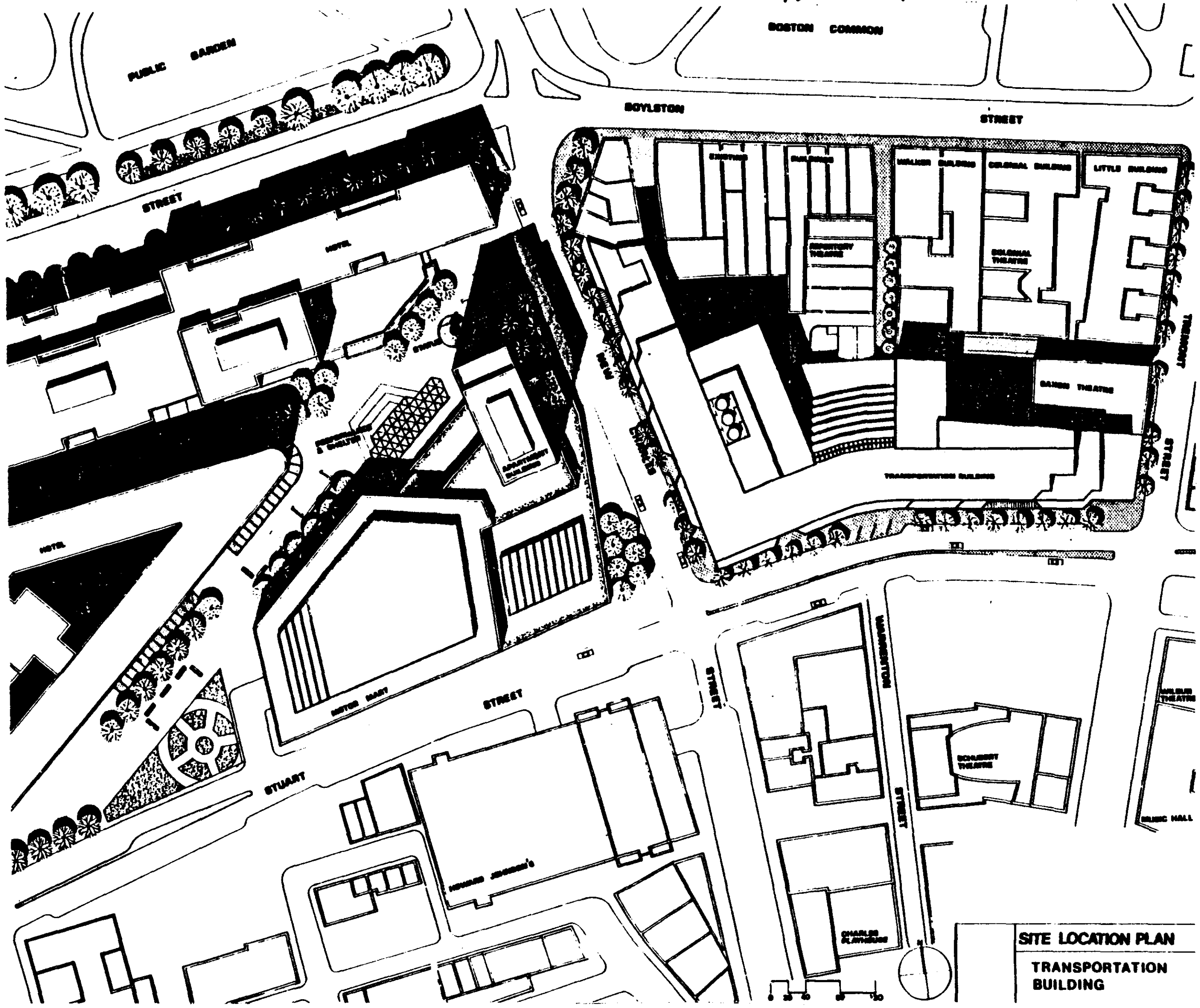

Figure 1-2: Site Plan of the State Transportation Building

The design criteria included:

1) a low building with an irregular brick facade preserving the scale and texture of the adjacent historic structures;
2) retail space to revitalize the street level beyond regular business hours (see Figure 1-3(a))[1];
3) an internal pedestrian pattern to reinforce the links between the theatre district, the Boston Common, and Park Square (see Figure 1-3(b)); and
4) a demonstration of energy efficient building design.[2]

With energy efficient building design as an important part of the program, the designers examined architectural and energy system design integration at an early stage of the design development. The designers proposed to exceed the minimum requirements of the Massachusetts State Energy Code. Thermal envelope, solar control, building massing, lighting systems, and mechanical and electrical system designs were considered together.

An overall building heat conductivity limit of U=0.30 $Btu/hr \cdot ft^2 \cdot F$ ($U=0.52\ W/m^2 \cdot K$) was established, with a maximum glass surface area of 30%. Using a computer study of sun angles and window setback, a twenty inch window recess was designated to control solar gain in the summer but allow winter passive solar heating. A ceiling mount ambient lighting system with parabolic reflectors was

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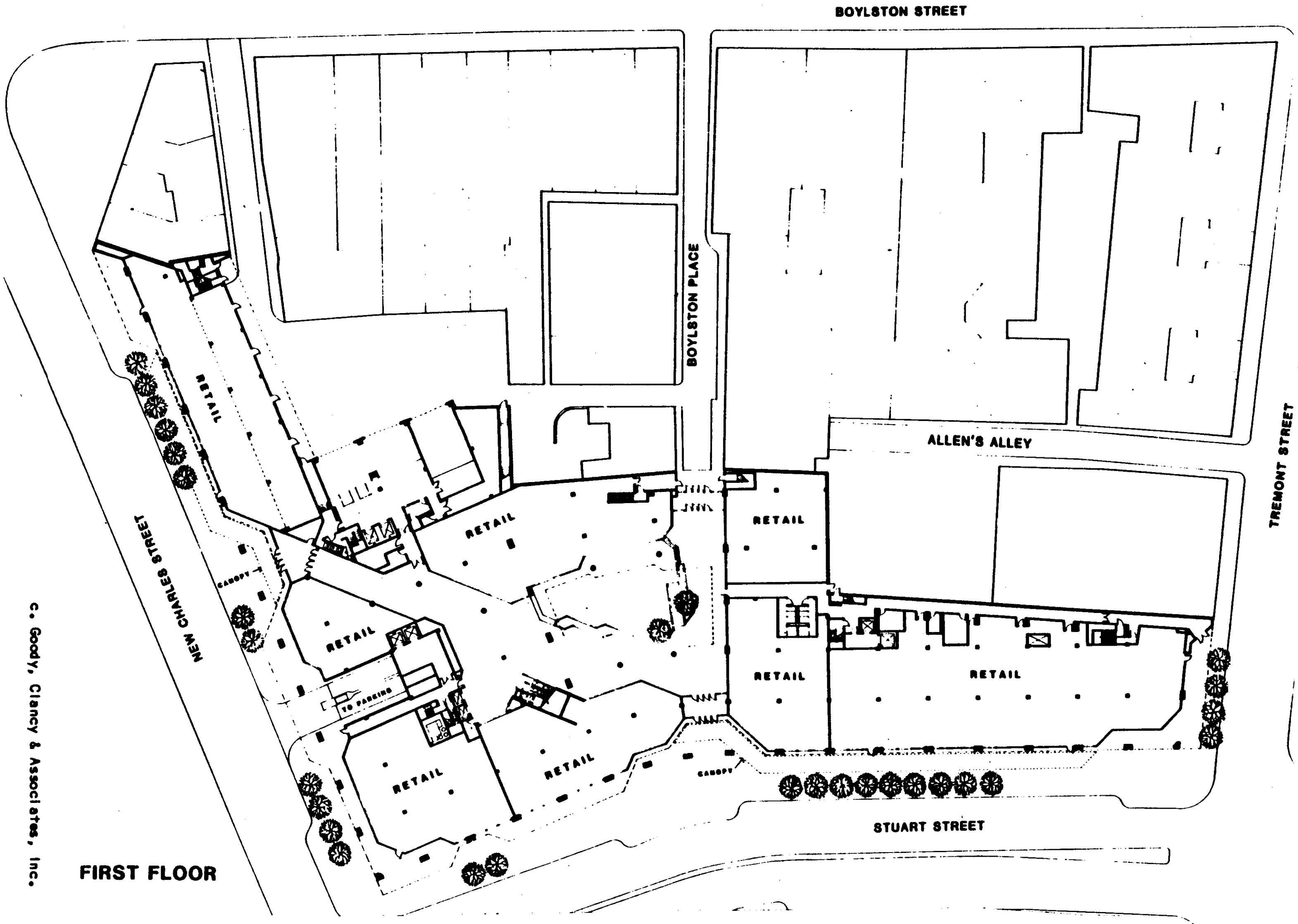
[1]The first floor retail areas will not be occupied until after July 1986.

[2]John M. Clancy and Edward Shooshanian, "The Transportation Building", General Proceedings, AIA Building Redesign and Energy Challenges Conference, November 15-17, 1984 (Boston: 1984, p. 63).



C. Gody, Clancy & Associates, Inc.

Figure 1-3(a): Plan of Retail Spaces at the State Transportation Building

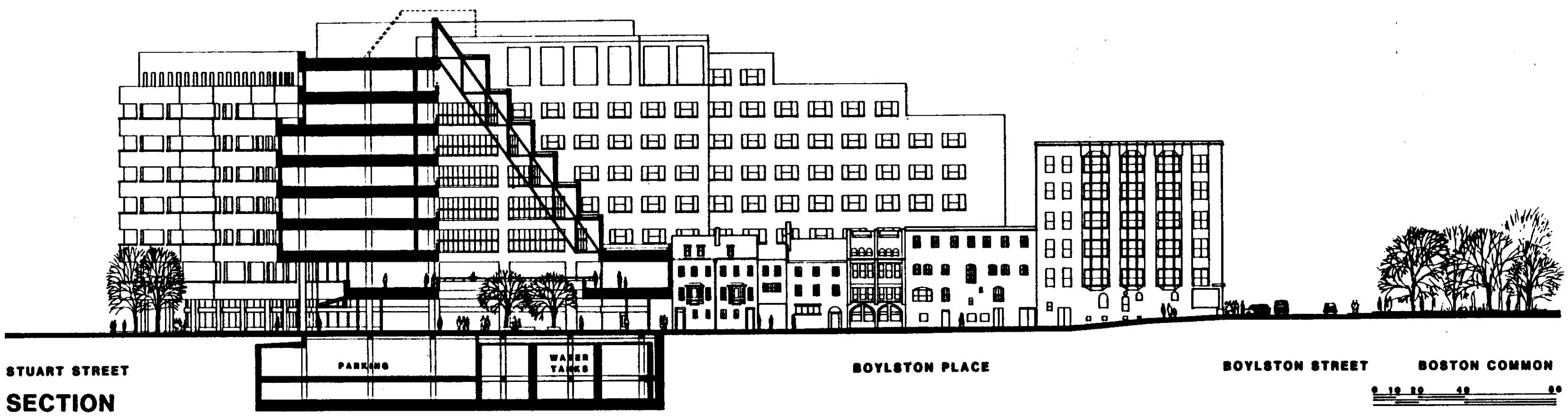


Figure 1-3(b): Section Through State Transportation Building Atrium chosen to provide 48 footcandles at 2.1 W/ft^2 (22.6 W/m^2) in the office spaces.[3]

The resulting eight-story building is situated on an irregularly shaped site which wraps around two sides of a full city block. A central atrium serves as a unifying architectural and psychological element. The atrium rises the full height of the building, creating a thermal buffer on the north side and providing daylight and a sense of openness to the retail spaces, cafeteria, and offices which open on to it (see Figure 1-4).

The office spaces in the building are generally open-plan to allow view and daylight to penetrate into the interior working spaces. The windows on levels three through eight are operable in order to provide the occupants with control over their environments. The above-ceiling mechanical, and cellular floor deck electrical distribution systems are zoned for adaptability, and most interior partitions are movable.

Energy System Design Concept

Shooshanian Engineers, Inc., of Boston was the mechanical/electrical system designer. After analyzing the anticipated heating and cooling loads for the building over the course of a year, the engineers determined that the building would be internal-load dominated, and predicted that at all times the cooling loads in the building would exceed the heating loads. After modeling a variety of HVAC systems for the building, they chose an all-air variable-air-volume system with internal-source heat pumps and water thermal storage tanks. The

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[3]Goody Clancy and Assoc., Inc., Transportation Building: B-4 Design Statement (Boston: 29 June 1978).

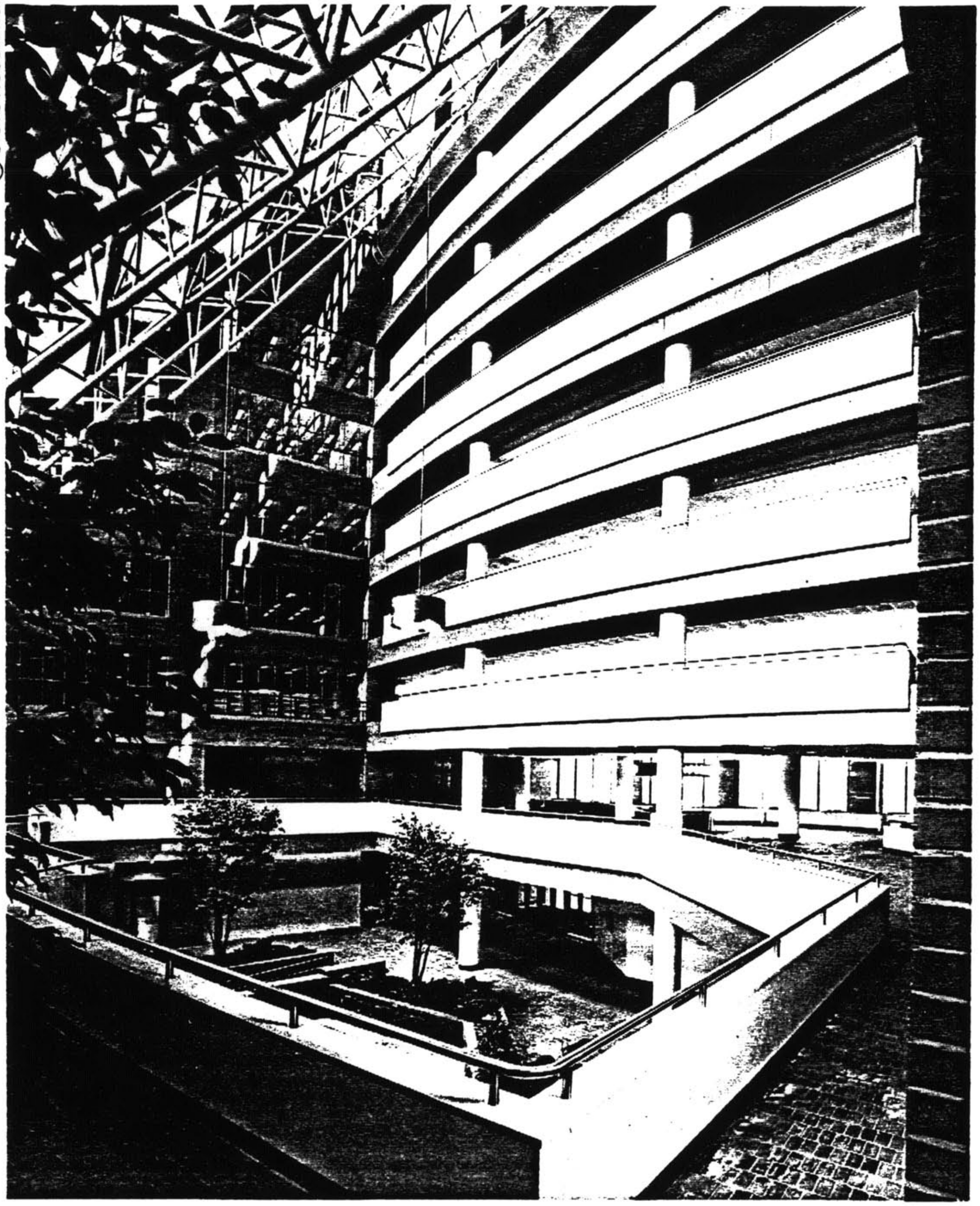

Figure 1-4: The State Transportation Building Atrium

engineers predicted that with full building occupancy this system would satisfy all of the heating and cooling demands in the building, and gained approval to omit any back-up heating system from their design.

The main objective of the system design is heat recovery. The building is zoned with an exterior zone along the perimeter of the building, and an interior zone. The heat generated by lights, people, and equipment in the interior of the building is recovered and used to heat the perimeter of the building which is exposed to the outside temperatures. A chilled water loop extracts heat from the return air at the central air handlers and brings it to the evaporators at the central heat pumps. Using a compressed refrigerant cycle, the heat pumps extract heat from the chilled water loop and transfer the heat to the hot water loop on the condenser side of the heat pumps. This hot water loop which circulates through the building provides heat where necessary at the perimeter. Any excess hot water is diverted from the hot water loop and routed to the three 250,000 gallon water thermal storage tanks.

During the cooling season when heat is rarely needed in the building, the condenser heat is circulated via a condenser water loop to cooling towers which exhaust the heat to the environment. At this time of year, the water thermal storage tanks are used to store chilled water which can be generated around the clock by the heat pumps. The chilled water storage provides additional cooling capacity so that fewer heat pumps need to be run during the day, which reduces electric demand. The storage capacity also allows the heat pumps to be downsized from the capacity required to meet the peak design cooling load in the building. This allowed a lower first cost in equipment and more efficient heat pump operation by more closely matching heat pump capacity with average cooling loads.

In the spring and fall, the thermal storage and heat pump system make a gradual transition from heating season operation to cooling season operation and vice versa. In the spring the storage tanks are gradually cooled in sequence, as the need for hot water storage decreases. In the fall the storage tanks are gradually heated in sequence, as the the need for hot water storage increases.

There is a utility-source district steam line into the building. Steam is used in the winter for entry way unit heaters, humidification at the air handlers, and for emergency back-up heating.

The designers predicted that this heat recovery system would have a significantly lower energy use than a conventional hot water boiler and chiller system. Using the Trane Trace system simulation program, they predicted approximately 54,000 $Btu/ft^2 \cdot yr$ (15.8 $kWh/ft^2 \cdot yr$) for the proposed system (excluding steam) as compared to approximately 93,000 Btu/ft^2 (27.3 $kWh/ft^2 \cdot yr$) for a conventional system of variable air volume with district steam terminal reheat.[4]

The designers sought to save energy both with the heating system, and the fan and domestic hot water systems. The fans in the major air handlers are variable pitch with a static pressure control, so that they use the minimum power necessary to supply the air requirements in the building. Similarly, the large fans which supply and exhaust air from the underground garage levels are controlled to incremental volumes by carbon monoxide sensing devices. The domestic hot water system, which is separate from the heating and cooling system, consists of 160 active solar hot water collectors designed to provide eighty-three percent of the annual domestic hot water requirements of the building.[5] A back-up electric hot water heater boosts the solar heated domestic hot water temperature to the 120 degF setpoint when necessary.

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[4]Howard McKew, "ASHRAE Design Award Submittal", 26 April 1985.

[5]Ibid.

Description of the Energy System

Controls

The Transportation Building has a pneumatic/electric control system.[6] The control system consists of automatic temperature and air controls (ATC and AAC), and an automatic central controller (ACC). The ATC and AAC are remote systems that function separately from the ACC. These systems consist of sensors, thermostats, transmitters, receiver-controllers, control valves, damper operators, P/E switches, E/P relays, etc. They are located in or near local control panels close to the mechanical equipment, and perform automatic control functions.

The ACC is a central computerized monitoring and control system. It utilizes a Honeywell Delta 1000 building management system to monitor the energy system in the building. The Delta 1000 consists of a central processing unit (CPU), remote data gathering panels (DGP's), sensors and detectors. The CPU has a user interface which consists of a video display terminal (VDT) with an integral keyboard and printers. This unit is located in the HVAC control room and is staffed around the clock.

The Delta system has a multitude of sensors and detectors which transmit information such a temperatures, pressures and flow rates to the DGP's, and the DGP's pass this information on to the CPU. The CPU gives information from the sensors and detectors to the system operator, indicating whether equipment is on or off, and providing data on temperatures, humidities, pressures, and flows within the system. See Table B-1 for a listing of the data available from the

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[6]The designers considered a Direct Digital Control (DDC) system, but at the time the buiding was designed (1976-78) control companies offering DDC systems did not meet the specified criteria of five years automatic air control experience and ten fan system installations of 50,000 cfm or more.

CPU. The CPU has the capability to perform logical, programmed functions based upon information transmitted from the DGP's, such as optimized start/stop. The CPU can also perform simple time-clock on/off functions. From the VDT console, the system operator can command equipment on and off, and command certain pre-programmed sequences to occur.

There are separate automatic fire and security systems in the building which interface some information with the Delta 1000.

Air Systems

There are four air handlers in the building: AC-1, AC-2, AC-3, and AC-4. AC-1 - 3 are the air handlers for building levels two through eight. Each has a maximum capacity of 200,000 cfm. AC-4 is a 17,000 cfm constant volume unit which serves a small underground area of the building. Air handlers for the first floor retail spaces have yet to be installed, and will operate independently of the central energy system although they will use chilled water supplied by it.

AC-1, 2, and 3 each serve approximately one third of the building (see Figure 1-5). Each unit has a similar configuration, with four Flakt direct-drive, variable pitch supply fans and return fans (a total of eight fans per air handler). Each fan has a maximum capacity of 50,000 cfm with the pitch capable of varying from full capacity down to 5,000 cfm. Maximum static pressures at the fans are approximately 7 inches of water.

The air handlers are zoned so that two fans supply the interior of the building and two supply the exterior (see Figure 1-6). The interior and exterior fans have separate cooling coils so that they can be set to provide different air discharge temperatures in the winter. The valves controlling the flow of chilled water into the cooling coils throttle open and closed to maintain a constant discharge temperature setpoint. These setpoints are adjusted seasonally at the local controller panel.

c. Goody, Clancy & Associates, Inc.

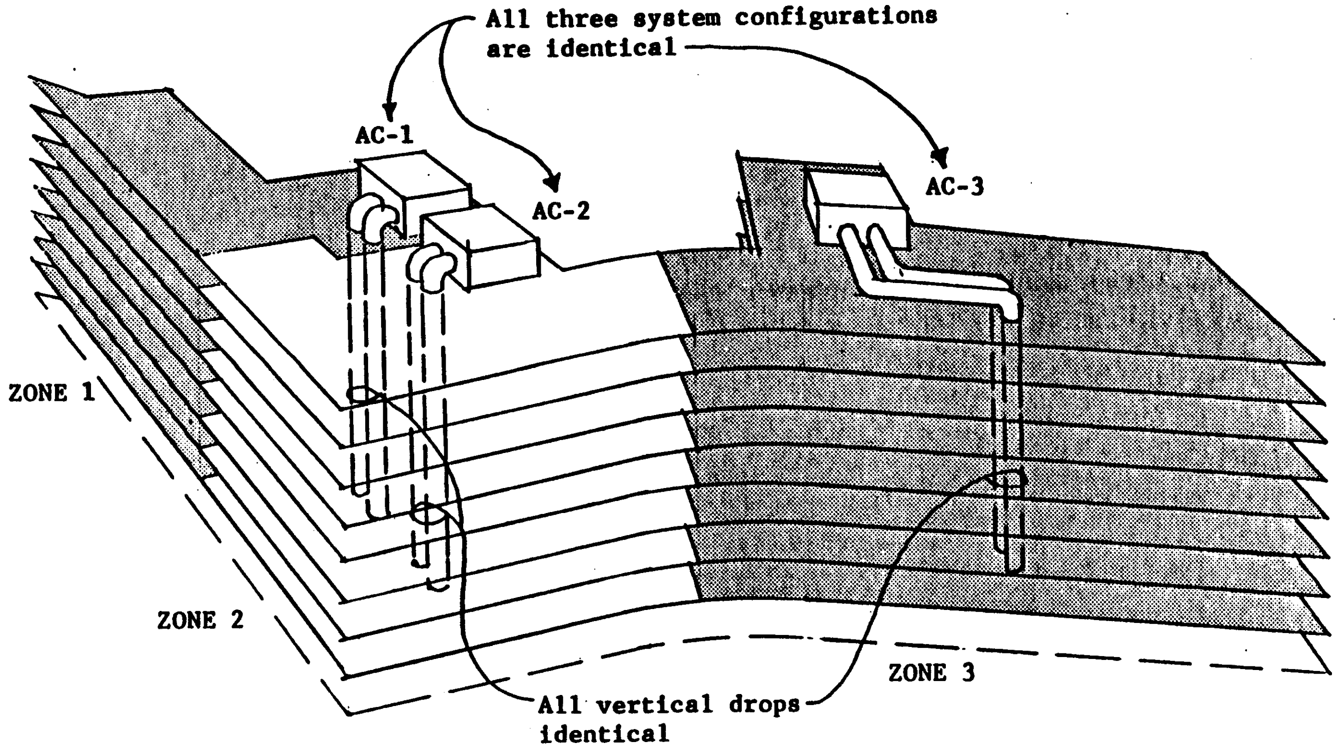


Figure 1-5: Central Air Handler Locations

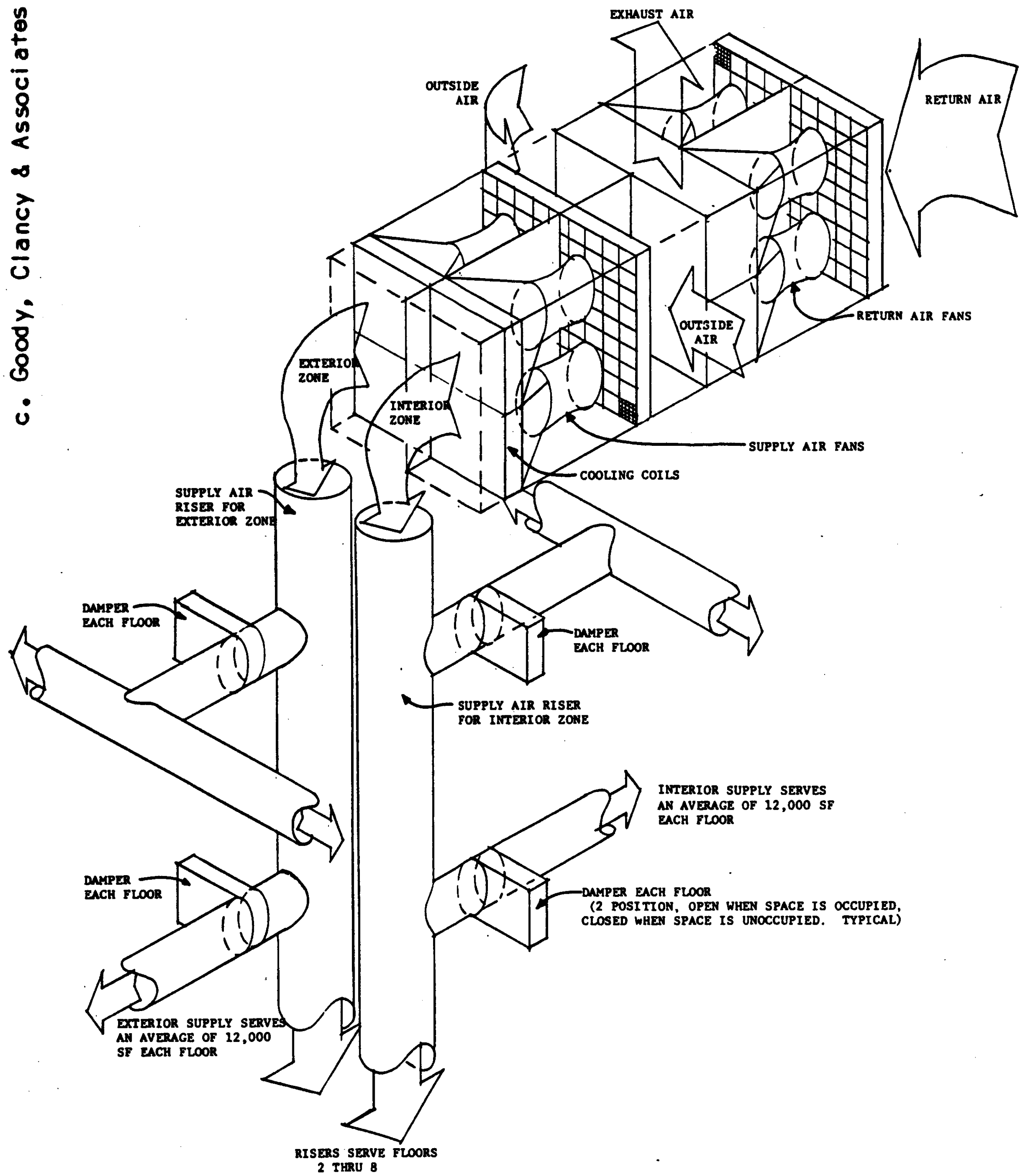


Figure 1-6: Typical Central Air Handler Configuration, AC-1, 2, and 3

The air handlers have two sets of air dampers, delayed vents (minimum fresh air dampers) and enthalpy vents (economizer dampers) which control the amount of return air that is exhausted from the building, and the amount of fresh outdoor air drawn into the building (See Figure 1-7). These dampers are commanded open or closed by the operator of the Delta 1000. When the delayed vents are commanded open, a portion of the outdoor air intake dampers admit fresh air to make up the difference between the supply and return air flow rates. This difference is controlled to remain constant.

When the enthalpy dampers are commanded open, all of the outdoor air intake dampers modulate open to bring in a maximum of 100 percent outdoor air, and the exhaust air dampers modulate open to discharge return air from the building. This enthalpy capability allows the building operators to use cool outdoor air for "free cooling" in the spring, fall, and summer cooling seasons when the outdoor air enthalpy is less than the indoor air enthalpy.

The enthalpy dampers have a local control override from the cooling coils. If the outside air is cooler than the setpoint on the cooling coils, the outside air intake, return, and exhaust air dampers will modulate to mix the appropriate amount of return air with outside air required to maintain the coil setpoint temperature. In this situation, no chilled water cooling is needed.

When all dampers are commanded closed, the fans go into a warm-up cycle mode where the return air flow rate should equal the supply air flow rate.

From each air handler, one interior and one exterior high-velocity supply and return riser extend down to levels two through eight with a main branch to each floor. Each supply and return branch has a damper, commanded open or closed remotely by the Delta 1000, which permits air conditioning to be cut off from unoccupied floors (see Figure 1-6).

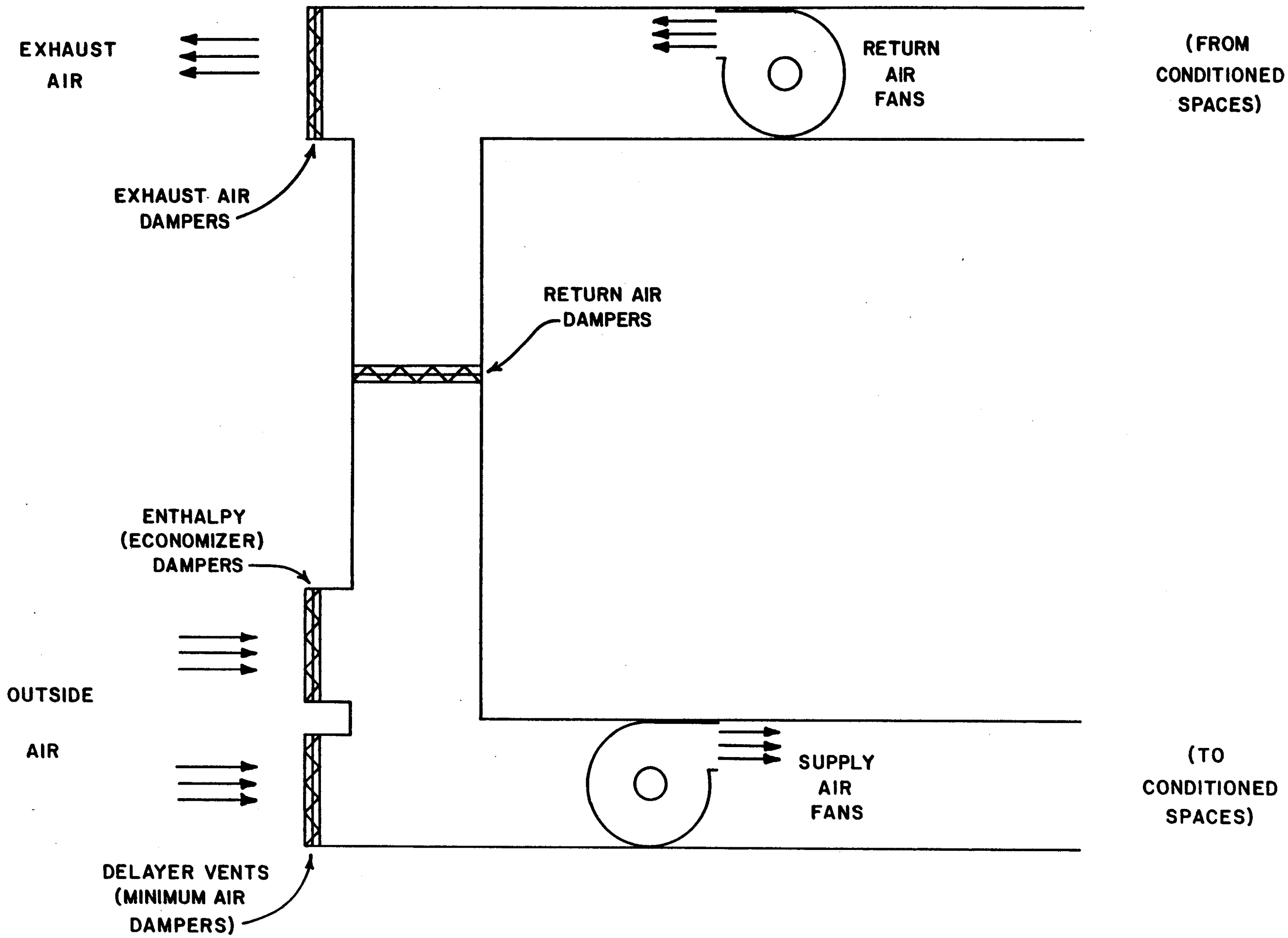


Figure 1-7: Schematic of Air Handlers

Each floor has an above-ceiling supply air duct network with variable air volume (VAV) boxes and diffusers. The interior zone VAV boxes supply cool air to ceiling light troffer diffusers, and are controlled by local thermostats (See Figure 1-8). When the thermostat senses space temperature above the thermostat setpoint (typically 76 degF), the VAV box will begin to modulate open from a minimum position, to supply additional cool air to the diffusers. Conversely, if the thermostat senses a space temperature below the setpoint, the VAV box will modulate to its minimum supply air position.

In the exterior zone, dead-band thermostats control VAV boxes with heating coils which discharge upward across the windows at the perimeter of the building (see Figure 1-8). These thermostats have two setpoints: the lower one for heating, the higher one for cooling. When the thermostat reads a space temperature above the cooling setpoint (typically 76 degF), the VAV box will modulate open to supply more cool air. When the thermostat senses a temperature in the dead-band region between the cooling and heating setpoints, the VAV box will modulate to its minimum supply air position. When the thermostat senses a temperature below the heating setpoint (typically 70 degF), the VAV box will modulate open and the hot water valves on the heating coil will open to allow hot water to pass through the heating coil.

All return air is drawn around light troffers and through an open plenum above the hung ceiling. The return ducts are along the corridors.

With the locally controlled VAV boxes modulating open and closed throughout the building, the flow rate required at the fans is constantly changing. The flow rate on the variable-pitch fans is controlled by a static pressure sensor at level two, the end of the duct network for each AC-unit. The second floor design requirement

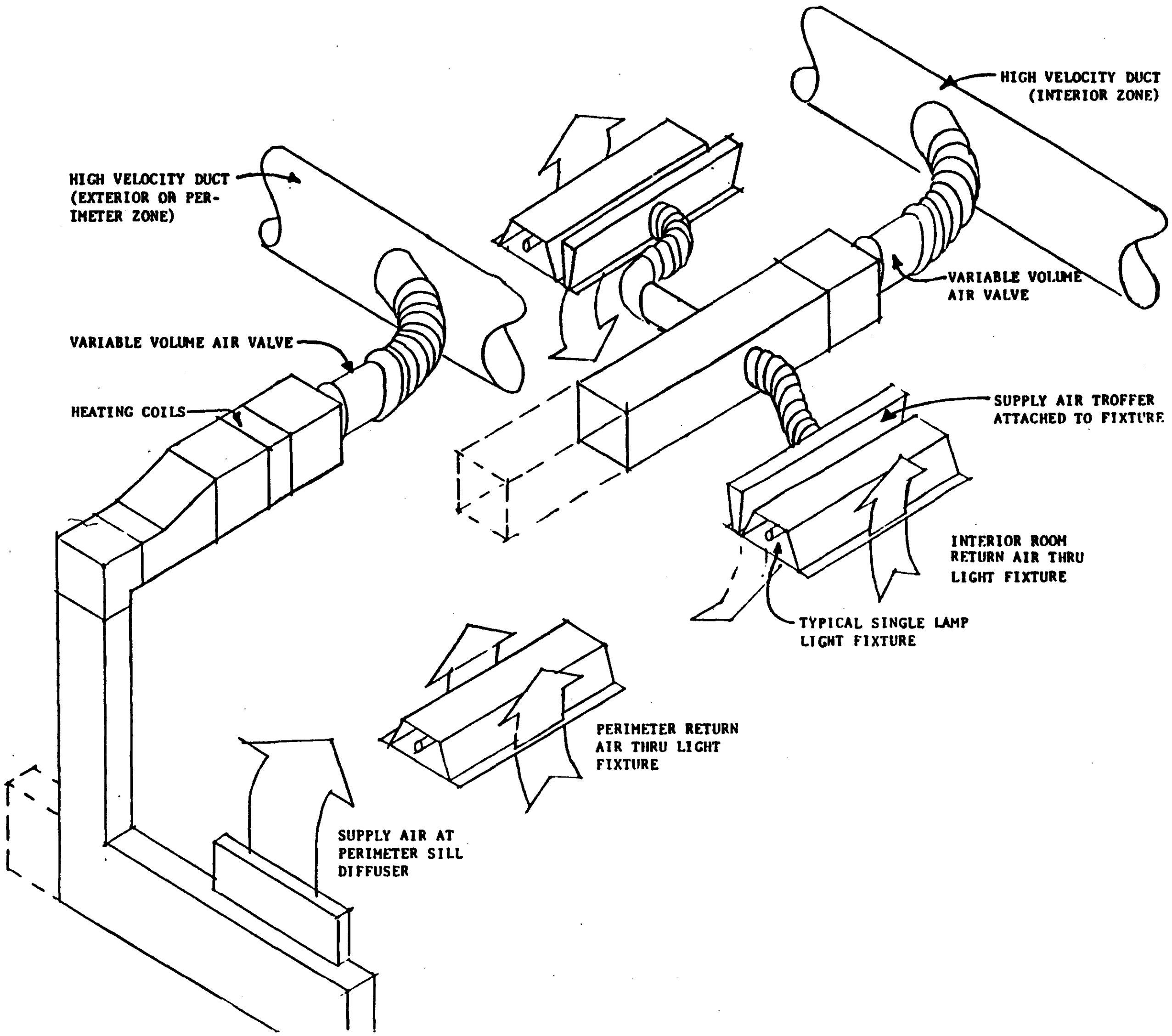


Figure 1-8: Typical Local Exterior and Interior Zone Supply and Return Air Configurations

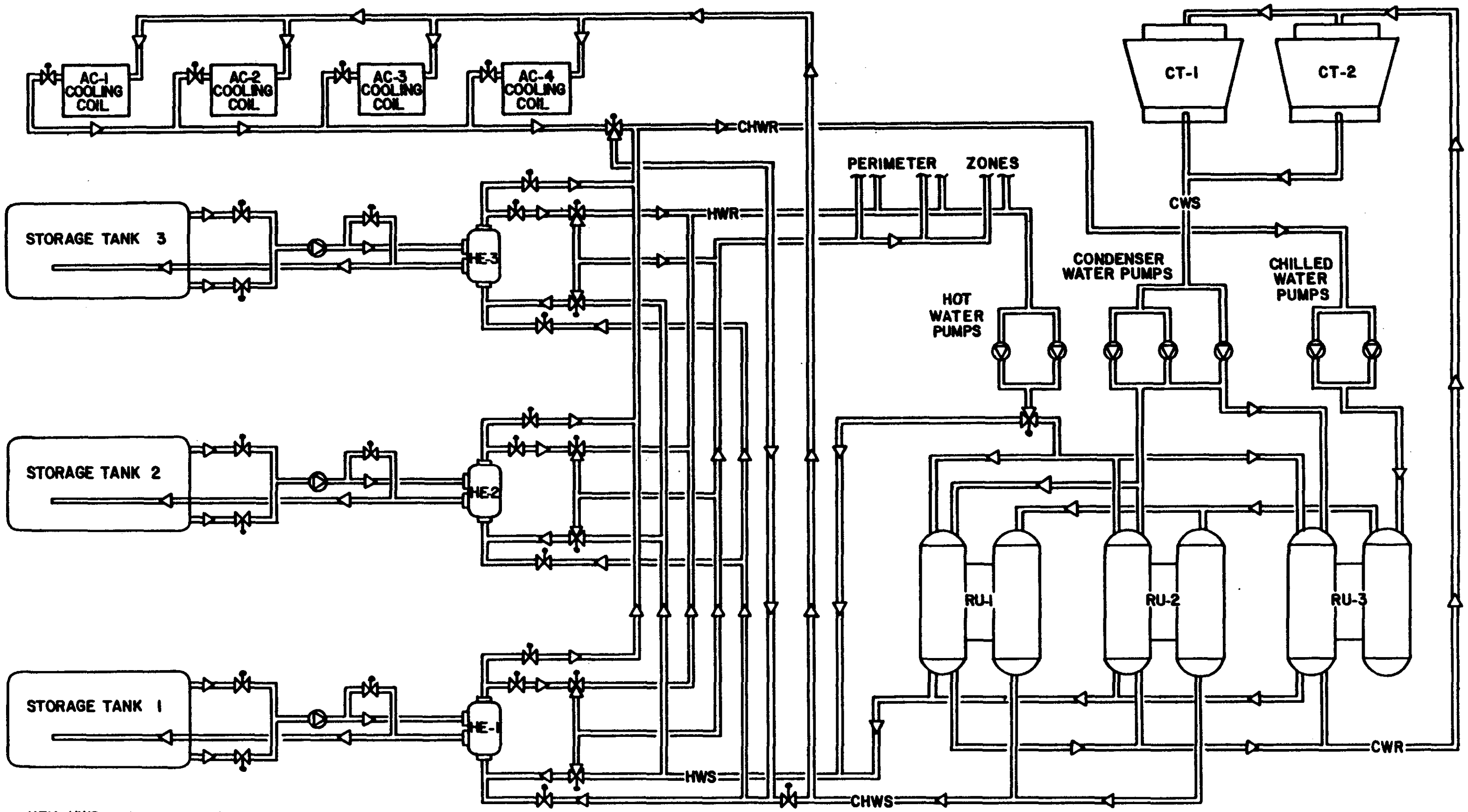
for static pressure is one inch of water. When the VAV boxes modulate closed, static pressure builds up in the duct system. The controls then vary the pitch at the fans to reduce the flow rate and static pressure. When the VAV boxes modulate open and the static pressure drops in the system, the pitch is varied at the fans to increase the flow rate and static pressure. The return fans are controlled to track the supply fan flow rates as they increase and decrease, thereby maintaining a constant differential setpoint.

See Table A-10 for a listing of the fans in the building and their characteristics.

Heat Pumps

There are three centrifugal heat pumps in the main heating and cooling system for the building: RU-1, RU-2, and RU-3 (see Figure 1-9). They are all Trane Heat Recovery Centravac refrigeration units (RU's). The units have double-bundle condensers, with separate hot water and condenser water circuits running through them. In each heat pump the refrigerant gas from the compressor flows over both condenser tube bundles allowing heat rejection to either one or both condenser water circuits depending upon the system heating requirements. Other features include a two-stage compressor, economizer cycle, and dual-inlet vanes - all for increased efficiency over a broad range of loads.

RU-1 and RU-2 each have a 300 ton (1,055 kW) capacity, and RU-3 has a 600 ton (2,110 kW) capacity. The hot water and condenser water circuits pass through the three units in parallel (see Figure 1-9). The chilled water circuit passes through RU-3 and then through RU-1 and RU-2 in parallel. This chilled water configuration allows RU-3 to be used to pre-cool the chilled water before it enters RU-1 and RU-2.



<u>KEY</u>: HWS = Hot water supply
HWR = Hot water return
CWS = Condensed water supply
CWR = Condensed water return
CHWS = Chilled water supply
CHWR = Chilled water return

<u>Figure 1-9: Schematic of Energy System</u>

The heat pumps are controlled to maintain a chilled water discharge temperature setting by adjusting the refrigerant inlet guidevanes at the compressors. This setpoint is set at the local RU control panels, and can be increased and decreased remotely by the Delta 1000 operator.

The heat pumps also have a demand limiter setting which is set manually at the heat pumps. RU-1 and RU-2 can be set to 60, 80, and 100 percent of their capacities. RU-3 can be set to 40, 60, 80, or 100 percent of its capacity. If the motor current exceeds the setting, the demand limiter setting will automatically adjust the compressor inlet vanes and the power to the compressor to reduce the electricity demand.

The heat pumps have many other built-in control features. There is a refrigerant flow control to maintain the correct pressure differential between the evaporator and the economizer. There are also safety shut-offs for insufficient evaporator or condenser water flows, low evaporator pressure, high condenser pressure, high motor temperature, and low oil pressure.[7]

Water Systems

There are three water loops in the energy system: the chilled water, hot water, and condenser water loops, all of which flow through the heat pumps.

The chilled water loop is pumped at a constant rate of about 1,800 gpm by a single pump. The chilled water flows through the evaporator of RU-3, and then divides into two parallel

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[7]"Heat Recovery Centravac Design Manual", The Trane Company, Dec. 1978.

flows through the evaporators of RU-1 and RU-2. After the heat pumps, the chilled water flows to the cooling coils at the air handlers, and/or to the thermal storage tank heat exchangers, depending upon the mode of operation (see Figure 1-10).

The hot water loop is pumped at a constant rate of about 1,240 gpm by a single pump. The hot water flows through the three heat pumps in parallel and then flows to the heating coils at the perimeter of the building and/or to the thermal storage tanks, depending upon the mode of operation (see Figure 1-11).

The condenser water loop flows first through the condensers of the heat pumps in parallel and then to the two cooling towers. There are three condenser water pumps in parallel, two of which flow at approximately 1,200 gpm, and one at 3,200 gpm. The requirements of the heat pumps determine which condenser water pumps are used. The computer room AC units are also tied into the condenser water loop (see Figure 1-12).

The condenser water flows through the two cooling towers in parallel. Each cooling tower has a 25 horsepower fan which is controlled automatically by a temperature sensor in the return condenser water. The two cooling tower fans will switch on and off in sequence to maintain the condenser water return setpoint, typically 85 degF. These cooling tower controls work only when the condenser water pumps are running (see Figure 1-12).

Chilled water, hot water, and condenser water flows can be manually valved off at each heat pump. The building pumps and their characteristics are listed in Table A-9.

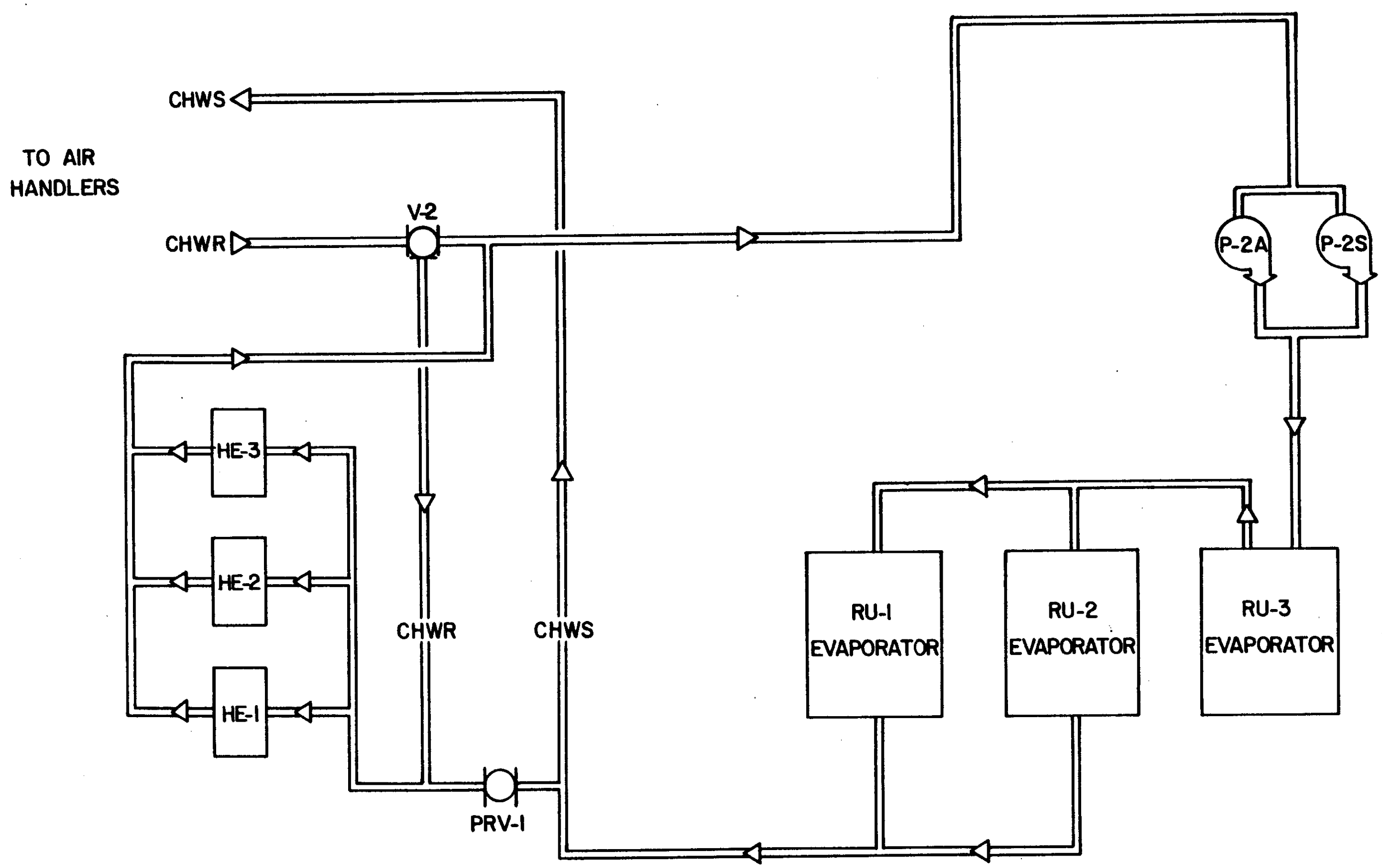

Figure 1-10: Schematic of Building Chilled Water Circuit

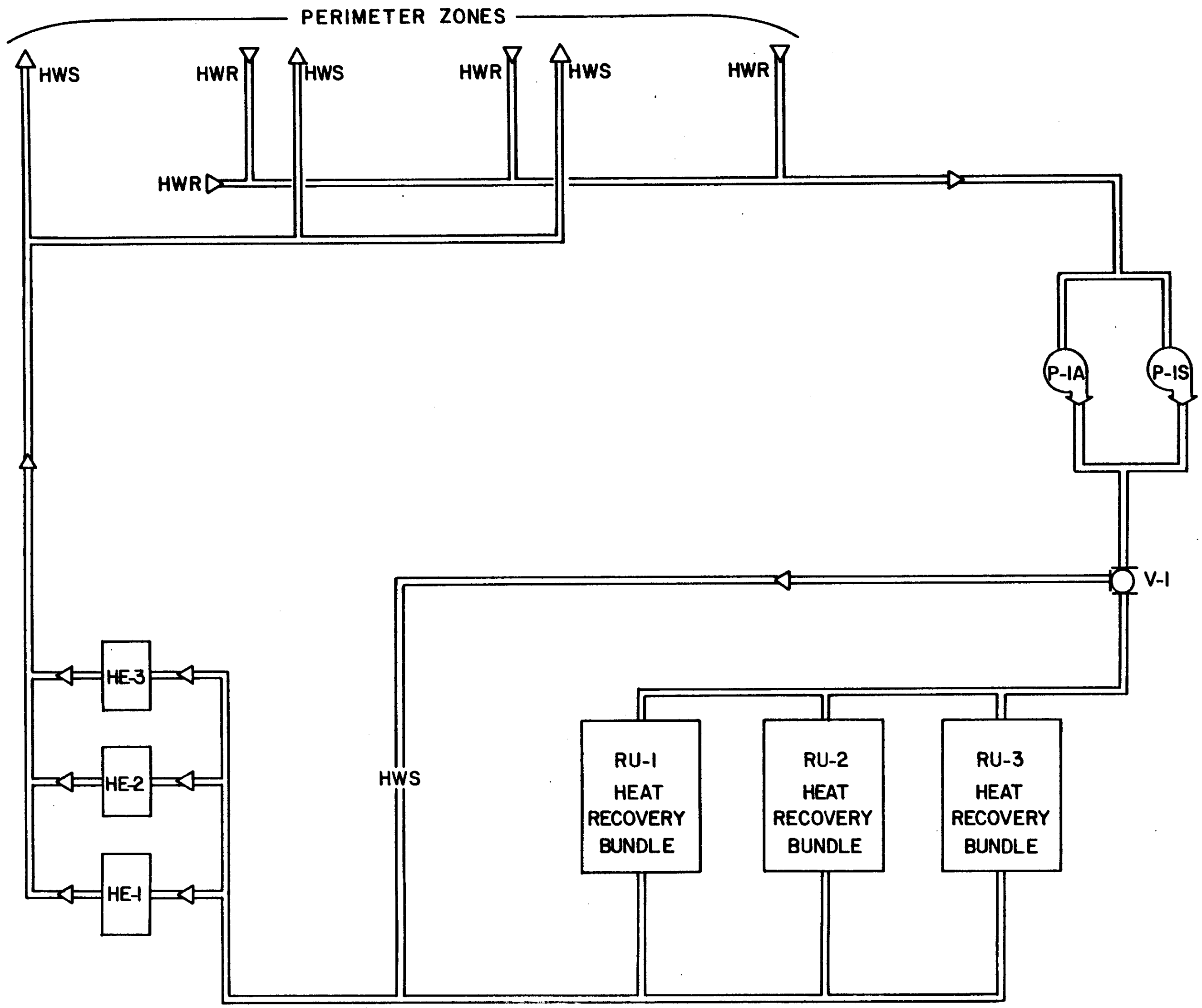

Figure 1-11: Schematic of Building Hot Water Circuit

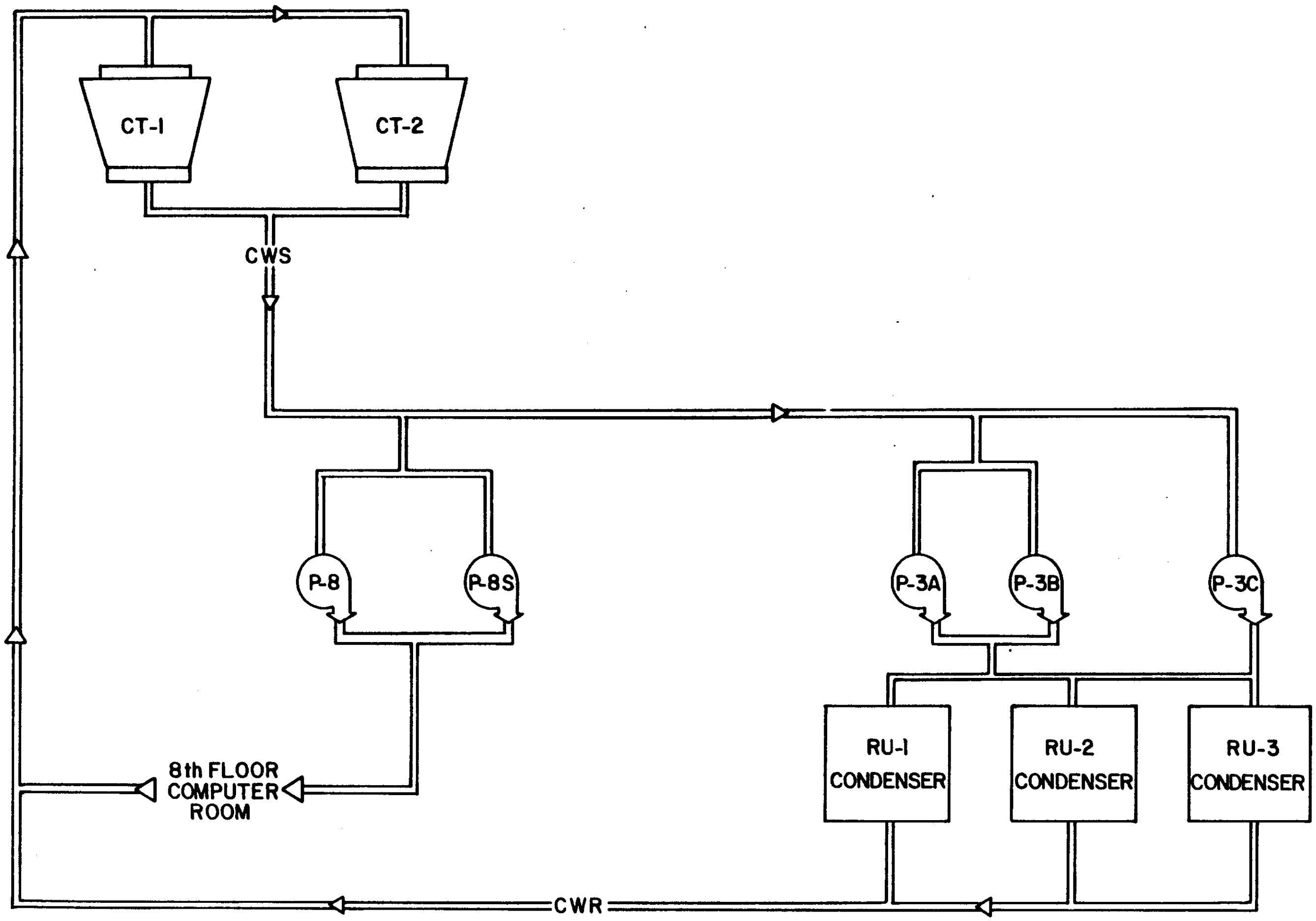

Figure 1-12: Schematic of Building Condenser Water Circuit

Thermal Storage Tanks

The Transportation Building has three 230,000 gallon thermal storage tanks for storing hot water and chilled water for heating and cooling. Located in an underground mechanical room near the heat pumps, the tank inside dimensions are approximately 22 feet wide, 60 feet long, and 23 feet high, and are unpressurized. They have 14 inch thick concrete walls, a 5 foot thick concrete floor, and 8 inch thick precast concrete covers with manholes. All sides are insulated with 2 inches of rigid styrofoam insulation. (See Figure 1-13).

Hot water and chilled water from the heat pumps is not deposited directly into the tanks. To avoid contamination, each tank has a plate and frame heat exchanger and a pump which circulates water from the tank through the heat exchanger and back into the tank. The flow rate through the pump is adjusted to a setting of approximately 420 gpm in the heating season, and 640 gpm in the cooling season. Each tank has 8 inch diameter low and high water outlets so that water can be taken from either the bottom or the top of the tank. After passing through the heat exchanger, the return water is pumped back into the tank through a central tank diffuser. The diffusers on the tanks were designed to maximize mixing of temperature in the tanks.[8] (See Figure 1-13).

The heat exchangers have both hot water piping and chilled water piping connected to them which allows either hot water or chilled water from the heat pumps to be passed through the tank heat exchangers. The valves on the hot water and chilled water supplies to

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[8]Interview with Henry Eggart, Shooshanian Engineering, Boston, October 11, 1985.

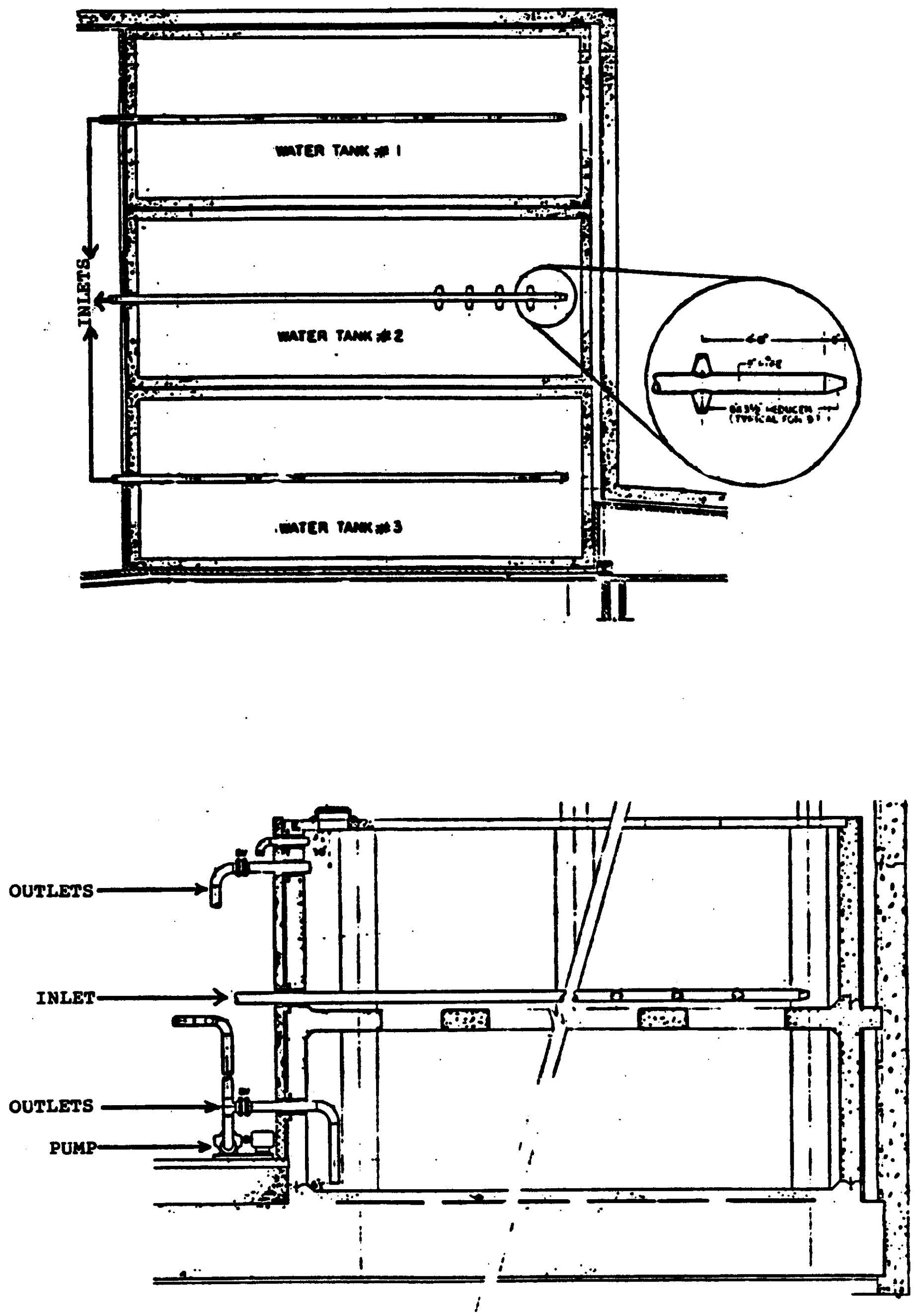

Figure 1-13: Thermal Storage Tanks Plan and Section
(Section Typical for 3)

the heat exchangers are controlled at the local control panel in response to remote commands from the Delta 1000. There are three tank commands at the Delta 1000: heating, cooling or auto, and off.

Because the storage tanks are used for hot water storage in the winter, chilled water storage in the summer, and seasonal transitional storage from one to the other in the spring and fall, there is a "tank time of year schedule" programmed into the Delta 1000 for the tanks. Below is a summary of this schedule:

Tank Time of Year Schedule

MONTH	TANK #1	TANK #2	TANK #3
January	Heating	Heating	Heating
February	Heating	Heating	Heating
March	Off	Heating	Heating
April	Cooling	Off	Heating
May	Cooling	Cooling	Off
June	Cooling	Cooling	Cooling
July	Cooling	Cooling	Cooling
August	Cooling	Cooling	Cooling
September	Cooling	Cooling	Off
October	Cooling	Off	Heating
November	Off	Heating	Heating
December	Heating	Heating	Heating

When the tanks are in the "cooling" period, commanding the tanks into cooling will take suction from the bottom tank valve, and commanding the tanks into heating will take suction from the bottom tank valve. The chilled water valves will always remain open on the heat exchanger, and the hot water valves remain closed.

When the tanks are in the "heating" or in the "off" season, commanding the tank into heating will take suction from the bottom tank valve and open the hot water valves on the heat exchanger. Commanding the tank into cooling will take suction from the top tank valve and open the chilled water valves on the heat exchanger. If the tank is in heating while the system is operating in the reduced heating mode and no hot water is being sent to the tank heat exchanger from the heat pumps, the tank will automatically go into the turbulation mode. In order to reduce tank water temperature stratification the tank pump continues to operate but tank water bypasses the heat exchanger and is returned to the tank.

Computer Room AC Units

There are two computer rooms in the building which have their own packaged AC units. Each Trane unit has two small compressors and a small five horsepower fan. These computer room units operate 24 hours a day, 365 days per year, and are provided with an uninterruptable power supply. The computer room condenser water is part of the central system condenser water loop (see Figure 1-12), with its own constantly-operating condenser water pump.

The computer room condenser water is circulated through the cooling tower pans, whether or not the central system condenser water pumps are operating.

Modes of Operation

When designing the Transportation Building's energy system, Shooshanian Engineering and Associates developed ten "modes of operation" for the system.[9] It should be noted that all of the modes of operation are manually controlled by the system operators.

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[9]John M. Clancy and Edward Shooshanian, "The Transportation Building", General Proceedings, AIA Building Redesign and Energy Challenges Conference, November 15-17, 1984 (Boston: 1984, p. 64).

Automatic sequences to enable and disable the modes were originally specified by the system designers but have not yet been programmed into the Delta 1000. However, once the modes are enabled, some automatic control sequences do occur. Some modes of operation are directly commanded on by the Delta 1000 operator - others are indirectly implemented by commanding pieces of equipment on or off.

Transportation Building Energy System
Modes of Operation

1.	Maximum Heating	6.	Peak Chilled Water
2.	Reduced Heating	7.	Part Chilled Water
3.	Heat Recovery	8.	Off-peak Storage
4.	Standby	9.	Economizer
5.	False Loading	10.	Heat Rejection

Below is a general description of the purpose of each mode of operation and how they are typically used. More detailed descriptions of the automatic controls for the modes of operation are included in Appendix A.

Reduced Heating/Part Chilled Water Modes. Figure 1-14 is a schematic of the Reduced Heating and Part Chilled Water modes, which are typically used together on an occupied winter day. These modes together supply cooling at the interior zones, heating at the perimeter zones, and store any excess heat recovered from the warm return air in the water thermal storage tanks.

With the heat pumps operating, typically RU-1 and RU-2, the hot water and chilled water loops are both circulating. The hot water stream is split between the hot water loop to the perimeter of the building and the hot water supply to the storage tank heat exchangers. If

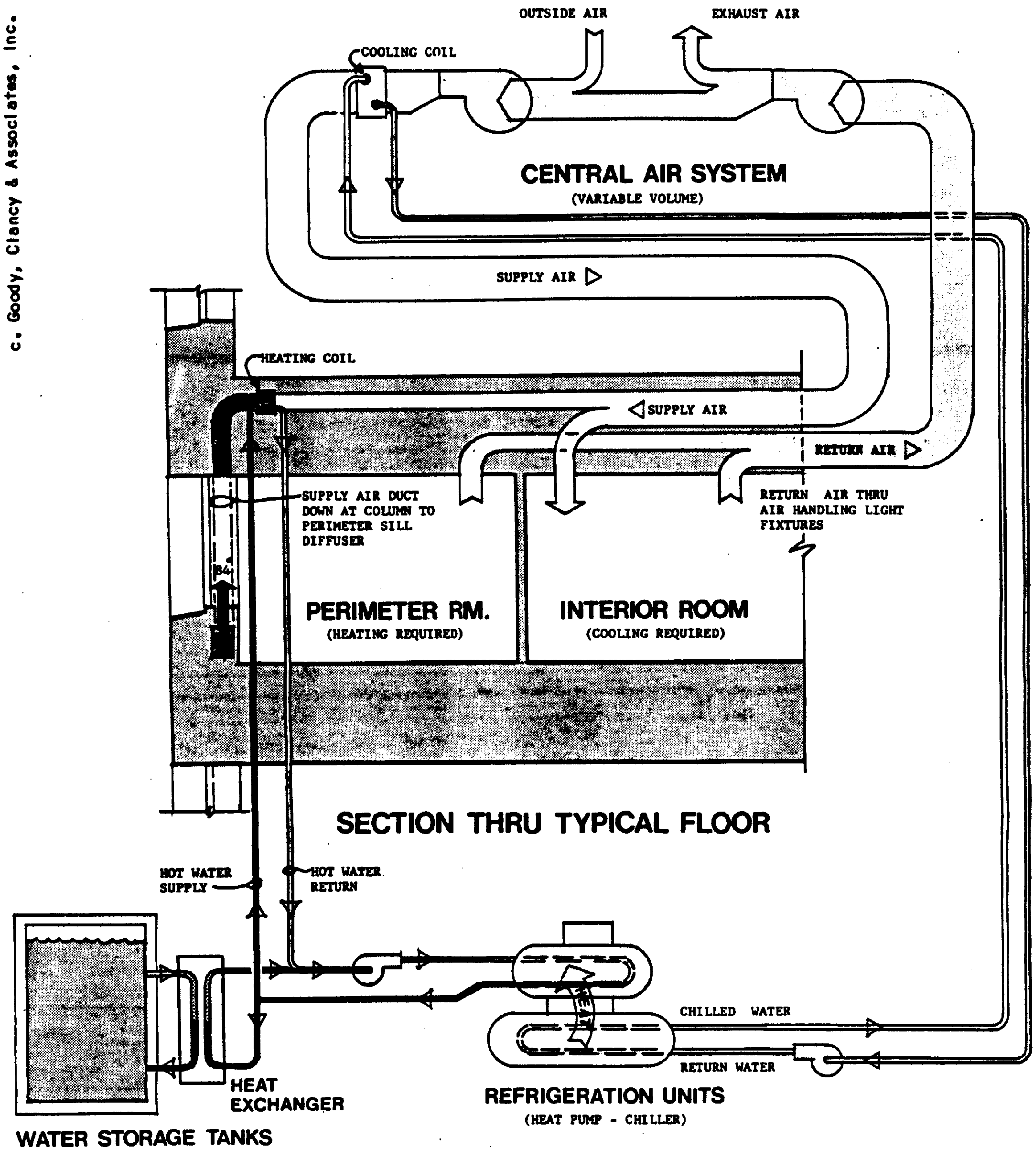


Figure 1-14: Schematic of Reduced Heating/Part Chilled Water Modes

insufficient heat is being used at the perimeter of the building to maintain the hot water temperature setpoint (typically 85-95 degF), then the hot water temperature valves at the tank #3 heat exchanger automatically modulate open to store heat in the tank. If more hot water is available, the tank #2 heat exchanger hot water valves will modulate open in sequence. If the hot water temperature drops below the setpoint, then the reverse sequence occurs.

The Part Chilled Water mode is controlled to maintain the differential pressure across the chilled water pump. If some of the air handler chilled water valves modulate closed and pressure increases across the chilled water pump, chilled water is diverted to the tank #1 heat exchanger for pressure relief. However, heat will not automatically be exchanged with tank #1 unless the tank is commanded into heating or cooling. With a pressure reduction across the chilled water pump, the reverse sequence will occur. In practice, when the part chilled water mode is in use chilled water is usually diverted to tank #1.

Maximum Heating Mode. Figure 1-15 is a schematic of the Maximum Heating mode which, like the Reduced Heating mode, is typically used in conjunction with Part Chilled Water mode. The Maximum Heating mode is usually used when warming up the building for first occupancy or on particularly cold days. When the mode is enabled, all hot water from the heat pumps is sent to the building perimeter hot water loop, and no hot water is diverted to the thermal storage tanks. The Maximum Heating mode is manually commanded on and off; there is no automatic control to maintain return hot water temperatures or hot water pump differential pressures.

False Loading/Reduced Heating Modes. Figure 1-16 is a schematic of the False Loading and Reduced Heating modes. The False Loading mode is used when there is an insufficient cooling load from building internal gains, typically during unoccupied hours or early occupied

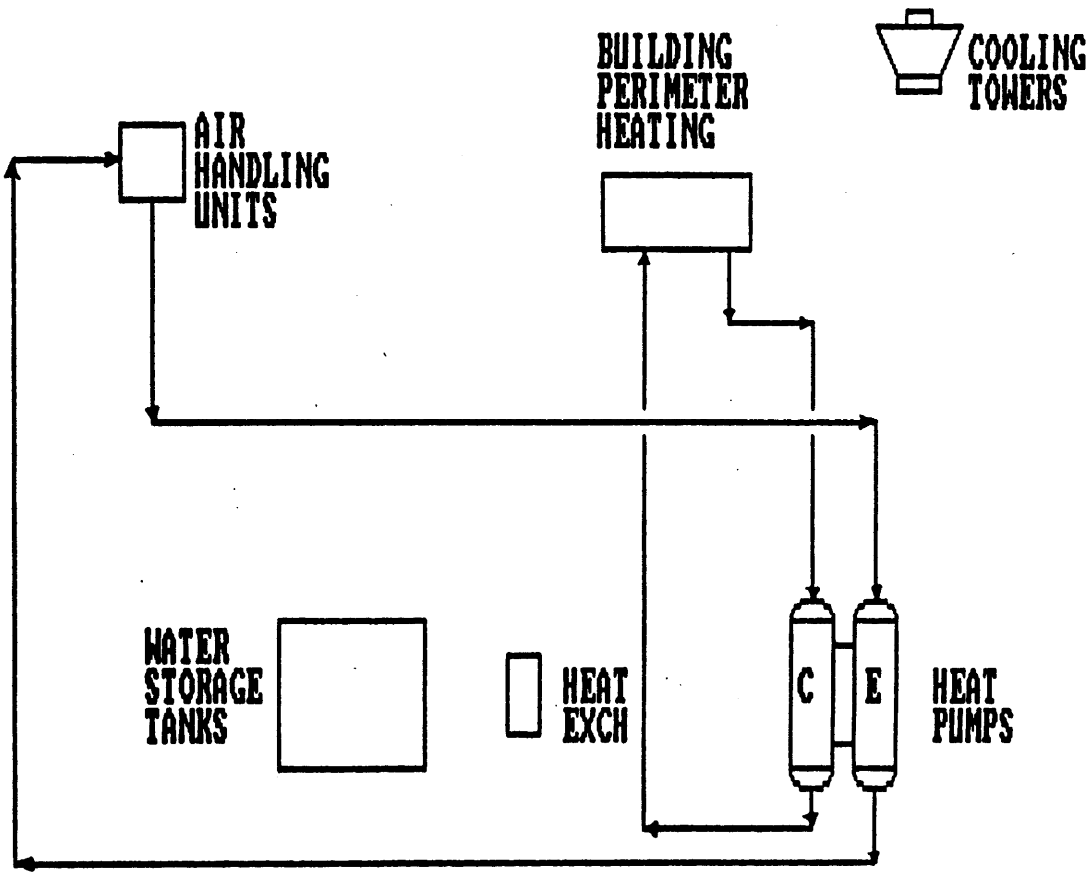


Figure 1-15: Schematic of Maximum Heating Mode

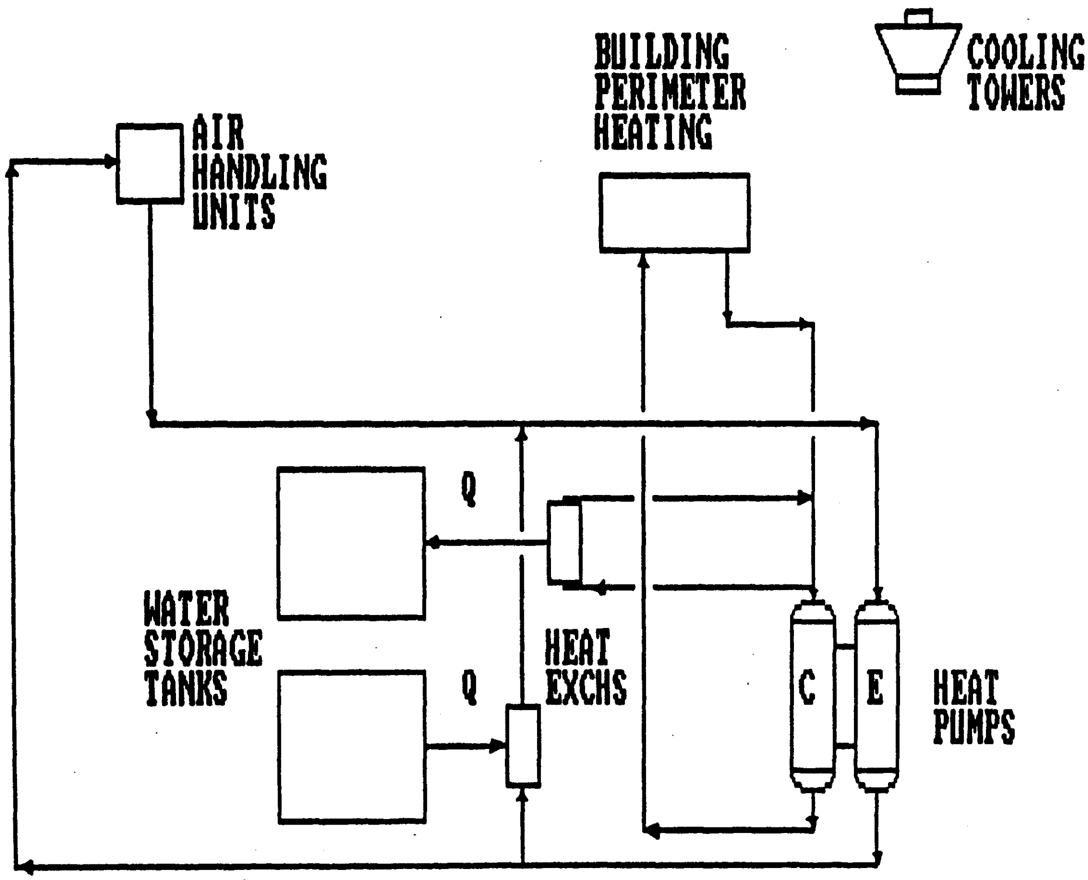


Figure 1-16: Schematic of False Loading/Reduced Heating Modes

hours. When the False Loading mode is manually enabled, chilled water is diverted to the tank #1 heat exchanger and heat is transferred from the storage tank to the chilled water loop, thereby increasing the cooling load on the heat pumps. Tanks #2 and #3 can be used to false load by commanding them into cooling. The False Loading mode can also be used in combination with the Maximum Heating mode.

Peak Chilled Water/Heat Rejection Modes. Figure 1-17 is a schematic of the Peak Chilled Water and Heat Rejection modes. These modes would typically be used during an occupied summer day. The Peak Chilled Water mode utilizes the cooling effect of chilled water stored in the tanks to reduce the cooling load on the heat pumps. When the Peak Chilled Water mode is manually enabled, return chilled water from the air handlers is automatically diverted to the storage tank heat exchangers for pre-cooling before it returns to the heat pumps. The amount of return chilled water sent to the tank heat exchangers is automatically modulated to maintain a return chilled water temperature setpoint.

The Heat Rejection mode is automatically enabled when a condenser water pump is commanded on and condenser water heat is being rejected at the cooling towers.

Part Chilled Water/Heat Rejection Modes. Figure 1-18 is a schematic of the Part Chilled Water and Heat Rejection modes. These modes would be used during the cooling season when cooling is being supplied to both the building and the thermal storage tanks.

Similar to the reduced heating mode, the Part Chilled Water mode sends excess chilled water not needed at the cooling coils to the storage tanks for cooling. The amount of chilled water diverted to the storage tanks is controlled to maintain a constant differential pressure across the chilled water pump. Excess chilled water is first

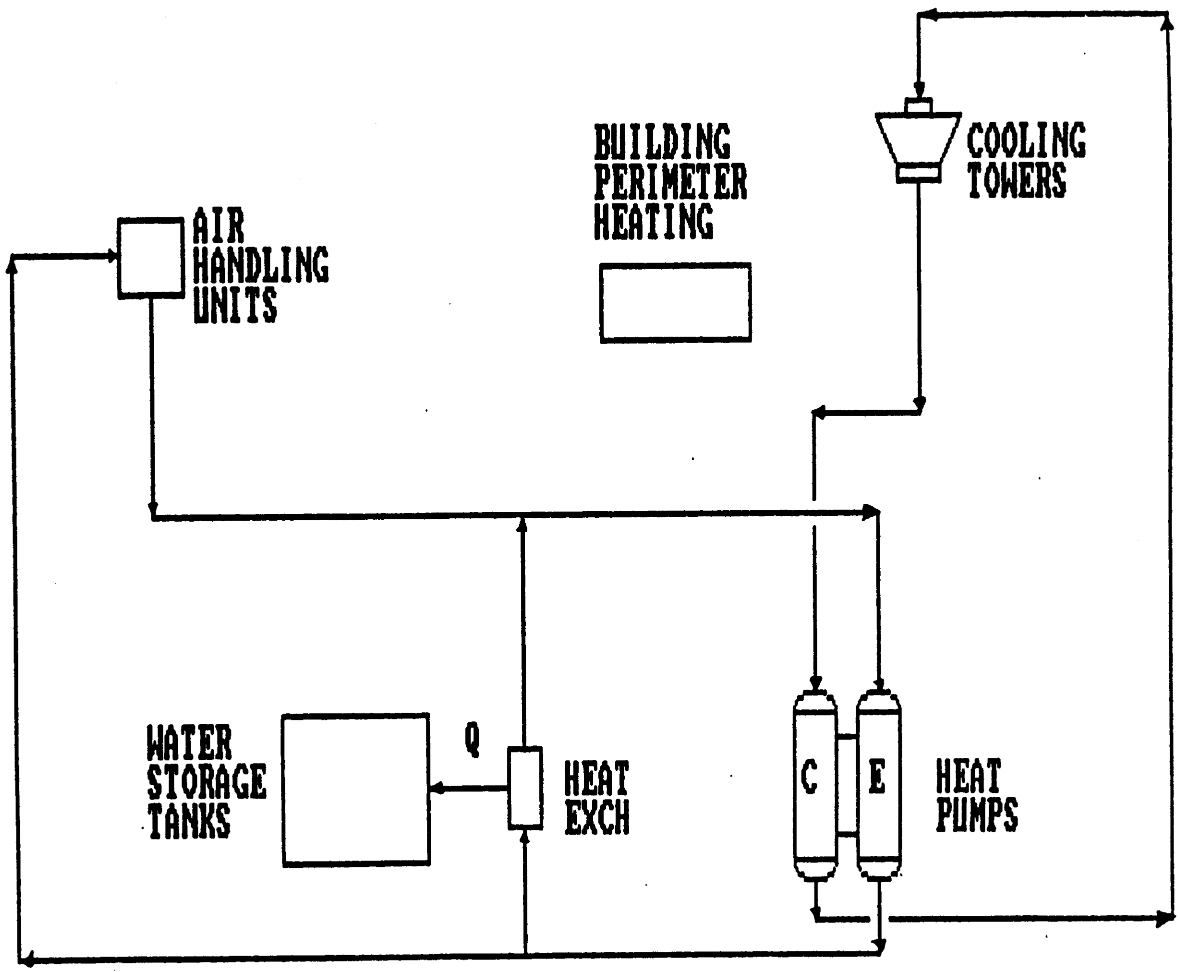


Figure 1-17: Schematic of Peak Chilled Water/Heat Rejection Modes

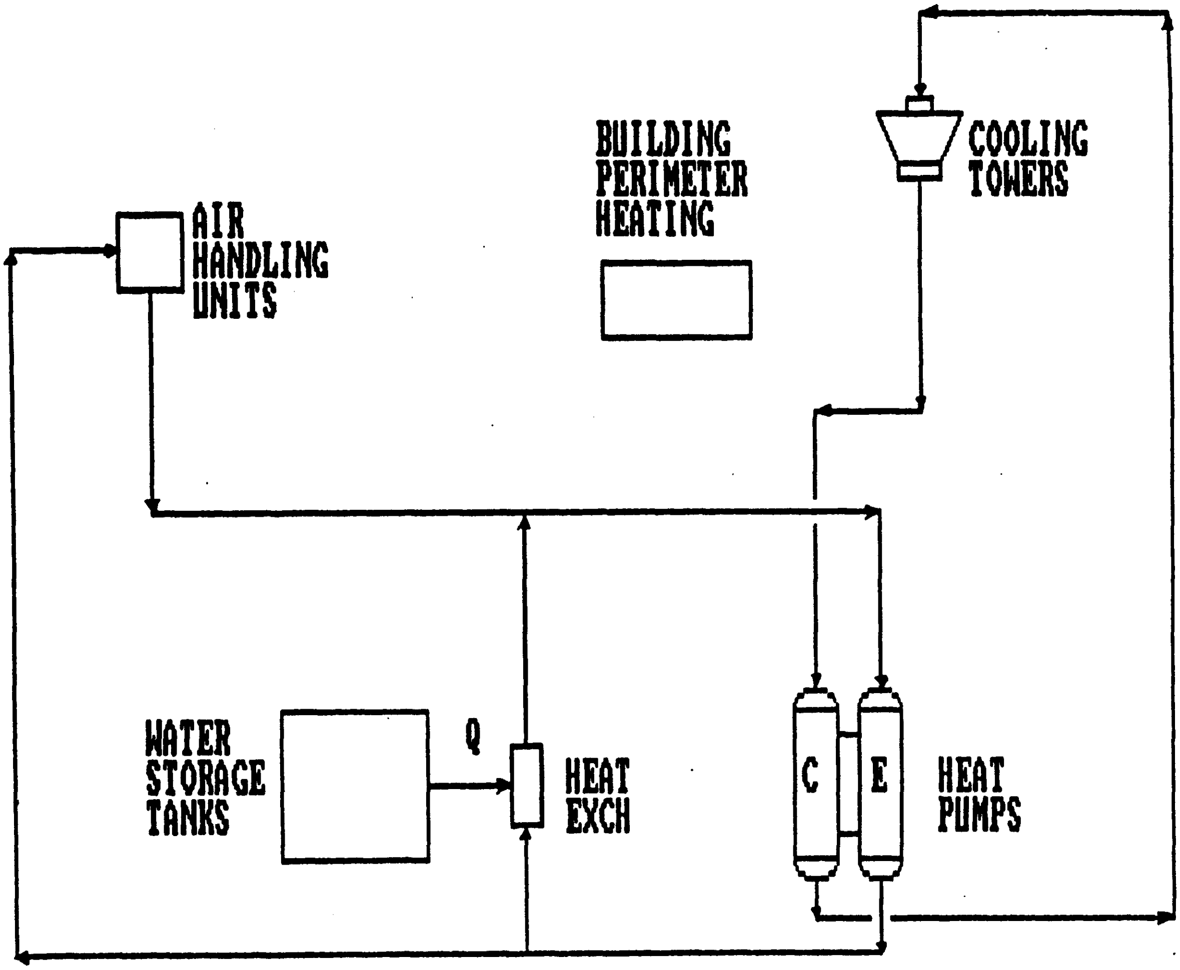


Figure 1-18: Schematic of Part Chilled Water/Heat Rejection Modes

diverted to tank #1. If more chilled water is available it is sent to tank #2 and then to #3. With a decrease in chilled water pump differential pressure the reverse sequence occurs.

Off-Peak Storage/Heat Rejection Modes. Figure 1-19 is a schematic of the Off-Peak Storage and Heat Rejection modes. The Off-Peak Storage mode is designed to be used during cooling season unoccupied hours when the storage tanks are to be cooled and no chilled water is required at the handlers. With all chilled water from the heat pumps supplied to the storage tanks, this mode is designed to cool the storage tanks for the next day's operation.

Heat Recovery/Economizer Modes. Figure 1-20 is a schematic of the Heat Recovery and Economizer modes. These modes would typically be used together during the spring and fall occupied hours. With the heat pumps commanded off, the storage tanks are used to supply any heating which might be required at the building perimeter (Heat Recovery mode) while outdoor air is being used for "free cooling" (Economizer mode).

The Heat Recovery mode is also used when necessary during heating season unoccupied hours to keep building space temperatures from dropping too low. The Economizer mode is used any time during the cooling season when the enthalpy vents are commanded open to supply free cooling.

This chapter has provided a general overview of the State Transportation Building's design, and most specifically the Building's energy system design. Chapter II presents the building's overall energy use data, and discusses the energy performance of the building as compared to other buildings and energy codes.

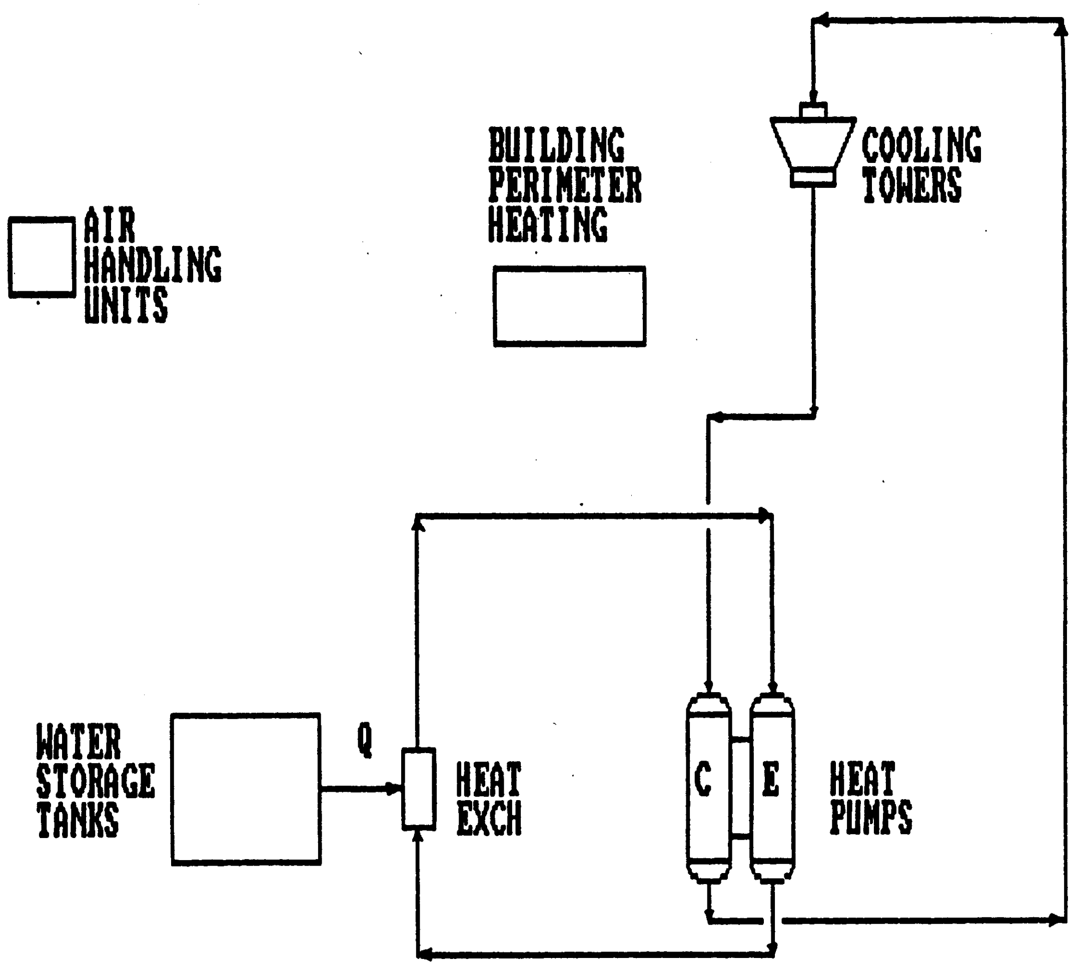


Figure 1-19: Schematic of Off Peak Storage/Heat Rejection Modes

c. Goody, Clancy & Associates, Inc.

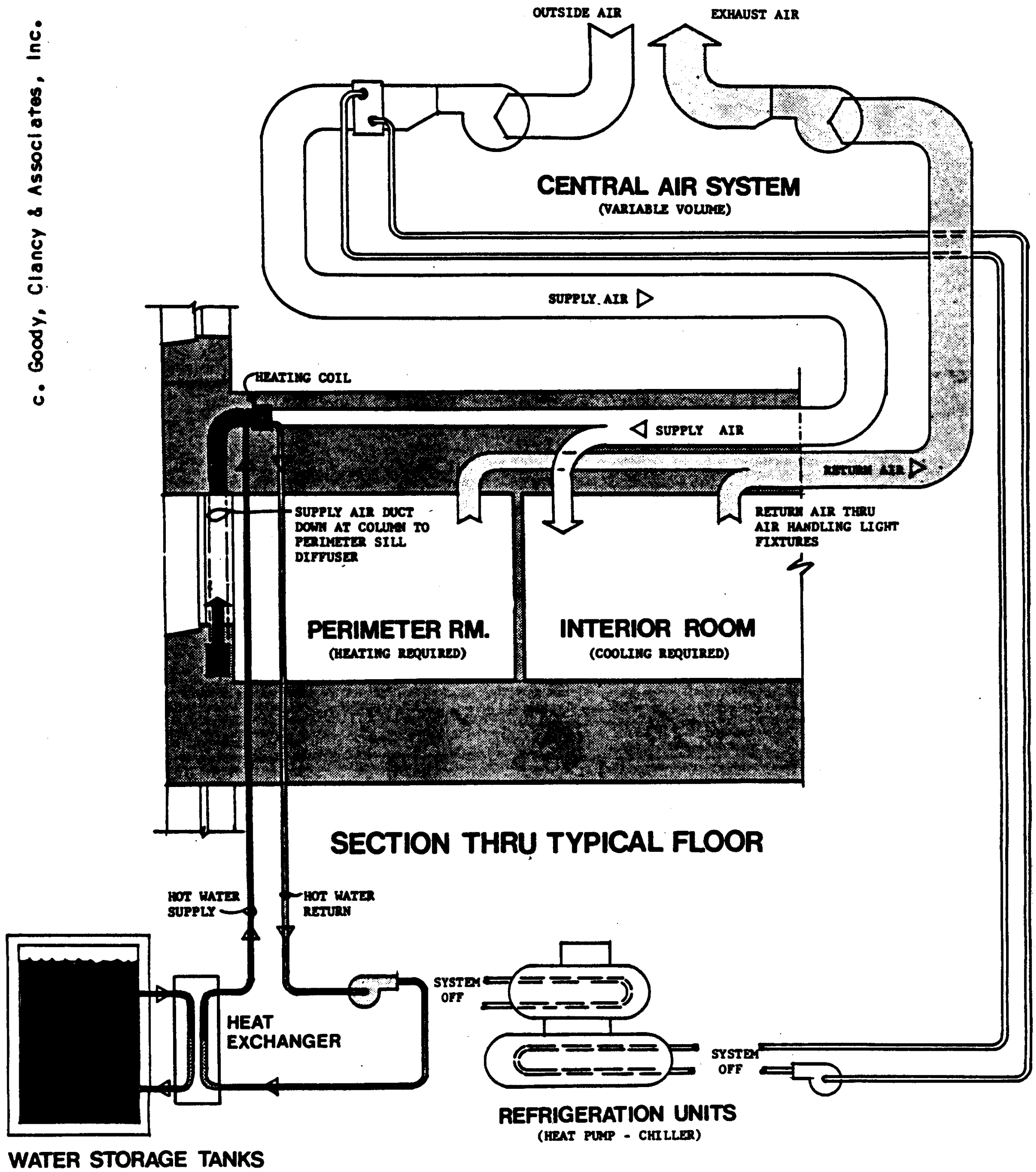


Figure 1-20: Schematic of Heat Recovery/Economizer Modes

CHAPTER II: ENERGY USE AND CONSUMPTION IN THE BUILDING

Introduction

To evaluate the performance of the energy system at the State Transportation Building it is necessary to look at how much energy is being used in the building and to account for how and when the energy is being used. It is then possible to compare the Transportation Building's energy use to other buildings, and to predict the impact of changes in the present operation of the energy system upon future energy consumption and cost.

The principle energy supply to the building is electricity, which is used to operate the central heating and cooling system and other mechanical equipment, and also the lights and appliances in the building. A relatively small amount of utility-source district steam is used during the winter months for heating at entryways, for air humidification, and for emergency back-up heating.

Although back-up heating was not originally planned by the system designers, due to gradual occupancy of the building and continued unoccupancy of the first floor retail spaces, the building operators found it necessary to supplement the heat supply available from the central heat pumps.

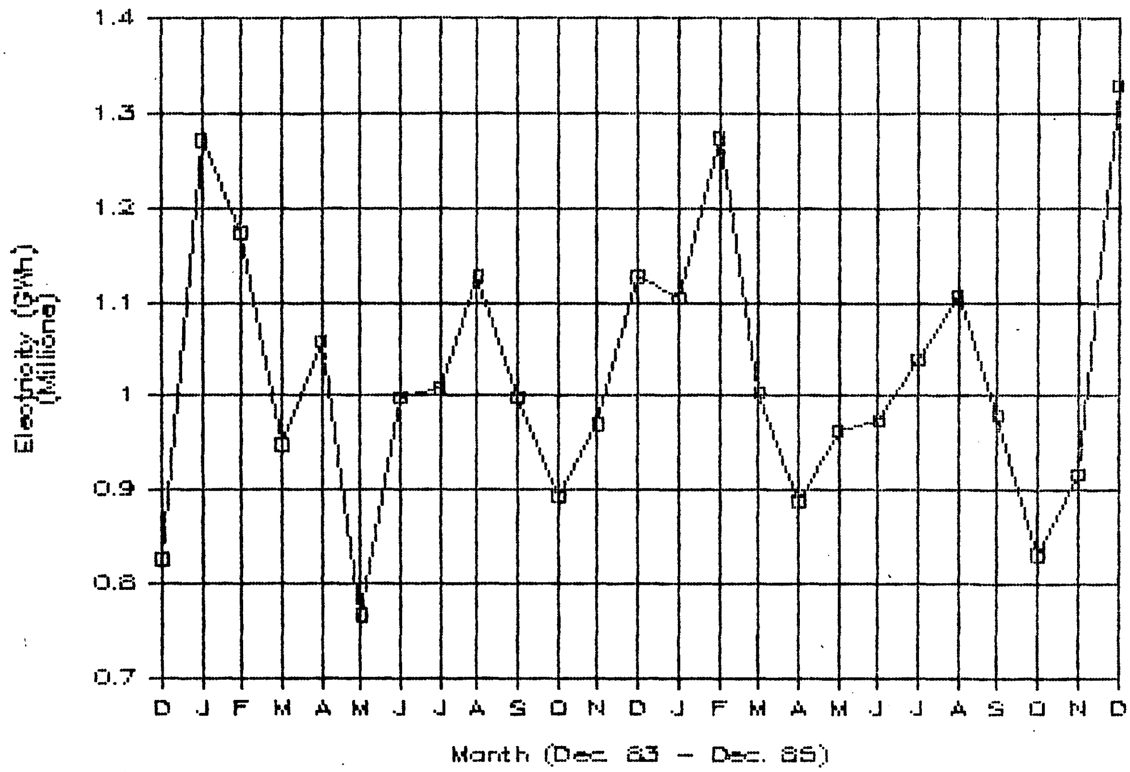
Every winter since the building was opened the lights have frequently remained on around the clock during the coldest winter months (December through February) to increase the building's internal gains. Also, an apparatus is available to inject district steam into the building's hot water loop, but is infrequently used due to the corrosive qualities of the steam. This past winter (December 1985) steam heating coils were installed in the interior zone return air plenums of AC-1 and AC-2 and were operated continuously from mid-December until mid-February.

Table 2-1: State Transportation Building Monthly Electric Utility Data

Date	Electric Use (kWh)	Electric Demand (kW)	Cost of Fuel per kWh ($)	Total Electric Cost ($)
13-Dec-83	825,600	1,944		$74,678.62
13-Jan-84	1,272,000	2,112		$106,600.59
13-Feb-84	1,173,600	2,016		$100,755.88
13-Mar-84	948,000	2,136		$86,335.22
11-Apr-84	1,058,400	2,088		$93,521.79
11-May-84	765,600	1,920		$72,244.68
19-Jun-84	998,400	2,448		$93,696.53
13-Jul-84	1,008,000	2,328		$109,539.22
21-Aug-84	1,128,000	2,520		$120,813.08
20-Sep-84	998,400	2,520	$0.045722	$109,981.62
15-Oct-84	892,800	2,400	$0.045722	$99,894.05
14-Nov-84	969,600	2,280	$0.042258	$91,383.01
13-Dec-84	1,128,000	2,400	$0.042258	$103,959.56
11-Jan-85	1,104,000	2,304	$0.042258	$101,332.16
12-Feb-85	1,274,400	2,328	$0.038070	$108,549.46
13-Mar-85	1,003,200	2,208	$0.038070	$88,945.35
11-Apr-85	888,000	2,184	$0.038040	$80,868.16
13-May-85	962,400	2,376	$0.031540	$81,437.46
12-Jun-85	974,400	2,448	$0.031540	$82,845.17
15-Jul-85	1,039,200	2,640	$0.031540	$99,915.56
14-Aug-85	1,106,400	2,808	$0.024530	$98,589.70
13-Sep-85	979,200	2,568	$0.024530	$88,130.57
11-Oct-85	830,400	2,376	$0.031190	$73,008.79
12-Nov-85	916,800	2,177	$0.031190	$76,459.31
12-Dec-85	1,329,600	2,294	$0.031190	$102,850.09
14-Jan-86				

Source: Boston Edison Monthly Electric Utility Bills

(a)



(b)

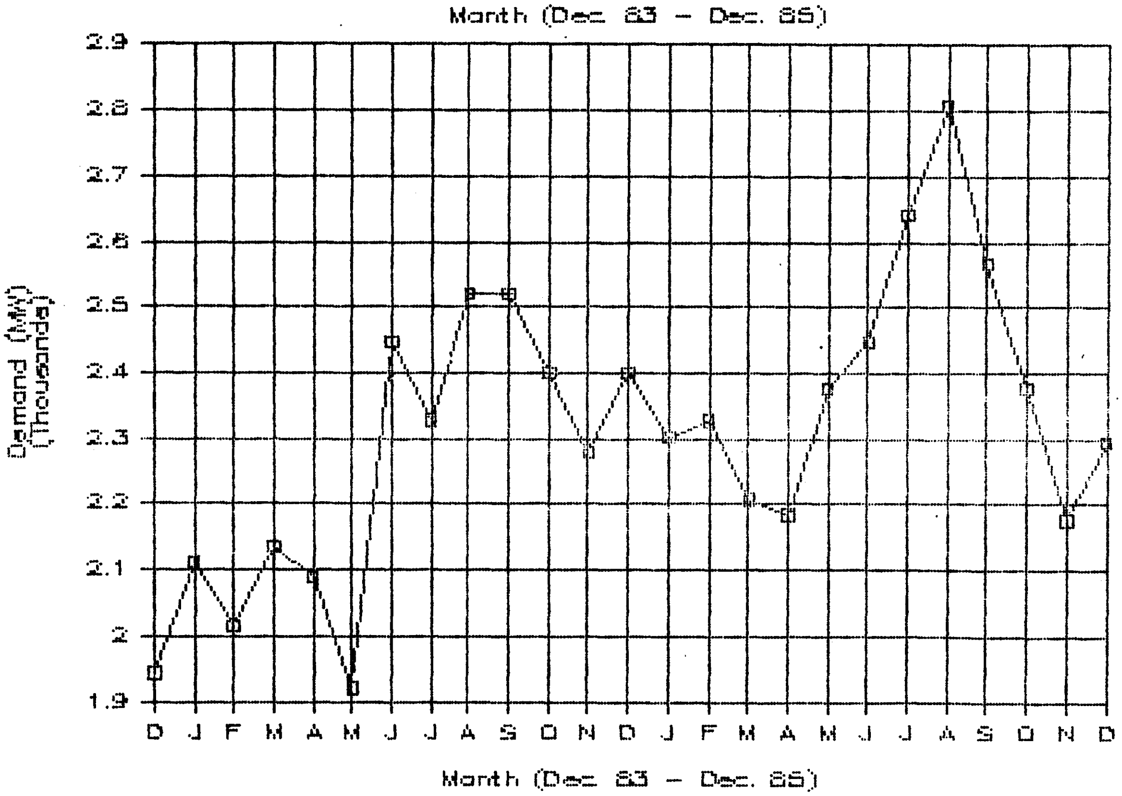


Figure 2-1: Monthly Electric Use and Demand - 12/83 - 12/85
(a) Electric Use (b) Electric Demand

The electric and steam utility bills provide a monthly account of energy consumption and peak electric demand in the building. The Delta 1000 monitoring system records the daily electric consumption at the end of each day on its hardcopy printouts. These sources have provided the factual data to which empirical models have been correlated. Unfortunately, there is no submetering of electric use in the building, or electric demand records beyond the monthly maximum demand from the utility meter.

Electric and Steam Utility Consumption

Table 2-1 lists the monthly billed electric use and demand starting with December, 1983, when the Transportation Building was first occupied, through January, 1986. Figures 2-1 (a) and (b) graphically show the monthly electric use and demand.

Both electric use and demand have increased with time as the offices in the building have become occupied. All but the first floor retail areas[1] of the building have been fully occupied since late November of 1984. Therefore it is most accurate to consider only the year since that time as representative of the building's energy performance.

Figures 2-1 (a) and (b) demonstrate that the electric comsumption and demand in the building peak in the winter and summer respectively, with the highest use (kWh) peaks in the winter and the highest demand (kW) peaks in the summer. The consumption peaked in December, 1985 at 1,330 MWh, and the demand peaked in August, 1985 at 2,808 kW. These peaks demonstrate the effect of the winter heating and summer cooling loads on the building's energy consumption. The winter electric use peak results from the large winter lighting load, and the summer demand peak is due to the increased refrigeration equipment demand during the cooling season.

[1]Construction of the retail areas began in December of 1985 and is expected to be completed in 1986.

Table 2-2: State Transportation Building Monthly Steam Utility Data

Date	Steam Use (M-lbs)	Fuel Charge ($ per M-lbs)	Total Steam Cost ($)	Average Steam Cost per M-lbs ($)	Steam Use (mBtu)	Steam Use (kWh)
14-Dec-83	198		$3,462.53	$17.49	176,547	51,728
13-Jan-84	922		$15,682.47	$17.01	822,101	240,874
14-Feb-84	338		$6,084.04	$18.00	301,378	88,303
14-Mar-84	297		$4,536.85	$15.28	264,820	77,592
13-Apr-84	191		$3,035.24	$15.89	170,305	49,899
14-May-84	57		$1,103.66	$19.36	50,824	14,891
14-Jun-84	0		$56.70		0	0
13-Jul-84	0		$56.70		0	0
14-Aug-84	0		$56.70		0	0
14-Sep-84	0		$56.70		0	0
15-Oct-84	5	8.9631	$106.97	$21.39	4,458	1,306
14-Nov-84	21	9.1028	$461.72	$21.99	18,725	5,486
14-Dec-84	437	9.1028	$8,005.53	$18.32	389,651	114,167
14-Jan-85	1022		$17,731.10	$17.35	911,266	266,999
14-Feb-85	1015	8.1904	$17,114.81	$16.86	905,025	265,170
14-Mar-85	788	8.3489	$13,530.37	$17.17	702,620	205,866
12-Apr-85	773	8.9268	$13,726.91	$17.76	689,245	201,947
14-May-85	439	8.9268	$7,963.14	$18.14	391,434	114,689
14-Jun-85	150		$304.77		133,748	39,188
12-Jul-85	0		$59.40		0	0
13-Aug-85	0		$59.40		0	0
13-Sep-85	0		$59.40		0	0
15-Oct-85	242	7.9451	$4,417.81	$18.26	215,779	63,223
14-Nov-85	557	7.9871	$9,668.66	$17.36	496,649	145,517
13-Dec-85	1034		$17,846.77	$17.26	921,966	270,134
14-Jan-86						

Source: Boston Edison Monthly Steam Utility Bills

Assumes:
1. 891.65 Btu/lb steam (1186.25 Btu/lb of 95 psi saturated steam minus 294.6 Btu/lb of condensate) (Source: ASME Steam Tables)
2. 3413 Btu/kWh

Table 2-3: State Transportation Building Total Energy Use Summary

Month/Year	Monthly Average Temp. (degF)	Electric Use (kWh)	Total Electric Cost ($)	Steam (M-lbs)	Total Steam Cost ($)	(a) Steam Use* (kWh)	(b) Building Line Steam Use** (kWh)	(c) Total Energy Use* (Stm+Elec) (kWh)	(d) Total Building delivered Energy Use** (Stm+Elec) (kWh)	(e) Total Source Energy Use*** (Stm+Elec) (kWh)
13-Dec-83		825,600	$74,678.62	198	$3,462.53	51,728	68,818	877,328	894,418	2,850,312
13-Jan-84		1,272,000	$106,600.59	922	$15,682.47	240,874	320,458	1,512,874	1,592,458	4,697,797
13-Feb-84		1,173,600	$100,755.88	338	$6,084.04	88,303	117,478	1,261,903	1,291,078	4,079,826
13-Mar-84		948,000	$86,335.22	297	$4,536.85	77,592	103,228	1,025,592	1,051,228	3,307,468
11-Apr-84		1,058,400	$93,521.79	191	$3,035.24	49,899	66,386	1,108,299	1,124,786	3,622,836
11-May-84		765,600	$72,244.68	57	$1,103.66	14,891	19,811	780,491	785,411	2,580,302
19-Jun-84		998,400	$93,696.53	0	$56.70	0	0	998,400	998,400	3,328,000
13-Jul-84		1,008,000	$109,539.22	0	$56.70	0	0	1,008,000	1,008,000	3,360,000
21-Aug-84		1,128,000	$120,813.08	0	$56.70	0	0	1,128,000	1,128,000	3,760,000
20-Sep-84		998,400	$109,981.62	0	$56.70	0	0	998,400	998,400	3,328,000
15-Oct-84		892,800	$99,894.05	5	$106.97	1,306	1,738	894,106	894,538	2,978,483
14-Nov-84		969,600	$91,383.01	21	$461.72	5,486	7,299	975,086	976,899	3,242,427
13-Dec-84		1,128,000	$103,959.56	437	$8,005.53	114,167	151,887	1,242,167	1,279,887	3,976,982
11-Jan-85	27.5	1,104,000	$101,332.16	1022	$17,731.10	266,999	355,215	1,370,999	1,459,215	4,187,449
12-Feb-85	39.1	1,274,400	$108,549.46	1015	$17,114.81	265,170	352,782	1,539,570	1,627,182	4,751,974
13-Mar-85	42.6	1,003,200	$88,945.35	788	$13,530.37	205,866	273,884	1,209,066	1,277,084	3,735,262
11-Apr-85	54.6	888,000	$80,868.16	773	$13,726.91	201,947	268,670	1,089,947	1,156,670	3,343,815
13-May-85	62.9	962,400	$81,437.46	439	$7,963.14	114,689	152,582	1,077,089	1,114,982	3,425,975
12-Jun-85	68.1	974,400	$82,845.17	150	$304.77	39,188	52,135	1,013,588	1,026,535	3,322,479
15-Jul-85	72.8	1,039,200	$99,915.56	0	$59.40	0	0	1,039,200	1,039,200	3,464,000
14-Aug-85	70.3	1,106,400	$98,589.70	0	$59.40	0	0	1,106,400	1,106,400	3,688,000
13-Sep-85	58.8	979,200	$88,130.57	0	$59.40	0	0	979,200	979,200	3,264,000
11-Oct-85	52.1	830,400	$73,008.79	242	$4,417.81	63,223	84,111	893,623	914,511	2,888,159
12-Nov-85	39.4	916,800	$76,459.31	557	$9,668.66	145,517	193,595	1,062,317	1,110,395	3,332,565
12-Dec-85	30.0	1,329,600	$102,850.09	1034	$17,846.77	270,134	359,385	1,599,734	1,688,985	4,945,408

January 1985 - December 1985 12 Month Totals	Electric	Steam*	Steam**	Energy Use* Total	Building Delivered Total**	Source Energy** Total
12 month kWh=	12,408,000	1,572,732	2,092,360	13,980,732	14,500,360	44,349,086
12 month kWh/sq.ft.=	13.77	1.75	2.32	15.51	16.09	49.21
12 month Btu/sq.ft.=	46,988	5,956	7,924	52,944	54,912	167,947
12 month annual cost=	$1,082,932	$102,483	$102,483	$1,185,414	$1,185,414	$1,185,414

Source: Boston Edison Steam and Electric Utility Bills

Assumes:
1. 901,259 gross sq.ft. (includes garage and 1st floor)
2. 3413 Btu/kWh
3. * - 891.65 Btu/lb steam (1186.25 Btu/lb of 95 psi saturated steam minus 294.6 Btu/lb of condensate)
4. ** - 1186.25 Btu/lb of saturated steam
5. *** - 30% electric and 70% steam generation and distribution efficiencies (Source: Dubin and Long)

Note: Monthly average temperatures based upon utility bill dates, not calendar months.
(Source: National Oceanic and Atmospheric Administration Boston Climatological Data Monthly Summary)

Table 2-2 lists the monthly steam consumption in the building. The steam use has increased considerably in the 1985 - 1986 winter as compared to the previous year, largely due to the installation of the steam heating coils in the AC-1 and AC-2 air handlers.

Table 2-3 summarizes the combined electric and steam consumption in the building since December 1983. Table 2-3 lists two different columns for steam use and three different columns for total energy used. The first steam use column, column (a), calculates the steam energy actually used for heating and humidification in the building by using a Btu/lb steam conversion factor which subtracts out the energy lost from the condensate (which is mixed with city water and drained into the sewage system). The second steam use column, column (b), calculates the energy delivered to the building, including the energy in the steam condensate. The first total energy column, column (c), uses column (a) for steam use, and reflects the total energy used in the building. Total energy column (d) uses column (b) for steam use, and reflects the total energy delivered to the building. Column (e) lists total source energy use. Source energy use accounts for the source of the energy, in this case electric power stations, and the generation and distribution inefficiencies. A 30% efficiency was assumed for electricity and 70% for steam.[2] When comparing the Tranportation Building's energy use to other buildings or energy performance guidelines, columns (d) and (e) are used.

At the bottom of Table 2-3 is a summary of the annual total energy use over the twelve month period from mid-January 1985 until mid-January 1986. Annual total energy kWh/sq.ft. and Btu/sq.ft. quantities are calculated using the building's gross square footage of 901,259 sq.ft., which includes the garage and first floor retail areas. These values vary, ranging from 15.51 kWh/sq.ft. to 49.21 kWh/sq.ft., depending upon the method used to calculate total building energy use.

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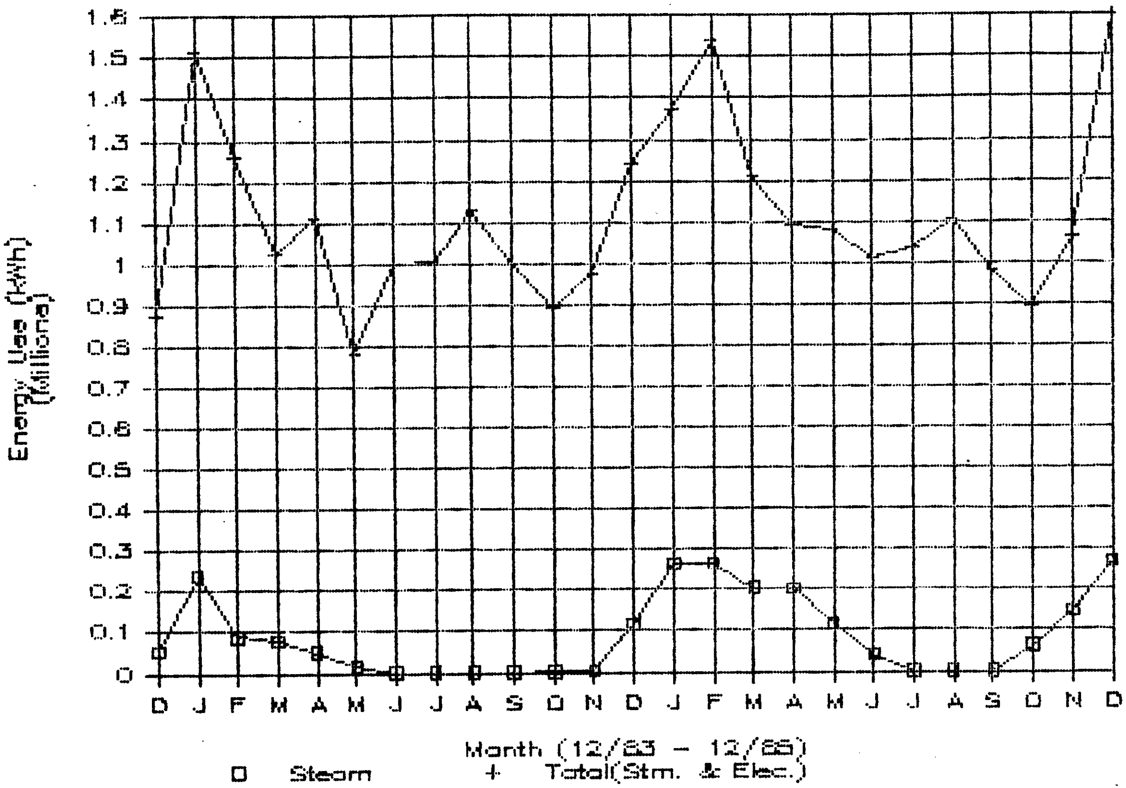
[2]F. Dubin and C. Long, Energy Conservation Standards, McGraw-Hill (NY, 1978), p. 2.

(a)



(b)

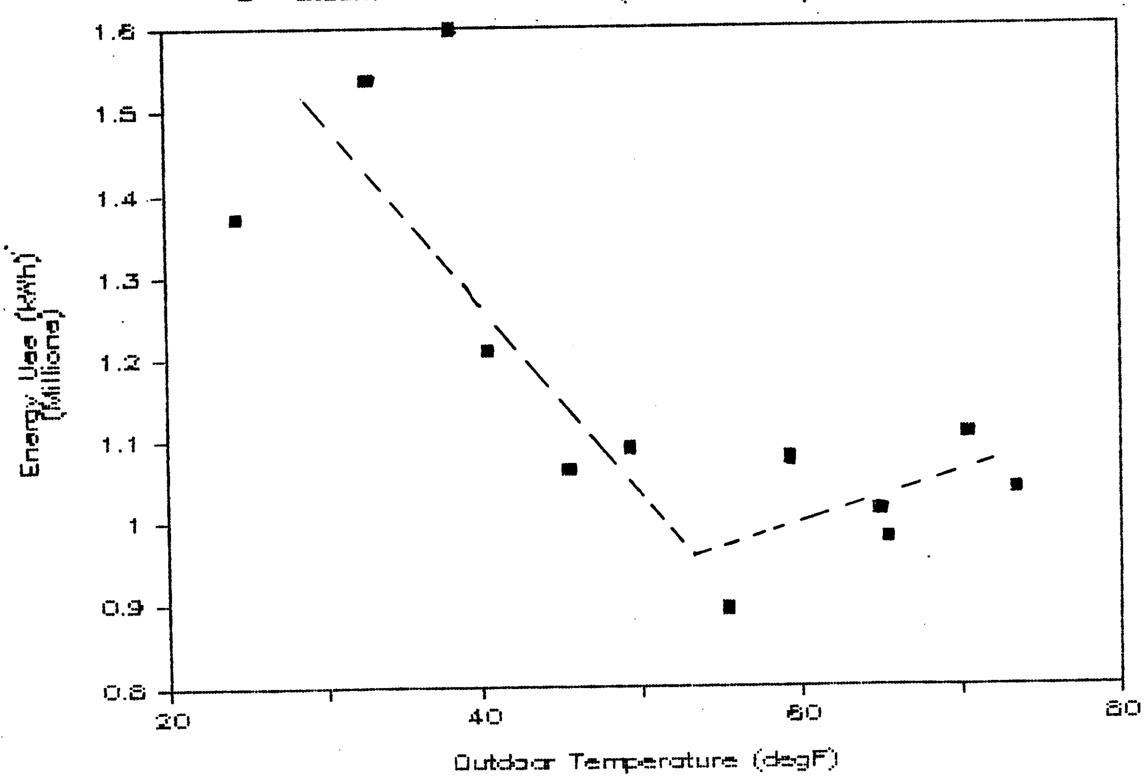


Figure 2-2: Monthly Total Energy Use (Electric & Steam) - 12/83 - 12/85
(a) vs. Time (b) vs. Average Monthly Temperature

Figure 2-3 (a) graphically illustrates the total energy use in the building (Table 2-3, column (c)) and the portion attributed to steam consumption since December 1983. With the steam consumption included, the winter energy use (kWh) peaks are even more pronounced than the electric consumption peaks in Figure 2-1(a). December 1985 had the highest ever monthly total energy use of 1,600 MWh. Though the electric use was somewhat lower than the previous year, the steam use was much higher.

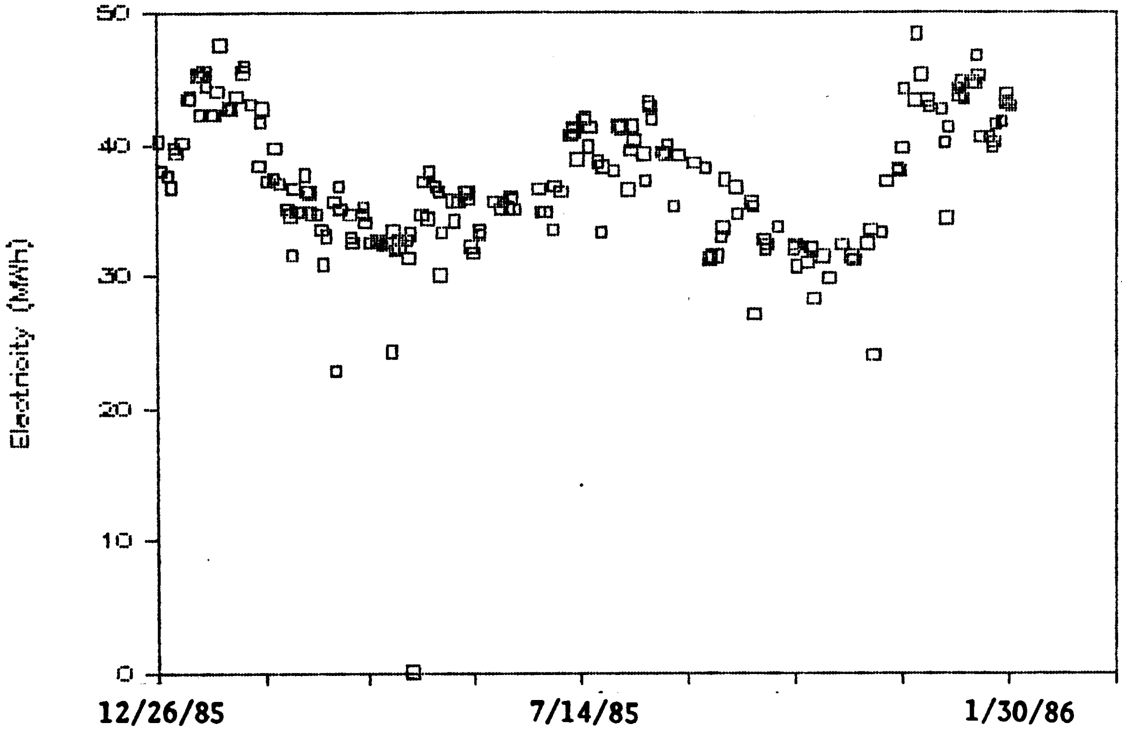
Figure 2-2(b) graphs the total monthly energy use vs. average monthly temperature for the twelve month period from January to December 1985. This curve shows a balance point at about 53 degF for the building. As the average monthly outdoor temperature increases the curve gently slopes up with the increasing cooling load. As the average monthly outdoor temperature decreases, the curve steeply rises with the increase in the heating load.

Daily electric use information was compiled from the Delta 1000 monitoring system hardcopy printouts (see Table A-1). Figure 2-3(a) graphs the daily occupied electricity use during 1985. Similar to the monthly electricity use in Figure 2-1, the curve peaks in the winter and summer, with valleys in the spring and fall. Daily winter peaks occur at about 45 MWh, summer peaks at about 39 MWh, and spring and fall valleys at about 31 MWh.

Figure 2-3(b) graphs the same occupied hour electric data vs. average daily temperature. Similar to the monthly data in Figure 2-2(b), the daily occupied data shows a balance point at about 50 degF, with the curve rising with increasing outdoor temperature and the corresponding cooling load, and also rising with decreasing temperature and increasing heating load. The heating load curve is not as steep as in Figure 2-2(b) because Figure 2-3(b) does not include steam use.

Figure 2-4(a) graphs daily unoccupied electricity use during 1985. Figure 2-4(b) graphs this same unoccupied daily electric data vs. average daily outdoor temperature. The curves in Figures 2-4(a) and (b) are much less pronounced than the occupied days in Figures 2-3(a)

(a)



(b)

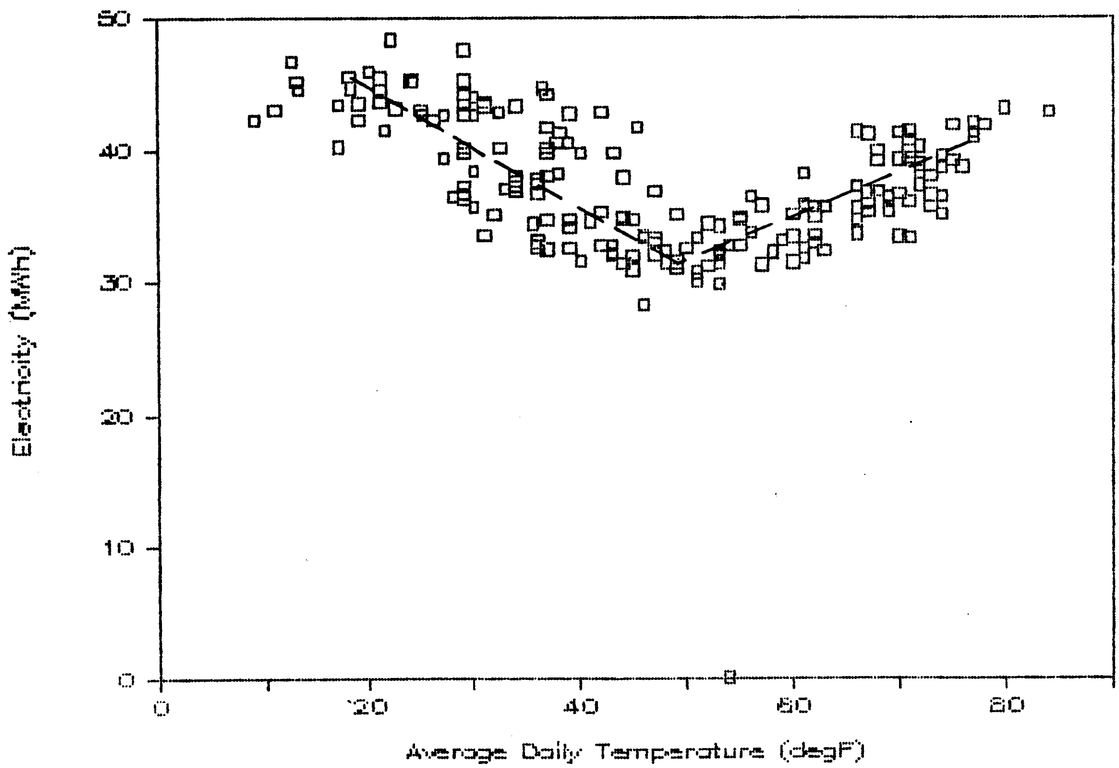
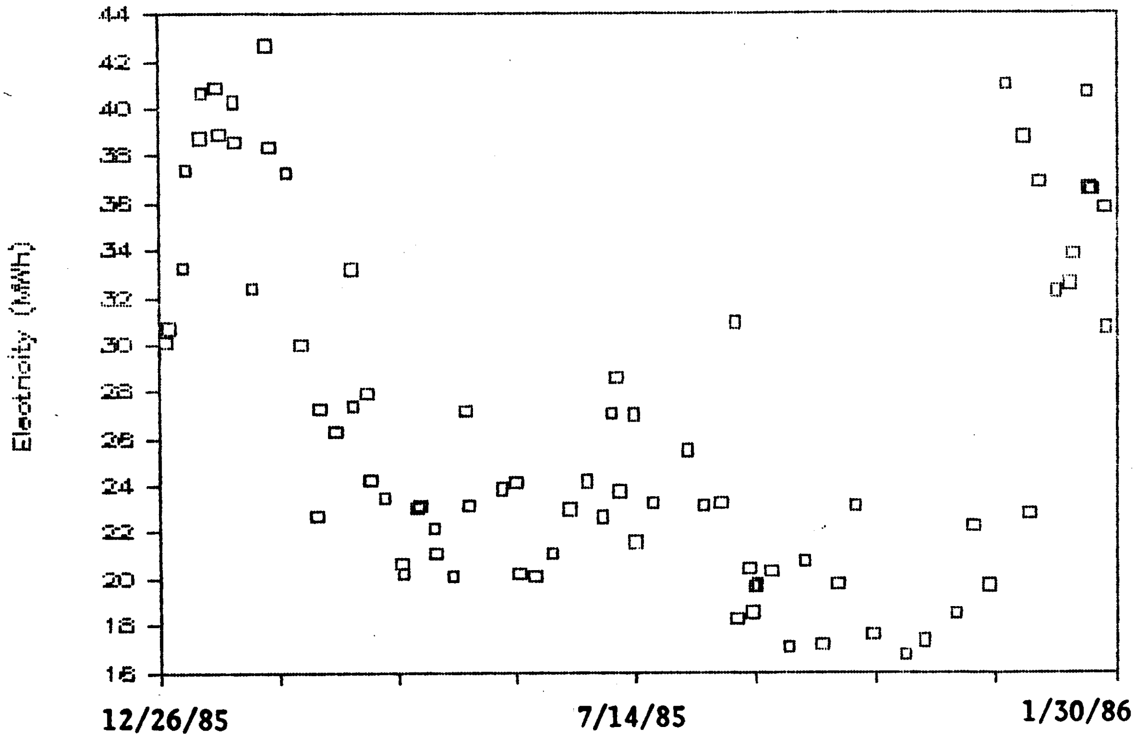


Figure 2-3: Occupied Day Electric Use - 12/85 - 1/86
(a) vs. Time (b) vs. Average Daily Temperature

(a)



(b)

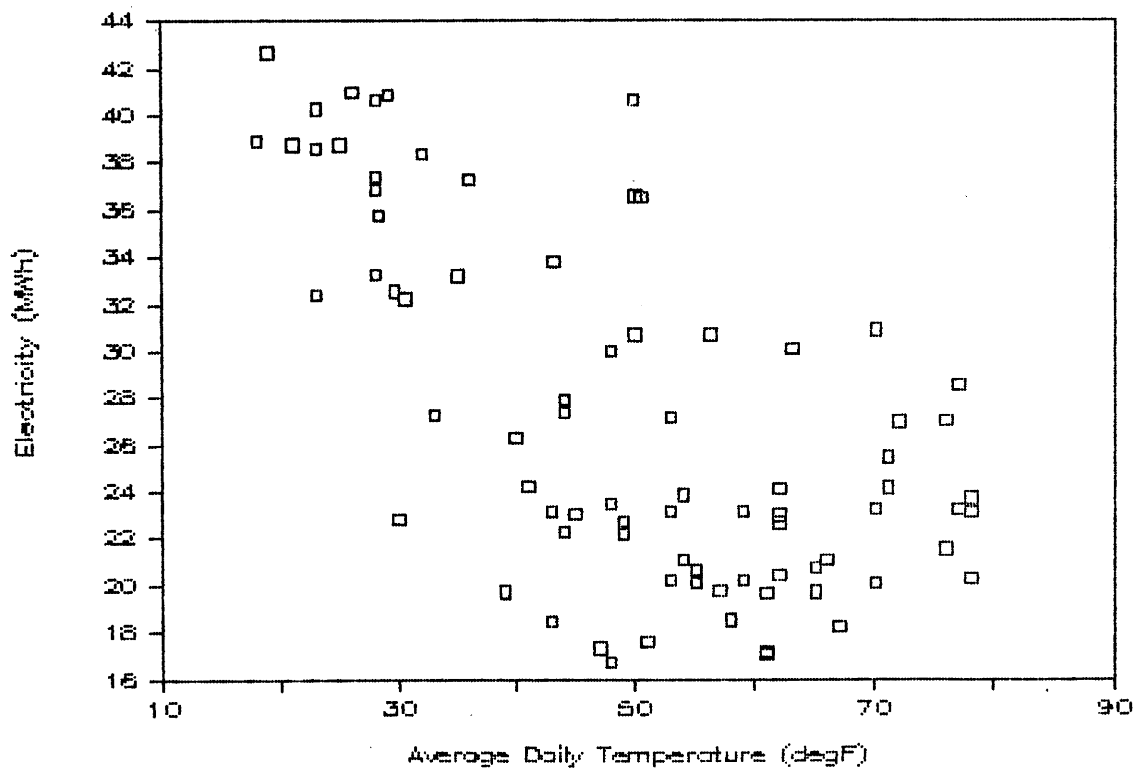


Figure 2-4: Unoccupied Day Electric Use - 12/85 - 1/86
(a) vs. Time (b) vs. Average Daily Temperature

and (b). Figure 2-4(a) shows a similar rise and fall with the seasons as Figure 2-3(a), but the curve is less definite due to more scattering and fewer data points. Figure 2-4(b) shows a poor correlation between outside temperature and unoccupied daily electric use.

The scattering of unoccupied data relative to occupied data is due to a number of factors. Outside temperature has less of an impact upon building energy consumption during unoccupied periods, especially in the spring, summer, and fall, because the building is allowed to drift out of its normal temperature range of 72 to 78 degF. Also, the energy use during unoccupied times will be affected by the operation of the storage system, which varies depending upon the depletion of the storage tanks.

Note that Figure 2-4(b), the unoccupied electric use vs. temperature curve, seems to have a balance point at about 60 degF, as compared to 50 degF for the occupied curve, Figure 2-3(b). This difference is probably due to the difference in building internal heat gains between occupied and unoccupied periods.

Figures 2-4(a) and (b) seem to indicate a winter daily electric use peak of about 42 MWh, a summer peak at about 28 MWh, and a spring/fall valley at about 19 MWh. When comparing with occupied days, in winter the difference between occupied and unoccupied is about 9 MWh, and in the spring, summer and fall the difference is about 15 MWh. This discrepancy is due to the fact that the lights are frequently on 24 hours a day during the winter months.

Accounting for Energy Consumption

To break down the electricity and steam consumption in the building, information on the mechanical equipment, lighting systems, and appliances was compiled. The sources of this information include the design documentation and equipment schedules, equipment nameplates, the air and water system balancer report, maintenance data, manufacturer's data, Delta 1000 data, and field measurements and observations.

When accounting for the electrical consumption in the building, the equipment loads were catagorized into base loads and variable loads. The base loads consist of consumption which stays relatively constant from day to day, not related to change in the energy system operation. Variable loads consist of: the main air handler fans; heat pumps; hot, chilled and condenser water pumps; storage tank pumps; and the cooling towers. The daily consumption due to these items varies considerably depending upon the weather, energy system operation, and occupancy of the building.

Base Loads

Separate base loads were established for typical winter and spring/summer/fall occupied and unoccupied days, and are graphically represented in Figures 2-5 through 2-6. The major difference between these base loads is due to lighting. Tables A-2 through A-5 list all of the equipment included in the base loads and their hourly electric consumption.

Lighting. Lighting energy consumption accounts for the single largest component of electricity use in the building. With a peak demand wattage of 1,150 kW, the lighting load accounts for 41 percent of the building peak demand. Table A-6 lists the lamps in the building by floor and location. Table A-7 subtotals the lamps by location, listing their wattage per lamp, approximate hours of operation, peak total wattage, and typical weekday and weekend watt-hours.

As can be seen in Figures 2-5 and 2-6, the winter lighting electric use is considerably larger than the typical spring/summer/fall use.

(a)

(b)

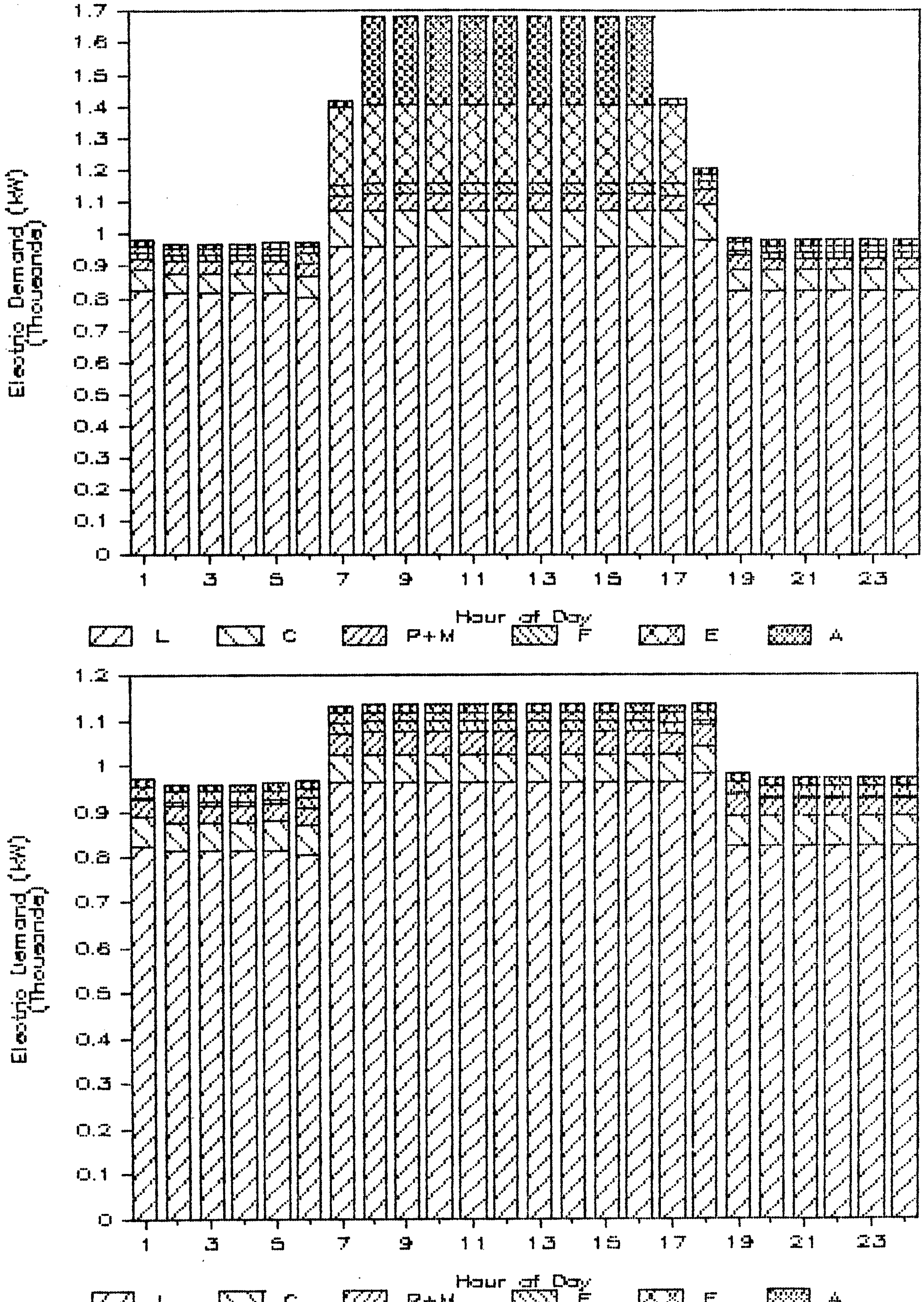


Figure 2-5: Winter (lights on 24 hours) Base Electric Loads
(a) Occupied Day (b) Unoccupied Day

L = Lights, C = Computer Rooms, P+M = Pumps & Miscellaneous, F = Fans, E = Elevators, A = Appliances

(a)

(b)

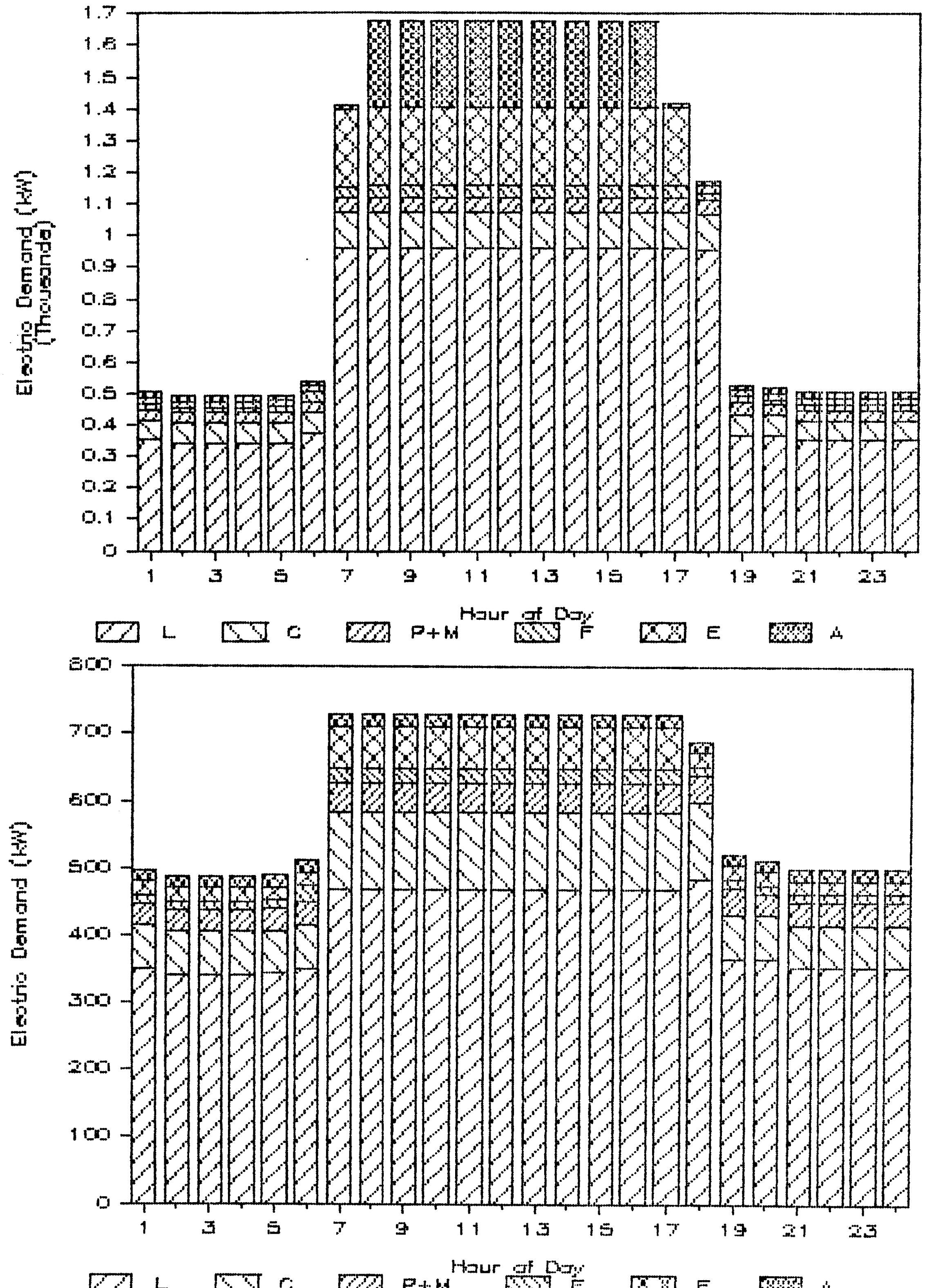


Figure 2-6: Spring/Summer/Fall Base Electric Loads
(a) Occupied Day (b) Unoccupied Day

L = Lights, C = Computer Rooms, P+M = Pumps & Miscellaneous, F = Fans, E = Elevators, A = Appliances

This is due to the fact that since the building opened, the lights in the building have frequently been left on 24 hours per day during the winter months (December through February) to increase the building internal heat gain.

Computer Rooms. The computer room energy consumption includes both the computers and the packaged air conditioning units in the computer rooms. These items are included in Table A-8.

Pumps and Miscellaneous. The pumps included in the base load are the computer room condenser water pump, domestic hot water and solar pumps, and sewage pumps. The major pumps in the energy system are included in the variable loads. See Table A-9 for pump information. Miscellaneous equipment includes pneumatic control system and sprinkler system compressors, unit heater fans, vestibule fans, and AC-5, a small packaged unit. Their schedules and electric loads are listed in Table A-8.

Fans. This item includes all of the major fans in the building, except those in AC-1, AC-2, and AC-3, which are considered variable loads. Included are the garage ventilation fans, AC-4, toilet exhaust fans, and various mechanical room exhaust fans. See Table A-10 for fan information.

Elevators. There are twelve elevators in the Transportation Building which create a considerable electricity load during occupied hours, when they are in almost constant use. See Table A-8 for elevator information.

Appliances. This catagory includes all items on the 110 volt circuits in the building such as typewriters, personal computers, task lights, and other appliances. See Table A-8 for an appliance load breakdown by floor.

Variable Loads

Variable electric loads in the building were determined by creating a computer model of the major components of the energy system. It uses the hourly recorded operation information data to calculate hourly electric loads and heating and cooling demands. This model is described in detail in Chapter III and Appendix B.

The items included in the variable loads model are:

- AC-1, AC-2, AC-3 supply and return fans
- Hot, chilled, and condenser water pumps, and storage tank pumps
- RU-1, RU-2, and RU-3 heat pumps
- Cooling towers

Incorporating measured electric use data, the model was used to calculate typical variable electric loads during occupied and unoccupied times under different weather conditions. By adding these variable loads to the base loads, total daily electric load profiles were created and compared to actual electric load data as recorded by the Delta 1000.

Correlation between the modeled and actual electric data for some modeled days is shown in Figure 2-7. This correlation has proved to be accurate enough to rely upon the model to provide a good estimate of building electric loads throughout the year. Figures 2-8 and 2-9 are typical total load profiles for summer, spring/fall, and winter. Note that with variable loads included in the load profiles, mechanical equipment, and particularly the heat pumps, account for a much larger proportion of the overall building electric use than in the base loads in Figures 2-5 and 2-6.

The typical summer load profile in Figure 2-8(a) shows how the heat pump electric load is distributed over the day due to the cooling of

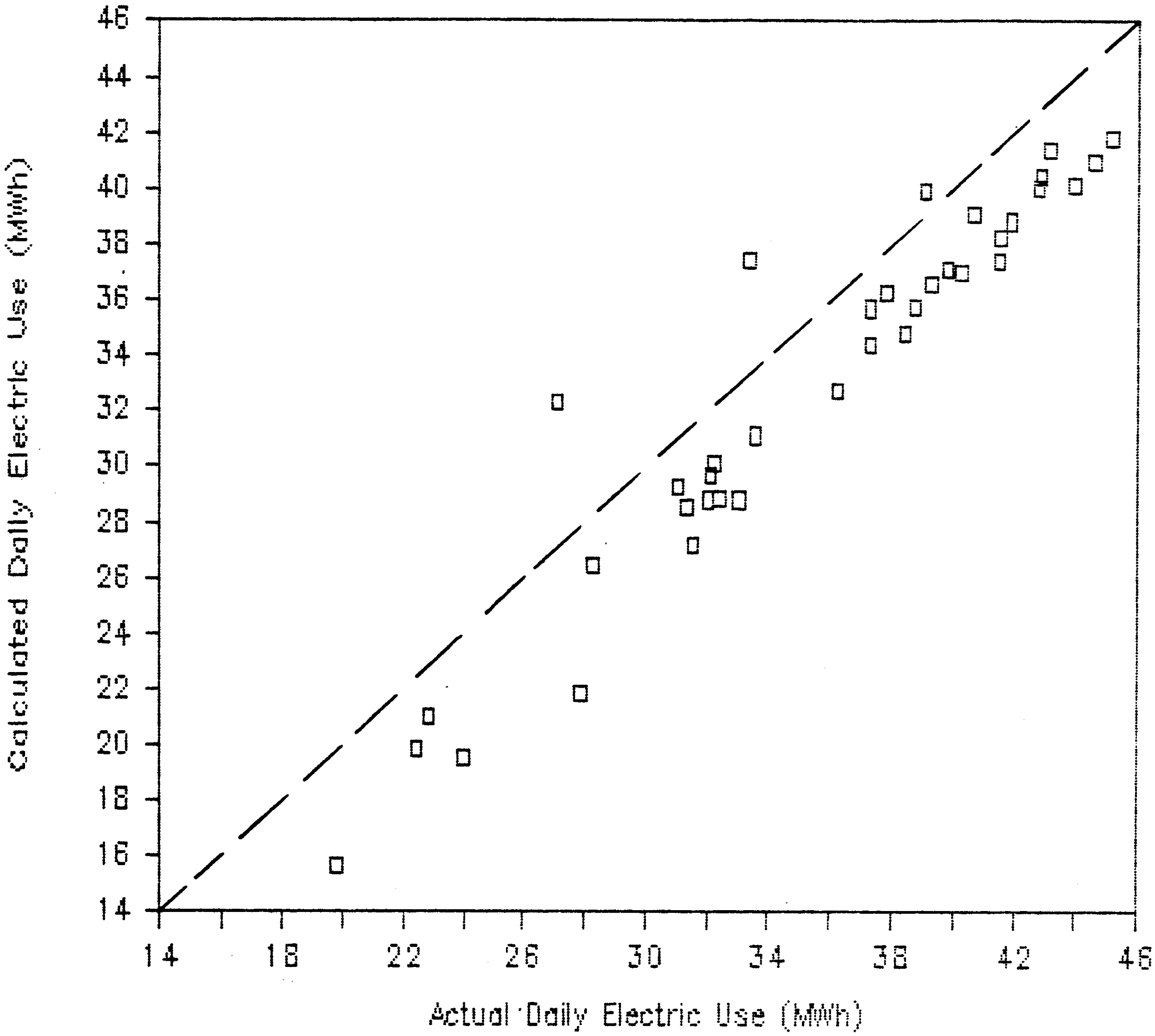


Figure 2-7: Comparison of Actual vs. Calculated Total Daily Electric Loads

(a)

(b)

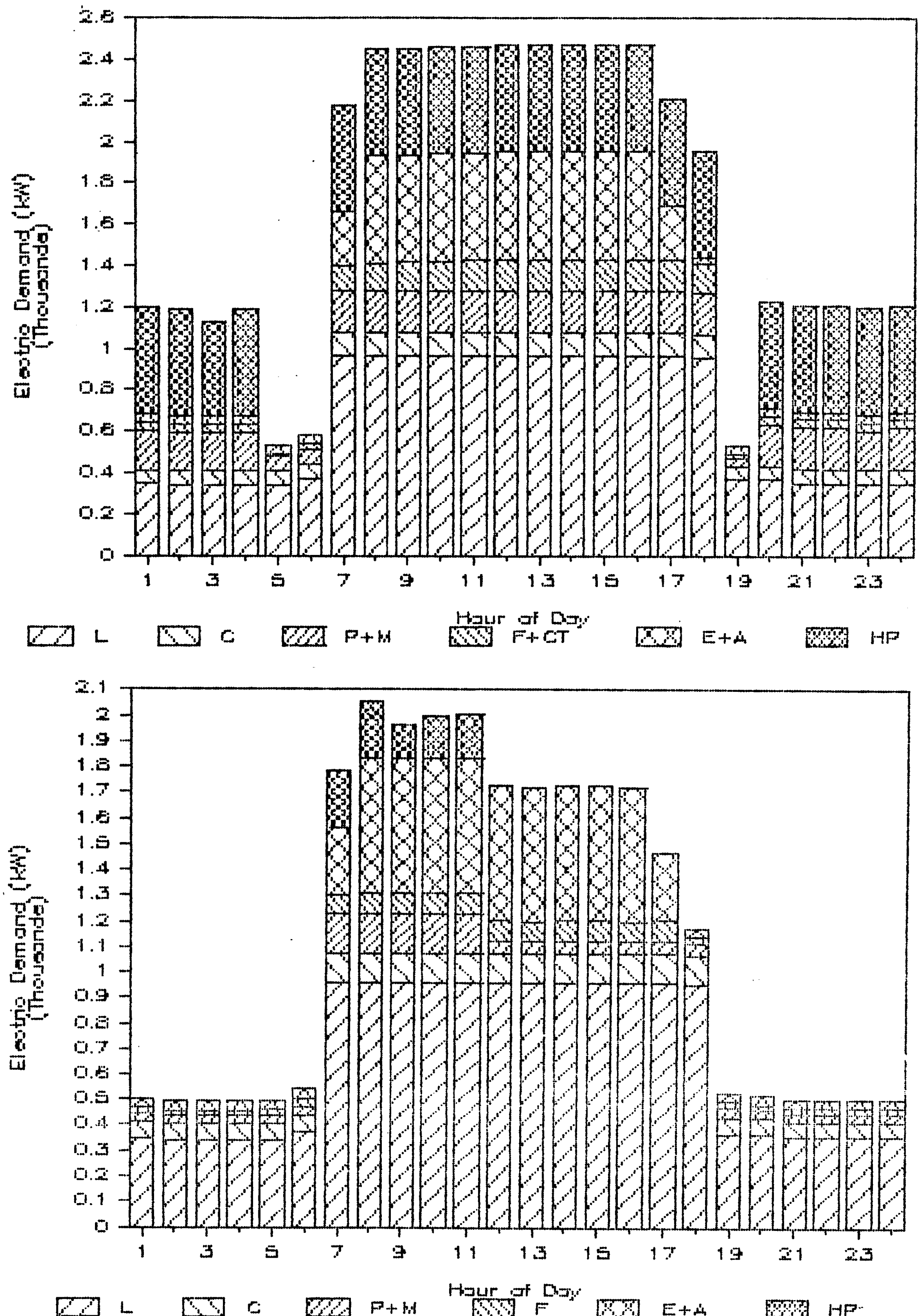


Figure 2-8: Typical Total Daily Electric Load Profiles
(a) Summer (b) Spring/Fall
L = Lights, C = Computer Rooms, P+M = Pumps & Miscellaneous,
F+CT = Fans & Cooling Towers, E+A = Elevators and Appliances, HP = Heat Pumps

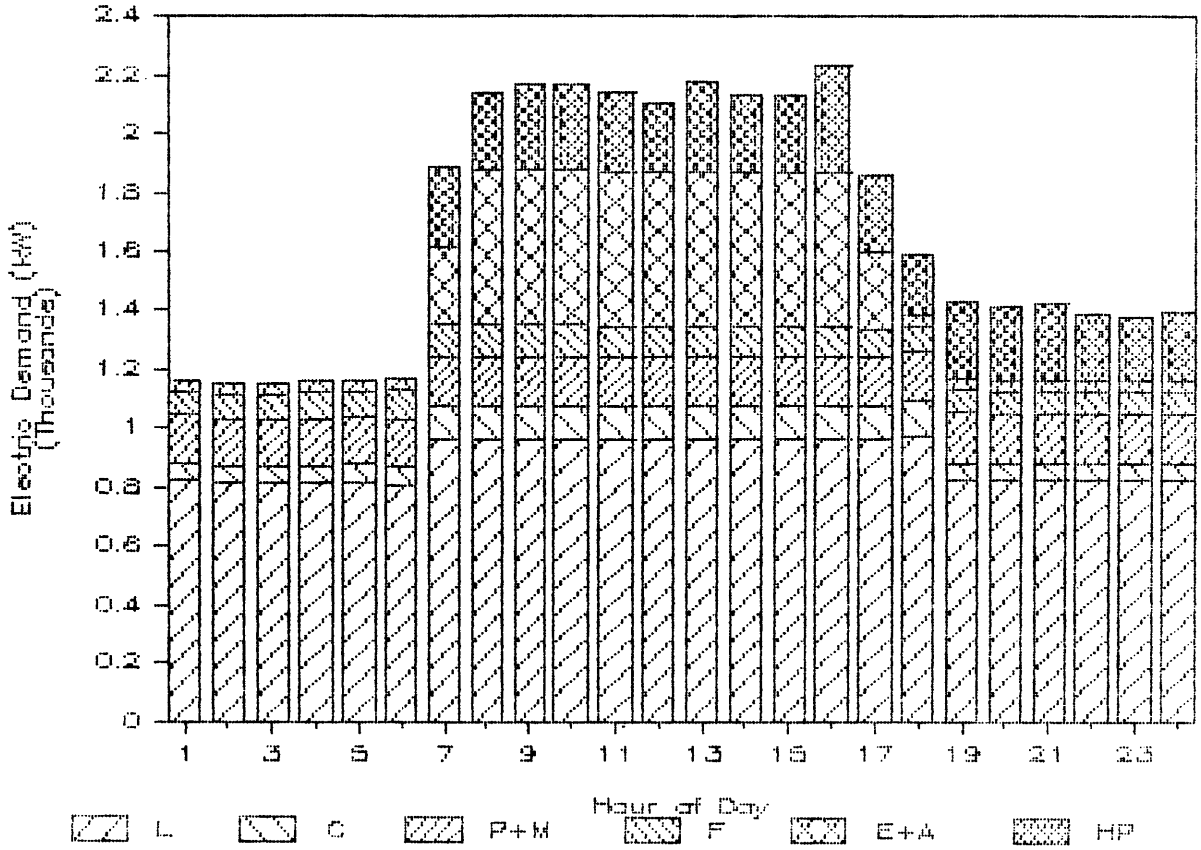


Figure 2-9: Typical Total Daily Electric Load Profile - Winter

L = Lights, C = Computer Rooms, P+M = Pumps & Miscellaneous,
F+CT = Fans & Cooling Towers, E+A = Elevators and Appliances, HP = Heat Pumps

the storage system during unoccupied hours. The spring/fall load profile in Figure 2-8(b) has a low unoccupied hours mechanical load since the mechanical system is generally shut down. The winter load profile in Figure 2-9 is dominated by the lighting 24-hour load.

By integrating the variable profiles over the year, total energy use can be attributed to different components of the building's energy use. Figure 2-10 is a pie-chart of the 1985 total annual energy use with lighting, base mechanical, variable mechanical, steam, computer rooms, elevators, and appliance subdivisions. Lighting accounts for 41.6 percent of the overall annual building energy use of 14,500 MWh. Variable mechanical loads (heat pumps, fans, pumps, cooling towers) account for 26.1 percent. Steam accounts for 11.2 percent of the total annual building energy use. Appliances and computer rooms each account for 5.4 percent of the total. Base mechanical loads are 4.0 percent and elevators are 6.2 percent of the annual building energy use.

Impact of Garage and Retail Space on Total Energy Use

When assessing the overall energy use of the State Transportation Building, and comparing it to other buildings' energy use and energy performance standards, questions arise concerning the impact of including the retail area and garage area in the overall building energy consumption. To consider this issue, an energy use breakdown was compiled for the garage and retail spaces to determine their relative impact on overall building energy consumption.

It was found that the garage has a lower energy use per gross sq.ft. than the rest of the building due to the fact that it is a generally unconditioned and unoccupied space. Garage energy use was found to be 3.07 kWh/sq.ft./yr., and when the garage energy use and floor area was excluded from overall building energy use, the building energy use went up from 16.09 kWh/sq.ft./yr. to 20.34 kWh/sq.ft./yr.

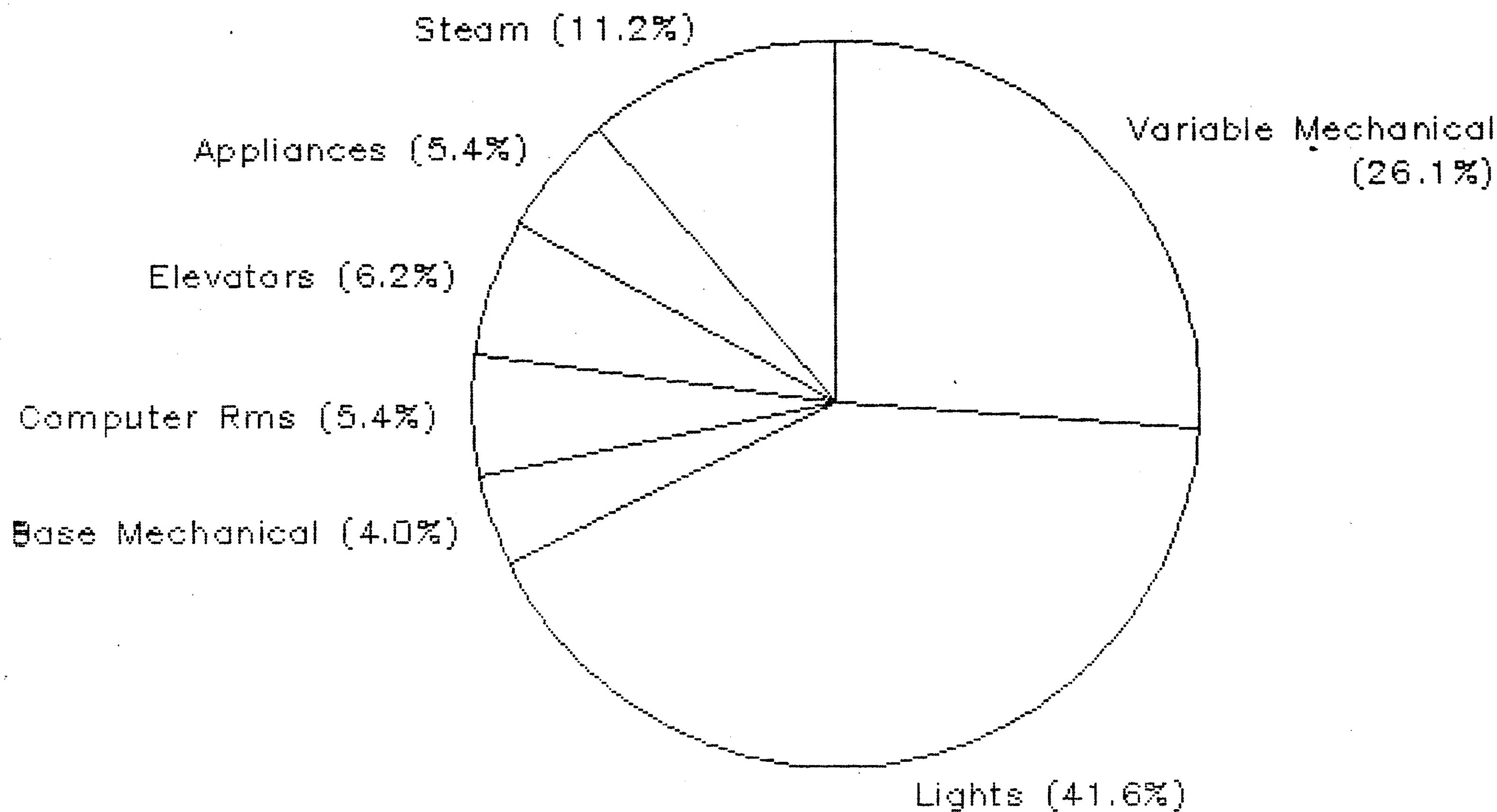


Figure 2-10: Total Annual Energy Use Distribution

By contrast, it was found that the retail area has a higher energy use per gross sq.ft., even with the retail spaces unoccupied. This is due to the fact that the retail area includes the first floor of the atrium and the major entrances to the building, and therefore has a significant lighting and entryway winter heating load. The retail area presently uses about 17.18 kWh/sq.ft./yr., and when the retail floor area and energy use are deleted from the building overall energy use figures, the building energy use drops from 16.09 to 14.05 kWh/sq.ft./yr.

With both garage and retail energy use and floor areas deleted, the annual building energy use is 19.87 kWh/sq. ft./yr. These results are summarized in Table 2-4.

Is the Transportation Building a "Low Energy" Building?

In an attempt to answer this question, the overall energy consumption of the Transportation Building for the past year will be considered in relation to some other Massachusetts state office buildings and Boston commercial office buildings. The Transportation Building is also referenced to the findings of the Building Energy-Use Compilation and Analysis (BECA) project at Lawrence Berkeley Laboratory, to the ASHRAE Standard 90, and to the Building Energy Performance Standard (BEPS) proposals.

State Office Buildings

The Transportation Building is one of three large state office buildings in Boston. The other two, the Saltonstall Building and the McCormack Building, are older and use significantly more energy than the Transportation Building.

Table 2-4: Energy Use and Cost Comparison Between the State Transportation Building and Other Buildings and Energy Standards

Building	Gross Area (sq.ft.)	Electric Use (kWh)	Electric Demand (kW)	Electric Demand (W/sqft)	Steam (Mlbs)	Gas (Therms)	Total Energy (kWh)	Total Energy (kWh/sqft)	Source Energy (kWh)	Source Energy (kWh/sqft)	Total Energy Cost ($)	Total Energy Cost ($/sqft)
Transportation Building	901,259	12,408,000	2,808	3.1	6,020	-	14,500,360	16.09	44,349,086	49.21	$1,185,415	$1.32
without garage	679,429	11,727,660	2,724	4.0	6,020		13,820,020	20.34	49,055,319	72.20	$1,126,307	$1.66
without retail	847,794	11,489,523	2,763	3.3	5,680		11,908,005	14.05	36,595,028	43.17	$1,099,730	$1.30
without garage and retail	625,964	10,809,183	2,695	4.3	5,680		12,435,802	19.87	38,850,877	61.27	$1,040,336	$1.66
Saltonstall*	630,000	15,588,000	3,568	5.7	65,213	-	38,253,960	60.72	84,339,943	133.87	$2,191,492	$3.48
McCormick*	660,000	18,844,800	4,067	6.2	72,361	-	43,995,177	66.66	98,745,110	149.61	$2,517,866	$3.81
Commercial Bldg. A	676,100	11,827,721	3,705	5.5	-	175,835	16,979,630	25.11	46,785,607	69.2	$1,017,219	$1.50
Commercial Bldg. B	227,917	4,158,479	-	-	-	-	4,158,479	18.25	13,861,597	60.82	$417,088	$1.83
Commercial Bldg. C	817,734	14,139,185	-	-	-	-	14,139,185	17.29	47,130,617	57.64	$1,267,488	$1.55
BECA	-	-	-	-	-	-	-	17.87	-	51.57	-	-
ASHRAE 90	-	-	-	-	-	-	-	12.6 - 16.7		36.33 - 46.59		-
BEPS	-	-	-	-	-	-	-	13.18	-	35.75	-	-

Notes:

1. * - Source: Electric and Steam Utility records, State Division of Capital Planning and Operations
2. 3413 Btu/kWh
3. 1186.25 Btu/lb Steam
4. Source energy calculations assume 70% efficiency, gas and steam; 30% efficiency electric

The Saltonstall Building is a high-rise, 630,000 gross sq. ft. office building. Built in 1965, it provides office space for about 4,200 people. The McCormack Building is a newer high-rise in the same complex, built in 1974, with 660,000 gross sq. ft. and about 3,775 workers. Both have occupancy schedules similar to the Transportation Building, and both have underground garage space (garage floor area is included).

The Saltonstall and McCormack buildings have central constant volume air handlers and perimeter steam heaters. District steam is used from the perimeter heat, and to fuel absorption chillers for cooling. Therefore, district steam use is the major component of the heating and cooling energy used, and about 58% of the overall energy use for both buildings.

Table 2-4 summarizes the 1985 energy use and cost of the Saltonstall and McCormack buildings as compared to the Transportation Building. The McCormack Building use totalled 66.66 kWh/sq.ft./yr. in 1985, or 149.61 kWh/sq.ft./yr. in source energy. The Saltonstall Building performed slightly better with 60.72 kWh/sq.ft./yr. and 133.87 kWh/sq.ft./yr. in source energy. The Transportation Building use was about one fourth as much energy consumption per sq.ft., 16.90 kWh/sq.ft./yr., and about one third as much source energy use per sq.ft., 49.21 kWh/sq.ft./yr. The Transportation Building's annual energy cost per sq. ft. of $1.32 was about one third of the energy costs of the other two state buildings. The Transportation Building's peak electric demand per sq. ft. was about half of the peak demand at the Saltonstall and McCormack Buildings.

Commercial Office Buildings

Commercial office buildings A, B, and C are managed by an unusually energy-conscious developer, and are probably some of the more energy efficient office buildings in Boston. All three buildings have tight building envelopes, and have undergone various degrees of energy conserving retrofits.

Building A is a 676,100 sq.ft. building, built in the 1960's, and has undergone numerous energy conserving retrofits. Similarly to the Transportation Building, it includes both a garage and retail space. The building has central VAV air handlers with electric reheats and four-pipe perimeter fan coils. A gas-fired boiler is used for heating and electric centrifugal chillers for cooling. Currently Building A has an annual energy use of about 25.11 kWh/sq.ft./yr., which is only 5 kWh/sq.ft./yr. more than the Transportation Building's when the garage floor area and energy use are deleted. Annual energy costs for Commercial Building A were $1.50 per sq. ft., which is almost as low as the State Transportation Building. The peak electric demand of Commercial Building A is 45 percent higher than the Transportation Building.

Building B was completed in the late 1970's, and has 227,917 gross sq. ft. An all-electric building, a double-bundle chiller is used for heating in the winter and a centrifugal chiller for cooling in the summer. There is no water thermal storage used in the building, and an electric boiler is used for back-up heating. Building B has constant volume core air handlers with hot water reheats and four-pipe fan coil perimeter heaters. Building B compares relatively favorably to the Transportation Building, using 18.25 kWh/sq.ft./yr., and source energy use of 60.82 kWh/sq/ft./yr., which is comparable to the Transportation Building's performance when the garage and retail areas and energy uses are deleted. At $1.83 per sq. ft., annual energy use costs are about 30 percent higher than at the State Transportation Building.

Building C was first occupied in the early 1980's , and has 817,734 gross sq. ft. including a garage. Building C's HVAC system is similar to Building B's, with three double-bundle chillers used for heating and cooling, two back-up electric boilers, constant volume air handlers with hot water reheats, and perimeter four-pipe fan-coil units. Building C's total annual energy use is 17.29 kWh/sq.ft./yr., 57.64 kWh/sq.ft./yr. source energy. Building C's energy use is only 10 percent more than the State Transportation Building and its energy costs only 15 percent more.

The performance of buildings B and C strengthens the argument that "bootstrap heating" systems are energy conserving for office buildings.

BECA Data

The preceding discussion indicates that the State Transportation Building can be considered a low energy use building as compared to other state and commercial office buildings in Boston. The BECA data allows us to compare the Transportation Building to other new energy-efficient large office buildings in North America.

BECA is an ongoing project at Lawrence Berkeley Laboratory which includes recently published[3] energy performance data on 69 energy efficient new commercial buildings in the U.S. and Canada. Many of the buildings included in this data base , which was begun in 1982, are award winners from competitions sponsored by Owens-Corning, ASHRAE, AIA, and the Government of Canada, and are buildings described at conferences or in special programs. Included is some limited data on conventional buildings to establish a performance baseline for comparison.

The annual energy use of the 69 large office buildings range from 4.4 to 37.8 kWh/sq.ft./yr. with a mean of 17.87 kWh/sq.ft./yr. and a median value of 17.29 kWh/sq.ft./yr. Source energy use numbers range from 13.77 to 127.45 kWh/sq.ft./yr., with a mean of 51.57 and a median of 48.05 kWh/sq.ft./yr.

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[3]M. Piette, L. Wall, B. Gardiner, "Measured Performance", ASHRAE Journal, (Jan. 1986), pp.72-78.

The Transportation Building's annual use of 16.09 kWh/sq.ft./yr. is below the mean and median values of the BECA data base, and its source energy use of 49.31 is close to the mean and median source values. This comparison indicates that the Transportion building can be considered a low-energy building from a continental perspective.

ASHRAE 90 and BEPS Standards

The ASHRAE 90 standard has more of a component approach to building envelope and energy equipment requirements, but simulations from large prototype office building data under the standard have been used to establish over-all building energy use predictions.[4]

This simulated performance data ranges from 12.6 to 16.7 site use kWh/sq.ft./yr., and 36.33 to 46.59 kWh/sq.ft./yr. source. The Transportation Building's 1985 performance is at the high end of the site use range, and above the source use range. However, when considering Standard 90 component efficiency standards, as summarized in Table 2-5, the Transportation Building compares favorably.

The Federal Building Energy Performance Standards, BEPS, proposed that a large office building in Boston should use 13.18 kWh/sq.ft./yr. site and 35.74 kWh/sq.ft./yr. source.[5] The Transportation Building does not meet this standard, and is especially high in source energy by comparison.

See Table 2-4 for a summary of the building and standard performances.

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[4]Battelle Pacific NW Labs, "Recommendations for Energy Conservation Standards and Guidelines for New Commercial Buildings", DOE/NBB-0051/6,(Oct. 1983).

[5]Federal Register.

Table 2-5: State Transportation Building Characteristics as Compared to ASHRAE Standard 90

Component	ASHRAE Standard 90A-1980*	ASHRAE Standard 90.1P*	State Transportation Building
# glazing	2	2	2
shading coeff.	0.55	0.43	0.51
Roof U	0.15	0.061	0.08
Opaque Wall U	0.262	0.163	0.10
Lighting(W/sq.ft.) (av. power density)	2.46	1.72	1.27
Heat Pump Heating COP	3.03	3.45	4.94**
Heat Pump Cooling COP	2.56	2.65	3.94**

* - Source: D. Crawley & R. Briggs, "Standard 90: the value", ASHRAE Journal, Nov. 1985, pp.18-23.

** - Rated for RU-1 and RU-2

In general, when compared to other buildings' operating data and the various building performance standards, the Transportation Building seems to fall within the definition of a low energy building. However, it performs better by site energy standards than by source energy standards, due to the electric-dominated energy use of the building.

Chapters I and II have provided a general description of the building energy system and its performance. The remaining chapters delve more deeply into documenting and analyzing system operation and energy use, eventually leading to recommendations for improved operation.

Chapter III describes the computer model which was developed to help determine how the building energy system responds to different weather, occupancy, and operating conditions.

Chapter III: Description and Documentation of Computer Model

Introduction

A computer model was created to simulate the operation of the Transportation Building energy system. The purpose of the model is to help determine how the building heating and cooling system responds to different weather, occupancy, and operating conditions. The model provides a summary of the heating and cooling requirements of the building under various conditions, by summing the contributions of the thermal storage tanks, heat pumps, and outside air to meet those loads using either actual operating data or assumed operating conditions. It also calculates the variable electric use and demand of the equipment. Finally, the model serves as a tool which is used to compare the effectiveness of different energy system operating strategies, based upon actual operating data.

Instead of predicting the heating and cooling demands of the building by simulating weather conditions, internal gains, and building thermal conductivity, the model assumes that the heating and cooling actually supplied to the building will at least as accurately measure the requirements of the building. The model performs an hourly energy balance on the heating and cooling system. The heating and cooling supplied to the building are calculated by adding together the contributions of the heat pumps, thermal storage tanks, and outside ventilation air. These contributions are calculated using actual operating data as monitored by the Delta 1000.

This chapter describes the general structure of the model and the assumptions behind it, while referring to more specific documentation in Appendix B. Finally, a comparison between the model's results and assumptions and a simplified energy prediction analysis is presented.

Data Collection

Since the model has been constructed from actual building operation data and has been extensively used to process and interpret monitored building data, before describing the model it is instructive to first explain what sort of building operations data was available and how it was collected. At the Delta 1000 central processor unit information is available from the remote sensors and detectors indicating whether equipment is on or off, and providing data on temperatures, humidities, pressures, and flows (see Table B-1 for a listing of all Delta 1000 data points). However, the Delta 1000 does not store historical information, so system operation records must be printed out or recorded in written form.

As changes occur, the Delta 1000 automatically prints out information about when equipment is commanded on and off, and whether the command cames from a programmed sequence or from a human operator. But monitored data such as temperatures, humidities, and flows must be manually requested to be printed out by the Delta operator in the form of an all-points log (all points printed out), a group log (small groups of points printed out), or a trend log (specified points printed out at specified intervals). All-point logs have been printed out at eight-hour intervals since the opening of the building, but are of little use in determining what occurred between these eight-hour intervals.

Since the building began operation, manual hourly logs have been maintained by the Delta operators to record information on storage tank temperatures; hot water, chilled water, and condenser water temperatures; air handler temperatures and dewpoints; and outside air temperatures. Unfortunately, this data is of little value unless coupled with knowledge of what equipment is on or off. For example, the storage tank temperature readings are not useful unless the tank pumps are running because the sensors are located in the piping between the tank outlets and inlets and the pumps. Similarly, without knowledge of which fans are running and which dampers are open at the air handlers, it is impossible to predict outside air intake or fan power consumption.

Coupling these written logs with the Delta 1000 computer printouts to determine which equipment is on or off would be an enormously difficult process involving a search through reams of computer paper, some of which has been lost or discarded. There is also doubt about the validity of temperature and humidity records in light of the building's history of sensor inaccuracies (this issue is discussed in Chapter V).

Recognizing this problem, a new hourly log was designed and put into use in July 1985 (see Figure 3-1). This log includes the status of all of the pumps and heat pumps, which modes of operation are in use, which air handler dampers are open, and temperature and humidities in the air and water systems. Fan status is recorded in a form on the back of the log sheet by the Delta operator. The Delta operators also record exact times that equipment is commanded on and off, and any unusual operation information on the back of the log sheet. Coupled with the fact that the building's temperature sensor problems have improved since early summer when sensors were replaced, relocated, and recalibrated, the new logs provide a fairly accurate record of the energy system operation.

Structure of the Computer Model

The Lotus 1-2-3 computer software package was used to create the computer model. Lotus was chosen over a programming language such as Fortran or Pascal for several reasons. Lotus's spreadsheet format facilitates data entry and makes viewing, formatting, and manipulation

STATE TRANSPORTATION BUILDING
HVAC SYSTEMS LOG

DATE: ____/____/____
(mo.) (day) (yr.)

DELTA OPERATOR: ____________________

		A	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00
		B	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00
		C	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
DESCRIPTION	UNIT	POINT								
1. Outside Air Temp. and Dew Point		14602								
	~ ~	14603								
2. Operation Mode(s): *(Circle correct numbers)* 1. Maximum Heating 6. Peak Chilled Water 2. Reduced Heating 7. Part Chilled Water 3. Heat Recovery 8. Off Peak Storage 4. Standby 9. Economizer 5. False Loading 10. Heat Rejection			1 6 2 7 3 8 4 9 5 10	1 6 2 7 3 8 4 9 5 10	1 6 2 7 3 8 4 9 5 10	1 6 2 7 3 8 4 9 5 10	1 6 2 7 3 8 4 9 5 10	1 6 2 7 3 8 4 9 5 10	1 6 2 7 3 8 4 9 5 10	1 6 2 7 3 8 4 9 5 10
3. Storage Tank Temps. (only when pump running) — Tank #1	Status	10101								
	Tank	10102								
	Return	10108								
Tank #2	Status	10201								
	Tank	10202								
	Return	10208								
Tank #3	Status	10301								
	Tank	10302								
	Return	10308								
4. Hot Water Pump Status (ON/OFF)	P-1A	10601								
	P-1S	10602								
5. Hot Water Temps. (only when pump running)	Return	10606								
	Supply	10607								
	Zone Supply	10611								
6. Chiller Status (ON/OFF)	RU #1	10901								
	RU #2	10902								
	RU #3	10903								
7. Chilled Water Return Temp. (only when pump running)		10904								
8. Chiller Discharge Temps. (only when running)	RU #1	10905								
	RU #2	10906								
	RU #3	10907								
9. Chilled Water CPA ± (PCT)		10908								
10. Chilled Water Pump Status (ON/OFF)	P-2A	11001								
	P-2S	11002								
11. Condenser Water Pump Status (ON/OFF)	P-3A	11301								
	P-3B	11302								
	P-3C	11303								
12. Condenser Water Return Temp. (only when		11305								
13. Condenser Water Supply Temp. pump running)		11306								
14. Condenser Water CPA ± (PCT)		11307								
15. Computer Room Space Temp.		11405								
16. Computer Room Supply Temp.		11406								
17. Space Temps.	AC #1	12001								
	AC #2	13001								
	AC #3	15001								
	AC #4	16003								
18. Return Air Temp. and Dew Point (only when fans running)	AC #1	12406								
		12407								
	AC #2	13406								
		13407								
	AC #3	15406								
		15407								
	AC #4	16005								
		16006								
19. Delayed Vent Status (OPN/CLO)	AC #1	12305								
	AC #2	13305								
	AC #3	15305								
20. Enthalpy Status (OPN/CLO)	AC #1	12405								
	AC #2	13405								
	AC #3	15405								
	AC #4	16007								

Figure 3-1: Sample Energy System Monitoring Log

of data extremely easy. It has many of the calculating and logical function capabilities of Fortran and Pascal such as if...and/or...then statements; certainly all of the functions necessary for this simple model. Finally, Lotus has very good graphing capabilities that make the analysis and illustration of building operation trends easier.

The energy system model is set up as a spreadsheet similar to the log sheet in Figure 3-1, with the titles of the inputs in the lefthand column and twenty four input columns on the right (one for each hour of the day). Below the input section is the output section with the same sort of spreadsheet structure: the titles of the outputs in the lefthand column and the outputs for twenty-four hours on the right. For each hour, the output section references the operation data from the input section to calculate the outputs. Table 3-1 lists the inputs and outputs of the spreadsheet. Table B-2 lists the algorithms used to calculate the outputs. Table B-3 is a sample listing of one day's computer model spreadsheet.

Algorithms

The model uses the hourly input data to calculate the heating and cooling supplied by the thermal storage tanks, heat pumps, cooling towers, and outside air for each hour of the day, and their associated electric loads. Integrating over the day, daily loads are calculated.

Heating and cooling supplies are calculated using the steady-state equation:

$$q_{12} = \dot{m} \cdot c_p \cdot (T_2 - T_1) \qquad (3\text{-}1)$$

Flow rates at the pumps are assumed constant (see Table A-9), and a specific heat value of 1 Btu/lb is used for the water systems. The temperatures leaving and entering each piece of equipment are taken from the input section of the spreadsheet.

Table 3-1: Inputs and Outputs of Energy System Computer Model

INPUTS
T out
Dew T out
Tank 1 gpm
Tank 1 Status
Tank 1 Supply T
Tank 1 Return T
Tank 2 gpm
Tank 2 Status
Tank 2 Supply T
Tank 2 Return T
Tank 3 gpm
Tank 3 Status
Tank 3 Supply T
Tank 3 Return T
HW gpm
HW pump on?
HW Return T
HW Supply T
Chiller on?
RU-1 on?
RU-2 on?
RU-3 on?
CHW return T
CHW supply T-RU-1
CHW supply T-RU-2
CHW supply T-RU-3
CHW gpm
CHW pump on?
P-3A on?
P-3B on?
P-3C on?
CW return T
CW supply T
int coil T
ext coil T
AC-1 int. fans
AC-1 ext. fans
AC-2 int. fans
AC-2 ext. fans
AC-3 int. fans
AC-3 ext. fans
AC-1 RA T
AC-1 RA dew T
AC-2 RA T
AC-2 RA dew T
AC-3 RA T
AC-3 RA dew T
Delayed vents open?
Enthalpy open?
Maximum Heating?
Floor dampers?

OUTPUTS
OA enthalpy(Btu/lb)
RA enthalpy(Btu/lb)
HP Htg supply
Tank 1 Htg supply
Tank 2 Htg supply
Tank 3 Htg supply
Tank Htg supply
Clg Twr Heat Disch
Bldg. Htg Demand
RU-1 clg supply
RU-2 clg supply
RU-3 clg supply
HP Clg supply
Tank 1 Clg supply
Tank 2 Clg supply
Tank 3 Clg supply
Tank Clg supply
AC-1 int cfm
AC-1 ext cfm
AC-2 int cfm
AC-2 ext cfm
AC-3 int cfm
AC-3 ext cfm
AC-1 int free clg
AC-1 ext free clg
AC-2 int free clg
AC-2 ext free clg
AC-3 int free clg
AC-3 ext free clg
free cooling (Btu/hr)
Ventilation (Btu/hr)
Infiltration (Btu/hr)
Bldg. Clg Demand
OA dewpoint(K)
RA dewpoint(K)
OA partial pressure
RA partial pressure
OA Humidity ratio
RA Humidity ratio

Daily Bldg.Htg. Demand

Daily HP Htg. Supply
Dly Tank Htg. Sup
Daily Clg.Twr. Disch.

Daily Bldg.Clg. Demand

Daily HP Clg. Supply
Dly Tank Clg. Sup
Daily Free cooling
Daily Ventilation
Daily Infiltration

Electrical Loads

AC-1 int fans
AC-1 ext fans
AC-2 int fans
AC-2 ext fans
AC-3 int fans
AC-3 ext fans
Total fans

Pumps
Miscel. pumps
Tank1
Tank2
Tank3
Pumps total

Cooling Towers

Total Cooling Towers

Heat Pumps
RU-1
RU-2
RU-3
Total Heat Pumps

Total electric load

Total Var.Dly. Elec. Load

Daily Fans
Daily Pumps
Daily Cooling Towers
Daily Heat Pumps

COP's

Heat Pump Htg. COP
RU-1 Clg COP
RU-2 Clg COP
RU-3 Clg COP
Bldg. Htg. COP
Bldg. Clg. COP
Bldg. Overall COP

The heat supplied to the building perimeter is assumed equal to the heat supplied by the heat pumps plus the heat supplied by the storage tanks. If a storage tank is being heated by the heat pump, its heat supply is negative, and therefore subtracted from the heat pump heat supply when calculating the building's heat supply.

The cooling supplied to the building is assumed equal to the cooling supplied by the heat pumps, plus the cooling supplied by the storage tanks, plus the cooling supplied by the air handlers. In the model cooling is always considered negative, since when cooling T_2 is less than T_1 in equation (3-1). If the storage tanks are cooled by the heat pumps, their cooling supply to the building is positive when added to the negative heat pump cooling supply.

Below is a general description of the algorithms used to simulate the thermal and electric performance of the air handlers, cooling towers, heat pumps, storage tanks and heat exchangers. Refer to Table B-2 for a complete listing of the model's algorithms.

Modeling of the Air Handlers

Cooling (or heating) supplied by outside air is more difficult to determine than for the water systems since the fans are variable flow, and the tracking between the supply and return fans is often inconsistent. Unfortunately, the Delta 1000 cfm readings for the fans are inaccurate so these readings could not be used to monitor fan air flow. An empirical method was developed to predict approximate fan flow rates and the amount of ventilation or infiltration air admitted under different conditions. This amount was assumed constant when the enthalpy vents (free cooling dampers) were closed but had to be calculated with a different method when the enthalpy vents were open, because under these conditions the amount of outdoor air varies depending upon outdoor air temperature, return air temperature, and the cooling coil setpoint.

Because the air handler flow rates were not available from the Delta 1000, they had to be recorded manually by reading the magnehelic cfm gauges at the Cambridge fan control panels near the air handlers. Table B-4 summarizes the authors manual readings at the air handlers for AC-1, 2, and 3. Flow rates for each supply and return fan, damper settings, and static pressures for the exterior and interior level two ducts are listed. In many cases, temperature readings for mixed air, outdoor air, and return air were also taken.

Interior and exterior supply and return flow rates were calculated by adding together fan flow rates. The amount of outdoor air was calculated by two methods, one using fan flow rates and the other using mixed air, return air, and outdoor air temperatures. Equations are listed at the bottom of Table B-4.

Fan Flow Rates. When observing and analyzing the fan flow rate data for different times of the year, certain trends seemed to emerge. In the summer, the fan flow rates were generally higher than in the spring and fall. In the winter, the exterior fan flow rates increased and the interior fan flow rates decreased as compared to the spring and fall flow rates. This observation led to the conclusion that outdoor air temperature has an effect upon fan flow rate. When fan flow rates were observed at hourly intervals over a day (11/12/85) while the outdoor air temperature stayed relatively constant, significant flow rate variations did not occur.

Table B-4 summarizes the exterior and interior supply flow rates, outdoor air temperatures, dampers in use, and amount of outside air. Exterior and interior fan supply flow rates were graphed for each air handler in relation to the outdoor air temperature (see Figures 3-2 to 3-4). Although there was some scattering of the supply flow rates, the data generally correlates with the observed trends.

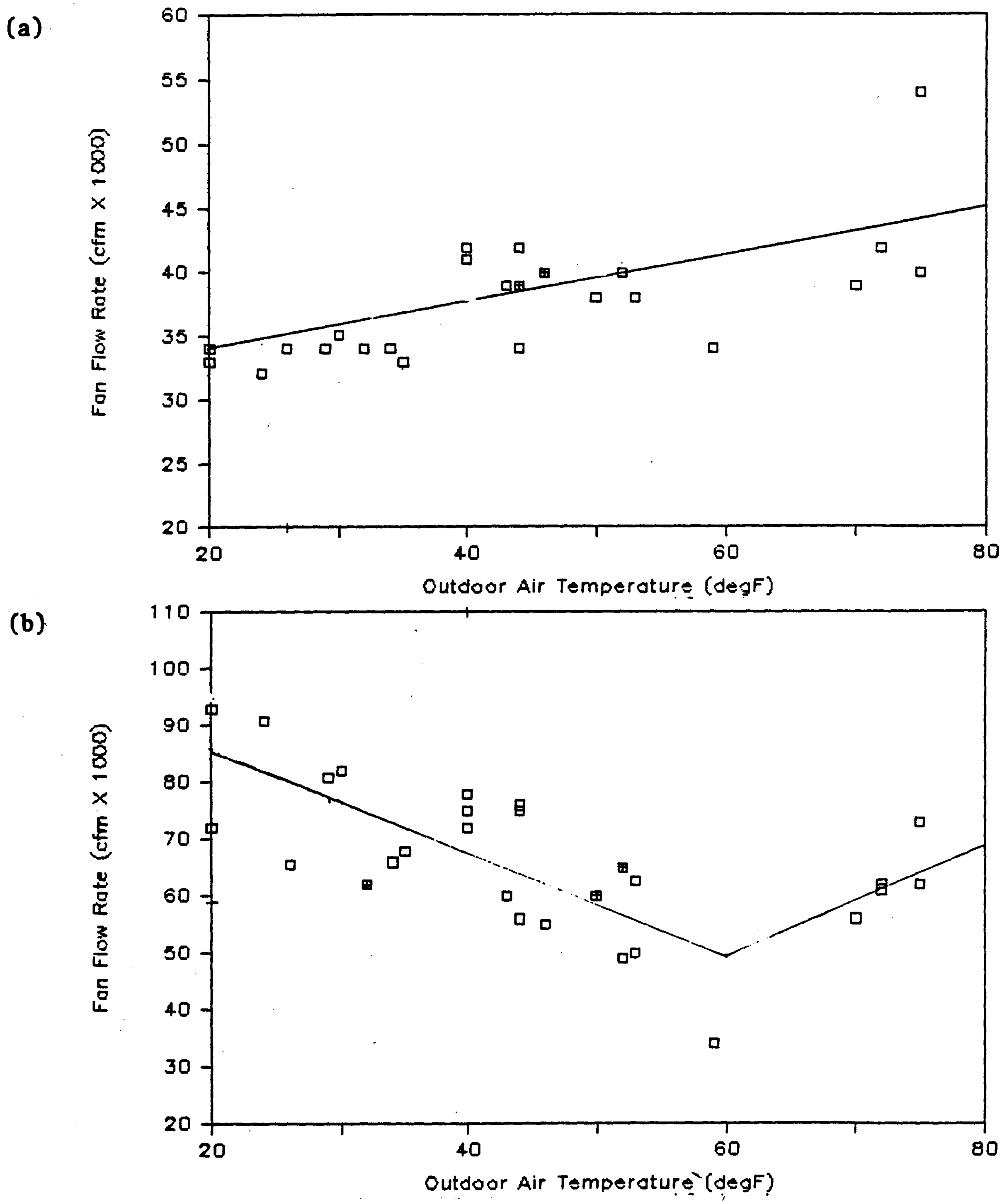


Figure 3-2: AC-1 Monitored Supply Fan Flow Rates (a) Interior Fans (b) Exterior Fans

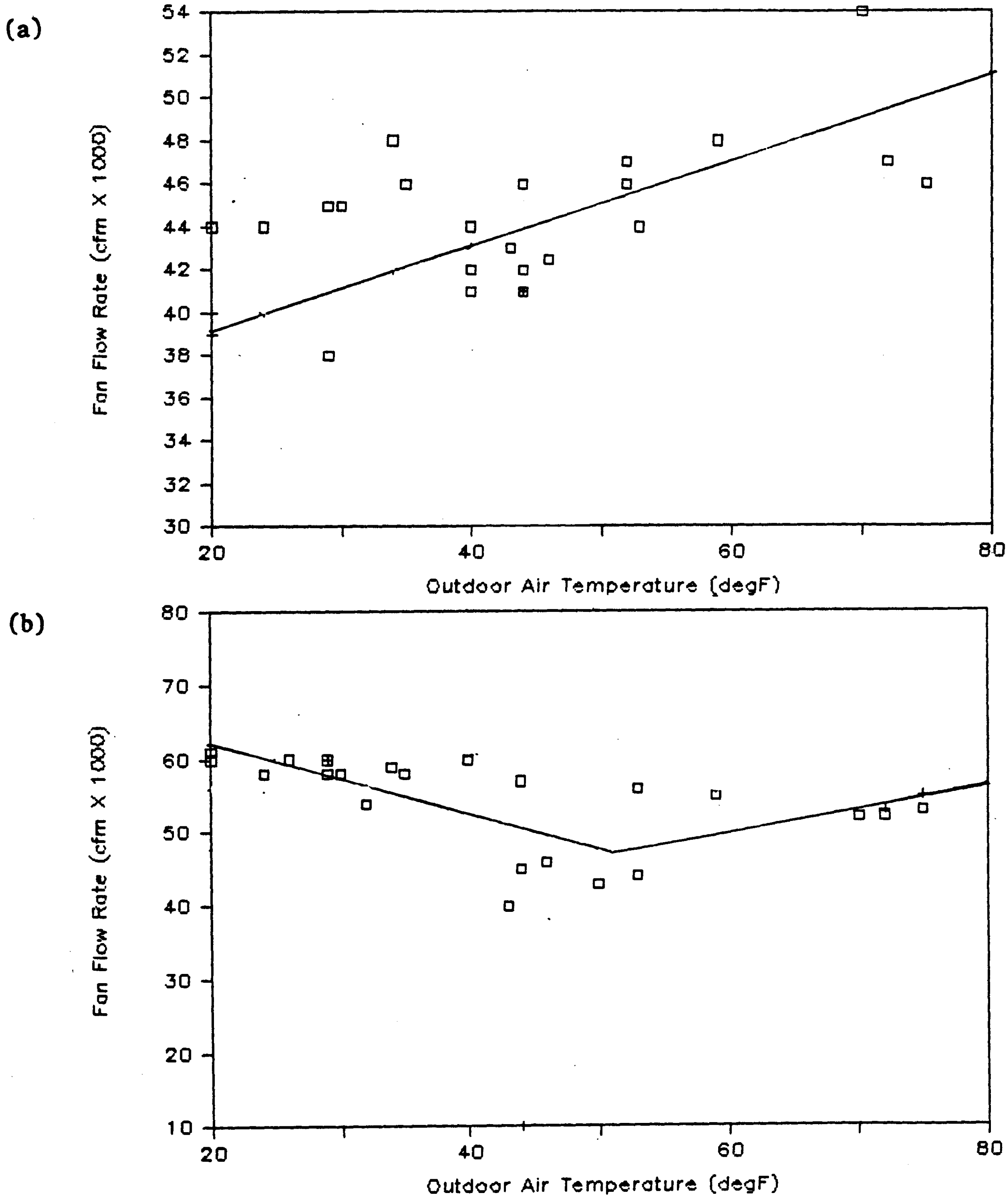
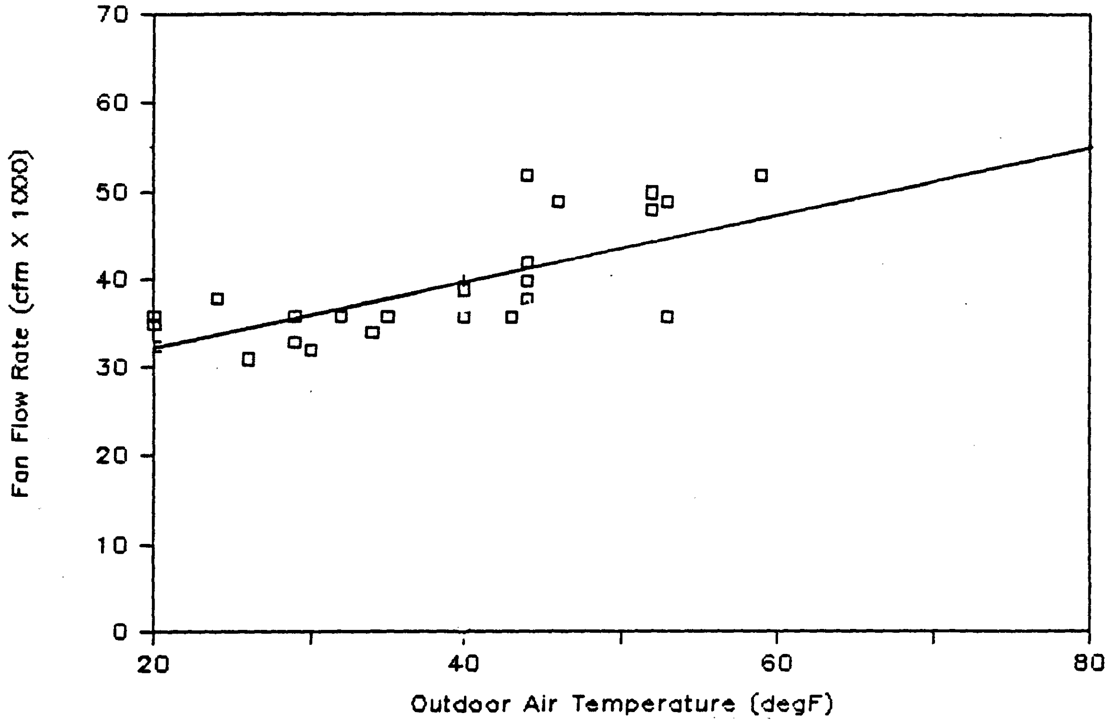


Figure 3-3: AC-2 Monitored Supply Fan Flow Rates
(a) Interior Fans (b) Exterior Fans

(a)



(b)

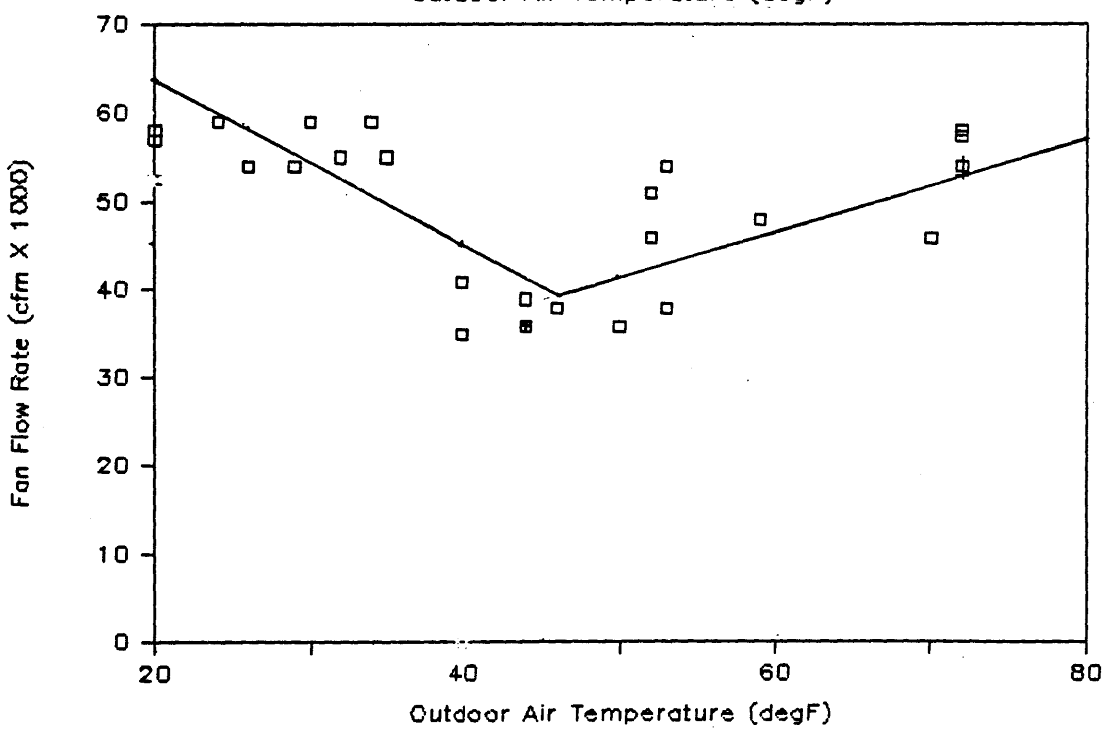


Figure 3-4: AC-3 Monitored Supply Fan Flow Rates
(a) Interior Fans (b) Exterior Fans

These results make sense when related to the manner in which the air handlers operate. In the exterior zones, as increased cooling is required due to hotter outdoor conditions, the VAV boxes call for more air. In the winter as increased heating is required due to colder outdoor conditions, the VAV boxes call for more air to pass across their heating coils. In this way, exterior air handler flow rates relate proportionately to outdoor air temperatures.

In the interior zones one would expect the flow rates to stay relatively constant since the interior core zones are not exposed to outdoor conditions. However in most areas of the Transportation Building, due to the open plan design, the perimeter zone of the building is in complete convective contact with the interior zone. Therefore it is concluded that the perimeter conditions do have some effect upon the interior cooling demand, explaining why there is an increased call for cool air in the interior zones in the warmer weather, and a decreased call for cool air in the interior zones in the colder weather. Outdoor ventilation air temperature could also have an impact upon the interior zones if the cooling effect of the ventilation air brings the interior supply air temperature below the cooling coil setpoint.

Least square curve fitting was performed for each air handler's interior and exterior set of fans. The curve equations and their correlation coefficients (ranging from 0.64 to 0.77) are summarized in Table B-5(a) and drawn on Figures 3-2 through 3-4. There is a curve and equation for each air handler's two interior or exterior fans added together. These equations were used in the model to approximate the fan flow rates. Confirmation of these approximations is discussed in the "Confirmation of Model" section of this chapter.

The curves seem to substantiate the observations of the building staff about the performance of AC-1,2, and 3. Although the interior air curves are similar in slope and intercept, the exterior curves have somewhat different shapes and balance points. AC-1, which has been observed to have the coldest return air temperatures, has a higher balance point of 60 degress F, which means that heat is required at relatively warmer outdoor air temperatures. The AC-1 curves also have steeper slopes than in AC-2 or 3. AC-3, which is considered the warmest air handler, has a lower balance point of 46 degrees F. The balance point of AC-2 is 51 degrees F, which is closer to the overall building energy balance point discussed in Chapter II.

Ventilation and Infiltration. As shall be discussed in Chapter V, recurring tracking problems have occurred between the supply and return fans at the air handlers. Two methods were initially used to attempt to estimate the amount of outdoor air brought in at the air handlers: calculating the difference between the supply and return fan air flow rates from the Cambridge panel gauges, and calculating the amount of outdoor air from the return air, outdoor air, and mixed air temperatures.

Using the first method, when a positive differential between supply and return fan flow rates was observed, it was assumed that the difference between the two was equal to the amount of outdoor air being pulled into the air handler. When a negative differential between supply and return fan flow rates was observed, it was assumed that the difference between the two was equal to the amount of infiltration air being pulled into the building through doors and other openings. The net effect on the building would be the same.

The second method of estimating the amount of outdoor air from the return air, outdoor air, and mixed air temperatures rarely agreed with the results of the first method (see Table B-4). This method was discarded as inaccurate, presumably because of significant temperature gradients within the mixed air plenums which inhibit accurate temperature readings.

To estimate average outdoor air infiltration and ventilation rates with different damper configurations, frequency distributions were performed using the fan flow rate data from Table B-4. Figure 3-5 graphically shows the frequency distributions of different amounts of infiltration and ventilation air when the outdoor air dampers were closed and when the delayed vents (minimum outdoor air vents) were open. Enthalpy damper data was disregarded since in this case the amount of outdoor air is not exclusively a function of the supply and return air fan flow rates. Frequency distribution data is listed in Table B-5.

Theoretically, when the dampers are closed the differential between the supply and return fans is zero. However, as Figure 3-5 shows, non-zero differentials were usually observed, some as high as +35,000 and as low as -35,000 cfm when the dampers were closed. When the delayed vents were opened, differentials would tend to be in the +10,000 to -8,000 cfm range, which is closer to the desirable range. These fan tracking control problems are discussed further in Chapter V.

Since the net effect on the building of negative and positive differentials between supply and return fan flow rates is the same, the negative values were made positive, and new frequency distributions were performed. Figure 3-6 shows these positive frequency distributions (data is listed in Table B-6). With all differentials made positive, the average infiltration value with the outdoor air dampers closed was 9,500 cfm, and with the delayed vents open the average ventilation value was 5,500 cfm. These values were used in the computer model to estimate heating and cooling loads due to outdoor air ventilation and infiltration with their respective damper configurations, using the equation:

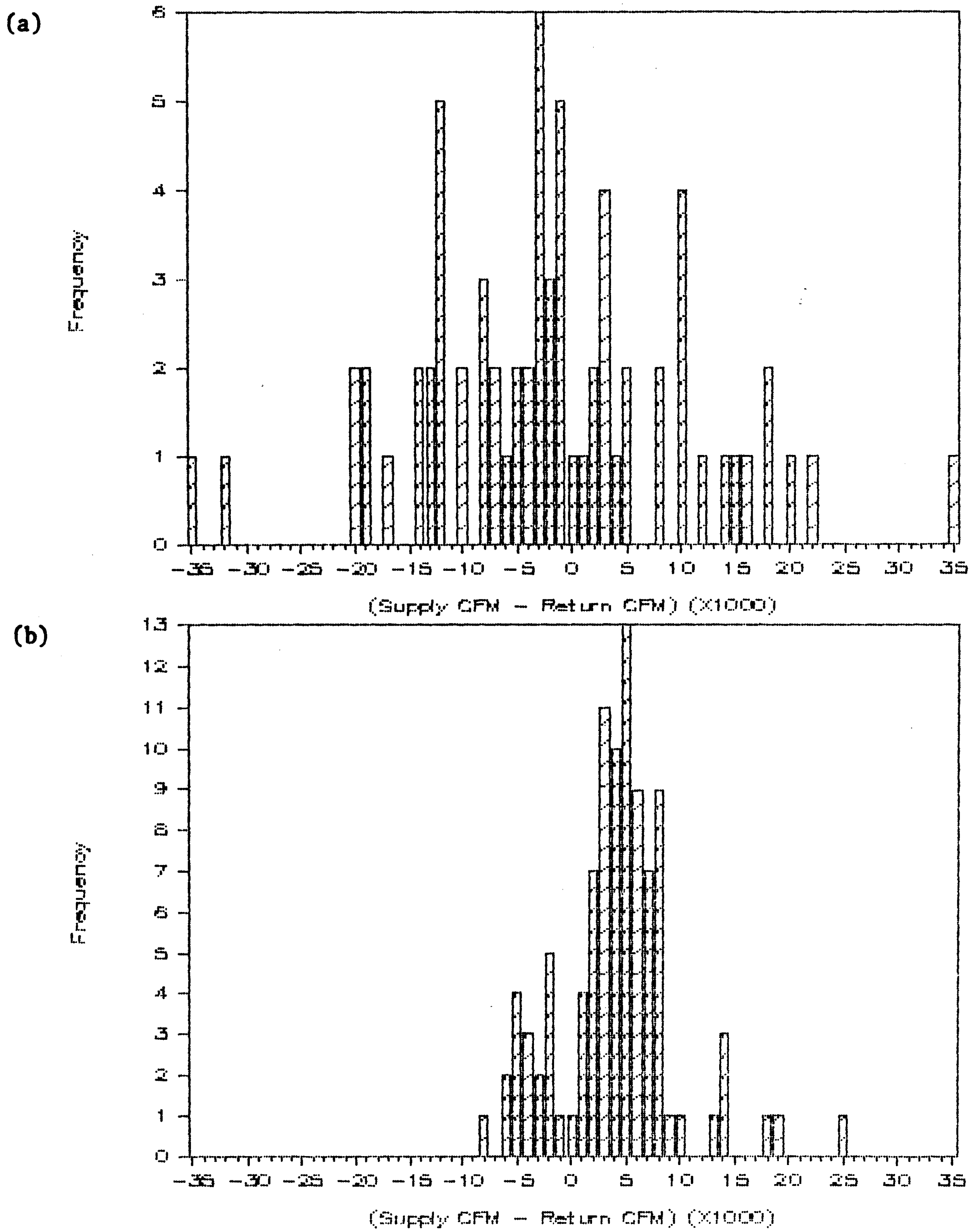
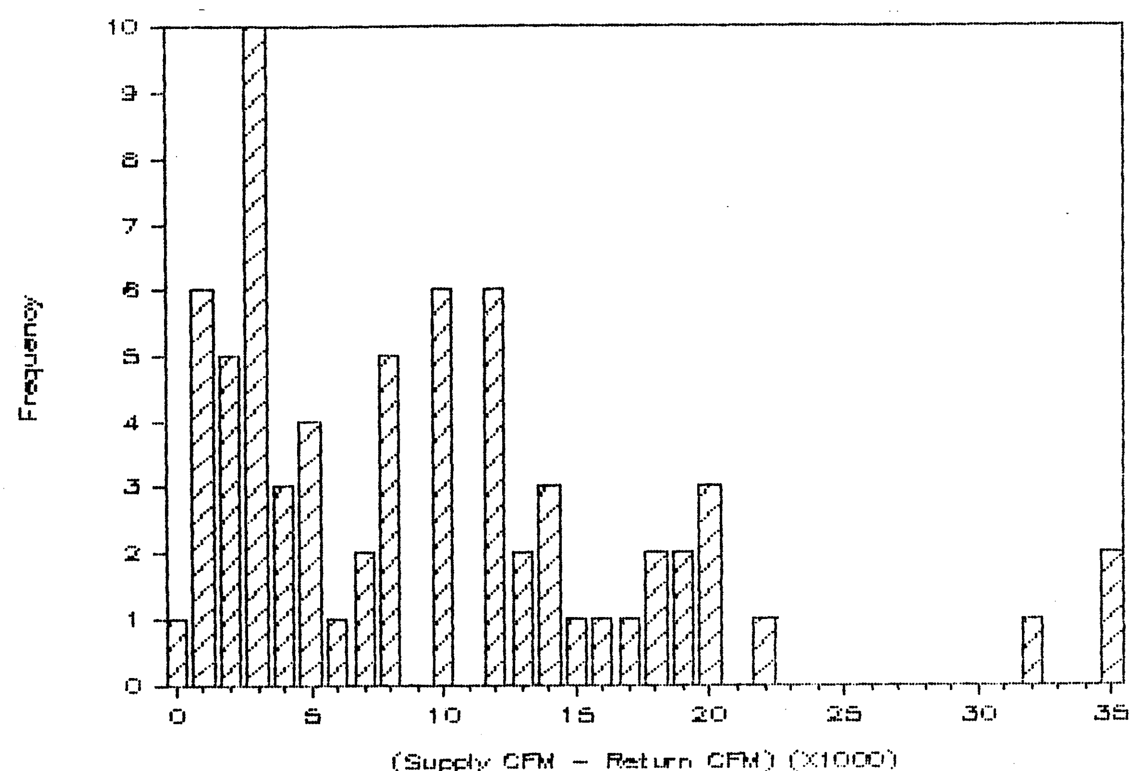


Figure 3-5: Monitored Air Handler Fan Tracking Distribution
(a) Dampers Closed (b) Delayed Vents Open

(a)



(b)

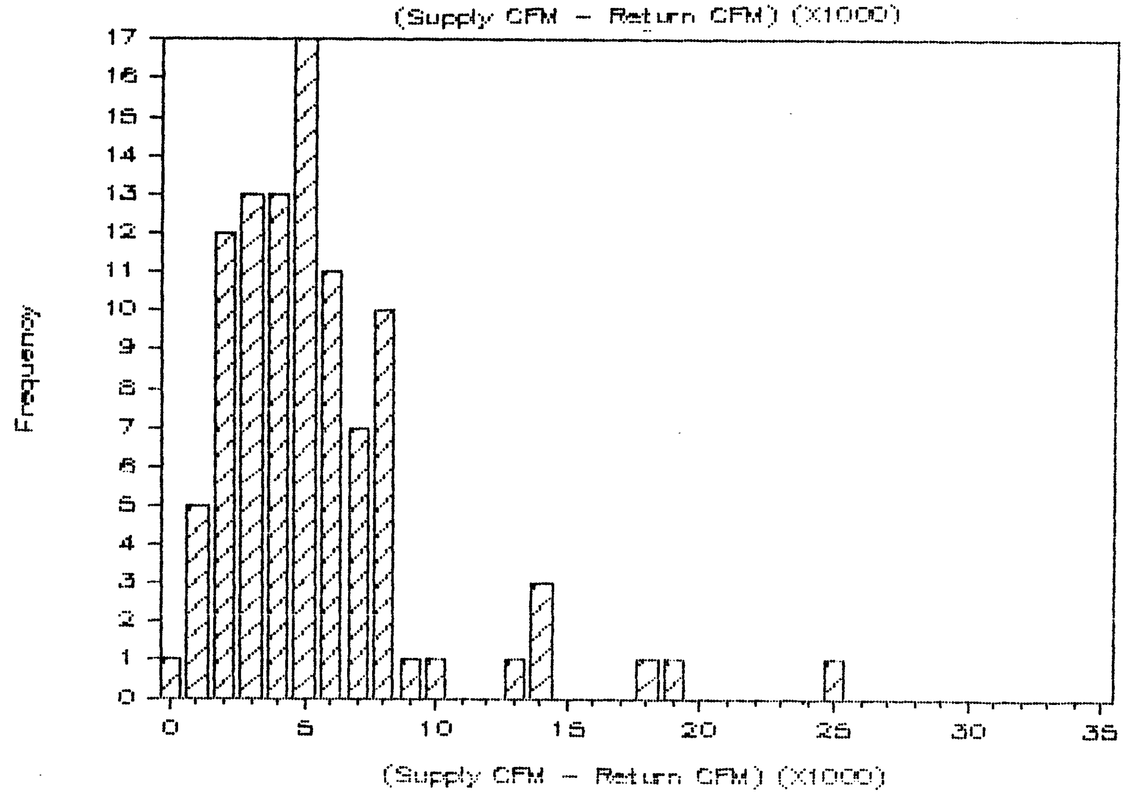


Figure 3-6: Monitored Air Handler Fan Tracking Distribution - All Positive (a) Dampers Closed (b) Delayed Vents Open

$$q_{oat} = \text{Outdoor air CFM} \cdot 4.5 \cdot (h_{oa} - h_{ra}) \quad (3\text{-}2)$$

where:

q_{oat} = Total (sensible and latent) cooling or heating effect
h_{oa} = Outdoor air enthalpy (degF)
h_{ra} = Return air enthalpy (degF)

(Source: ASHRAE Handbook of Fundamentals, pg. 26.3)
See Appendix B for equations used to calculate air enthalpies from drybulb and dewpoint temperatures.

Amount of Outdoor Air When Enthalpy Dampers Are Open. As described in Chapter I, the Transportation Building air handlers have an economizer option which is enabled by commanding the enthalpy dampers open. Under enthalpy control, if the outdoor air enthalpy is less than the return air enthalpy and if the outdoor air temperature is greater than or equal to the cooling coil setpoint, the exhaust, return, and outdoor air dampers will modulate to provide 100 percent outdoor air. If the outdoor air temperature is less than the cooling coil setpoint, then the dampers will modulate to maintain the setpoint, mixing outdoor air with return air.

This was modelled by an if...and...else statement: if the enthalpy dampers are commanded open and the exterior air temperature is less than the cooling coil setpoint temperature, then the amount of sensible outdoor cooling, q_{oat}, is proportional to the amount of outdoor air necessary to make the mixed air temperature equal to the cooling coil setpoint temperature. In this case the outdoor air flow rate was derived from an energy balance, resulting in the equation:

Outdoor air CFM=$(T_{cs} - T_{ra})/(T_{oa} - T_{ra}) \cdot$Supply Fan cfm (3-3)

where:

T_{cs} = cooling coil temperature setpoint

T_{ra} = return air temperature

T_{oa} = outdoor air temperature

Otherwise, 100 percent outdoor air is assumed in the model when enthalpy dampers are open, with the first term in equation (3-2) equal to the supply fan flow rate.

Fan Electric Loads. The fan power is calculated with the fan law equation where the fan power is proportional to the cube of the fan flow rate. Measured fan flow rates and electric use from the balancer report were used to calculate fan power for variable flow rates using the equation:

$$P_2 = P_1 \cdot (CFM_2/CFM_1)^3 \qquad (3\text{-}4)$$

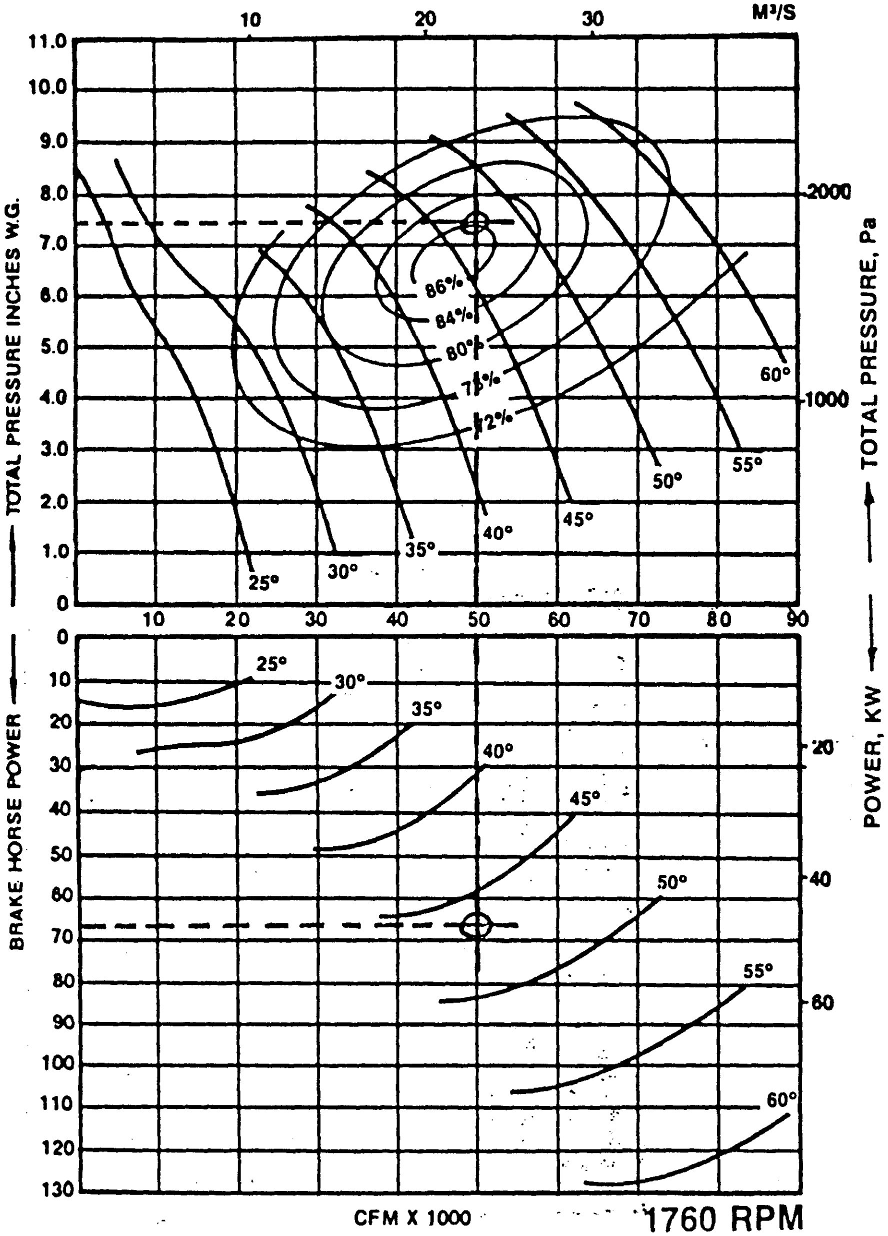
where:

P = fan electric power (kW)

CFM = fan flow rate

(Source: McQuiston and Parker, HVAC: Analysis and Design, p. 373)

Balancer report power demands and their associated flow rates are listed in Table A-10. Figure 3-7 shows the fan curves for the AC-1, 2, and 3 supply and return fans, which vary depending upon fan blade pitch.



(Source: Flackt Manufacturer's Documents)

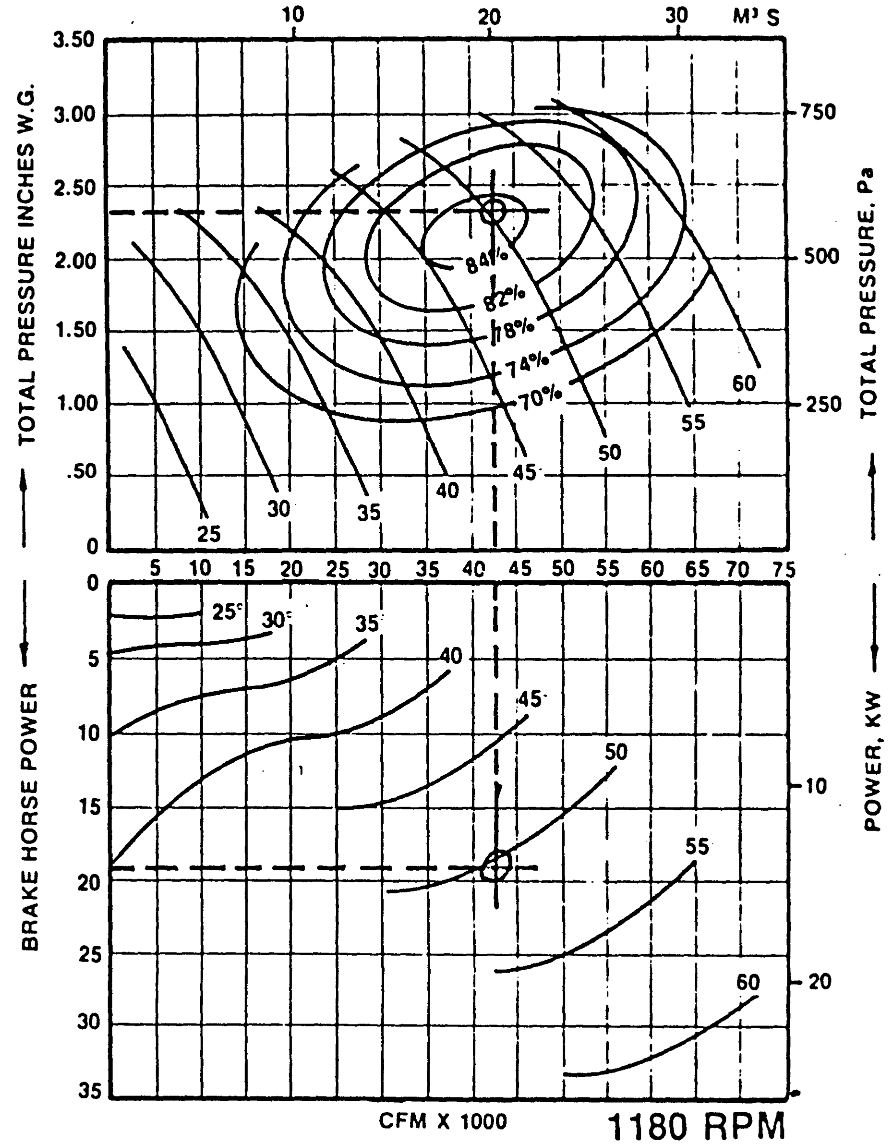


Figure 3-7: Air Handler Supply and Return Fan Curves

Modeling of Heat Pump Performance

As the major source of heating and cooling in the Transporation Building, the heat pumps are the most important part of the energy system. They are also the most difficult part of the energy system to model because of the many variables which effect their performance.

The heat pumps are designed to maintain chilled water-discharge temperatures under fully loaded conditions for particular design flow rates and condenser water or hot water supply temperatures. The manufacturer's fully-loaded design parameters for the Transportation Building heat pumps are:

RU-1 and RU-2:

Cooling capacity: 300 tons (cooling), COP: 4.10
288 tons (heat recovery), COP: 3.92
Heating capacity: 4350 MBH, COP: 4.94
(heat recovery)
Compressor electric loads: 257 kW, .857 kW/ton (cooling)
258 kW, .896 kW/ton (heat recovery)

Water circuit	Flow rate(gpm)	EWT(degF)	LWT(degF)
evaporator	900	48	40
condenser	864	85	95
heat recovery condenser	435	85	105

RU-3:

Cooling capacity: 600 tons (cooling), COP: 5.07
597 tons (heat recovery), COP: 4.88
Heating capacity: 8640 MBH, COP: 5.89
(heat recovery)
Compressor electric loads: 416 kW, .694 kW/ton (cooling)
430 kW, .720 kW/ton (heat recovery)

Water circuit	Flow rate(gpm)	EWT(degF)	LWT(degF)
evaporator	1800	56	48
condenser	1728	85	95
heat recovery condenser	864	85	105

(Source: Manufacturer's Data, the Trane Co.)

Note that the hot water (heat recovery) design flow rates are incompatible with the hot water pump design flow rate of 1240 gpm.

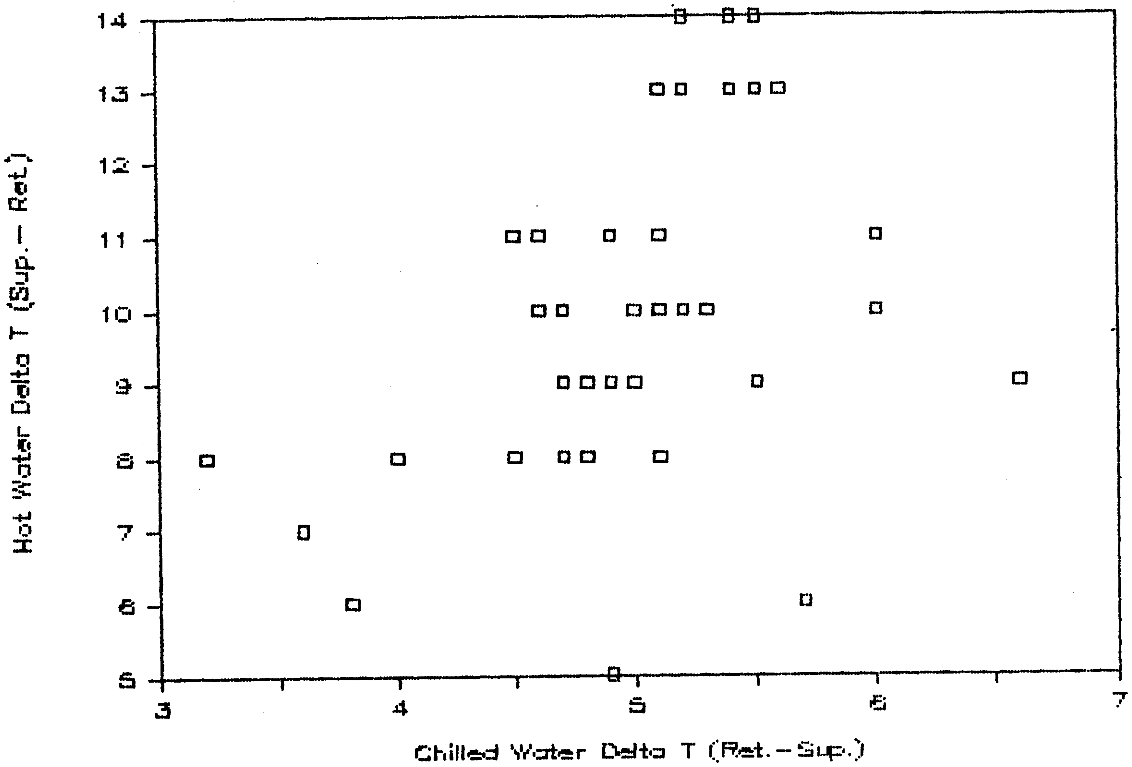
Heat Pump Thermal Performance. To help assess the actual performance of the heat pumps, monitoring of temperature and electric load data for RU-1, 2, and 3 was done over weekly periods under spring, summer, and winter operating conditions. When the spring and summer data was collected, manual temperature readings were taken because the Delta 1000 temperature records were considered inaccurate. For the winter monitoring, Delta 1000 temperature records were used. In all cases, recording ammeters were used to monitor heat pump compressor electric consumption.

The collected data is summarized in Table B-7, with associated calculations of heating and cooling effects, coefficients of performance, kW/ton, percent full load tons and percent full load kW capacities. Equations for calculated values are listed at the bottom of the table. A discussion of the results of the heat pump monitoring is included in Appendix B.

Figures 3-8 through 3-10 graphically illustrate the range of actual heat pump operating points that were monitored. It was found that the actual heat pump performance will significantly vary from the design parameters with different water flow rates and chilled water, hot water, and condenser water supply temperatures. All of these parameters will vary depending upon the modes of operation, control system setpoints, demand limiter setting, the heating and cooling requirements of the building, the state of the storage system, and manual valve adjustments of the water circuits.

Because of the difficulty of accurately simulating actual heat pump thermal performance, inlet and outlet temperatures and their corresponding heating and cooling loads from the monitored data were used in the model.

(a)



(b)

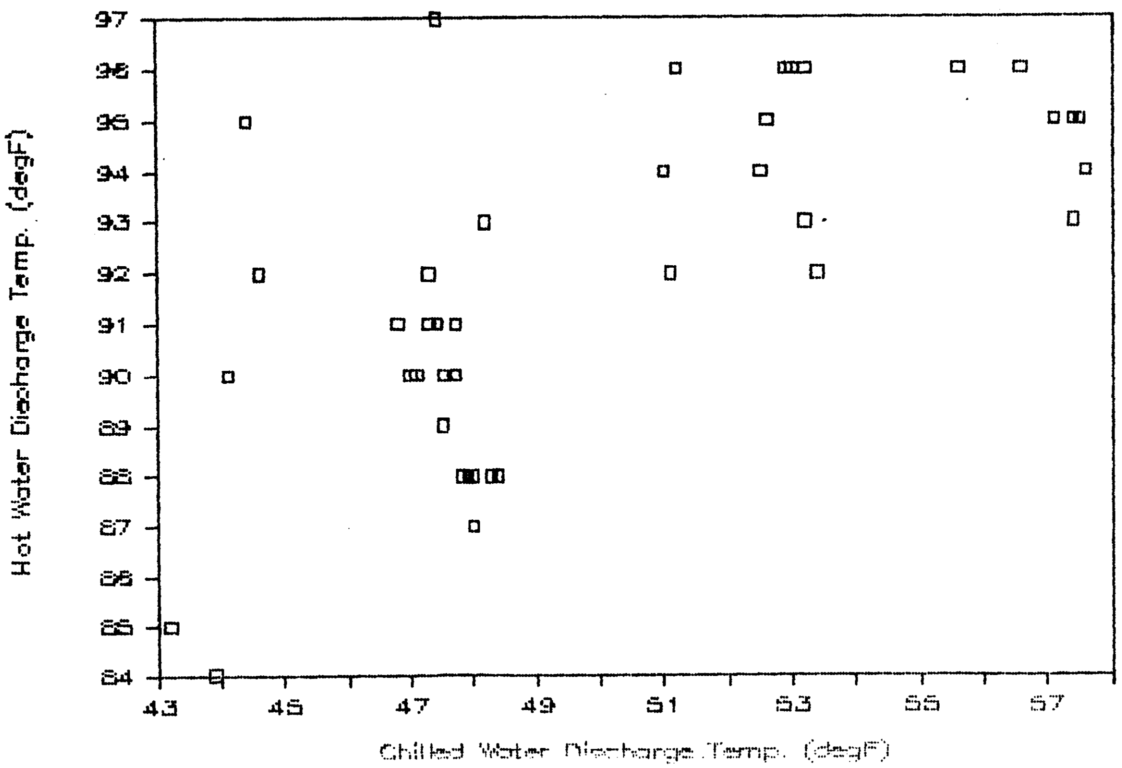


Figure 3-8: Monitored Heat Pump Performance
(a) Hot Water Return vs. Chilled Water Delta T
(b) Hot Water Discharge vs. Chilled Water Discharge

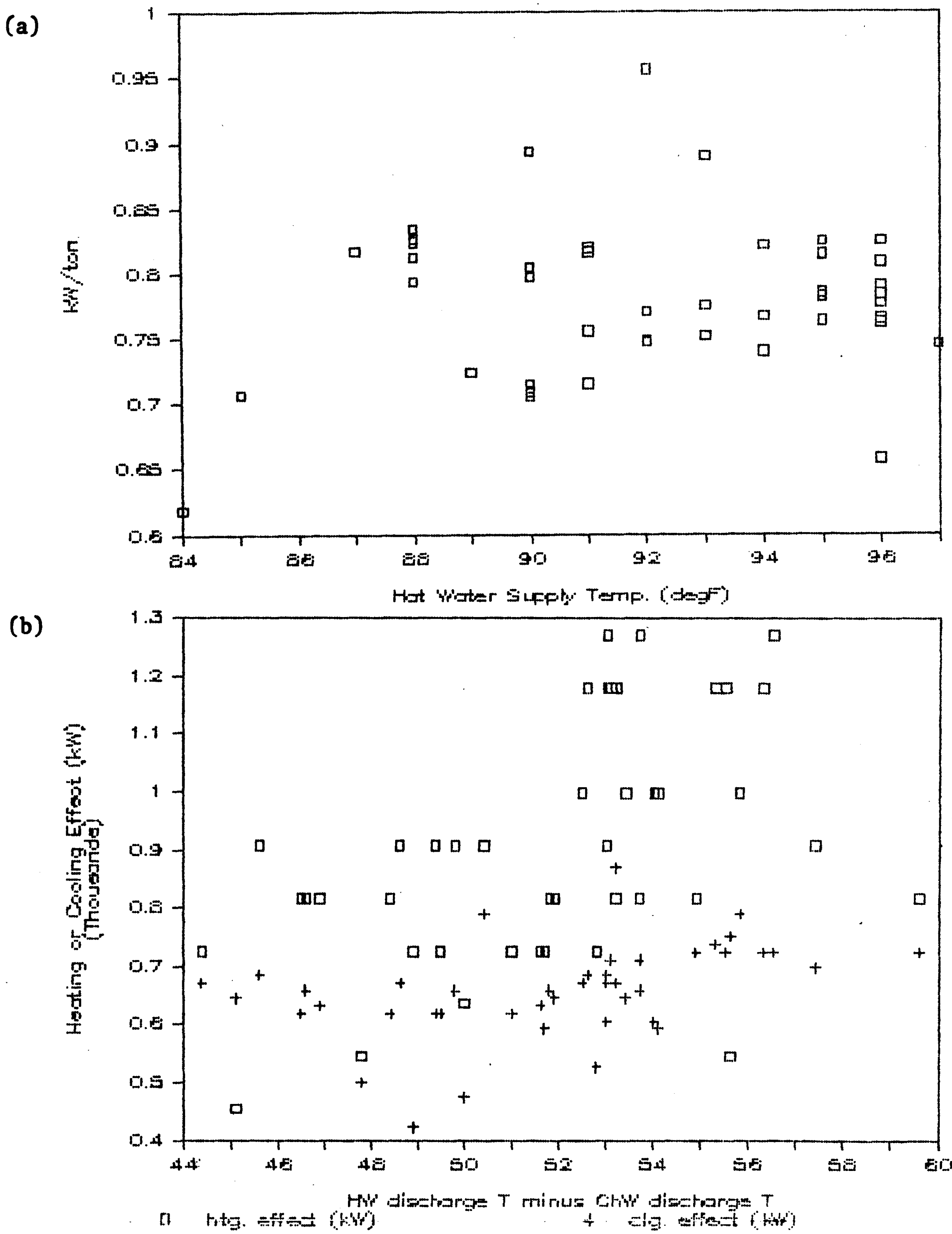


Figure 3-9: Monitored Heat Pump Performance
(a) kW/ton vs. Hot Water Supply Temperature
(b) Heating and Cooling Effects vs. (HW - ChW Discharge Temps)

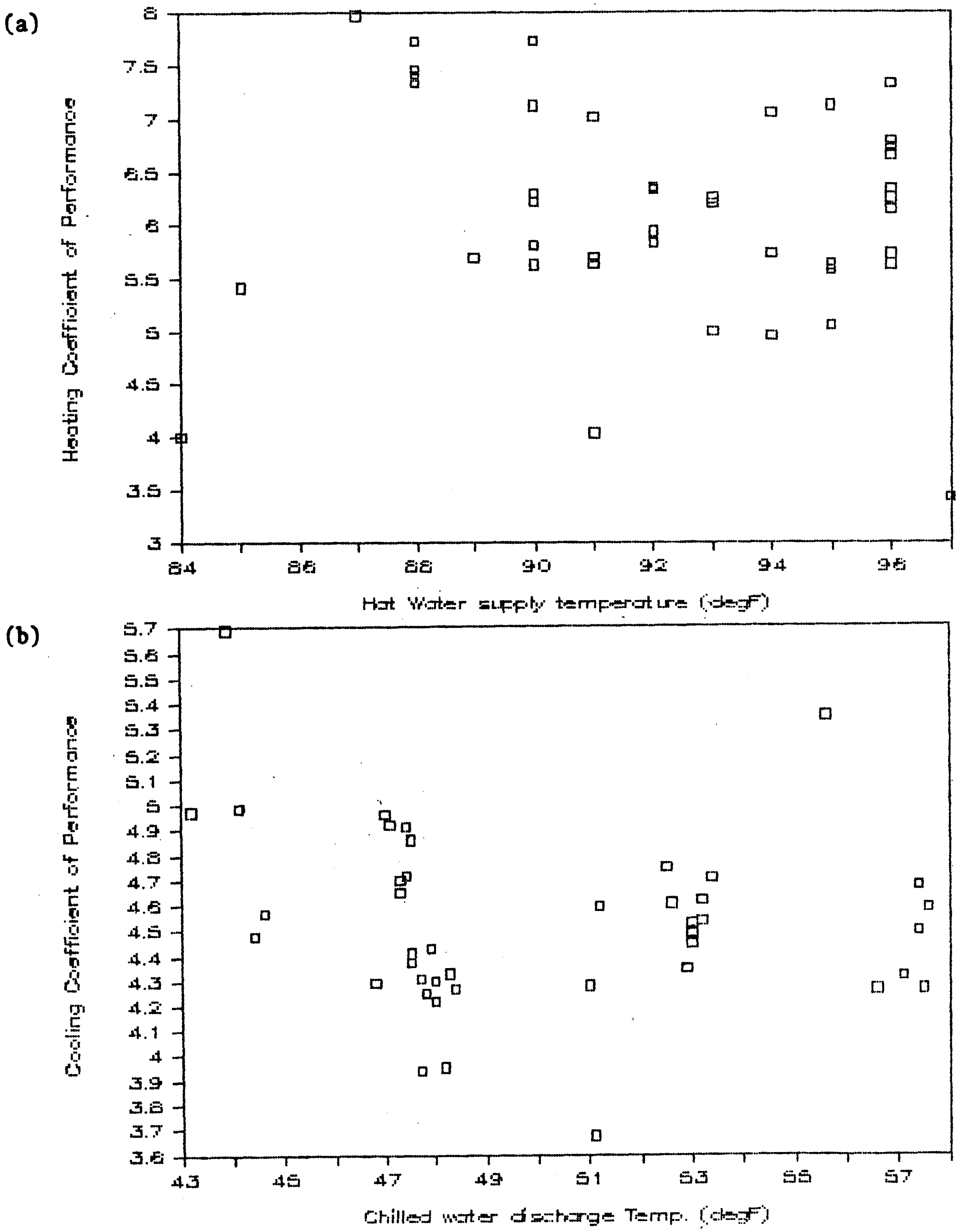


Figure 3-10: Monitored Heat Pump Performance
(a) Heating COP vs. Hot Water Supply Temperature
(b) Cooling COP vs. Chilled Water Discharge Temperature

Net and gross coefficients of performance were calculated in the model for different operations using the equations:

$$COP_{net} = q/L_c \tag{3-5}$$

$$COP_{gross} = q/(L_c + L_{aux}) \tag{3-6}$$

where:

q = heating effect or cooling effect, depending respectively upon if a heating operation or an exclusively cooling operation

L_c= compressor electric use (kW)

L_{aux}= auxiliary electric use of pumps and fans to distribute heating and cooling

(Source: Cube and Steimle, Heat Pump Technology, p. 26)

The COP_{net} values can be used as a basis for comparing heat pump performance under different operating conditions. The COP_{gross} values can be used as a basis for comparison of different operating strategies.

Heat Pump Electric Use. Manufacturer's part-load performance data was obtained relating percent full-load kW (part-load vs. full-load compressor electric use), percent full-load tons (part-load vs. full-load cooling), and entering condenser and hot water temperatures (see Figure B-1). It was found that the manufacturer's curves could be numerically fitted to an exponential equation:

$$\%\ FLkW=(0.185408 \cdot T_{hws}-1.7440018) \cdot e^{0.02(\%FLtons)} \tag{3-7}$$

where:

% FLkW = percent full-load kW electric use
T_{hws} = hot water or condenser water supply temperature (degF)
% FLtons = percent full-load tons cooling

To test how well the manufacturer's data compared to actual heat pump performance data, equation (3-7) was used to calculate percent full-load kW values from operating data. When compared with the actual percent full-load kW data as calculated from ammeter readings, a fairly good correlation occurred, as is illustrated in Figure 3-11b.

Based upon these results, it was decided that equation 3-7 would provide a sufficiently accurate estimate of compressor electric consumption for the computer model.

Modeling of the Cooling Towers

The two cooling tower fans are controlled by a thermostat which senses the condenser water supply temperature and sequences the fans to maintain an 85 degF setpoint. If the condenser water temperature reaches 88 degF the second cooling tower fan will sequence on. This control logic was used in the model to predict cooling tower power use from condenser water supply temperatures, assuming the cooling tower fan electric loads listed in Table A-8. Cooling tower inlet and outlet temperatures are assumed equal to heat pump condenser water outlet and inlet temperatures respectively.

Modeling of Storage Tanks and Tank Heat Exchanger Performance

In the model the heat input and output from the three 230,000 gallon storage tanks is calculated using equation (3-1) where the temperatures of the water entering and leaving the storage tanks is

(a)

(b)

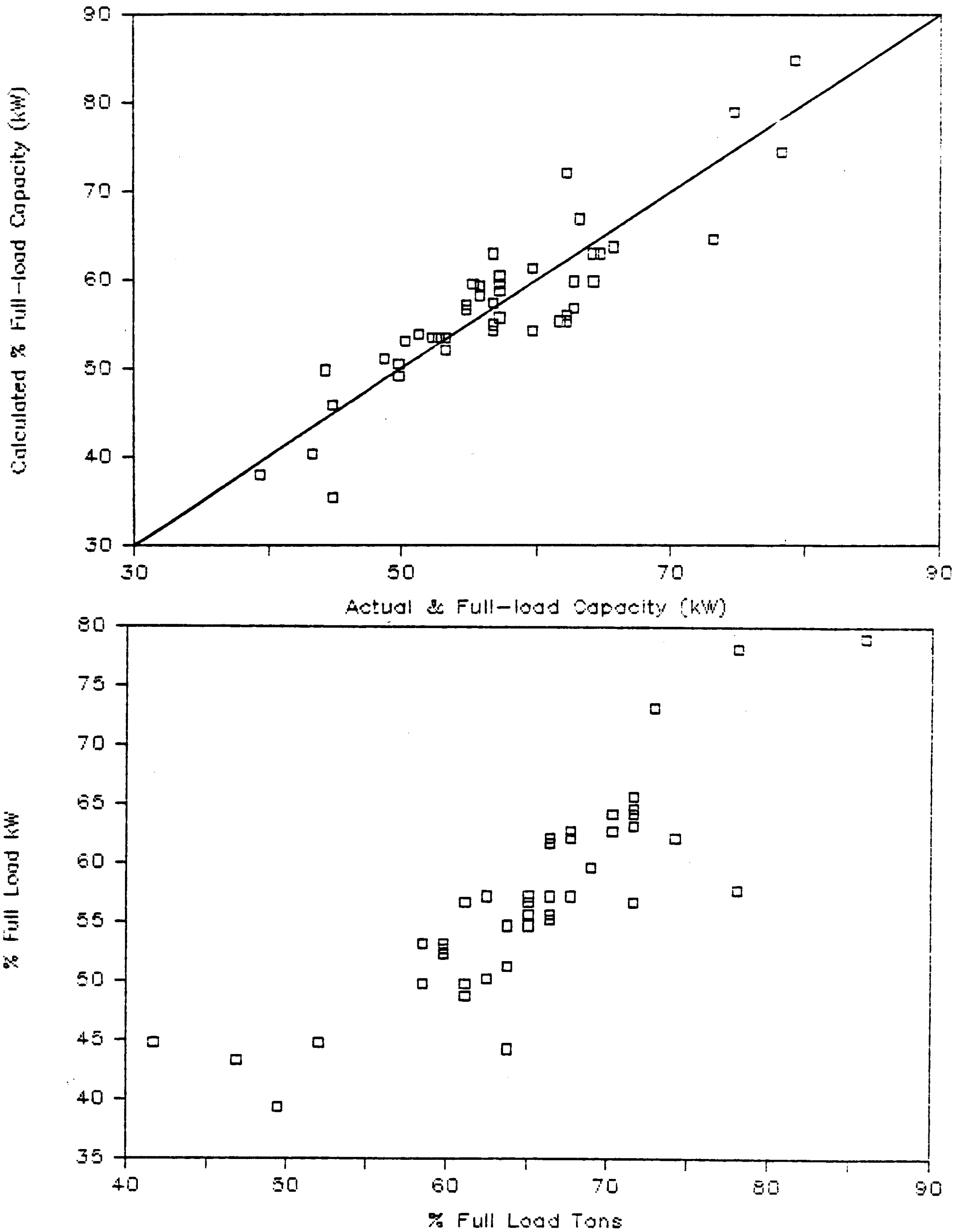


Figure 3-11: Monitored Heat Pump Performance
(a) % Full Load kW vs. % Full Load Tons
(b) Calculated vs. Actual % Full Load Capacity Data

used, and flow rates of 420 or 645 gpm are assumed, depending upon whether the pump valves are adjusted to their summer or winter positions (see Table A-9). Storage tank input and output temperatures can be taken from actual operating data, or can be calculated based upon heat exchanger tank side and system side flow rates and temperatures. Tank heat losses are assumed negligible (see Appendix B).

It is assumed that the designers were successful in mixing the tank water, and therefore tank temperatures are considered uniform when the tank pumps are operating. Changes in tank temperature were calculated using the equation:

$$T_{t2} = T_{t1} + (\dot{m} \cdot c_p \, (T_{in} - T_{t1}) \cdot \text{delta } t)/M \cdot C_p \qquad (3\text{-}8)$$

Where:

T_{t2} = Tank temperature at hour 2 (degF)
T_{t1} = Tank temperature at hour 1 (degF)
$\dot{m}$ = flow rate of water into and out of tank (lbm/hr)
c_p = specific heat of water (1 Btu/lbm·degF)
T_{in} = Temperature of water going from heat exchanger into tank (degF)
delta t = time interval (1 hour)
$M \cdot C_p$ = Thermal capacity of water stored in tank (1,888,392 Btu/degF)

The storage tank heat exchanger performance can be described by equations (3-9) through (3-11):

$$q = C_{tank} \, (T_{tout} - T_{tin}) = C_{system} \, (T_{sout} - T_{sin}) \qquad (3\text{-}9)$$

$$q = E \, C_{min} (T_{h,i} - T_{c,i}) \qquad (3\text{-}10)$$

$$E = (1 - \exp(-NTU(1-C)))/(1 - C \cdot \exp(-NTU(1-C))) \qquad (3\text{-}11)$$

where:

q = heat exchanger heat transfer rate

$C_{tank} = m_{tank} \cdot c_p$

T_{tout} = temperature of water leaving storage tank

T_{tin} = temperature of water entering storage tank

$C_{system} = m_{system} \cdot c_p$

T_{sin} = temperature of water entering heat exchanger on system side

T_{sout} = temperature of water leaving heat exchanger on system side

E = heat exchanger effectiveness

C_{min} = lesser of C_{tank} and C_{system}

$T_{h,i}$ = hotter fluid temperature entering heat exchanger

$T_{c,i}$ = colder fluid temperature entering ehat exchanger

NTU = (heat exchanger UA)/C_{min}

$C = C_{min}/C_{max}$

(Source: Incropera & DeWitt, Fundamentals of Heat Transfer, pp. 522-25)

In practice the flow rates on the system side of the heat exchanger will modulate under part chilled water mode, peak chilled water mode, and reduced heating mode control, depending upon the amount of hot or chilled water required for building space heating and cooling. The Delta 1000 does not record these flow rates or the water temperatures entering and leaving the heat exchangers on the system side. In analyses where different tank management strategies were compared, T_{sin} was assumed equal to the heat pump chilled water or hot water discharge temperature, and system hot water and chilled water flow rates were assumed for different heating and cooling load scenarios.

When full system side flow rates are assumed, the manufacturer's heat exchanger effectiveness values are used. These values are 0.84 for the cooling flow rate of 640 gpm, and 0.85 for the heating flow rate of 420 gpm.

Simple Validation of Computer Model

To check the validity of the computer model, an attachment to the computer model was created that uses monitored data to perform a simplified energy balance on building levels 2 through 8 (the areas served by AC-1, 2, and 3) including conductive heat loss/gain, ventilation, internal gains, and mechanical heating and cooling. Another attachment to the computer model checks the validity of the modeled fan air flow rates, by comparing cooling loads calculated using modeled fan air flow rates with the monitored cooling loads.

It is acknowledged that in both analyses many factors are disregarded which could effect both actual and calculated heating and cooling loads. The purpose of the analysis is not to find a perfect fit, but rather to compare the relative orders of magnitude of the monitored and modeled quantities.

Energy Balance on Building

A building energy balance was performed using the equation:

Mechanical heating + internal gains + conductive heat loss/gain + ventilation heat loss/gain + mechanical cooling = 0 (3-12)

Note that solar gains, building thermal capacitance, and convective (wind) effects are disregarded. Solar gains were found to be of a relatively small magnitude with respect to internal gains. Building thermal capacitance is a potentially large factor, but in practice the building temperatures are rarely allowed to vary more than a few degrees from the typical occupied conditions.

Mechanical heating, mechanical cooling, and ventilation heat loss/gain were taken from computer model output using Delta 1000 operation data. An overall UA value for levels 2 through 8 was used (45,740.33 Btu/(degF·hr)) for calculating conductive heat loss/gain using outdoor and average indoor temperatures. Average occupied internal gains due to lights, people, and appliances was estimated to be 4,979,000 Btu/hr during occupied hours. This quantity was multiplied times standard ASHRAE correction factors to account for variations in time of day. See Appendix B for detailed documentation of UA and internal gain calculations, and other equations used.

Actual Cooling Loads vs. Modeled Air Flow Rates

To examine whether or not the empirical fan flow rate estimates make sense in relation to the monitored cooling loads supplied to the building, cooling loads were calculated with the empirical fan flow rates and compared to the monitored cooling loads.

This analysis assumes that air is leaving the air handlers at the coil setpoint temperatures, which may not always be the case if the chilled water delivered to the air handlers is insufficient to meet the cooling coil setpoints. Chilled water coil setpoints are usually assumed to be 55 degF for both interior and exterior coils in the cooling season, and are usually assumed to be 55 degF for the interior coils and 65 degF for the exterior coils in the heating season. Coil setpoints are manually adjusted and read at the air handlers periodically, and may be adjusted up or down under certain building conditions. These assumed temperatures are probably in the right ballpark, but could be off by as much as 5 degF.

A portion of the chilled water in the system is delivered to AC-4, but this quantity is assumed negligible.

Empirical fan flow rates were calculated with the equations:

$$q_{cooling}(emp.)=4.5 \cdot CFM_{supply} \cdot (h_{mixed}-h_{supply}) \qquad (3\text{-}13)$$

Separate calculations were performed for interior and exterior fans to allow for different cooling coil setpoints. H_{mixed} was calculated using the equation:

$$h_{mixed} = ((h_{out} \cdot \dot{m}_{out})+h_{ret}(\dot{m}_{sup} - \dot{m}_{out}))/\dot{m}_{sup} \qquad (3\text{-}14)$$

where:
h = air enthalpy (Btu/lb dry air)

Enthalpy values for outdoor and return air are obtained from dry bulb and dew point temperature readings (see Appendix B for equations). H_{sup} is obtained by assuming that the supply air humidity ratio would be the same as for the mixed air, but the supply air dry bulb temperature would be the coil setpoint temperature. Using equation (3-13), $Q_{cooling}$(emp.) can then be compared to monitored $Q_{cooling}$ values obtained from the computer model's heatpump and storage tank data. See Table B-2 (pg. 3 of 3) for detailed documentation of equations used.

$Q_{heating}$ cannot be similarly calculated empirically using fan air flow rates because $Q_{heating}$ as delivered by the heat pumps is distributed to VAV boxes throughout the building that will be using various amounts of hot water and air depending upon each particular zone's heating requirements. Also, during the heating season steam is injected into the supply air stream for humidification, which furthur complicates any attempts at a heat and mass balance.

See Figure 3-15 for a sample listing of the energy balance and air handler cooling (CFM Study) calculations.

The Results

Monitored data for a range of weather conditions was analyzed to examine the results of the energy balance and the comparison between actual and calculated air handler cooling coil cooling loads.

When the energy balance is positive, it indicates that more heating was being added to the building than cooling. When the energy balance is negative, it indicates that more cooling was being added to the building than heating. Figure 3-12 (a) graphs the energy balance results from the monitored week of August 12-17. The graph shows that during occupied hours (the shaded area), the energy balance was negative, typically about -3.0 mmBtu/hr. This negative energy balance is probably due to a combination of the solar load and building mass, neither of which are accounted for in the balance.

Note that during unoccupied hours, there is also frequently a negative energy balance while cooling the thermal storage system when the building is being used to increase the load on the heat pumps (see the Summer operation section of Chapter IV).. With average occupied hour cooling loads which are typically 8.0 or 9.0 mmBtu/hr (see Figure 4-16), the order of magnitude of the energy balance from the computer model is reasonable.

Figure 3-12 (b) graphs the result of the comparison between actual and calculated fan flow rates during the August 14-16 period. During occupied hours (shaded area), there is a good correlation, typically within twenty percent, between the actual cooling supplied and the calculated cooling supplied at the air handlers, indicating that the assumed fan flow rates are fairly accurate. However during unoccupied hours, the actual cooling at the air handlers was 60-90 percent more than the calculated values based upon fan flow rates.

Typically when cooling the storage system at night, floor dampers are opened to minimize cooling to the building. In the model when floor dampers are closed, it is assumed that all are closed except for the few areas that are occupied. Obviously considerably more dampers were

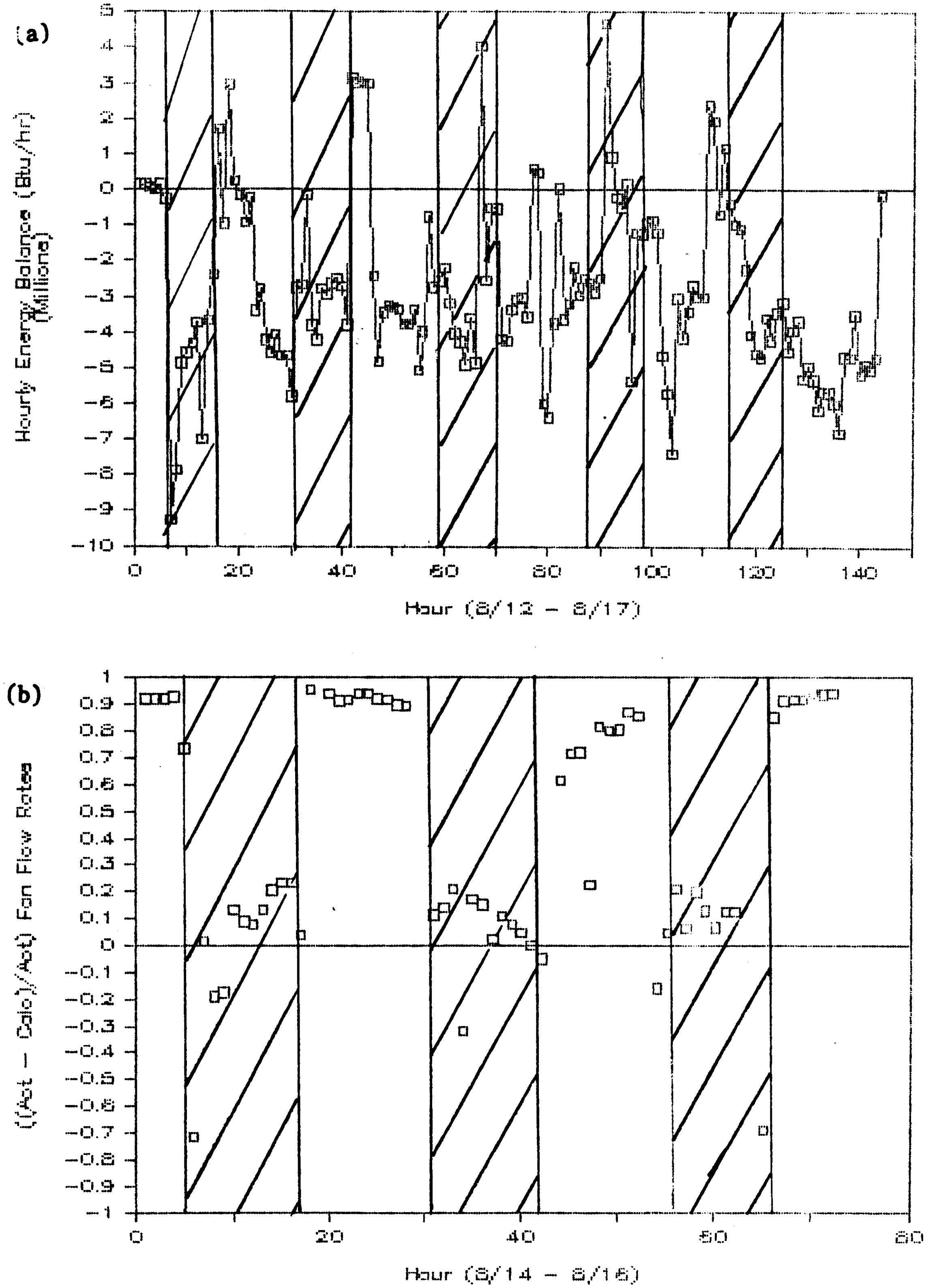


Figure 3-12: Validation of Computer Modeling - August Data
(a): Energy Balance (b): Cfm Study

opened during the August 14 - 16 time period than was assumed by the model.

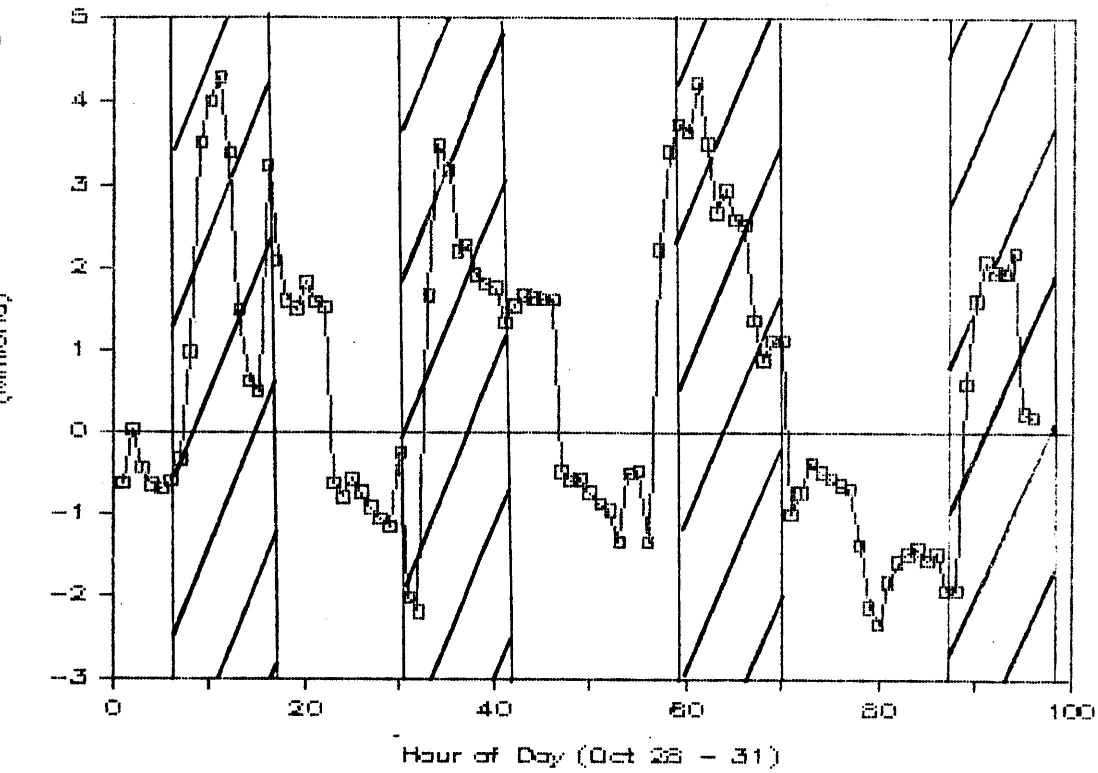
These results indicate that during the summer, the model does provide an order of magnitude estimate of building heating and cooling loads and a good fan flow rate correlation.

In Figure 3-12 (c), the results of the building energy balance from October 28-31 are graphed. Note that during occupied hours (the shaded area), energy balances are positive and usually about 1.0 or 2.0 mmBtu/hr. During unoccupied periods, energy balances are typically about -1.0 mmBtu/hr. These results imply that during unoccupied periods, excess heat is needed in the spaces to warm it, especially during the first hours of occupancy.

Figure 4-19 graphs the AC-1, 2, and 3 space temperatures over the same time period, indicating a corresponding rise in space temperatures during occupied hours. The fact that the order of magnitude of the balance is usually relatively low indicates an equilibrium between the modeled heating and cooling sources.

Figure 3-12 (d) graphs the percent difference between the actual and calculated cooling supply at the air handlers from October 28-30. Only occupied hours calculations were available since the fans were run only during these periods. No calculations were available for the 31st because no mechanicial cooling, only free cooling was used during that day. The figures show a good correspondence between the actual and calculated air handler cooling values except for a four hour period on the 28th. During this time, the enthalpy dampers were open. The model calculated that no mechanical cooling would be needed since outdoor temperatures were in the low fifties. But some mechanical cooling was provided, perhaps as a result of the relatively high humidity (55 percent).

(c)



(d)

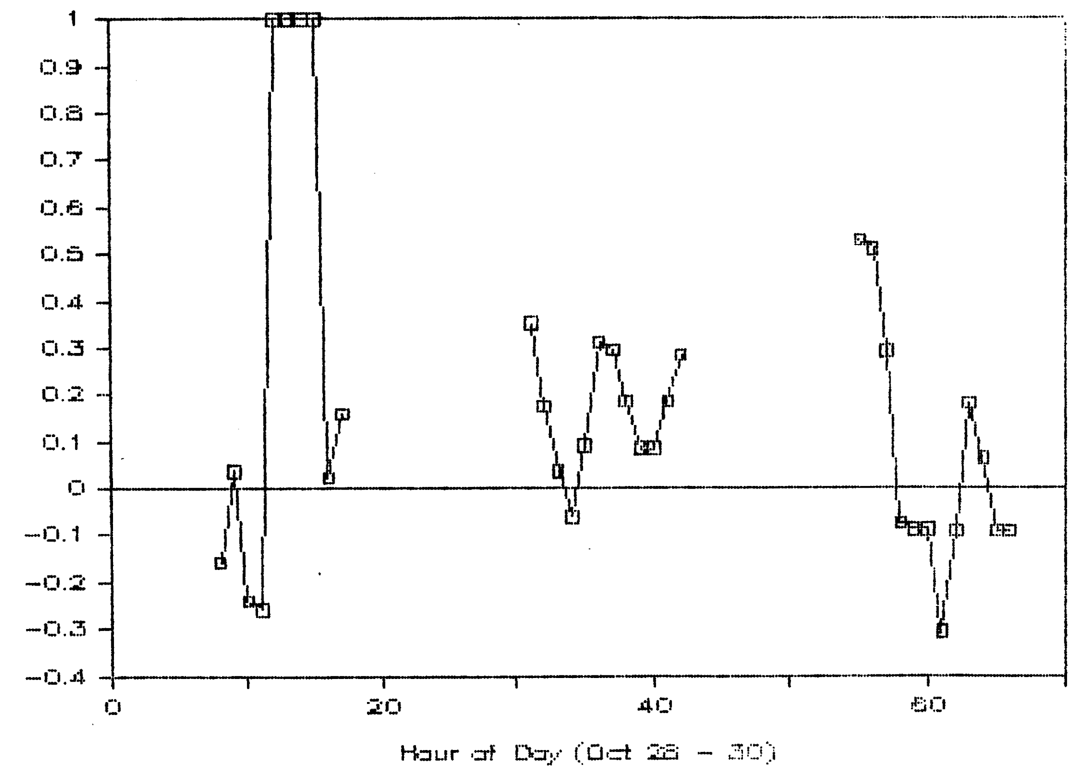


Figure 3-12: Validation of Computer Modeling - October Data
(c): Energy Balance (d): Cfm Study

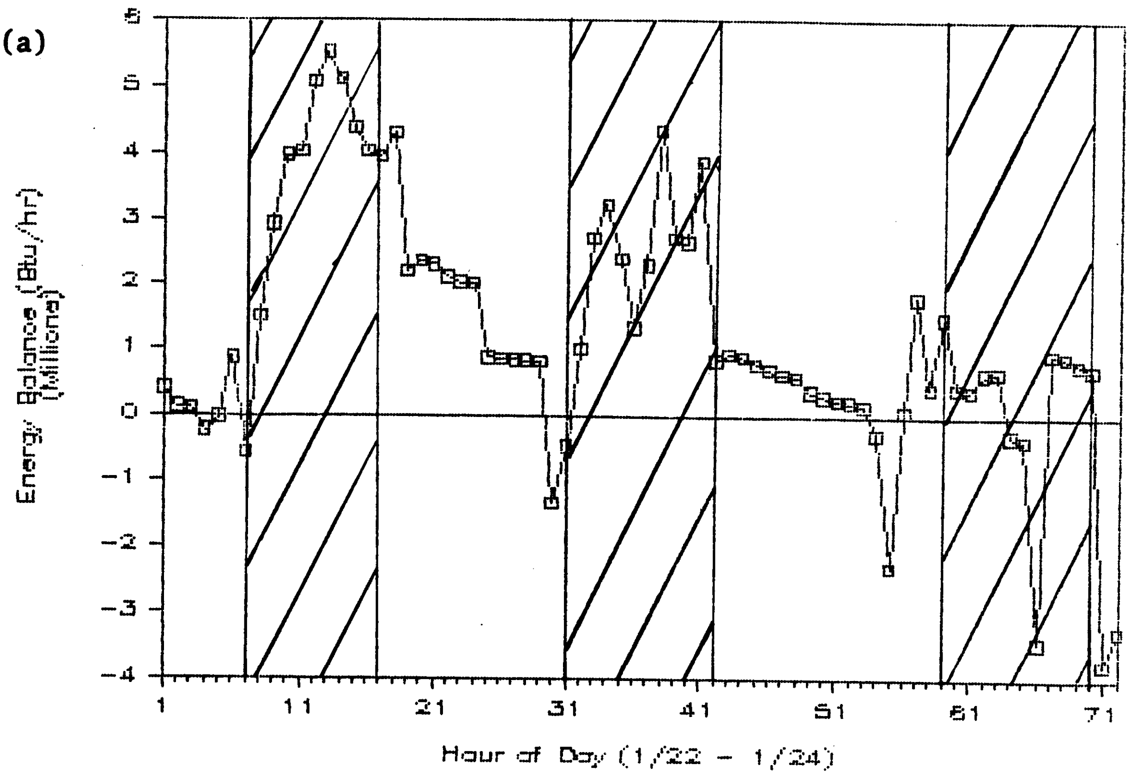
Figure 3-13 graphs the computer model energy balance and cfm study data for January 22-24. Similar to the October data, the energy balance during occupied periods (shaded) was positive.

During unoccupied periods, the balance was closer to zero as the building cooled down. Unoccupied hours energy balances were still positive, however, due to the fact that building lights were on for 24 hours for heating purposes.

Similar to the October data, cfm study data was only available for occupied hours since mechanical cooling was not provided during unoccupied hours. Figure 3-13 (b) shows a fairly good correspondence between actual and calculated air handler cooling quantities, usually within plus or minus 40 percent.

Generally, though the calculated and monitored quantities didn't match perfectly in any of the cases, it is reasonable to say that the model does generally provide an accurate order-of-magnitude estimate of heating and cooling loads and fan air flow rates.

(a)



(b)

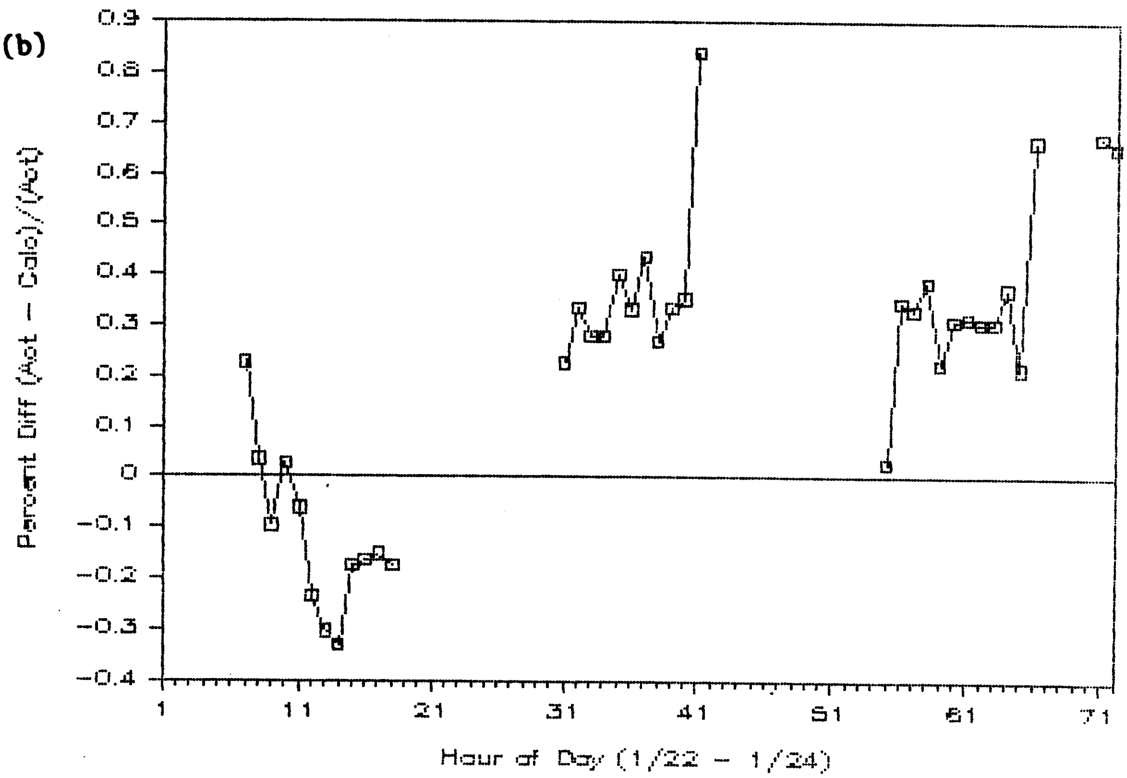


Figure 3-13: Validation of Computer Modeling - January Data
(a): Energy Balance (b): Cfm Study

Description of Daily Energy System Summary

Due to the unwieldy size of the inputs and outputs of the State Transportation Building energy system computer model, a Daily Energy System Summary was created to summarize the most important outputs from the computer model runs. Additional information not found in the computer model runs is also calculated in the Daily Summary, such as total building electric loads (including both variable and base loads), and storage tank potential for heating, cooling, and false loading.

The first page of the summary includes a listing of building heating, cooling, and electric loads broken down by source and time of use. Also included are daily average temperatures, dewpoints, and enthalpies. Figure 3-14 shows the first part of the sample Daily Summary Sheet. This summary gives a general overview of the order of magnitude of the daily heating and cooling loads, as well as how much of the loads was supplied by the heat pumps, storage tanks, and outdoor air. Outdoor air loads are divided into infiltration, ventilation, and free cooling loads. Infiltration is due to air leakage through the closed air handler dampers, ventilation is due to the opening of the minimum air dampers, and free cooling is due to more than minimum air supplied through the enthalpy dampers.

Reheat is a measure of the amount of cooling extracted by the exterior air handler cooling coils which must then be reheated by the heating coils at the perimeter VAV boxes. This quantity is calculated from the assumed mixed air temperatures and cooling coil discharge temperatures as described in the "Simple Validation of Computer Model" section of this chapter. Cooling at the exterior zone air handler cooling coils is considered reheat if the amount of heat supplied to the building is greater than the amount of heat extracted at the exterior cooling coils indicating that cooling is not required at the

Transportation Building Daily Energy System Summary Sheet

Date:	9/12/85	Thursday
Ave. outdoor Temp (degF)	60	
Ave. outdoor Dewpt. (degF)	34	
Ave. Outdoor Enthalpy (Btu/lb	18.79	
Ave. Indoor Enthalpy (Btu/lb)	22.35	

Storage Capacity Change	Tank 1	Tank 2	Tank 3
Hour 1-6 (Btu/hr)	(332,347)	(997,041)	2,658,776
Hour 7-17 (Btu/hr)	0	0	15,620,311
Hour 18-24 (Btu/hr)	0	0	0

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	30,366,025	0	30,366,025	0	0	2,760,548	0
Stor. Tank Htg. Sup	(15,620,311)	0	(15,620,311)	0	0	(1,420,028)	0
Reheat	(4,757,872)	(0)	(4,757,872)	(0)	(0)	(432,534)	(0)
Clg.Twr. Disch.	0	0	0	0	0	0	0
Totals*	9,987,842	0	9,987,842	0	0	907,986	0

Clg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Clg. Supply	(21,590,064)	0	(21,590,064)	0	0	(1,962,733)	0
Stor. Tank Clg. Sup	(1,329,388)	(1,329,388)	0	0	(221,565)	0	0
Free cooling	(26,655,065)	(5,416,608)	(20,995,569)	(242,888)	(902,768)	(1,908,688)	(34,698)
Ventilation	(3,398,446)	0	(3,398,446)	0	0	(308,950)	0
Infiltration	(1,574,512)	(833,843)	0	(740,669)	(138,974)	0	(105,810)
Reheat	4,757,872	0	4,757,872	0	0	432,534	0
Totals	(49,789,603)	(7,579,839)	(41,226,208)	(983,557)	(1,263,307)	(3,747,837)	(140,508)
Daily Energy Balance (Btu/hr)	5,380,385	(8,605,254)	(93,840)	14,079,479	(1,434,209)	(8,531)	2,011,354

Electric Use Summary (kW)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
Heat Pumps	1,446	0	1,446	0	0	131	0
Pumps and Miscellaneous	2,193	706	1,236	251	118	112	36
Fans and Cooling Towers	1,213	162	920	131	27	84	19
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	15,784	2,092	10,594	3,098	349	963	443
Totals	28,488	3,572	20,671	4,245	209	441	126

Figure 3-14: Sample Energy System Summary Sheet 1

exterior zone. The electric use summary takes the variable loads calculated in the computer model resulting from operation of the heat pumps, fans, pumps, and cooling towers and adds them to the base loads (as described in Chapter II) to provide a summary of the daily electric use and how much of it is attributable to the mechanical equipment, computer rooms, appliances, elevators and lights.

All of the heating, cooling, and electric loads are broken up into time of use periods of hours 1-6, 7-17, and 18-24 which occur before, during, and after typical building occupancy. Average hourly consumption for each time period is also calculated. This differentiation between occupied and unoccupied heating, cooling, and electric consumption is essential because occupied heating and cooling loads are a function of building comfort requirements, while unoccupied heating and cooling loads are more a function of energy system operation. Finally, the summary sheet lists the storage capacity change of each storage tank for each time period, which is simply a totaling of the amount of heat added to or extracted from each tank during each time period.

The second part of the summary sheet is a more detailed hour-by-hour listing of heating and cooling supplied to the building, various temperatures in the air and water systems, and electric loads. Also included are hourly heating and cooling coefficients of performance (COPs) and an hourly comparison of actual and calculated cooling of the air handler cooling coils as described in the "Simple Validation of Computer Model" section of this chapter. A sample Daily Summary Sheet-Part 2 is listed in Figure 3-15.

In addition to the storage tank, heat pump, and outdoor air heating and cooling loads, the Energy Use Summary section includes heat conduction and estimated internal gains. Hourly internal gains were estimated from lights, people, and appliances using standard ASHRAE

Energy Use Summary (Btu/hr)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Storage Tank Htg Supply	0	0	0	0	0	0	(1,994,082)	(1,994,082)	(1,994,082)	(2,991,123)	(2,658,776)	(1,994,082)	(1,994,082)	0	0	0
Heat Pump Htg Supply	0	0	0	0	0	0	4,957,718	4,338,004	4,957,718	4,957,718	2,478,859	4,338,004	4,338,004	0	0	0
Heat Pump Clg Supply	0	0	0	0	0	0	(3,148,551)	(3,148,551)	(3,148,551)	(3,148,551)	(3,148,551)	(3,148,551)	(2,698,758)	0	0	0
Storage Tank Clg Supply	(664,694)	(664,694)	(664,694)	(332,347)	(332,347)	1,329,388	0	0	0	0	0	0	0	0	0	0
Infiltration	(151,030)	(161,375)	(164,201)	(178,618)	(178,618)	0	0	0	0	0	0	0	0	0	0	0
Ventilation	0	0	0	0	0	0	0	(554,255)	(532,804)	(558,927)	(558,955)	(620,344)	(573,160)	0	0	0
Free Cooling	0	0	0	0	0	(5,416,608)	(5,226,347)	0	0	0	0	0	0	(4,361,476)	(3,936,764)	(3,936,764)
Heat Conduction (Btu/hr)	(766,365)	(817,456)	(868,547)	(919,638)	(919,638)	(919,638)	(919,638)	(715,274)	(664,183)	(664,183)	(664,183)	(715,274)	(613,092)	(613,092)	(613,092)	(613,092)
Internal Gains (Btu/hr)	912,848	801,434	721,686	641,938	593,855	514,107	482,441	402,693	3,803,208	4,039,777	4,201,608	4,335,725	4,464,723	4,539,461	4,646,922	4,199,471
Balance (Btu/hr)	(669,242)	(842,092)	(975,757)	(788,665)	(836,748)	(4,492,751)	(5,848,459)	(1,671,466)	2,421,306	1,634,711	(349,999)	2,195,477	2,923,634	(435,108)	97,066	(350,385)
Reheat	(0)	(0)	(0)	(0)	(0)	(0)	(0)	2,292,233	2,465,638	0	0	0	0	(0)	(0)	(0)
Building Heating Demand	0	0	0	0	0	0	2,963,636	51,688	497,998	1,966,595	(179,917)	2,343,921	2,343,921	0	0	0
Building Cooling Demand	(815,724)	(826,070)	(828,895)	(510,965)	(510,965)	(4,087,220)	(8,374,898)	(1,410,573)	(1,215,717)	(3,707,478)	(3,707,506)	(3,768,895)	(3,271,918)	(4,361,476)	(3,936,764)	(3,936,764)
Temperature Summary (degF)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Outdoor Air Temperature	58	57	56	55	55	54	54	58	60	60	61	60	62	63	64	64
AC-1 Space Temperature	72	72	72	72	72	72	72	73	73	74	75	75	75	75	76	76
AC-2 Space Temperature	73	73	73	73	73	72	72	72	73	73	74	74	74	75	76	76
AC-3 Space Temperature	74	74	73	73	73	73	73	73	74	74	75	75	75	75	75	75
Tank 1 Temperature	0	0	0	0	0	48	0	0	0	0	0	0	0	0	0	0
Tank 2 Temperature	0	0	0	0	0	48	0	0	0	0	0	0	0	0	0	0
Tank 3 Temperature	60	60	60	61	61	0	61	61	61	62	62	64	65	0	0	0
Hot Water Return Temp	0	0	0	0	0	0	79	81	82	83	83	82	81	0	0	0
Chilled Water Return Temp	0	0	0	0	0	0	57	57	57	57	57	57	57	0	0	0
Total Electric Summary (kW)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Heat Pumps	0	0	0	0	0	0	206	212	215	218	218	215	163	0	0	0
Pumps and Miscellaneous	116	116	116	116	116	128	152	152	152	152	152	152	152	43	43	43
Fans and Cooling Towers	18	18	18	18	18	74	74	81	82	82	84	82	85	86	88	88
Computer Rooms	64	64	64	64	64	64	114	114	114	114	114	114	114	114	114	114
Appliances and Elevators	38	38	38	38	38	38	262	522	522	522	522	522	522	522	522	522
Lights	351	341	341	341	343	374	963	963	963	963	963	963	963	963	963	963
COP's	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Heat Pump Htg. COP	0.00	0.00	0.00	0.00	0.00	0.00	7.06	6.00	6.76	6.67	3.34	5.92	7.79	0.00	0.00	0.00
RU-1 Clg COP	0.00	0,00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RU-2 Clg COP	0.00	0.00	0.00	0.00	0.00	0.00	4.48	4.36	4.30	4.24	4.24	4.30	4.84	0.00	0.00	0.00
RU-3 Clg COP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bldg. Htg. COP	0.00	0.00	0.00	0.00	0.00	0.00	2.43	1.89	2.36	1.55	0.00	1.87	2.15	0.00	0.00	0.00
Bldg. Clg. COP	2.90	2.94	2.95	1.82	1.82	8.72	6.86	1.13	0.97	2.93	2.92	3.00	3.00	26.63	23.39	23.39
Bldg. Overall COP	2.90	2.94	2.95	1.82	1.82	8.72	9.29	3.02	3.33	4.49	2.92	4.87	5.16	26.63	23.39	23.39
CFM study	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Q(calc.) (ext)(Btu/hr)	0	0	0	0	0	0	0	(2,292,233)	(2,465,638)	(2,466,284)	(2,678,043)	(2,607,047)	(2,729,884)	0	0	0
Q(calc.) (int)(Btu/hr)	0	0	0	0	0	0	0	(2,082,275)	(2,274,296)	(2,274,887)	(2,437,559)	(2,404,391)	(2,470,474)	0	0	0
Q(calc.) total(Btu/hr)	0	0	0	0	0	0	0	(4,374,508)	(4,739,935)	(4,741,171)	(5,115,602)	(5,011,438)	(5,200,358)	0	0	0
Q(act.) total (Btu/hr)	(664,694)	(664,694)	(664,694)	(332,347)	(332,347)	1,329,388	(3,148,551)	(3,148,551)	(3,148,551)	(3,148,551)	(3,148,551)	(3,148,551)	(2,698,758)	0	0	0
diff. (act - calc)(Btu/hr)	(664,694)	(664,694)	(664,694)	(332,347)	(332,347)	1,329,388	(3,148,551)	1,225,957	1,591,384	1,592,620	1,967,051	1,862,887	2,501,600	0	0	0

Figure 3-15: Sample Energy System Summary Sheet 2

techniques (See Appendix B for documentation). The balance entry of the Energy Use Summary totals the heating and cooling supplied to the building to indicate a net heat gain or loss for the building using equation 3-12.

The last part of the Energy Use Summary lists the hourly reheat and building heating and cooling demands. The building heating demand is the amount of heat supplied to the building from the heat pumps and storage tanks, minus reheat. The building cooling demand is the amount of cooling done from the heat pumps, storage tanks, and outdoor air, minus reheat. If the outdoor air load is positive, meaning that it is being cooled by the air handler cooling coils, then this load is not added to the hourly building cooling load.

The Temperature Summary section gives hourly outdoor and indoor air temperatures, storage tank temperatures, and hot and chilled water return temperatures. AC-1, 2, and 3 temperatures are as monitored in the air handlers unless the air handler fans were off; in this case, monitored eighth floor space temperatures (the only space temperatures available from the Delta 1000) are used. Tank temperatures are the temperatures of water leaving the storage tanks. Hot water and chilled water return temperatures are measured at the hot and chilled water system pumps. Tank and water system temperatures are listed as zero when the pumps are not operating.

In the COP section, an overall heat pump heating COP is calculated as the ratio of heat provided by the heat pumps to heat pump electric use. An overall heat pump heating COP must be used since temperature readings are only recorded in the mixed stream from all three heat pumps in parallel. Individual cooling COPs are calculated for each heat pump. Building heating and cooling COPs are calculated by dividing the heating effect or cooling effect supplied to the building by the total energy system electric use including fans, pumps, heat pumps, and cooling towers. Building overall COP's are the ratio of total heating and cooling effects added together to total energy system electric use. These COPs allow for a comparison of the relative energy efficiencies of different strategies of heating and cooling, for example, free cooling versus chiller operation.

Part 2 of the Daily Energy System Summary sheet also lists the output from the CFM study described in the "Simple Validation of Computer Model" section of this chapter, which compares calculated and monitored air handler cooling loads.

Part 3 of the Daily Energy System Summary Sheet (see Figure 3-16) deals exclusively with storage tank performance. Storage tank heating and cooling potential and actual storage tank heat transfer rates are summarized. In the Storage Tank Potential section, the total potential of each storage tank for heating and cooling or false loading is quantified. Storage tank potential is measured in Btus, and is defined by the equation:

$$Q_{potential} = M\, C_p\, (T_{tank} - T_{system}) \quad \text{(Btu)} \qquad (3\text{-}15)$$

where:

M = mass of water in tank (approx. 1,888,390 lbm)

Cp = 1 Btu/lbm·degF

T_{tank} = temperature of water leaving tank

T_{system} = temperature of hot water, chilled water, or space with which heat is exchanged

Thus, each tank's potential to cool or false load is directly proportional to the difference between the tank temperatures and the chilled water loop temperature as measured at the chilled water pump. Similarly, a tank's heating potential is directly proportional to the difference between the tank temperature and the hot water loop temperature as measured at the hot water pump. If the tank pump or water system pump is not operating, these quantities are zero. The storage tank's space heating or cooling potential is estimated by using the space air temperature for T system in equation (3-15).

Storage Tank Potential (Btu)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Tank 1 Clg or FlsLdg Pot.	0	0	0	0	0	90,642,816	0	0	0	0	0	0	0	0	0	0
Tank 2 Clg or FlsLdg Pot.	0	0	0	0	0	90,642,816	0	0	0	0	0	0	0	0	0	0
Tank 3 Clg or FlsLdg Pot.	113,303,520	113,303,520	113,303,520	115,191,912	115,191,912	0	7,553,568	7,553,568	7,553,568	9,441,960	9,441,960	13,218,744	15,107,136	0	0	0
Tank 1 Heating Potential	0	0	0	0	0	90,642,816	0	0	0	0	0	0	0	0	0	0
Tank 2 Heating Potential	0	0	0	0	0	90,642,816	0	0	0	0	0	0	0	0	0	0
Tank 3 Heating Potential	113,303,520	113,303,520	113,303,520	115,191,912	115,191,912	0	(33,991,056)	(37,767,840)	(39,656,232)	(39,656,232)	(39,656,232)	(33,991,056)	(30,214,272)	0	0	0
Tank 1 Space Htg/Clg Pot.	0	0	0	0	0	(45,950,872)	0	0	0	0	0	0	0	0	0	0
Tank 2 Space Htg/Clg Pot.	0	0	0	0	0	(45,950,872)	0	0	0	0	0	0	0	0	0	0
Tank 3 Space Htg/Clg Pot.	(24,549,096)	(24,549,096)	(23,919,632)	(22,031,240)	(22,031,240)	0	(21,401,776)	(22,031,240)	(23,290,168)	(22,031,240)	(23,919,632)	(20,142,848)	(18,254,456)	0	0	0
Maximum Potential Rate of Storage Tank Heat Transfer (Btu/hr)																
Tank 1 Clg or FlsLdg Pot.	0	0	0	0	0	13,565,186	0	0	0	0	0	0	0	0	0	0
Tank 2 Clg or FlsLdg Pot.	0	0	0	0	0	13,565,186	0	0	0	0	0	0	0	0	0	0
Tank 3 Clg or FlsLdg Pot.	16,956,483	16,956,483	16,956,483	17,239,091	17,239,091	0	1,130,432	1,130,432	1,130,432	1,413,040	1,413,040	1,978,256	2,260,864	0	0	0
Tank 1 Heating Potential	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tank 2 Heating Potential	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tank 3 Heating Potential	0	0	0	0	0	0	(5,086,945)	(5,652,161)	(5,934,769)	(5,934,769)	(5,934,769)	(5,086,945)	(4,521,729)	0	0	0
Actual Rate of Storage Tank Heat Transfer (Btu/hr)																
Storage Tank 1	0	0	0	0	0	332,347	0	0	0	0	0	0	0	0	0	0
Storage Tank 2	0	0	0	0	0	997,041	0	0	0	0	0	0	0	0	0	0
Storage Tank 3	(664,694)	(664,694)	(664,694)	(332,347)	(332,347)	0	(1,994,082)	(1,994,082)	(1,994,082)	(2,991,123)	(2,658,776)	(1,994,082)	(1,994,082)	0	0	0

Figure 3-16: Sample Energy System Summary Sheet 3

Note that this analysis assumes that storage tank temperatures are uniform throughout the full mass of the storage tank. Though in practice there are sometimes stagnant portions of the storage tanks which are able to stratify, it is assumed for purposes of this analysis that the storage tank designers were successful in achieving unstratified conditions.

In the Maximum Potential Rate of Storage Tank Heat Transfer section of the Daily Energy System Summary Sheet, the limitations of the rate of water flow into and out of the storage tanks along with the effectiveness of the storage tank heat exchangers are accounted for when calculating the maximum rate by which heat can be transferred into or out of the storage tanks. This rate of heat transfer is calculated using equation (3-10):

$$\dot{q} = E \; C_{min} \; (T_{h,i} - T_{c,i}) \qquad \text{(Btu/hr)} \qquad (3\text{-}10)$$

where:

E = Heat exchanger effectiveness

C min = $\dot{m} \; c_p$ where $\dot{m}$ is the lesser of the tank side and system side flow rates through the heat exchanger.

Although in reality, the system side valves regulating water flow through the storage tank heat exchangers are modulated by pressure and temperature controllers, it is assumed in calculating the maximum potential rate of storage tank heat transfer that these valves are fully open so that C_{min} approximately equals C_{max}, the storage tank pump flow rate. By design under these conditions, the heat exchanger effectiveness is 0.85 when heating and 0.84 when cooling (Source: Paterson-Kelly heat exchanger design drawings). In the summary sheet, the tank temperature is used for $T_{h,i}$. When calculating tank cooling or false loading potential, the chilled water return temperature is used for $T_{c,i}$. When calculating tank heating potential, the hot water return temperature is used for $T_{c,i}$.

Finally, the actual rate of storage tank heat transfer is calculated with equation (3-1) using monitored temperatures leaving and entering the storage tanks.

In all cases, storage tank heating or cooling potentials and heat transfer rates are positive when heat is transferred to the system from the storage tanks and negative when heat is transferred from the system to the storage tanks.

The equations used for the Computer Model Summary Sheet are listed in Table B-8.

Chapter IV presents the results of several computer model runs using actual building operation data, and discusses the results in the context of optimizing building energy consumption through various energy system operation strategies.

Chapter IV: Presentation and Analysis of Building Operation Data

Introduction

Computer model runs were conducted using several days of State Transportation Building energy system operation data for a range of weather and occupancy conditions. The model outputs have then been used to determine the monitored heating and cooling requirements of the building under various conditions and the relative efficiencies of various operation strategies to meet those loads.

This chapter presents the results of the computer model analysis and examines these findings in the context of the following questions:

Seasonal Trends in Building Heating and Cooling Requirements

- What are the seasonal monitored heating and cooling requirements of the State Transportation Building?

- How much of this heating and cooling is attributed to various sources such as the heat pumps, outdoor air, and storage tanks?

- What are the relative orders of magnitude of the various heating and cooling loads including conduction, ventilation, and internal gains?

- To what extent does reheat and false loading occur in the building and what impact do they have upon the building's heating and cooling requirements?

- How might the occupancy of the retail spaces effect the present heating and cooling requirements of the building?

- How might improved air handler performance effect the present heating and cooling requirements of the building?

- How does the monitored performance of the system compare to the designer's predicted heating and cooling loads?

Relative Energy and Cost Effectiveness of Different Operation Strategies

Winter Operation

- Is the heating system capable of meeting the heating requirements of the building without back-ups, such as leaving the lights on for 24 hours or steam heating? How might this change with the occupancy of the retail spaces? What impact would improved air handler performance have?

- To what extent is excess heat stored during occupied hours available for unoccupied hours heating?

- What are the relative efficiencies of these auxiliary heating strategies--direct storage tank heating, false loading, leaving lights on for 24 hours, running heat pumps at night, and a back-up steam heating alternative?

Summer Operation

- To what extent is chilled water storage necessary to meet the cooling requirements of the building? What impact will the occupancy of the retail spaces have upon the building's cooling requirements?

- To what extent is chilled water storage advantageous economically? How will the proposed time-of-use electric rates effect the economics of off-peak storage?

Spring-Fall Operation

- What are the relative cost and energy efficiencies of free-cooling versus mechanical cooling?

- At what point in the autumn does mechanical cooling become necessary for heat recovery purposes?

- At what point in the spring does mechanical cooling become necessary to meet the cooling requirements of the building?

- At what point in the heating and cooling seasons should chilled water storage and hot water storage begin and end?

- At what point in the spring and the fall should the air handler cooling coil setpoints be changed?

Seasonal Trends in Building Heating and Cooling Requirements

Daily monitored heating and cooling loads during occupied hours were considered to determine the heating and cooling requirements of the building for different ambient conditions. Occupied and unoccupied hours are considered separately since it is necessary only during occupied times to maintain comfortable conditions in the building.

See Tables C-1 through C-45 for Daily Summary Sheet listings from computer model runs. Complete listings of each run's imputs and outputs are available from the author. Table C-46 lists some of the daily operation data compiled from the computer model outputs for several days of monitored data. Included in Table C-46 are daily electric and thermal energy use data. Heating and cooling supplied to the building from various sources are included, and are broken down into daily occupied and unoccupied listings.

Also included is the amount of reheat at the exterior cooling coils and reheat due to the steam heating coils which were installed in the AC-1 and AC-2 interior air handlers in December 1985 to increase the building heat supply. The exterior coil reheat was calculated from mixed air temperatures and cooling coil setpoints as described in Chapter III. The steam reheat was estimated from steam utility bills to be approximately 1.8 mmBtu/hr.[1]

Occupied Heating Loads

Figure 4-1(a) graphs the average daily outdoor temperature versus the daily occupied space heating load, which includes heat provided by the heat pumps and thermal storage tanks with reheat due to cooling at the exterior cooling coils subtracted out. For the days when lights were left on around the clock, the difference between the internal gains due to regular lighting levels and twenty-four hour lighting levels (approximately 10.47 mmBtu) is included in the heating load.

Heating was not required in the building at outdoor temperatures above 70 degF. At temperatures below 70 degF, heating requirements linearly increased with decreasing temperature, with peak daily heating loads of approximately 90 mmBtu at average daily temperatures of 10 degF. The monitored heating loads formed a linear curve with a correlation coefficient of -0.88.

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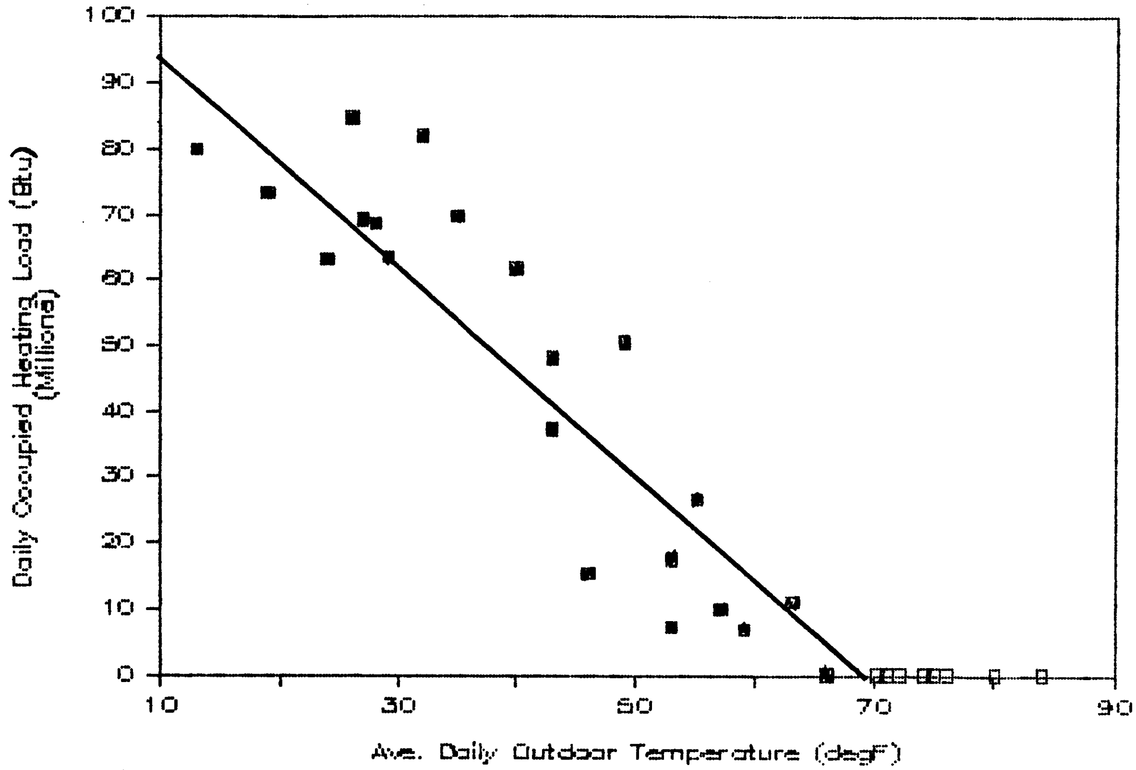
[1]There is no sub-metering of the steam to the reheat coils located in AC-1 and AC-2, which were valved open from mid-December until late February.

(a)



(b)

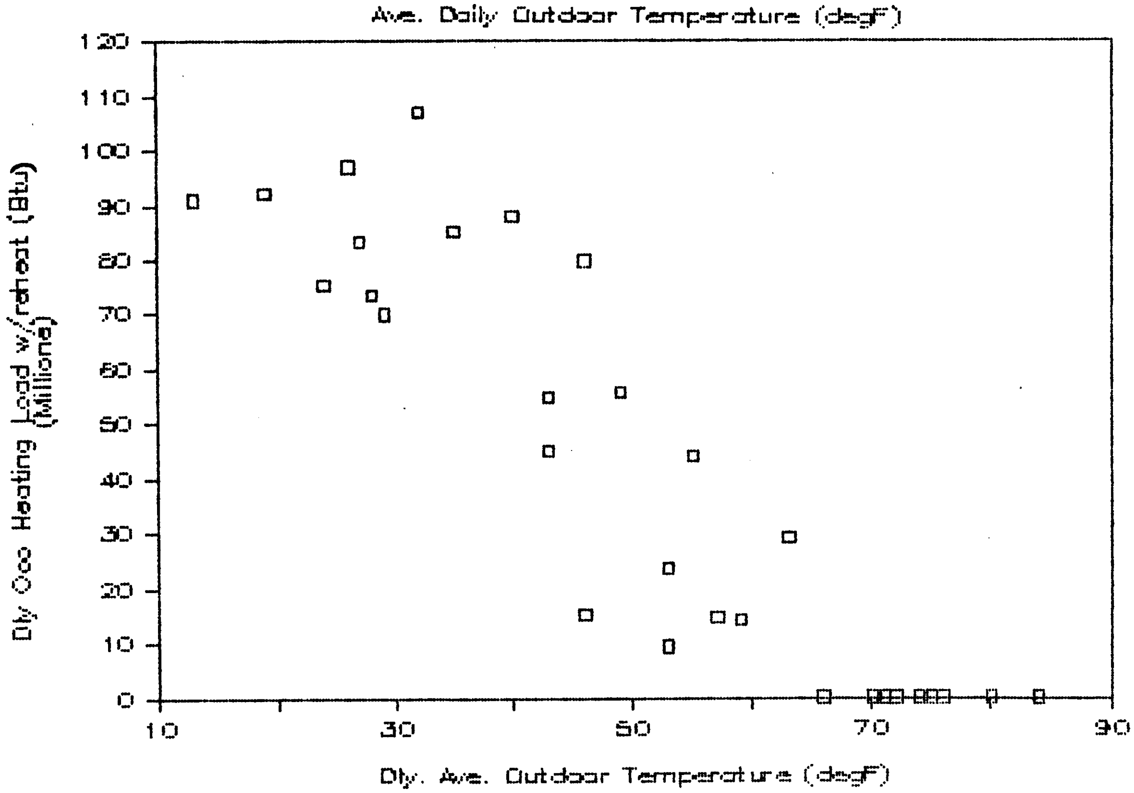


Figure 4-1: Monitored Daily Occupied Heating Loads
(a) Building Heating Requirements
Y= (-1,603,493 Btu/degF)X + 110,270,746 Btu, Correlation Coefficient: -0.88
(b) Building Heating Requirements Including Reheat

Figure 4-1(b) graphs the total heating actually supplied to the building, including reheat, for a range of outdoor air enthalpies. With reheat included, the building heating demand does not follow the smoother and more compact curve in Figure 4-1 (a).

Bar graphs were created to show the relative orders of magnitude of heating and cooling sources and loads in the building for a range of outdoor temperatures, using the monitored building operation data. The quantities of each day's heating sources and uses are not always equal, but rarely vary by much. The differences are due to either heating or cooling of building mass, or to inaccuracies in operation data or computer model algorithms.

Figure 4-2 consists of bar graphs presenting a break-down of the building's heating sources and uses for a range of daily outdoor temperatures, using monitored data. Figure 4-2 (a) includes the building's heating sources consisting of the heat pumps, storage tanks, and lights.

The heat pumps are the principle source of heating throughout the heating season. Total lighting loads are not included, but for the days when lights were left on around the clock, the difference between the internal gains due to regular lighting levels and 24 hour lighting levels is included. Direct space heating during occupied hours from the storage tanks was generally not used in colder weather, and was a fairly negligible part of the heating supply in the warmer weather.

Figure 4-2 (b) gives a breakdown of how heating was used in the building for different days. Conduction and ventilation proved to be the biggest parts of the heating load, and roughly of the same order of magnitude. As expected, both loads gradually decrease with rising outdoor air temperature. Reheat proves to be a fairly significant

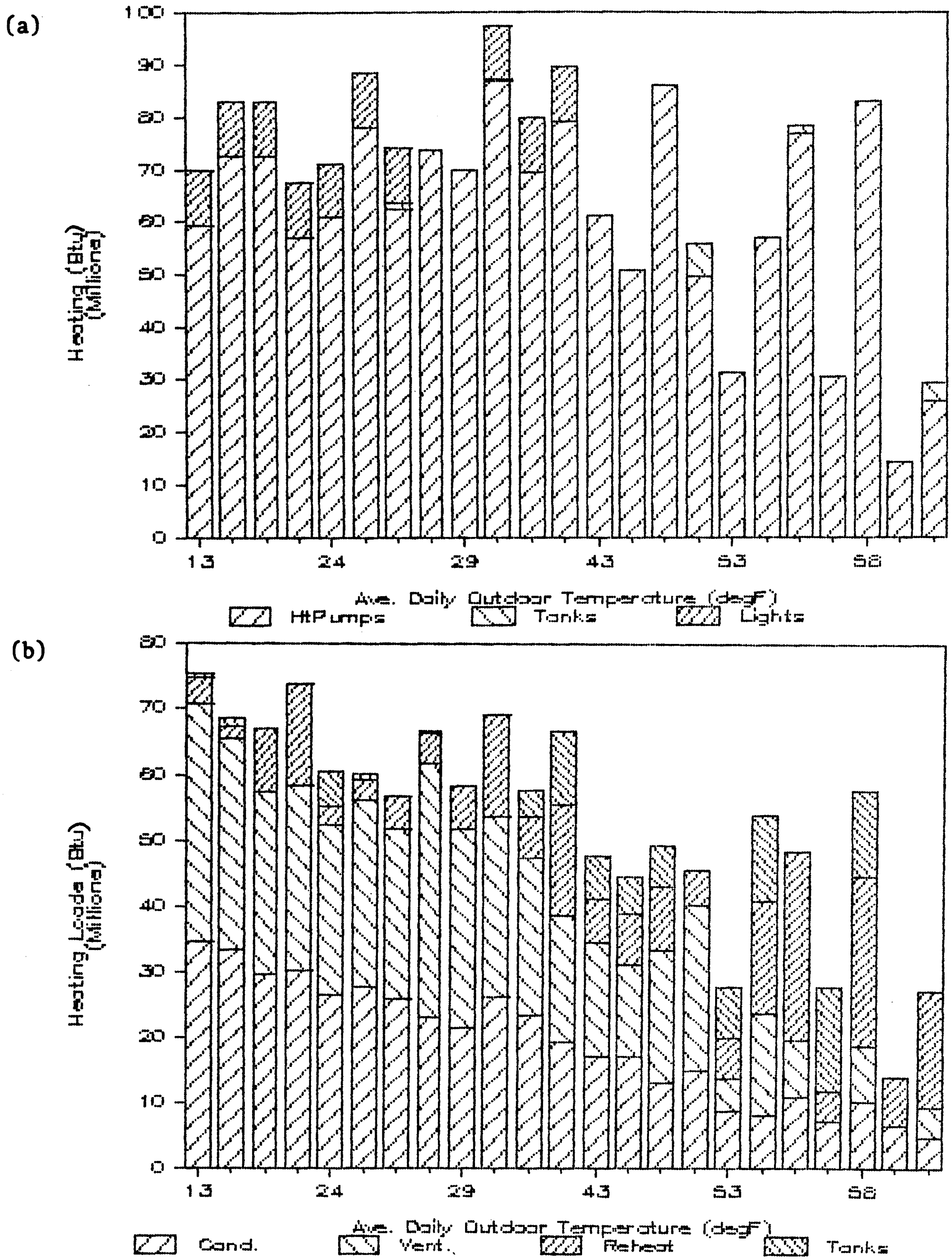


Figure 4-2: Monitored Daily Occupied Heating Loads
(a) Heating Sources (b) Heating Uses

part of the heating load, especially during the warmer days when the order of magnitude of the reheat load is sometimes greater than the conduction and ventilation loads. There was relatively little storage tank heating on the colder days but as the average outside temperature rose above 40 degF, more heat was available for storage. See Table C-48 for the data used in Figure 4-2.

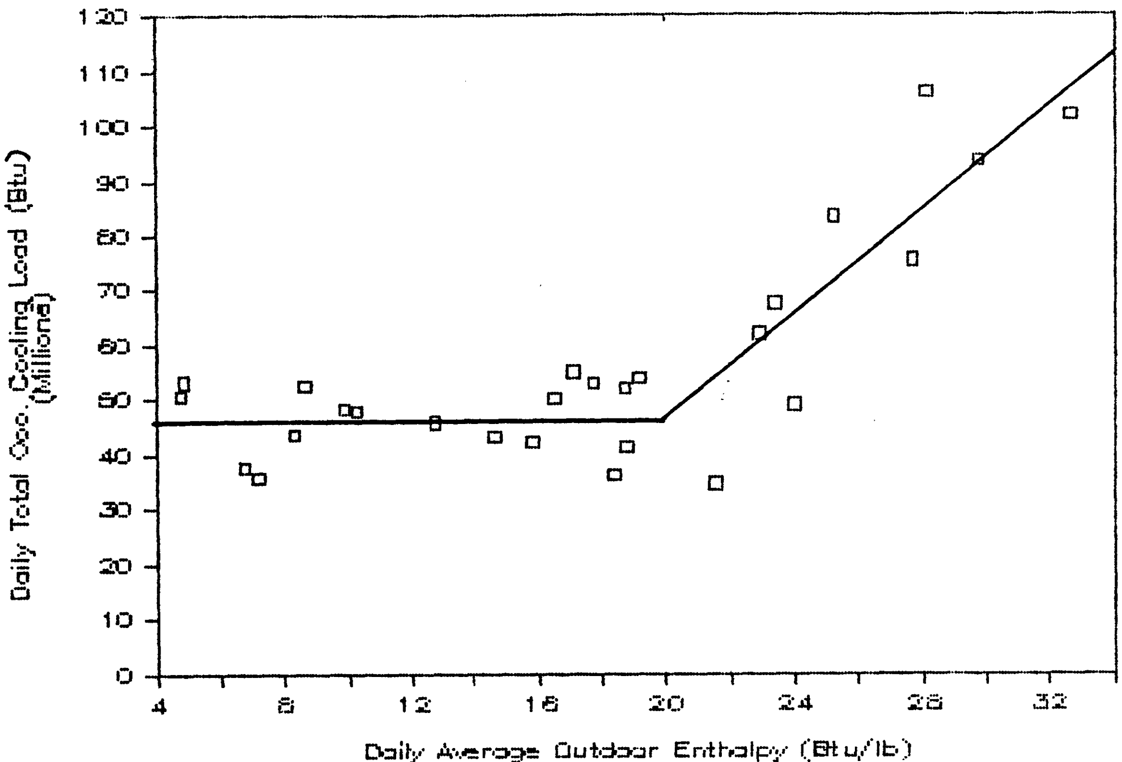
Occupied Cooling Loads

Figure 4-3 graphs daily building cooling requirements during occupied hours for a range of outdoor air enthalpies and temperatures. This cooling requirement includes the cooling supplied by the chillers, thermal storage tanks, and outside air with cooling for reheat and false loading subtracted out. It is interesting to note that curves a and b which respectively graph cooling load versus outdoor enthalpy and temperature, are quite similar.

Building cooling requirements remained generally stable at approximately 46 mmBtu/hr for outdoor enthalpies ranging up to approximately 20 Btu/lb, and temperatures ranging up to approximately 60 degF. This quantity roughly balances the estimated internal gains during occupied hours of 38.5 or 48.9 mmBtu/hr using ASHRAE correction factors to account for building mass, depending upon whether the lights were on for twenty-four hours. These results tend to justify the assumption that the effect of solar loads is relatively negligible in the Transportation Building as compared to internal gains from lights, appliances, and people.

Predictably, as the outdoor air enthalpy increases above 20 Btu/lb and the temperature increases above 60 degF the building cooling load increases, as the curves in Figure 4-3 illustrate. The enthalpy curve has a correlation coefficient of -0.88. The temperature curve has a correlation coefficient of -0.81. Surprisingly, the temperature correlation is almost as good as the enthalpy correlation.

(a)



(b)

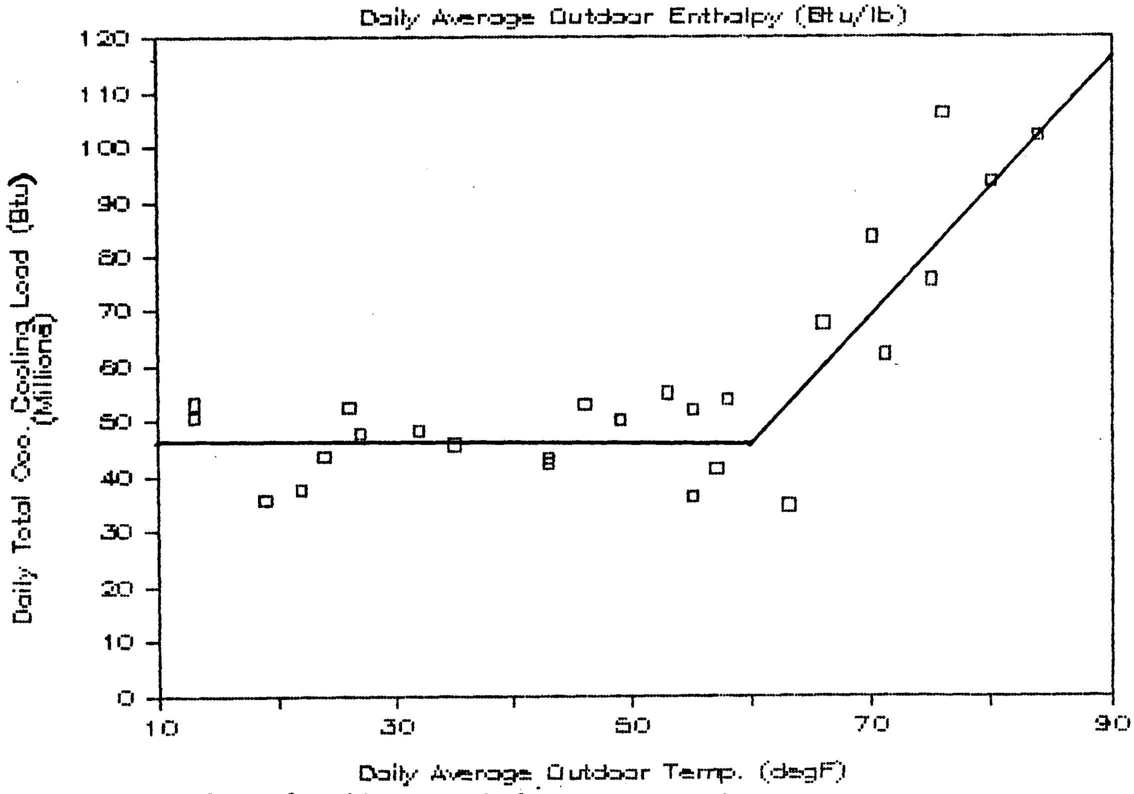


Figure 4-3: Monitored Daily Occupied Cooling Loads

(a) Cooling Loads vs. Enthalpy

Enthalpy less than or equal to 20 Btu/lb, X=46,227,650 Btu; Enthalpy greater than 20 Btu/lb, Y=(4,660,630)X-45,308,627, Correlation Coefficient = -0.88

(b) Cooling Load vs. Daily Average Outdoor Temperature

Temperature less than or equal to 60 degF, X=46,227,650 Btu; Temperature greater than 60 degF, Y=(2,303,167)X-91,693,800 Btu, Corr. Coeff.: -0.81

Figure 4-4 graphs the cooling supplied to the building versus average outdoor air enthalpy with the effects of reheat and false loading included. Note that during the heating season, the amount of cooling supplied to the building is sometimes significantly higher than the building space cooling requirement (See Figures 4-3 (a) and (b) due to the effects of reheat and false loading.

Figures 4-5 (a) and (b) graph the sources of cooling and uses of cooling, respectively, for a range of outside air temperatures. In Figure 4-5 (a), the sources of cooling are the heat pumps, storage tanks, and outdoor air. At the lower temperatures, outdoor air ventilation accounts for roughly forty percent of the cooling supplied to the building. In the spring and fall, outdoor air is a smaller part of the cooling supply, except on days when free cooling is used. In the summer, storage tank cooling provided relatively little of the cooling supply as compared to the heat pumps, ranging from zero to 25 percent.

Figure 4-5 (b) graphs the relative orders of magnitude of the uses of cooling in the building during occupied hours including internal gains, reheat, ventilation air, storage tanks, and conduction. Internal gains are by far the largest part of the cooling load. Reheat proved to be a significant part of the cooling load in January and February when the steam coils were in use, and also in the Spring and Fall due to low exterior air handler cooling coil setpoints. This explains why in Figure 4-4, with reheat included, building cooling loads seem to rise with the colder weather!

Outdoor air proves to be a fairly significant part of the summer cooling load, and conduction a relatively small load. Note that in the summer the cooling supplied to the building in Figure 4-5 (a) tends to greatly exceed the cooling required by internal gains,

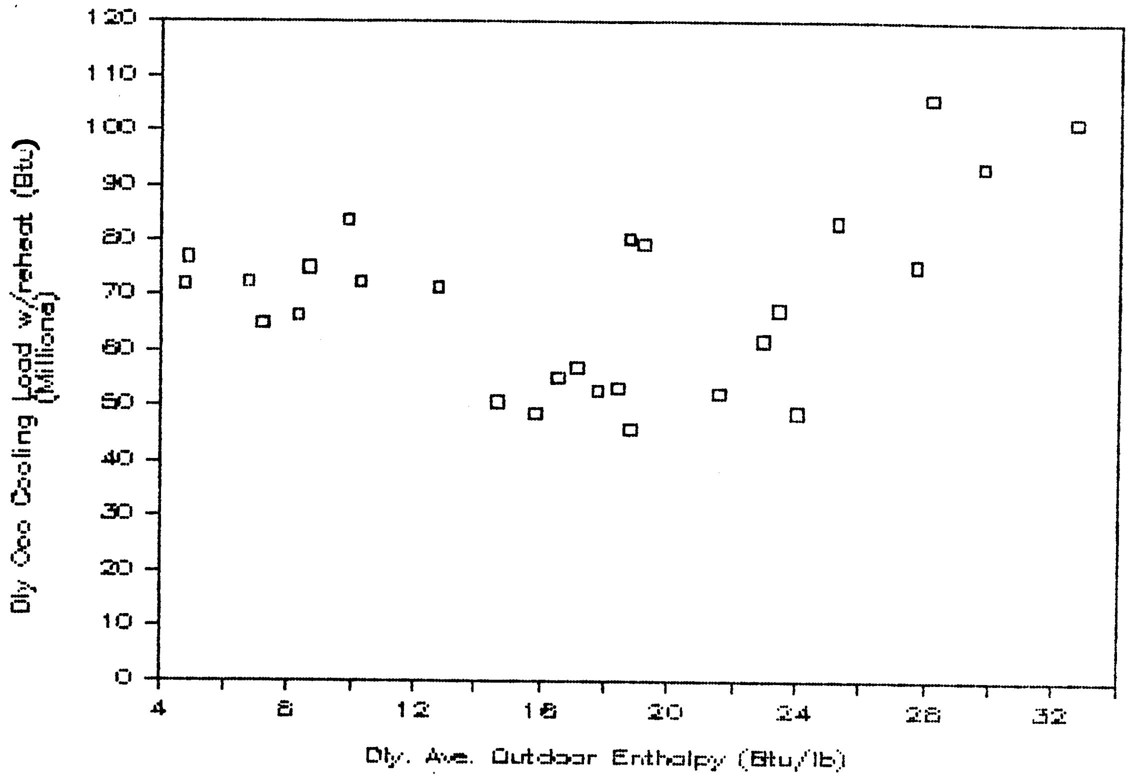


Figure 4-4: Daily Occupied Cooling Loads with Reheat Included

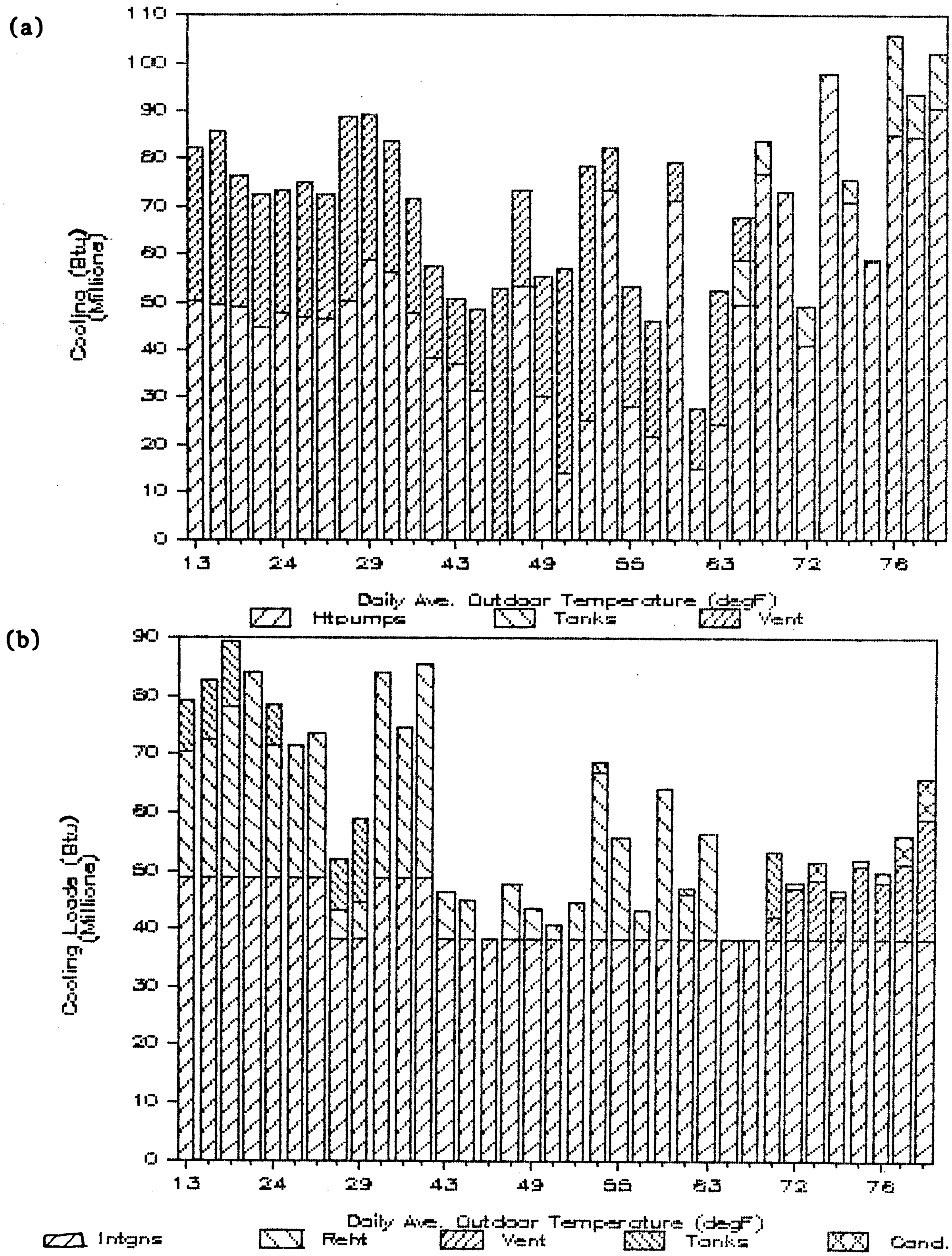


Figure 4-5: Monitored Daily Occupied Cooling Loads
(a) Cooling Sources (b) Cooling Uses

ventilation air, and conduction loads. Since building space temperatures are likely to rise during unoccupied hours, this discrepancy could largely be due to building thermal mass cooling requirements.

Storage tank false loading was frequently used for start-up on colder days and proved to be a significant part of the cooling load. It is interesting that the amount of false loading typically used (approximately 10 mmBtu/hr) is roughly equal to the difference between the internal gains from running the lights for 24 hours and a regular lighting schedule. As with false loading, the impact of the 24 hour lighting schedule would be felt in the morning, since without the 24 hour lighting load the thermal capacitance of the building mass absorbs most of the morning heat from the lights. See Table C-49 (a) for the data used in Figure 4-5.

Unoccupied Heating and Cooling Loads

Figures 4-6 (a) and (b) graph the monitored daily building heating and cooling loads during unoccupied hours. These graphs are very irregular as compared with the graphs for occupied heating and cooling loads. The difference is due to the fact that building space conditions are maintained at a fairly constant level during occupied hours, but can vary widely during unoccupied hours depending upon the way that the energy system is operated.

During the heating season unoccupied periods, building temperatures are maintained above a certain level, typically 70 degF. Building operators have observed that if the average building temperature was allowed to drop below this level, comfortable conditions could not be obtained in the building by first occupancy. In practice the average temperatures maintained in the building during heating season unoccupied hours will range from 71 degF to regular occupancy conditions of 74-76 degF depending upon how the energy system has been

(a)

(b)

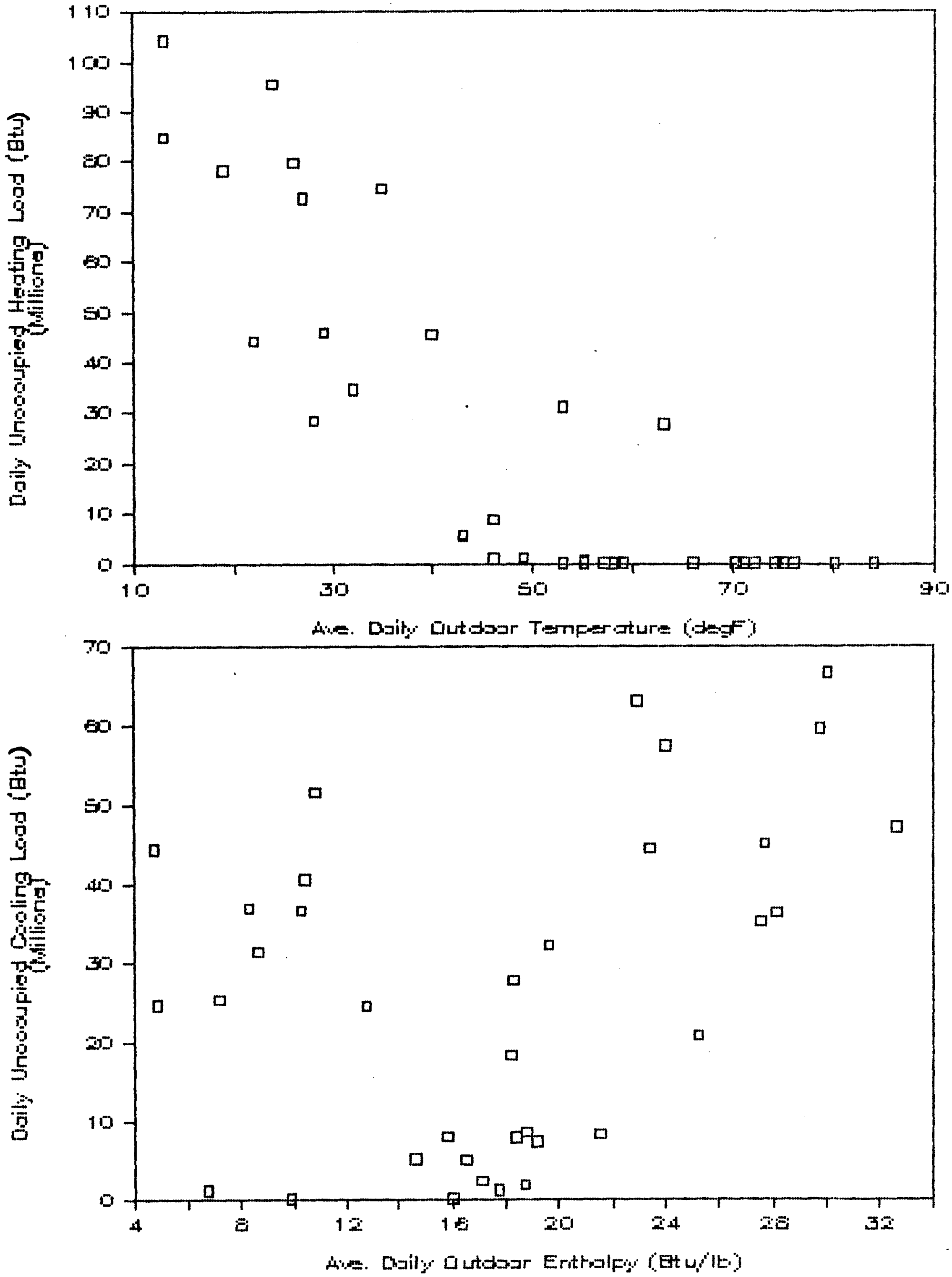


Figure 4-6: Daily Unoccupied Heating and Cooling Loads
(a) Heating Loads (b) Cooling Loads

operated. Unoccupied winter energy system operation strategies have ranged from completely shutting the energy system down to running the heat pumps all night. The relative effectiveness of different unoccupied operation strategies are discussed later in the winter operation section of this chapter.

Similarly, during the cooling season, the temperature conditions and operation strategies will vary widely. During unoccupied hours in the summer, generally the system operators will avoid providing unnecessary cooling to the building. Free cooling is sometimes used when available. When mechanical cooling is in use, dampers to unoccupied floors are often commanded closed to avoid cooling these unoccupied areas. When the heat pumps are used during unoccupied hours to cool the thermal storage, operators sometimes use some or all of the building to help increase the cooling load on the heat pumps. This practice is discussed later in the summer operation section of this chapter. Generally it is assumed that cooling of the building during unoccupied hours is not required.

To estimate the heating requirements of the building during unoccupied hours, the relative orders of magnitude of heat losses due to conduction and internal gains were examined. For this analysis, it is assumed that the fans are off and therefore ventilation and infiltration losses are negligible. The impact of ventilation is discussed later in this chapter.

A good correlation between average daily outside temperatures and unoccupied hours conduction loads was found by using monitored hourly conduction data (See Figure 4-7(a)), and a linear equation was derived. Internal gains due to lights, appliances, and people were calculated as described in Appendix B. Figure 4-7(b) graphs estimated daily unoccupied heating loads for a range of average daily outdoor temperatures by adding together daily conduction losses and internal gains. Different curves are shown for occupied weekdays and weekends, and unoccupied weekdays and weekends when the lights are left on for 24 hours. Table C-49(b) lists the inputs to Figure 4-7(b).

(a)

(b)

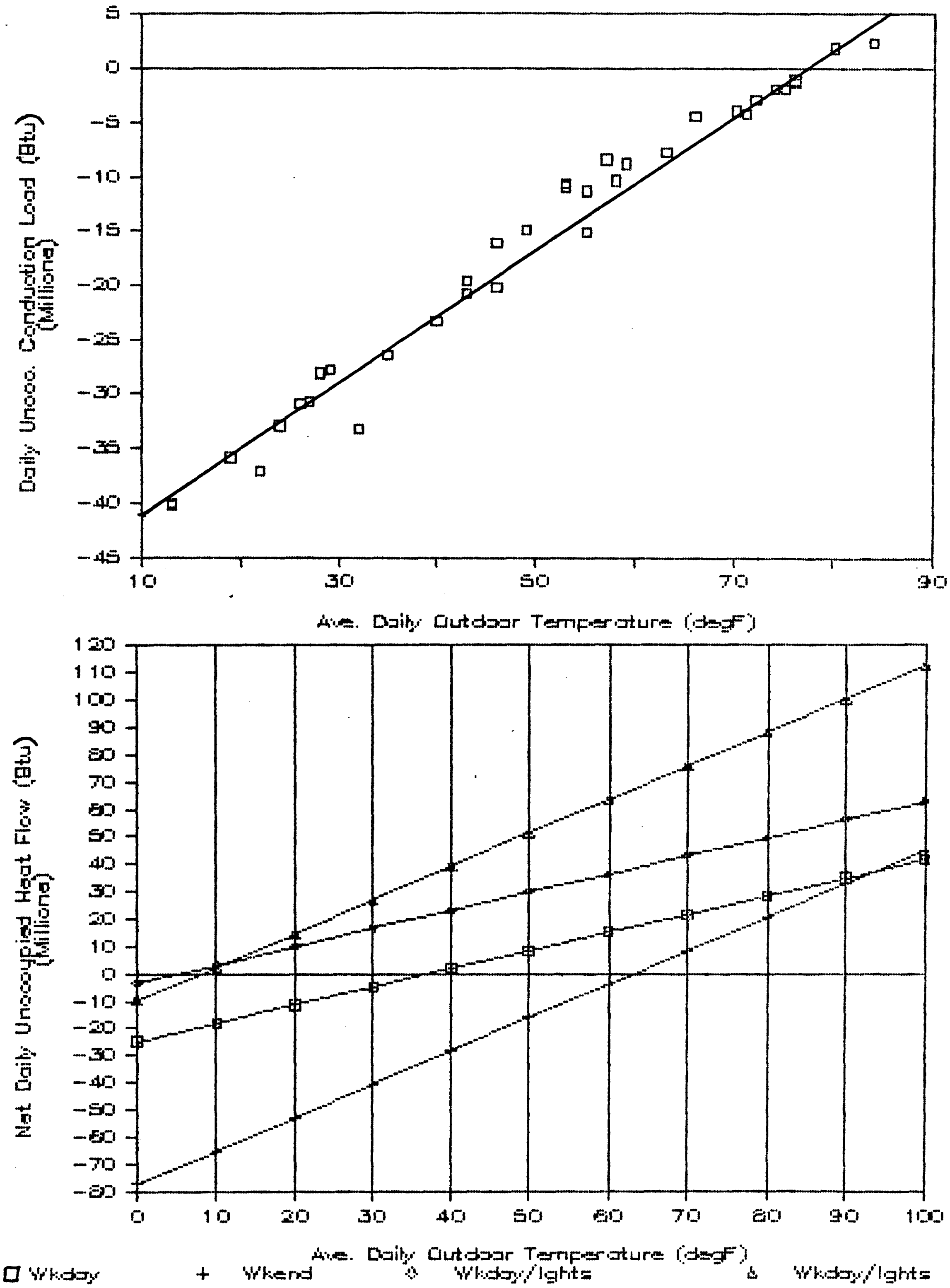


Figure 4-7: Unoccupied Hours Heating Requirements
(a) Unoccupied Hours Conduction Loads
Y=(647,366)X-47,588,931; Corr.Coeff.=-0.9886
(b) Unoccupied Hours Heat Flow Due to Conduction and Internal Gains

The figure shows that on weekdays for average outdoor temperatures above approximately 35 degF, heating is not required during unoccupied hours. With fewer internal gains during the day, the balance point is roughly 65 degF on weekends. When the lights are left on for 24 hours, no heat is required in the building during unoccupied hours for average daily outdoor temperatures down to about 10 degF.

The monitored winter operation data substantiates these temperature thresholds based upon three building temperature sensor locations when the air handler fans have been off (see December, January, and February computer model summary sheets). One experiment was conducted by building staff by taking several temperature readings with the fans off and some lights on. With average outdoor temperatures of 30 degF, indoor temperatures were maintained above 71 degF throughout the building, except in one "problem" area on level 2.

Potential Impact of Retail Spaces

How will the occupancy of the retail spaces influence the present heating and cooling requirements of the building? The occupancy of the retail space is expected to reduce the heating requirements of the building in the winter by providing a thermal buffer of heated space between the second floor offices and the ground floor, and increased heat gains in the atrium due to the influx of people and lights that will result from the opening of the retail spaces. Although chilled water from the central heating and cooling system may not be directly used by the retail area in the winter time, the heat gains from the retail spaces would indirectly increase the cooling load in the building. This effect is particularly pronounced in the atrium which is served by the central heating and cooling system. To simplify matters, since the building's central energy system will be providing chilled water but not hot water for the retail area the effect of the retail space on the building's heating and cooling requirements is be modeled as an increase in the building cooling load.

Accurate estimation of retail space heating and cooling loads is difficult because it has not yet been determined what tenants will occupy the spaces, what kind of equipment will be installed, and what the heating and cooling requirements will be. Shooshanian Engineering Associates estimated a peak cooling load of 190 tons (2,283,000 Btu/hr) and a peak heating load of 1,978,200 Btu/hr at the time the building was designed.[2] The retail space design firm, Sumner Schein Associates, has increased the peak cooling load estimates to 222 tons (2,664,000 Btu/hr).[3]

Using this designer information and other design data for retail space conduction and ventilation rates, heating season occupied hours internal gains from the retail space were estimated to be 15.712 mmBtu/day. The daily unoccupied hours winter heat gain was calculated to increase by 15.675 mmBtu/day due to the relatively late operation hours of the retail area (see Appendix C for calculations). An annual estimate of how the total building cooling load would be modified by the occupancy of the retail space was made by assuming that the present daily occupied winter cooling load of 46.228 mmBtu/hr would increase by 15.712 mmBtu/hr, and that the cooling season cooling load would increase proportionately to the peak cooling load increase (26 percent).

Figure 4-8(a) graphs the present daily occupied building heating, and cooling load curves. Figure 4-8(b) graphs the predicted daily occupied building heating and cooling load curves when the retail space is occupied. In addition to a fairly large overall increase in

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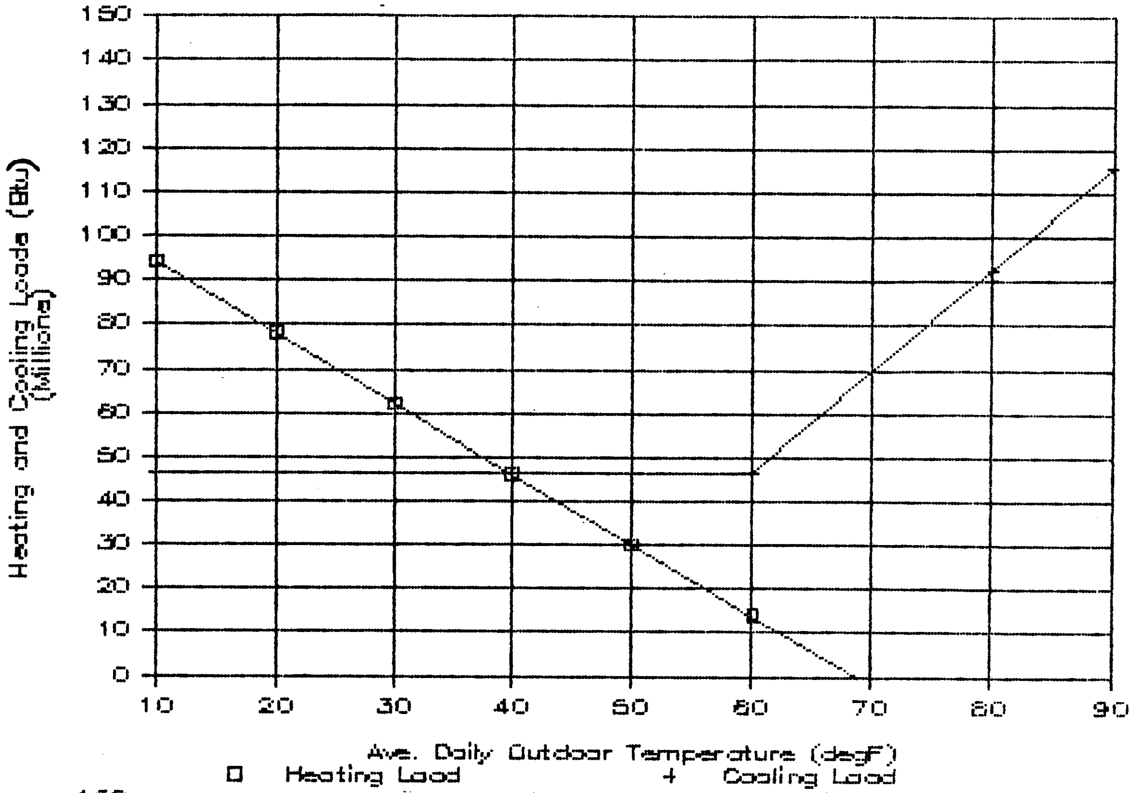
[2]Shooshanian Engineering Associates Transportation Building design documentation.

[3]Sumner Schein Associates Utility Budget data.

(a)



(b)

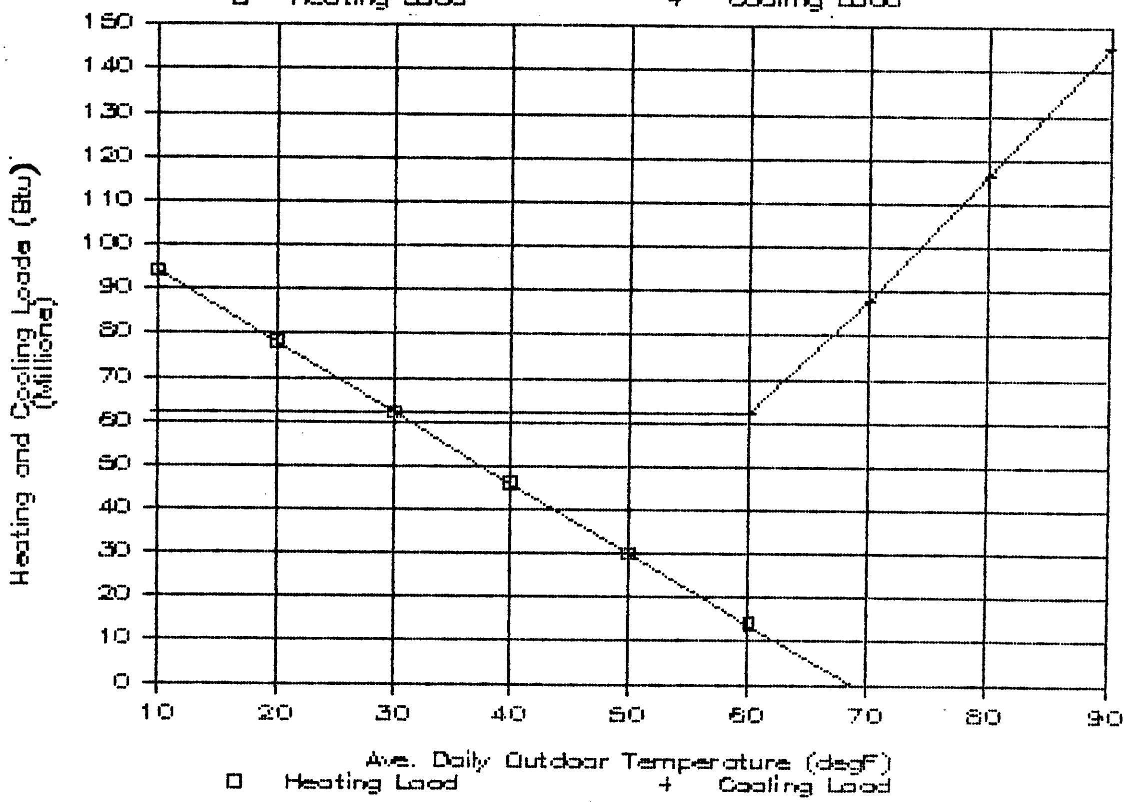


Figure 4-8: Daily Occupied Heating and Cooling Load Curves
(a) Present Daily Occupied Heating and Cooling Loads
(b) Daily Occupied Heating and Cooling Loads with Retail Occupancy

building cooling loads throughout the year, with this new curve, the balance point between daily occupied building heating and cooling loads is shifted from 40 degF to 30 degF. This shift would significantly improve the energy system's ability to meet building heating requirements with the heat recovery heat pumps.

Potential Impact of Improved Air Handler Performance

As Figure 4-2 (b) illustrates, outdoor air accounts for about 50 percent of the heating load in the State Transportation Building during occupied hours. Figure 4-9 (a) graphs the percent of the total monitored heating load due to outdoor air infiltration during unoccupied hours. This data indicates that during unoccupied hours, outdoor air infiltration at the air handlers accounts for quantities ranging from 40 percent to more than 100 percent of the unoccupied hours heating provided to the building.[4] These figures clearly demonstrate the significant impact of outdoor air upon the building's heating requirements.

As detailed in Chapter III, monitored air handler performance data reveals that when the delayed vents (minimum outdoor air dampers) are open as is typical during occupied hours, an average of 2,750 cfm per fan or 33,000 cfm total of outdoor air is admitted to the building. Monitored data also shows that when the delayed vents are closed, as is usually the case during unoccupied hours, an average of 4,750 cfm of outdoor air per fan is admitted to the building. If only the exterior fans are running, a total of 28,500 cfm of infiltration air enters the building. If both exterior and interior fans are running

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[4]Note that when the unoccupied infiltration load is more than 100 percent of the heating being provided, a more advantageous operation would be to turn the air handlers and hot water pump off, and let the building "sit".

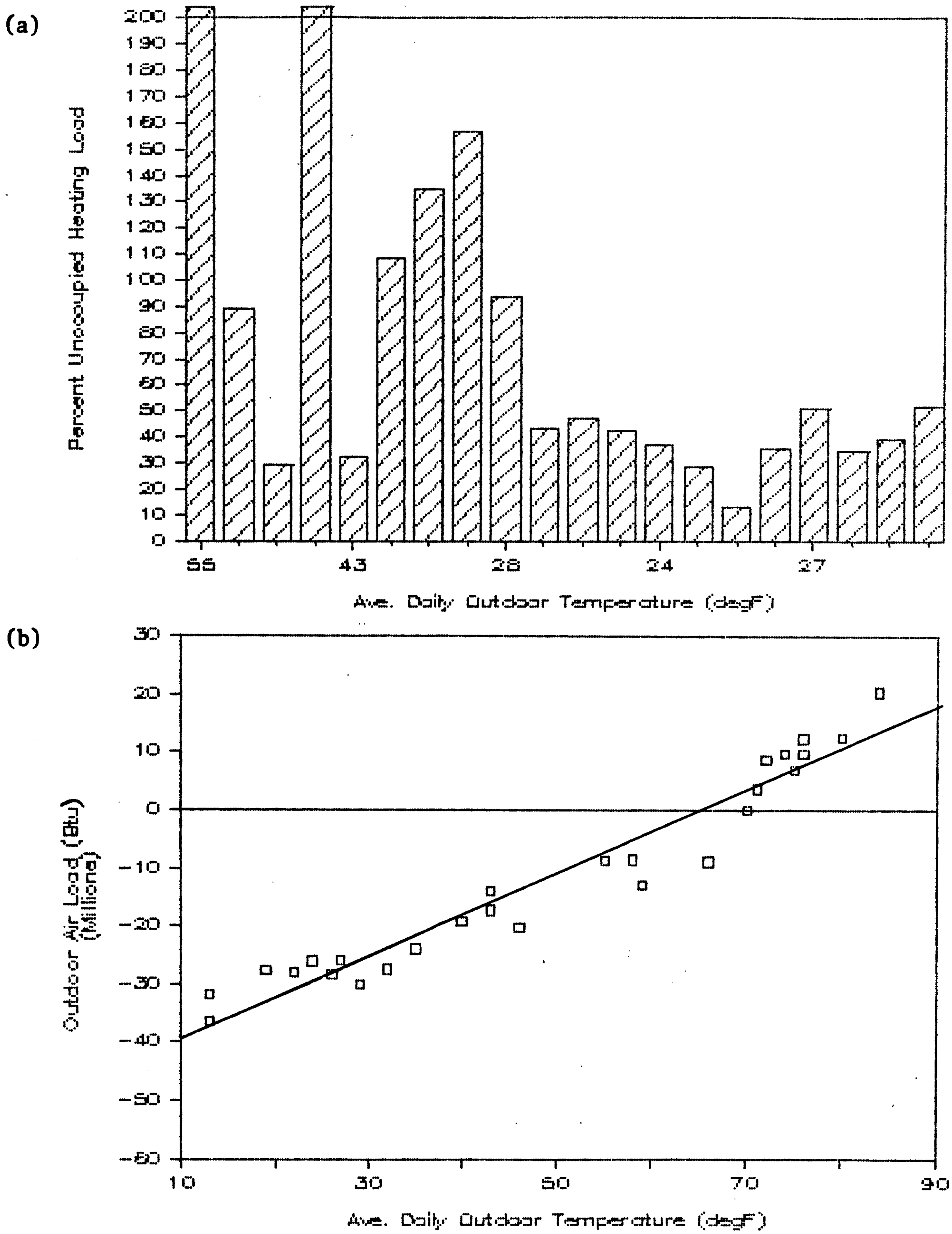


Figure 4-9: Monitored Heating Loads Due to Outdoor Air
(a) Percent Unoccupied Hours Heating Load Due to Outdoor Air
(b) Occupied Hours Heating Load Due to Outdoor Air
Y=(710,847)X-46,448,567 Btu/hr, Corr. Coeff.= 0.97

with the delayed vents closed, a total of 57,000 cfm of infiltration air enters the building. This discrepancy results from the fact that the tracking between the supply and return fans is better controlled with the delayed vents open.

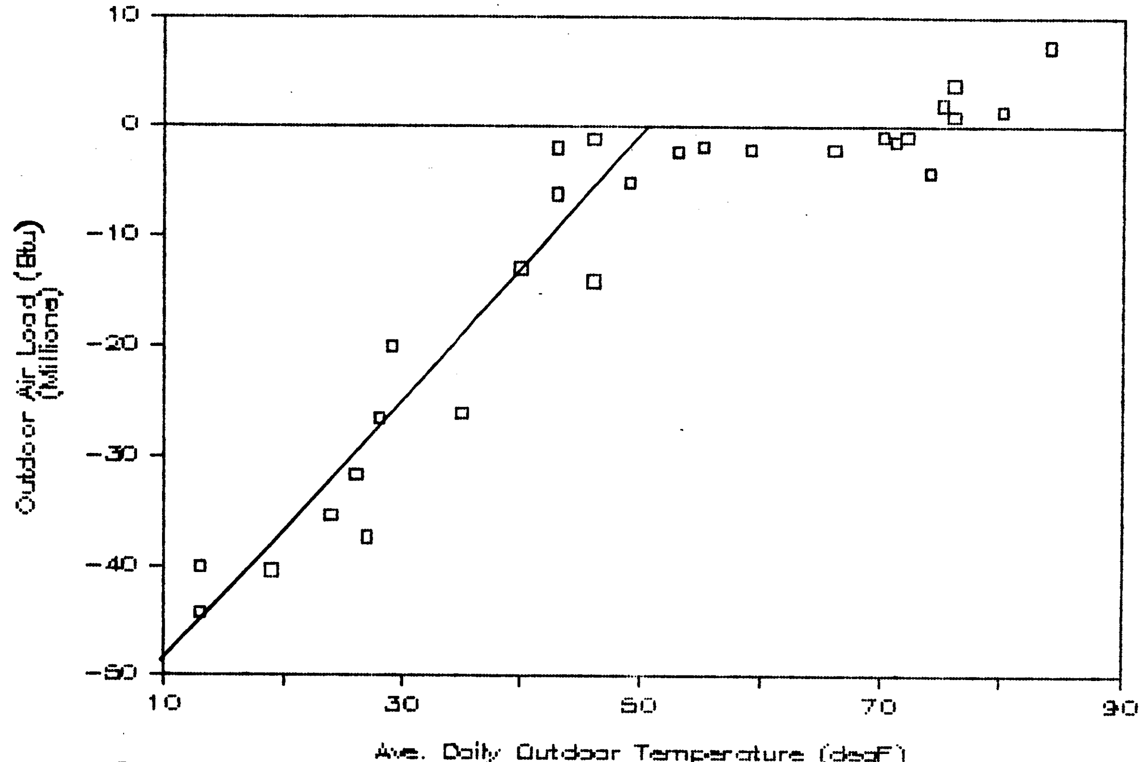
Under ideal conditions, 30,000 cfm of ventilation air would be supplied through the delayed vents during occupied hours to provide 15 cfm per person of fresh air, compensate for toilet exhaust, and provide some pressurization in the building. When the delayed vents are closed, the supply and return fan cfm would balance under optimal conditions and no infiltration would occur through the closed dampers. These ideal conditions would provide a slight decrease in the occupied hours ventilation air heating load and a significant decrease in the unoccupied hours infiltration load.

In Chapter V, ways to reduce infiltration at the air handlers through better fan tracking and improved damper performance are discussed. If these improved conditions were achieved through better fan tracking and air handler damper performance, what would be the impact upon the heating requirements of the building?

Occupied and unoccupied ventilation loads for different average outdoor temperatures were calculated using monitored data. Figures 4-9 (b) and 4-10 (a) graph daily monitored heat losses for occupied and unoccupied conditions. Linear equations for each curve were obtained with correlation coefficients of 0.97 and 0.94 respectively. Unoccupied infiltration loads above an average outdoor temperature of 50 degF were found to be negligible because the air handlers were usually off under these conditions.

To estimate the impact of improved air handler performance upon the building's daily heating requirements, air handler performance was assumed to improve linearly in proportion to reduced outdoor air flow rates. Occupied air loads were assumed to be reduced by 9 percent

(a)



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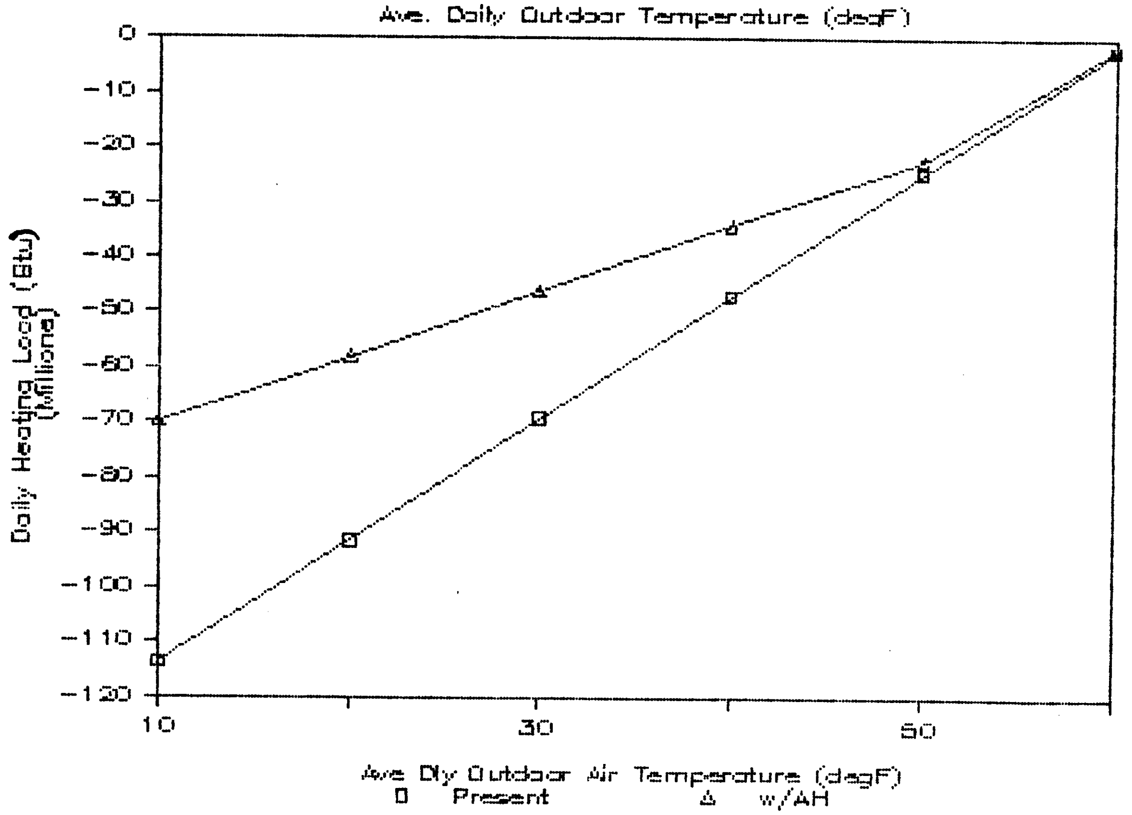

Figure 4-10(a): Monitored Unoccupied Hours Heating Load Due to Outdoor Air
Y=(1.182.789 Btu/degF)X-60,786,201 Btu/hr, Corr.Coeff.=0.94

Figure 4-10(b): Total Daily Heating Load (Occupied and Unoccupied) which is equivalent to the ratio of the ideal air flow rate of 30,000 cfm and the estimated existing flow rate of 33,000 cfm. Unoccupied air loads were assumed to be reduced by 82 percent which allows for approximately 850 cfm of infiltration air at each air handler fan.

Total daily heating loads were estimated by combining the daily occupied heating load curve in Figure 4-1 and the daily unoccupied heating load curve for week days in Figure 4-7 (b). This total heating load curve is graphed in Figure 4-10 (b) along with the new curve which includes the effect of improved air handler performance. The curves indicate an appreciable reduction in the building heating load with improved air handler performance. See Table C-49 (c) for equations.

The results of this analysis clearly indicate that excess outdoor air infiltration at the air handlers has significantly increased the daily heating requirements of the building.

Comparison with Designers' Predictions

How do the designers' predictions for the heating and cooling requirements of the State Transportation Building compare to the monitored heating and cooling loads? Although we have no record of the hourly heating and cooling load estimates used by the designers, we do know their peak heating and cooling load estimates. We also know that the designers predicted that cooling requirements due to internal loads in the building would be sufficient to meet the heating requirements of the building.

Peak Loads. The designers' peak cooling load estimate was 2,000 tons or 24 mmBtu/hr for a 2.5 percent outside design condition of 88 degF dry bulb, 74 degF wet bulb (approximately 37 Btu/lb enthalpy) and an inside design condition of 78 degF dry bulb, 62.5 degF wet bulb (approximately 27 Btu/lb enthalpy).

Balance between Winter Heating and Cooling Requirements. Given the present operation of the building, it appears obvious that the cooling load derived from internal gains is not always sufficient to meet the building heating requirements. As Figure 4-8 (a) illustrates, the heating load exceeds the cooling load in the building when average daily temperatures are below roughly 40 degF.

Will the designers' prediction be verified with occupancy of the retail space and improved air handler performance?

Figure 4-12 graphs the predicted daily occupied cooling load with retail space occupancy from Figure 4-8 (b) together with the daily heating load curve which accounts for improved air handler performance from Figure 4-10 (b). This curve shows a significant reduction from the 40 degF balance point in Figure 4-8 (a) to a lower 15 degF balance point.

These results suggest that with retail space occupancy for occupied days down to average outdoor temperatures of 15 degF, the heat recovery heat pumps should be able to meet the building's daily heating load without a back-up heating source. These results are given further study in the next section of this chapter.

Other factors in addition to retail occupancy and excess air infiltration could account for some of the discrepancy between the building's actual and predicted heating and cooling requirements. Because the Trane Trace computer runs were done early in the energy system design process, they did not account for several design changes. At the time load calculations were made, the building configuration was not finalized, including the window setbacks and mullions which may have significantly effected the solar heat gain estimates.[5]

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[5]Personal communication with H. McKew, May 6, 1986.

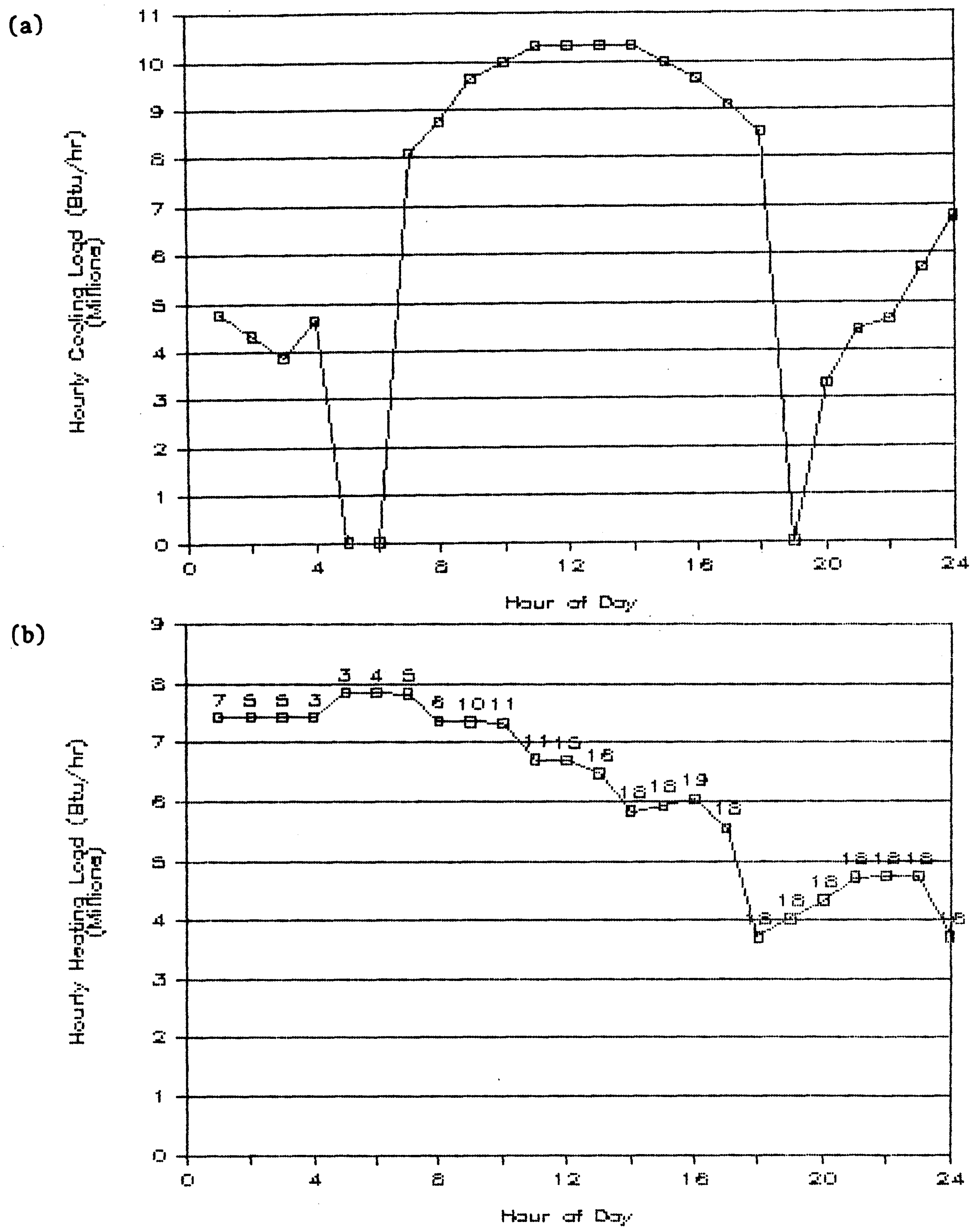


Figure 4-11: 1985 Peak Cooling Day and Heating Day Loads
(a) Peak Cooling Day (8/15/85)
(b) Peak Heating Day (1/15/86)
(heating loads are labeled with hourly outdoor temperatures)

The peak cooling load last year for the State Transportation Building was on August 15, 1985, the hottest day of the summer with an average daily outdoor temperature of 84 degF. On this day, the peak load was approximately 10,325,000 Btu/hr (see Figure 4-11(a) when the indoor enthalpy was about 26 Btu/lb (76 degF dry bulb, 50 degF dew point) and the outdoor enthalpy was about 34 Btu/lb (90 degF dry bulb, 61 degF dew point). Although these conditions were not quite as hot and humid as the 2.5 percent design conditions, they were close enough to expect a similar order of magnitude. But the large difference between the designers' 24 mmBtu/lb prediction and the monitored 10.325 mmBtu/hr cooling load indicates that the designers overestimated the building's cooling requirements. Even when the prediction for the retail space peak cooling load of 222 tons is added to the present peak load, the peak cooling load for the building still comes to only 13 mmBtu/hr which is 54 percent of the designers' prediction.

The peak heating load required by the building was predicted to be 5,025,000 Btu/hr for the 2.5 percent design conditions 9 degF outside and 72 degF inside (a 63 degF temperature difference). The peak heating day occurred this winter on January 15, 1986 when the daily average outdoor temperature was 13 degF. The average indoor temperature was 72 degF throughout the day, and outdoor temperatures ranged from 3 to 19 degF. The peak heating load during that day was 7.856 mmBtu/hr which occurred when the outdoor air temperature was 3 degF (see Figure 4-11(b)). When the outdoor air temperature rose to the 2.5 percent design condition, the heating load decreased to 7.35 mmBtu/hr which is 46 percent higher than the designer estimates. If the effect of excess outdoor air was taken into account, this would reduce the peak heating load to about 7.0 mmBtu/hr which is 39 percent higher than the designers' peak prediction.

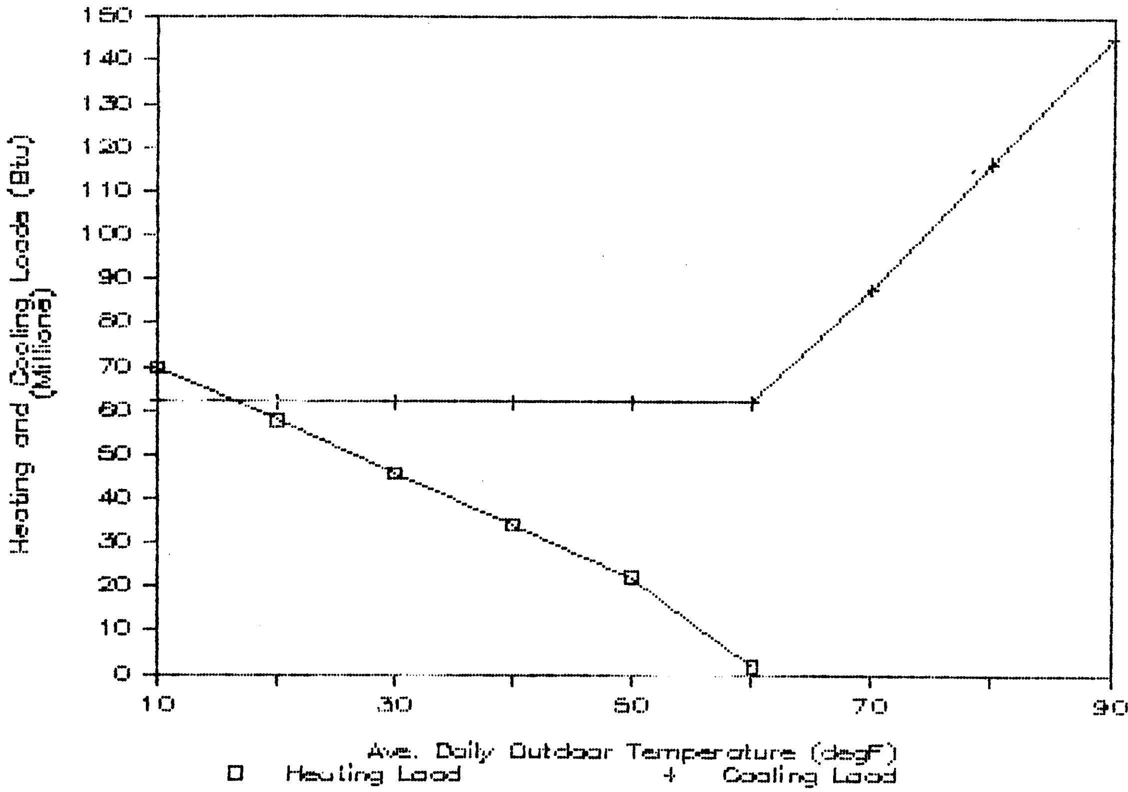


Figure 4-12: Predicted Daily Total Heating and Cooling Requirements with Retail Space Occupancy and Improved Air Handler Performance

Relative Energy and Cost Efficiencies of Different Operation Strategies

Winter Operation

As described in Chapter I, the winter design concept for the State Transportation Building energy system is heat recovery. Both 300 ton heat recovery heat pumps operate during occupied hours, extracting excess heat generated in the building and supplying this heat as needed to the perimeter of the building to offset heat losses. Hot water produced by the heat pumps and not immediately needed for heating would be stored in the water thermal storage tanks. Sufficient heat would be stored to offset unoccupied heating requirements during weekday nights and weekends.

Up until now, this sort of operation has not been possible in the building during the coldest months, and supplemental heating and cooling loads such as excess lighting and steam heating have been introduced. This section of the thesis uses the monitored building data along with the estimated impact of the retail space occupancy and air handler performance to address the questions: Under what conditions is back-up heating presently required in the building and how might the situation change with retail space occupancy and improved air handler performance? If back-up heating is required, what are the relative efficiencies of the options available?

To examine the first question, daily heating and cooling loads were calculated using weather data from the the past year (1985) and the temperature correlations described in this chapter. An estimate of the amount of excess heat available for storage was then derived from these findings. Next, weekly stored heat totals were compared with weekend heating requirements to see if supplementary heating would be necessary.

This weekly operation is described in the equation:

Net Weekly Heating =

$$\sum_{weekdays} \text{(Occupied Heat Supply - Occupied Heat Required - Unoccupied Heat Required) - Weekend Heat Required} \quad (4\text{-}1)$$

This simple algorithm assumes that all available excess heat is stored and later recovered with no losses. Of course, this would be an unreasonable expectation in reality because losses must be incurred in transferring heat to and from the storage, and other losses would take place as a result of reheat or other operation related factors. Nevertheless, this simplified analysis does provide an estimate of the best that could be achieved. The important issue of the performance of the storage system in storing and supplying heat will be set aside for the moment and taken up again in Chapter V.

The use of 1985 weather data rather than statistically normalized weather data yields a conservative result because 1985 was a relatively cold year with 1 percent more heating degree days and 7 percent less cooling degree days than normal.

Occupied heat pump heating supply was calculated using the ideal equation:

$$q = q_o + L_c \quad (4\text{-}2)$$

Where:

q = heat supply from the heat pump condenser

q_o = heat extracted by the heat pump evaporator

L_c = electrical energy used by the heat pump compressor

q_o was obtained from the monitored cooling data in Figure 4-3. L_c was calculated using heat pump performance equation (3-7) for typical hourly cooling loads.

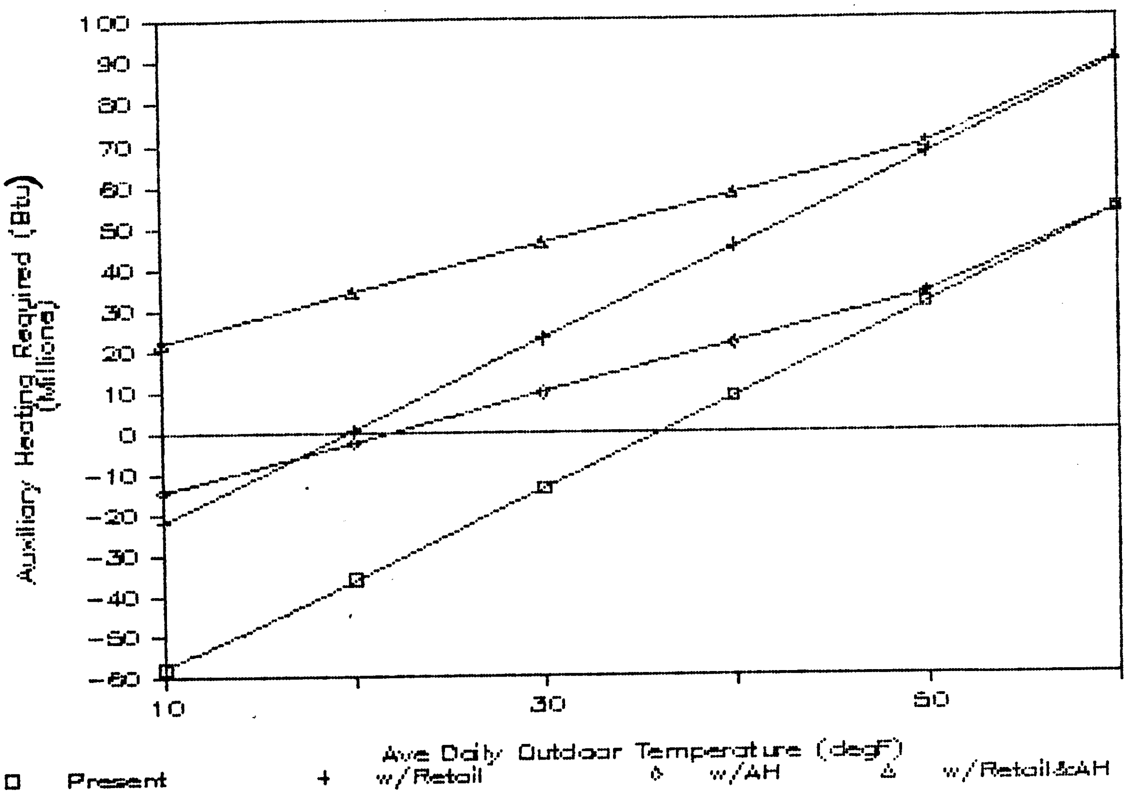
Occupied heating requirements from Figure 4-1(a) are used, and unoccupied and weekend heating requirements from Figure 4-7(b) are used. All equations and calculations are listed in Table C-49(c) and C-50.

Figure 4-13(a) graphs the net auxiliary heating required during occupied days, and compares the existing conditions to the anticipated conditions with the retail space occupied and improved air handler performance. The graph shows that on occupied days with average daily outdoor temperatures above 35 degF, excess heat is available for storage. On days with average daily outdoor temperatures below 35 degF auxiliary heating is required. The balance points with the air handler improvements or the retail space occupied are both around 20 degF. With both air handler improvements and retail space occupancy, excess heat would be available for unoccupied hours storage even with average daily outdoor temperatures as low as 10 degF.

Figure 4-13(b) graphs the result of the weekly analysis versus average weekly outdoor temperature. All of the average weekly outdoor temperatures in 1985 were above 20 degF. Since 1985 was an unusually cold year, we can reasonably assume that this will generally be the case.

This graph shows that for the existing building conditions, auxiliary heating is required for weeks with average temperatures of roughly 39 degF and below. Figure 4-14(a) graphs the existing building results over time with the cooling season data omitted. This analysis shows that sufficient heat was not available in the building until the end of February and it was not consistently available for two consecutive weeks until the beginning of April. Sufficient internally generated heat was available up until the end of November. These results are consistent with the actual conditions encountered when operating the system during this year. Excess lighting was used as a supplementary

(a)



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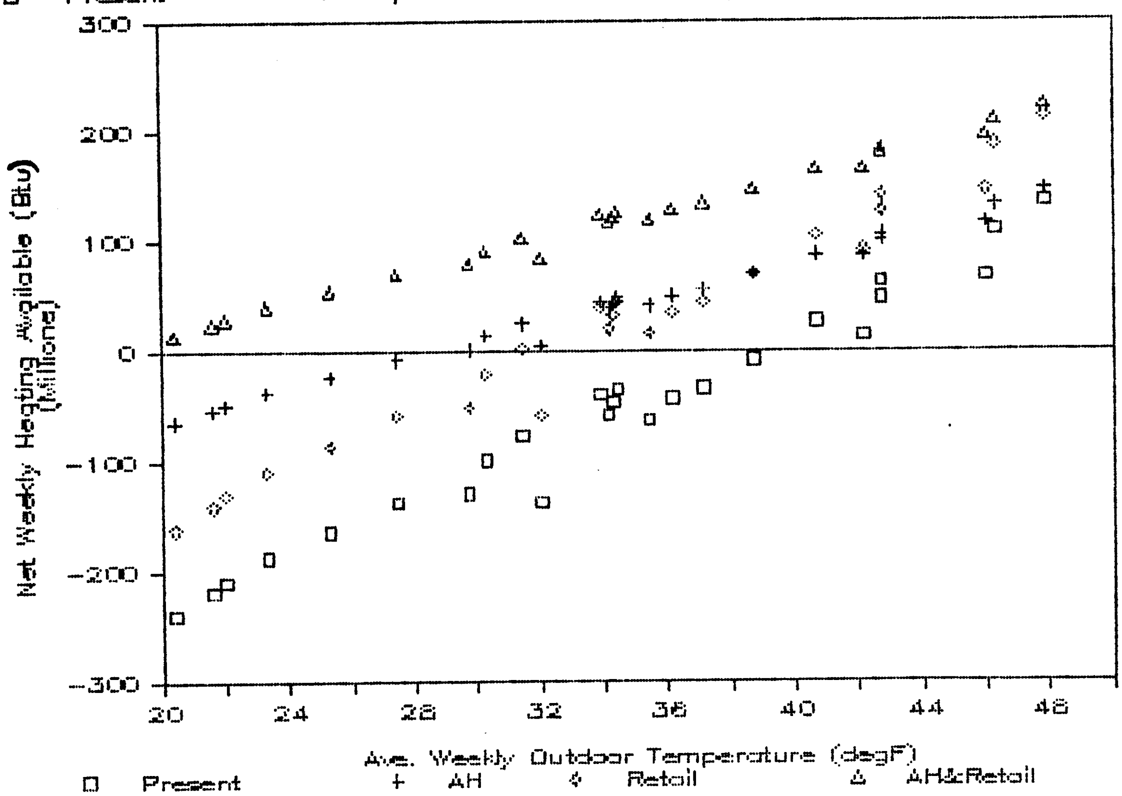
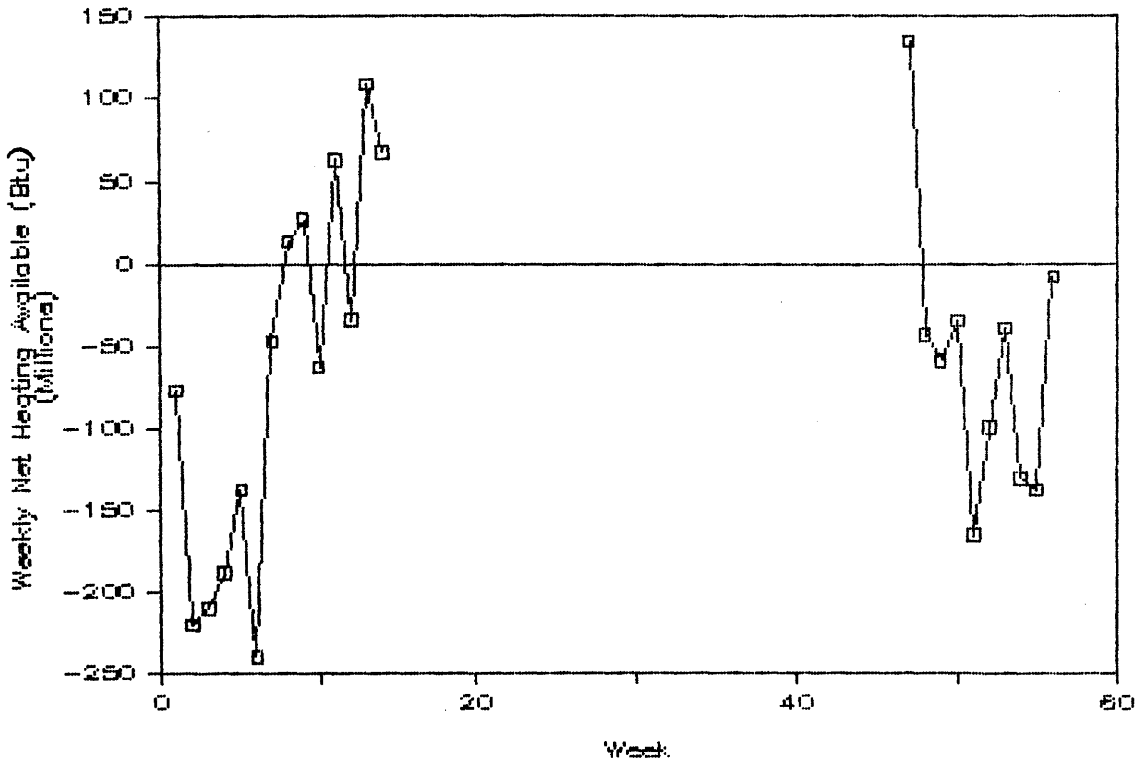


Figure 4-13(a): Net Occupied Day Auxiliary Heating Requirements
Figure 4-13(b): Net Weekly Excess Internally Generated Heat Available

(a)



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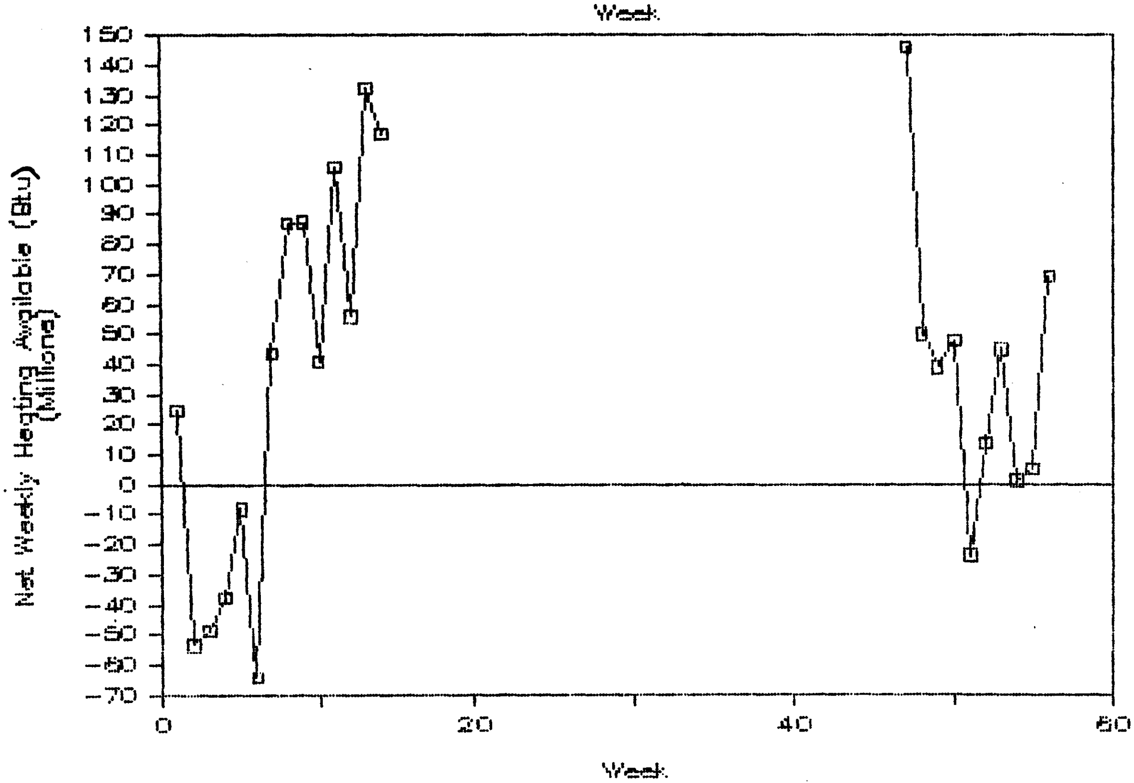


Figure 4-14: 1985 Net Weekly Excess Internally Generated Heat Available (a) Present (b) with Improved Air Handlers

heat source until the end of February last winter. Building operators found it necessary to resort to the same method again in early December, which was also when the installation of steam coils in the air handlers occurred.

In Figure 4-13 (b) the estimated auxiliary heating requirements with improved air handler performance or occupancy of the retail space both become positive at approximately 30 degF average weekly outdoor temperature. In 1985, these crossover points would have occurred in mid-February and in late December (see Figures 4-14 (b) and 4-15 (a)).

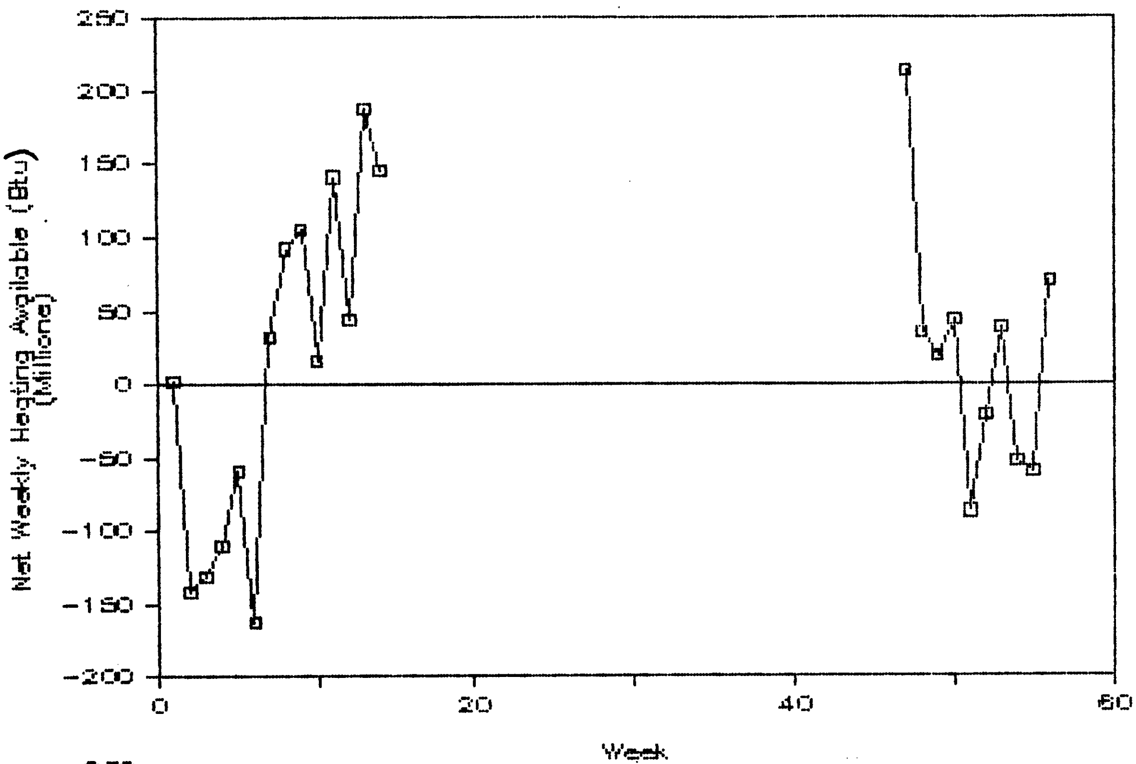
Figure 4-13 (b) indicates that with both improved air handler performance and retail space occupancy, auxiliary heating may not be required for average weekly outdoor temperatures down to about 20 degF. Figure 4-15 (b) shows this result over time and suggests that under these improved conditions, the building might not have needed any auxiliary heating in 1985.

Keeping in mind the simplicity of this analysis and the fact that losses and inefficiencies have been omitted, it seems likely that even with full retail space occupancy and improved air handler performance, some auxiliary heating will be required in the building during the coldest winter months (December through January).

In conclusion, this analysis confirms that auxiliary heating is presently needed to meet the heating requirements of the building. However with retail occupancy and improved air handler performance, auxiliary heating would be needed infrequently during the winter months.

Relative Efficiencies of Auxiliary Heating Stragegies. Assuming that supplemental heating may be needed in the building even with the

(a)



(b)

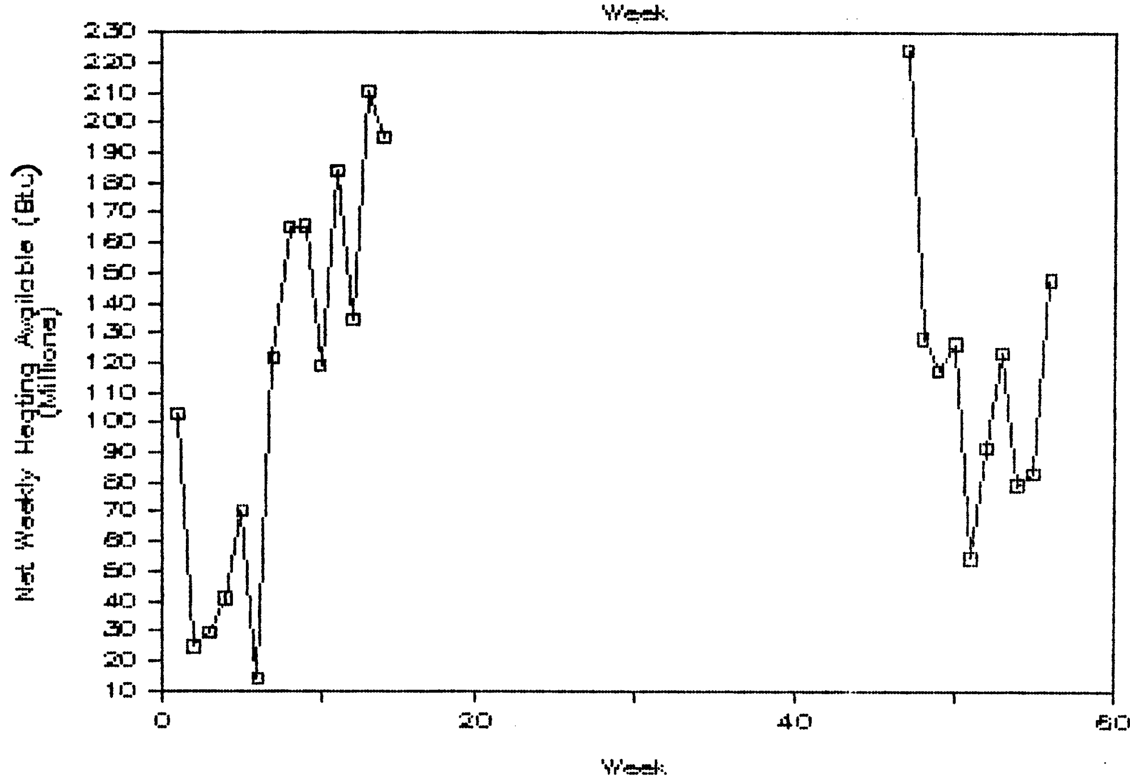


Figure 4-15: 1985 Net Weekly Excess Internally Genergated Heat Available
(a) with Retail Occupancy
(b) with Retail Occupancy and Improved Air Handlers

retail space occupied and improved air handler performance, what are the relative efficiencies of these auxiliary heating strategies?

- False loading with storage tanks
- False loading with steam coils in the air handlers
- Lights on for 24 hours
- Running heat pumps at night
- Direct steam heating to hot water loop

The heat recovery heat pump energy system is designed to extract "free" waste heat from necessary office heat sources such as lights, appliances, and people. The coefficient of performance of such an operation is equal to the ratio between the heat produced and the work performed. Using the terms from equation 4-2:

$$COP = q/L_c \tag{4-3}$$

$$COP_{net} = q/(L_c + L_{aux}) \tag{4-4}$$

where:

L_{aux} = energy use of auxiliary equipment

In the State Transportation Building, the heat pump COP for this type of operation typically ranges from about 4.0 to 6.0 for heating and about 3.0 to 5.0 for cooling.

If the heat extracted at the condenser is not entirely made up of "free" waste heat, then:

$$q_o = q_{free} + q_{sup} \tag{4-5}$$

where:

q_{sup} = supplemental heating

In this case, the COP would be defined as the ratio between the heat extracted and the work and heat supplied:

$$COP = q/(L_c + q_{sup}) \tag{4-6}$$

For example if the storage tanks, lights, or steam reheat coils are being used to increase the cooling load of the building or "false load", their contribution to the cooling load would be considered q_{sup}.

If q_{sup} was equal to the entire cooling load, then:

$$q_{sup} = q_o \tag{4-7}$$

$$COP = q/(L_c + q_o) = 1 \tag{4-8}$$

$$COP_{net} = q/(L_c + q_{sup} + L_{aux}) < 1 \tag{4-9}$$

Since the COP of false loading is unity, and COP_{net} when false loading is always less than unity, false loading will always be more costly than direct heating by the same source of heat.

The cost of false loading with storage tank water is proportional to the cost of producing the stored hot water. Assuming that the stored hot water was produced during occupied hours with "free" internally generated heat, then the cost of the stored heat would be equal to the cost of hot water produced by the heat pumps under regular occupied conditions.

If the steam coils in AC-1 and AC-2 are used to false load, then the cost of heat produced by this method would be proportional to the cost of steam. If the heat pumps are operated at night and the electric lights are used to false load by leaving them on for 24 hours, then the building is effectively being heated electrically because the heat produced is equivalent to the electric heat from the lights plus the electric heat from the heat pump compressors.

Table 4-1 summarizes the relative costs of false loading using different sources of heat. Also included for comparison are the cost of "free" heat pump heating, and directly heating with steam, lights, and the storage tanks.

All heat pump operation calculations assume that the amount of heat supplied to each heat pump evaporator is 2.101 mmBtu/hr, the amount of heat produced by each heat pump condenser is 2.575 mmBtu/hr, and the 300 ton chillers are each using 139 KWh of electricity (about 60 percent loading). This would be the typical occupied winter condition, neglecting ventilation losses. The false loading calculations assume that the heat supplied to the evaporators is entirely from a supplementary heat source.

COP_{net} quantities and net costs per mmBtu are also calculated for each case. These calculations include auxiliary energy costs for operating fans and pumps. When the heat pumps are operating, it is assumed that all fans are operating at their maximum winter flow rates, and that a hot water and chilled water pump are operating. When the storage tanks are being used for false loading, storage tank pump electric use is included. When heat is provided directly to the space from the storage tanks or steam, only the exterior fans and hot water pump electric use is included. Incremental costs for steam and electricity are $14.37/mmBtu and $0.08/kWh which are based upon current utility rates. The detailed calculations are listed in Appendix C.

In Table 4-1, different heating options are compared to the first item in the table, which is standard occupied heat pump operation or "free"

Table 4-1: Relative Costs and Coefficients of Performance of Different Building Heating Methods for Winter Part-Load Conditions

Method	COP	Gross Cost per mmBtu	COPnet	Net Cost per mmBtu	Percent of Standard
Standard Heat Pump Operation	5.42	$4.32	2.96	$7.92	100%
False Loading With Storage Tanks	1	$7.84	0.85	$14.96	189%
False Loading With Steam	1	$16.04	0.867	$19.65	248%
False Loading With Lights	1	$23.44	0.867	$27.04	341%
Direct Storage Tank Heating	1	$4.32	0.89	$12.27	155%
Direct Steam Heating	1	$14.37	0.91	$16.71	211%
Direct Electric Lights Heating	1	$23.44	1	$23.44	296%

heat recovery. The COP_{net} for this operation is 2.19 and the net cost per mmBtu is $10.29 when auxiliary equipment energy costs are included. This is the least expensive method for heating the building.

Of the different false loading methods, false loading with the storage tanks is the least expensive. With auxiliary equipment loads included, the cost of heating by storage tank false loading is 89 percent more than the cost of standard heat pump operation.

The next best false loading method would be to use steam. With auxiliary loads figured in, this option costs roughly two and a half times as much as standard heat pump operation.

The most expensive way to heat the building is to false load with the lights by leaving them on for 24 hours and running the heat pumps at night. When auxiliary equipment costs are figured in, this operation is even more expensive than direct electric resistance heating.

All three false loading options are less desirable than heating directly with the storage tanks. Direct storage tank heating costs about 50 percent more than standard heat pump operation, and 35 percent less than false loading with storage tank heat. At a net cost of $16.71 per mmBtu, direct steam heating is roughly twice as expensive as standard heat pump operation. Particularly notable is the fact that heating by false loading with the storage tanks is less expensive than direct steam heating. This is due to the fact that the net cost per mmBtu of the stored heat ($7.92) is considerably lower than that of the gross cost of steam heat ($14.37).

Directly heating the building with the electric lights costs $6.73/mmBtu more than direct steam heating, is more expensive than false loading with the storage tanks, and less expensive than false loading with either steam or lights.

This analysis results in a definite hierarchy of economic options for auxiliary heating in the building. As Figure 4-7 (b) illustrates, auxiliary heating should not be required on occupied days with average daily outdoor temperatures down to 35 degF if the building is allowed to 'sit' with all fans off to minimize infiltration losses at the air handlers.

The first choice for auxiliary heating would be to use the storage tanks directly for heating. If sufficient stored heat was not available, the next most economical option would be to false load with the storage tanks.

If neither of these options was feasible, the next best option is direct heating of the spaces with steam. The least desirable options would be running the heat pumps at night with the lights on, heating directly with the lights, or false loading with the steam coils.

A steam heat exchanger has been purchase although not yet installed to allow for the use of direct steam heating to the hot water loop as an emergency back-up. As the above analysis expalins, this is the most economical option next to using the storage tanks for direct heating of false loading.

For example, about 942.3 mmBtu of excess heat was supplied by leaving the lights on for 24 hours this past winter.[6] Using the COP_{net} value for direct electric lights heating, about $22,090 was spent for electric costs.[7] But the same amount of space heating could have been provided by direct steam heating via the building hot water loop for about $15,750 at a savings of $6,340.[8]

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[6]942.3 mmBtu = (10.47 mmBtu/day)(3 mnths)(30 dys/mnth)

[7]22,087=(942.3 mmBtu)($23.44/mmBtu)

[8]$15,746=(942.3 mmBtu)($16.71/mmBtu)

In conclusion, auxiliary heating is needed in the building from December through February with the present building heating requirements. However with retail space occupancy and improved air handler performance, the internal source heat pump and storage system should be able to meet the building's heating requirements in all but extreme conditions (average daily temperatures below 15 degF or average weekly temperature below 20 degF) when back-up heating will be necessary. Presently, heating during unoccupied hours is only required when average daily outdoor temperatures drop below 35 degF. If sufficient storage tank heating is not available, false loading with the storage tanks and direct steam heating are economically preferable over false loading with steam or leaving building lights on.

Summer Operation

To what extent is chilled water storage necessary to meet the cooling requirements of the building? How might this change with occupancy of the retail space?

As described in the Comparison with Designer's Predictions section earlier in this chapter, the peak cooling load in the building during this past summer was approximately 10.3 mmBtu/hr or 860 tons of cooling. Since the three heat pumps have a total cooling capacity of 1,200 tons, the thermal storage system has not been needed up until now to meet the building's cooling requirements except in the role of a back-up to the heat pumps in case they are not operable. Even with the occupancy of the retail space entailing an estimated additional peak cooling requirement of 222 tons, the peak cooling requirement in the building will most likely still be less than the 1,200 ton capacity of the heat pumps.

Although the storage system has not been necessary to meet the building's cooling requirements, the storage is potentially useful for reducing the building's electric demand for refrigeration equipment during occupied hours, and thereby reducing electric utility costs.

The energy system designers anticipated that typical summer operation (June-August) would be to use RU-1 and RU-2 during occupied hours to meet the building's cooling requirements, with the storage system used to partially meet the building's cooling load in conjunction with RU-1 and RU-2. The storage system would be cooled to 43 degF during unoccupied hours. During occupied hours, the thermal storage tanks would be used in the peak chilled water mode to meet cooling demands beyond the 600 ton combined capacity of RU-1 and RU-2. After heating the storage system during the day, the designers anticipated that the storage system would be cooled again to 43 degF at night using RU-1, RU-2, and RU-3 in preparation for the next day's operation.

This cooling system design actually uses more energy than a conventional cooling system because additional power would be required to run auxiliary pumping equipment as compared with conventional cooling systems which meet instaneous cooling loads. However the designers anticipated that this type of operation would save money by reducing utility demand charges during occupied hours and by taking advantage of off-peak electric rates during unoccupied hours.

Despite the apparent intentions of the designers, the energy system has not been able to function as they had planned. The energy management system was not installed with the demand limiting capability specified by the designers. Consequently, there is no signal given to building operators telling them when the building electric demand is approaching a pre-specified limit, and therefore no attempt is made to control building peak electric demand.

The building was assigned a conventional G-2 electric utility rate which does not have a time-of-use provision. There is a provision within the G-2 rate which allows for a demand charge reduction of 70 percent if the customer's peak electric load occurs during off-peak hours. However, taking advantage of this provision would require the installation of a utility meter which records when the peak electric demand occurs in the building. In any event, at present levels of building electric use even with off-peak storage the electric demand peaks always occur during occupied periods.

A special time-of-use electric rate, the J rate or G-8 rate, was available when the building was built but was not assigned to the building by Boston Edison. This rate would have required both separate metering of the energy system and heating of the building entirely by electricity. It was determined by Boston Edison that this rate would not be beneficial to the customer.[9]

Under the existing G-2 rate, the incremental demand cost is $9.2762 per kW November through June and $10.5152 per kW July through October. The incremental electric use cost has been about 0.08/kWh (including fuel charges) for the past year.

In December, new electric utility rates were proposed by Boston Edison to the Massachusetts Department of Public Utilities. These rates are presently under review by the DPW and may go into effect within the next year.[10] Under the prospposed G-2 rate, the incremental demand cost would be $9.8422 per kW for November through June and $16.2418 per kW for July through October. There is also a newly proposed T-2

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[9]According to Jack Ellis of the Boston Edison Energy Services Department.

[10]Source--James M. Russell, Boston Edison.

time-of-use rate. Under this new rate, the incremental demand charge would be $7.00 per kW for November through June and $13.00 per kW for July through October. Energy charges per kW would vary depending upon time of year and time of use. Off-peak hours would occur on weekdays between 9 p.m. and 8 a.m. EST and between 10 p.m. and 9 a.m. EDT. A summary of the existing and proposed utility rates is listed in Table 4-2. See Figures C-1 through C-3.

This section of the chapter presents some typical summer operation data along with a survey of other system operation alternatives. Included is a discussion of peak load and daily building cooling requirements at present and with retail space occupancy, how best to take advantage of the storage system cooling capacity, and the potential impact of the proposed utility rates upon the economics of the storage system operation.

Summer Operation Data. To determine the extent to which the storage system is typically used to meet the cooling requirements of the building and its impact upon electric demand, monitored data from the week of August 12-17, 1985 will be examined. This week includes August 15, the peak cooling day of the year.

Figure 4-16 graphs the daily cooling load profiles for Monday, August 12 through Saturday, August 17. From Monday the twelfth through Friday the sixteenth, only the two 300 ton heat pumps, RU-1 and RU-2, were in operation. Beginning with the evening of the sixteenth, the 600 ton heat pump, RU-3, was operated through Saturday the seventeenth. On every day except Tuesday, the typical operation was to run RU-1 and RU-2 during occupied hours from 7 a.m. to 5 p.m. while also using the storage tanks in the peak chilled water mode for additional cooling. On Tuesday which was a cooler day, only RU-2 was used during occupied hours with the peaked chilled water mode.

Table 4-2: Summary of Existing and Proposed Boston Edison G-2 and T-2 Utility Rates

Rate	Incremental Demand Cost		Incremental Use Cost		
	Nov-June ($/kW)	July-Oct ($/kW)	Nov-June ($/kWh)	July-Oct ($/kWh)	
Present G-2	9.2762	10.5152	0.08	0.08	
Proposed G-2	9.8422	16.2418	0.08	0.08	
Proposed T-2	7.0000	13.0000	0.0719	0.0756	(Peak)
			0.0561	0.0576	(Off-Peak)

Assumes:

For T-2 rate, Cost of Fuel = $0.2767/kWh
For G-2 rates, Incremental Use Cost based on 1985 electric use

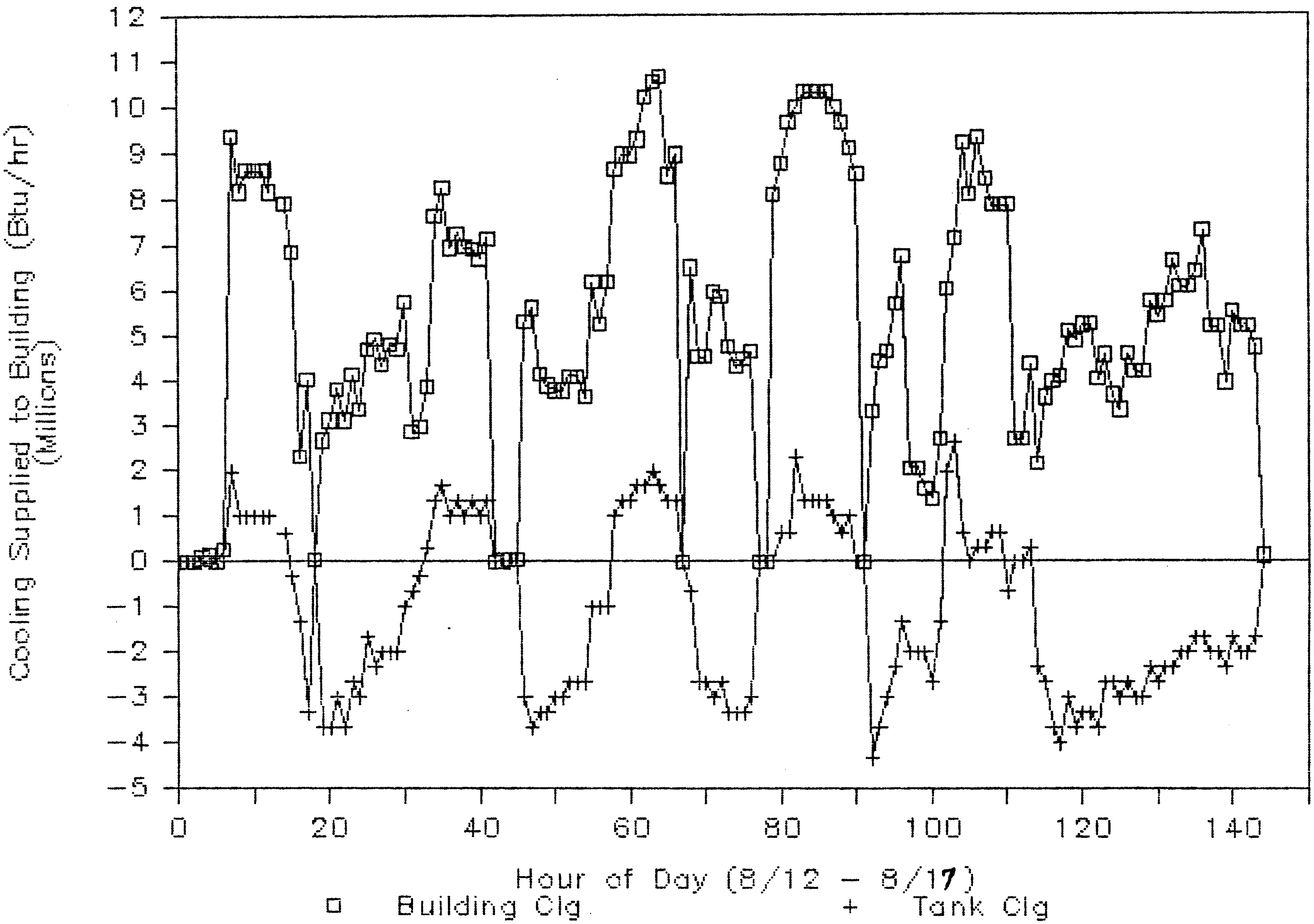


Figure 4-16: Monitored Building and Storage Tank Cooling Loads - (8/12/85 - 8/17/85)

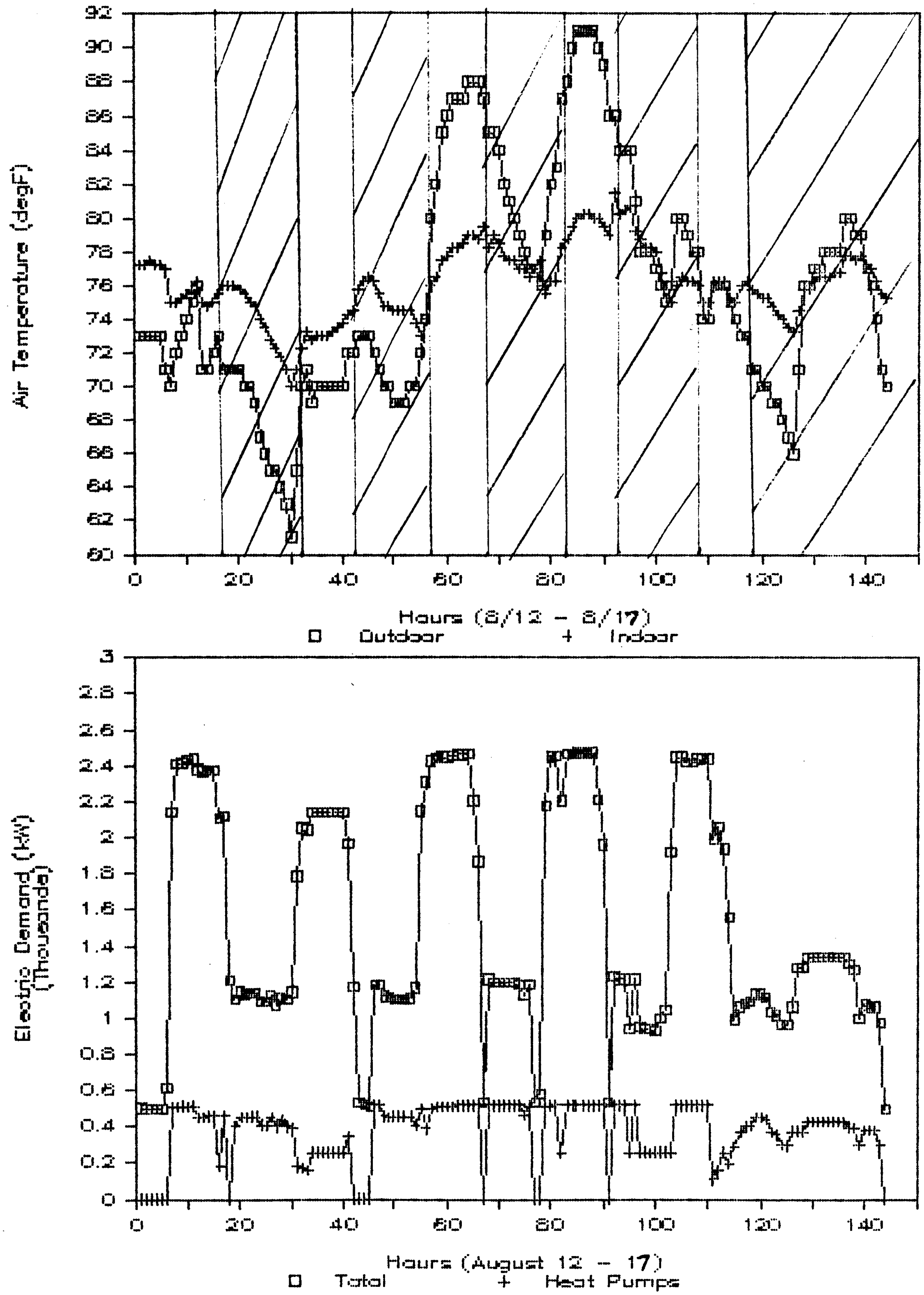
During unoccupied hours, RU-1 and RU-2 were usually run from about 7 p.m. until 5 a.m. in order to cool the storage tanks. On Friday night, RU-2 and RU-3 were both run from 7 p.m. through 4 a.m. RU-3 was then run alone all day on Saturday.

Figure 4-16 also graphs the storage tank cooling load curve. When the storage tank curve is positive, it shows the portion of the building cooling load being supplied by the storage tanks. When negative, it shows the amount of cooling supplied to the storage tanks. During occupied hours, the difference between the total cooling supplied to the building and the cooling supplied by the storage tanks was usually about equal to the peak cooling capacity of the heat pumps (600 tons or 7.2 mmBtu/hr). This is consistent with the method used to control the peak chilled water mode---to maintain the chilled water return setpoint and consequently the load on the heat pumps.

Note that frequently during unocccupied hours, a considerable amount of cooling was supplied to the building while the storage tanks were being cooled. The amount of cooling supplied to the building was usually roughly equivalent to the amount of cooling being supplied to the storage. Operators found that it was necessary to use the building to increase the cooling load on the heat pumps in order to achieve the low chilled water discharge temperatures (40-43 degF) needed to cool the storage.

Figure 4-17 (a) graphs the average monitored outside and inside return air temperatures over the week. The shaded portions of the graph are the occupied periods. Note that the lowest return air temperatures occur during unoccupied hours. This unoccupied cooling of the building is in effect pre-cooling some portions of the building, and may partially account for the difference between the designer's predicted peak cooling load and the monitored peak cooling load. However with night-time temperatures typically in the low sixties

(a)



(b)

Figure 4-17: Monitored Building Data - (8/12/85 - 8/17/85)
(a) Indoor and Outdoor Temperatures
(b) Total Building and Heat Pump Electric Demands

throughout the summer, pre-cooling could be done less expensively by using the cool night air instead of mechanical means. The question of why there is a need to use the building to increase the heat pump cooling load in this manner is discussed in the Thermal Storage section of Chapter V.

Figure 4-17 (b) graphs the total building electric load for the week and the portion of the electric load attributed to the heat pumps. By compensating for the difference between the building cooling demand and the peak capacity of the heat pumps, the storage tanks reduced the peak refrigeration equipment electric demand. For the heat pumps to meet the peak cooling demand of 10.3 mmBtu/hr or 860 tons without the storage, RU-3 and either RU-1 or RU-2 would be needed. This would require a total electric load of approximately 690 kW as opposed to approximately 500 kW for RU-1 and RU-2. There would also be some increase in the cooling tower electric loads depending upon ambient conditions. Since the magnitude of the cooling tower electric load is small in relation to that of the heat pumps, the cooling tower electric load is disregarded for the purposes of this analysis.

How valuable is this demand reduction of approximately 190 kW with the present utility rates? This analysis assumes that the peak electric demand for the month was 2500 kW (see Figure 4-17(b)) and that it would have been 2690 kW without the use of the storage system. Under the present utility rate, each kW of demand has an incremental cost of $10.5152 so the monthly savings in utility rates would be roughly $2,000. Out of the actual total August electric bill of $98,590, this is a savings of about 2 percent.

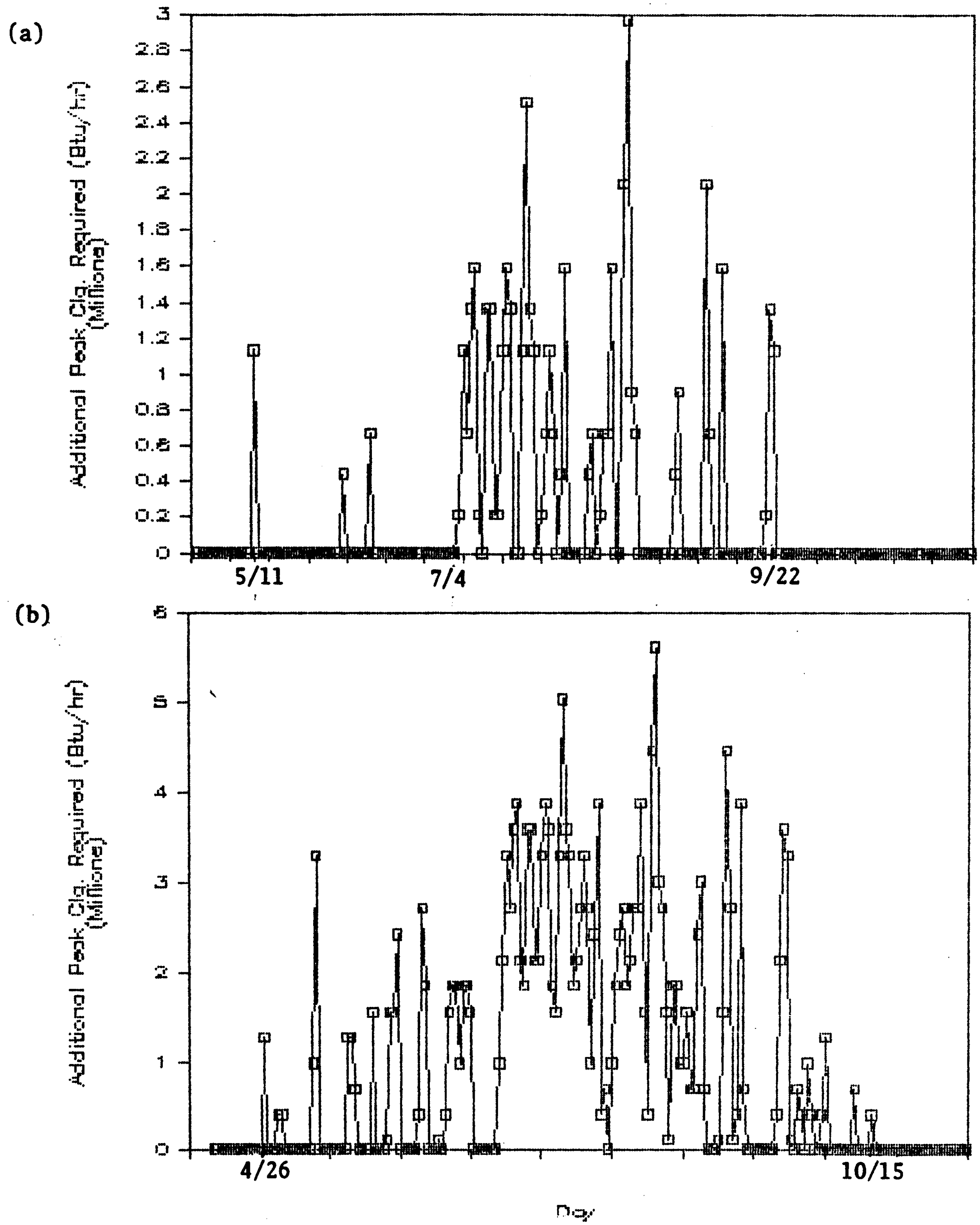
In fact, the peak electric load for the month of August (and for the entire year) was 2808 kW. Under the present Boston Edison G-2 utility rates, the customer is billed for the peak electric demand which occurred for at least fifteen minutes at any time during the month.

Since there is presently in the building no record of when the peak occurs and no capability to control the peak load, what probably happened is that at some time during the month, all three heat pumps were operated together for a short period while the lighting and appliance load in the building was still high. Therefore any demand reduction obtained by using the storage system was negated.

Part Chilled Water Storage. Using the storage system to offset cooling requirements above the 600 ton peak capacity of RU-1 and RU-2 as the designers proposed, how often and when during the cooling season is the storage system necessary? What is the potential for utility cost savings if the mechanical equipment electric demand was controlled?

Daily peak cooling requirements and total daily storage system cooling requirements were calculated for the cooling season using 1985 weather data and the cooling load equations from Figure 4-3(b) and Figure 4-8(b). For this analysis, based upon the monitored cooling load curve in Figure 4-11(a) it was assumed that the peak daily cooling load would be ten percent above the average daily occupied cooling load. See Table C-51 for calculations.

Using 1985 weather data, it was found that peak cooling loads exceeded 600 tons for a few days in May and June, and for many days in July, August, and September (see Figure 4-18(a)). These peak loads range up to 3 mmBtu/hr (250 tons) above the 600 ton capacity of RU-1 and RU-2. With retail space occupancy, peak loads above 600 tons were predicted from late April to mid-September (see Figure 4-18(b)). These peak loads ranged up to 5.6 mmBtu/hr or 470 tons above the 600 ton capacity of RU-1 and RU-2. The use of 1985 weather data yields a conservative estimate of potential peak electric demand reduction since 1985 was a relatively cool year.



<u>Figure 4-18: Estimated Daily Peak Cooling Requirements</u>
<u>Beyond 600 Tons - 1985</u>
(a) Present Cooling Loads (b) With Retail Occupied

Table 4-3 lists the monthly peak cooling loads for each utility billing period in Column (a) and the total amount of cooling which would be extracted from the storage system that month in Column (b). Note that with the present building cooling requirements, peak cooling demands and monthly storage system cooling supplies are small relative to the peak cooling available from RU-1 and RU-2 of 7.2 mmBtu/hr and to the daily peak cooling supply from RU-1 and RU-2 during occupied hours of 79.2 mmBtu.

Potential demand cost savings for each billing period were calculated using the equation:

Savings=Demand Savings+Operation Cost Savings-Operation Costs (4-10)

where:

Demand Savings = incremental cost savings for reduced demand in column (a)

Operation Cost Savings = savings due to off-peak electric rates

Operation Costs = additional pumping costs and other costs due to operating equipment during unoccupied hours

No operation cost savings were incurred for the G-2 rate calculations because there is no reduced off-peak rate. Operating costs were calculated by comparing the relative efficiencies of cooling instantaneously during occupied hours versus cooling the storage system during unoccupied hours. From summer operation data, it was found that COP_{net} when cooling during occupied hours was on average 3.99 while COP_{net} while cooling during unoccupied hours was on average 1.23. This difference is attributable to the fact that when the storage system is cooled, usually only about half of the cooling provided by the heat pump is stored while the rest is provided to the unoccupied building. Detailed calculations are listed in Appendix C.

Table 4-3: Potential Demand Cost Savings for Partial Chilled Water Storage with Present Unoccupied Hours Storage Efficiency

Utility Bill Time Period	(a) Present Storage System Peak Cooling Demand (Btu/hr)	(b) Present Storage System Cooling Supply (Btu)	Present G-2 Monthly Utility Bill Total Cost Savings	Proposed G-2 Monthly Utility Bill Total Cost Savings	Proposed T-2 Monthly Utility Bill Total Cost Savings	(c) w/Retail Storage System Peak Cooling Demand (Btu/hr)	(d) w/Retail Storage System Cooling Supply (Btu)	Present G-2 Monthly Utility Bill Total Cost Savings	Proposed G-2 Monthly Utility Bill Total Cost Savings	Proposed T-2 Monthly Utility Bill Total Cost Savings
Apr 11 - May 13	1,134,689	4,146,892	$697	$743	$534	3,301,708	33,921,395	$1,741	$1,874	$1,376
May 14 - June 12	674,056	0	$447	$474	$337	2,721,310	84,653,073	$688	$798	$676
June 13 - July 15	1,595,322	45,150,413	$603	$1,256	$1,112	3,882,106	356,431,375	($1,778)	($191)	$692
July 16 - Aug 14	2,516,589	74,172,700	$913	$1,942	$1,730	5,042,902	508,732,718	($2,912)	($850)	$525
Aug 15 - Sept 13	2,977,222	48,372,464	$1,599	$2,816	$2,369	5,623,300	274,078,632	$614	$2,913	$2,981
Sept 14 - Oct 11	1,365,005	10,596,951	$886	$1,444	$1,181	3,591,907	76,849,592	$1,685	$3,154	$2,707
Oct 12 - Nov 12	0	0	$0	$0	$0	399,718	0	$265	$281	$200
Total Annual Savings			$5,145	$8,675	$7,263			$302	$7,981	$9,158

NOTES

1. Assumes 0.857 kW/ton of cooling (Manufacturer's Rating)

Table 4-3 lists the calculated potential total cost savings with the present cooling load for the current and proposed G-2 rates, and for the proposed T-2 rates. (See Appendix C for calculations.) With operation cost losses included, annual savings of $5,145 could be obtained under the present G-2 utility rate. With the proposed G-2 rate, annual savings could be as much as $8,675 as a result of the increased demand charge. Lesser savings would accrue under the proposed T-2 rate because the demand charge is higher with the G-2 rate despite the fact that the off-peak electric use charge is lower with the T-2 rate than with the G-2 rate (see Table 4-2).

Column (c) of Table 4-4 lists the estimated peak cooling demand on the storage system with retail space occupancy. Column (d) lists the estimated monthly storage system cooling supply when the retail space is occupied. Note that with the retail space occupied, storage system peak cooling demands would be about twice as high as with the present building cooling load, and storage system cooling supply would be several times greater than with the present building cooling demands.

Utility cost savings with the retail space occupied are listed for the current and proposed G-2 rates and for the proposed T-2 rates. With the current G-2 rate, annual utility cost savings with retail space occupancy would be almost zero. Even though demand cost savings would be twice as high with the retail space occupied, the operation costs of cooling the storage would be several times higher due to the increased storage system cooling load. Higher savings would be gained with the proposed G-2 and T-2 rates as a result of their increased incremental demand costs, With retain occupancy, the proposed T-2 rate would save more money than the G-2 rate due to lower operating costs with the T-2 rate.

In conclusion, utility cost savings on the order of $5,000 annually are potentially available with the existing building electric use and

Table 4-4: Potential Demand Cost Savings for Partial Chilled Water Storage with Ideal Unoccupied Hours Storage Efficiency

Utility Bill Time Period	(a) Present Storage System Peak Cooling Demand (Btu/hr)	(b) Present Storage System Cooling Supply (Btu)	Present G-2 Monthly Utility Bill Total Cost Savings	Proposed G-2 Monthly Utility Bill Total Cost Savings	Proposed T-2 Monthly Utility Bill Total Cost Savings	(c) w/Retail Storage System Peak Cooling Demand (Btu/hr)	(d) w/Retail Storage System Cooling Supply (Btu)	Present G-2 Monthly Utility Bill Total Cost Savings	Proposed G-2 Monthly Utility Bill Total Cost Savings	Proposed T-2 Monthly Utility Bill Total Cost Savings
Apr 11 - May 13	1,134,689	4,146,892	$752	$798	$572	3,301,708	33,921,395	$2,187	$2,321	$1,690
May 14 - June 12	674,056	0	$447	$474	$337	2,721,310	84,653,073	$1,803	$1,913	$1,458
June 13 - July 15	1,595,322	45,150,413	$1,198	$1,850	$1,541	3,882,106	356,431,375	$2,915	$4,503	$4,076
July 16 - Aug 14	2,516,589	74,172,700	$1,890	$2,919	$2,435	5,042,902	508,732,718	$3,787	$5,849	$5,355
Aug 15 - Sept 13	2,977,222	48,372,464	$2,236	$3,453	$2,828	5,623,300	274,078,632	$4,223	$6,523	$5,583
Sept 14 - Oct 11	1,365,005	10,596,951	$1,025	$1,583	$1,281	3,591,907	76,849,592	$2,697	$4,166	$3,436
Oct 12 - Nov 12	0	0	$0	$0	$0	399,718	0	$265	$281	$200
Total Annual Savings			$7,547	$11,078	$8,994			$17,877	$25,556	$21,798

NOTES

1. Assumes 0.857 kW/ton of cooling (Manufacturer's Rating)

electric rates if demand peaks are controlled by operating only RU-1 and RU-2 during hours of peak electric demand. With retail space occupancy and the proposed electric rates, annual utility cost savings on the order of $9,000 would be possible.

Ideal Part Chilled Water Storage. The previous analysis was performed to estimate the potential for electric demand cost savings using the storage system to offset chilled water use beyond the combined capacities of RU-1 and RU-2. The analysis assumed off-peak cooling conditions similar to those experienced this past summer in the building where roughly 50 percent of the cooling produced during unoccupied hours was supplied to the storage system and 50 percent was supplied to the building.

If the system was operating ideally so that heat pump performance was comparable to that of fully loaded occupied conditions and all of the cooling supplied by the heat pumps was stored in the thermal storage tanks, then the cost savings of electric demand reduction could be more fully realized.

Table 4-4 summarizes these ideal demand cost savings with present occupancy and with retail space occupancy for the current and proposed utility rates. These costs were calculated in the same manner as in Table 4-3 except for a reduction of the operation cost loss term. (See Appendix C for calculations.)

With the present building cooling requirements, additional annual savings on the order of $2,500 would be obtained. With retail space occupancy, more substantial cost savings would be possible because more storage system cooling would be needed. With the existing G-2 electric rate, utility cost savings of $17,900 would be possible. With the proposed G-2 rate, cost savings of $25,560 would be possible. The proposed G-2 rate would provide more utilility cost savings than the proposed T-2 rate due to the higher demand costs under the G-2 rate.

The potential cost savings of $25,560 with retail space occupancy and the proposed G-2 rate would represent a 2.4 percent reduction in the annual electricity bill of the entire building. This major savings would be possible if the storage system could be efficiently cooled during unoccupied hours without using the building to increase the heat pump cooling load. Chapter V discusses operation methods through which this more efficient operation could be obtained.

The savings figures in Tables 4-3 and 4-4 were computed assuming that RU-1 and RU-2 are operated at 100% loading. Additional demand cost savings could be acheived by using the demand limiter settings on RU-1 and RU-2 and using the storage system to provide more of the building cooling. For example, operation with the 80% demand limiter setting would increase the monthly savings in Table 4-4 by about $1,100 under the current G-2 rate, and by about $1,700 under the proposed G-2 rate.

In conclusion, chilled water storage is not presently required to meet the building's cooling requirements nor is it likely to be necessary when the retail space is occupied except as a back-up to the heat pumps. Chilled water storage as presently used in the building, is not economically advantageous because the stated design goal of electric demand reduction is not being achieved, and the chilled water storage operation results in increased building electric use and wasteful cooling of unoccupied spaces.

However there is potential for electric utility cost savings with the thermal storage system if the mechanical system electric demand is controlled during peak electric use hours by operating only RU-1 and RU-2. With this type of operation, the storage system could save as much as $9,160 annually after the retail space is occupied and the new T-2 utility rate is available. If more efficient storage system cooling was obtained, electric utility savings of up to $25,560 would be possible with retail occupancy and the proposed G-2 rate.

Spring/Fall Operation

During the spring and fall when the transitions between the heating and cooling seasons occur, many questions arise concerning efficient energy system operation. In the spring as the need for heat decreases in the building, we need to address the questions of when heat storage should stop, when free cooling should be used, and when chilled water storage should begin? Similarly in the fall, we need to address such questions as when should chilled water storage stop, when should free cooling be used, and when should hot water storage begin?

Due to the nature of the energy system where heat supply depends upon mechanical cooling during occupied hours and stored heat during unoccupied hours, the energy and storage systems must be managed on both a daily basis and a seasonal basis in order for the system to work as designed. This system of the chapter examines the benefits of free cooling as compared with mechanical cooling and the inherent restraints imposed by heating requirements upon the time when free cooling can be used.

Weather data, and building heating and cooling data based upon monitored data from 1985 are used to predict at what time of year heating and cooling transitions occur. 1985 weather data yields somewhat conservative data since 1985 was a relatively cool year. However considering the nature of the energy system, conservative estimates of building heating requirements are appropriate.

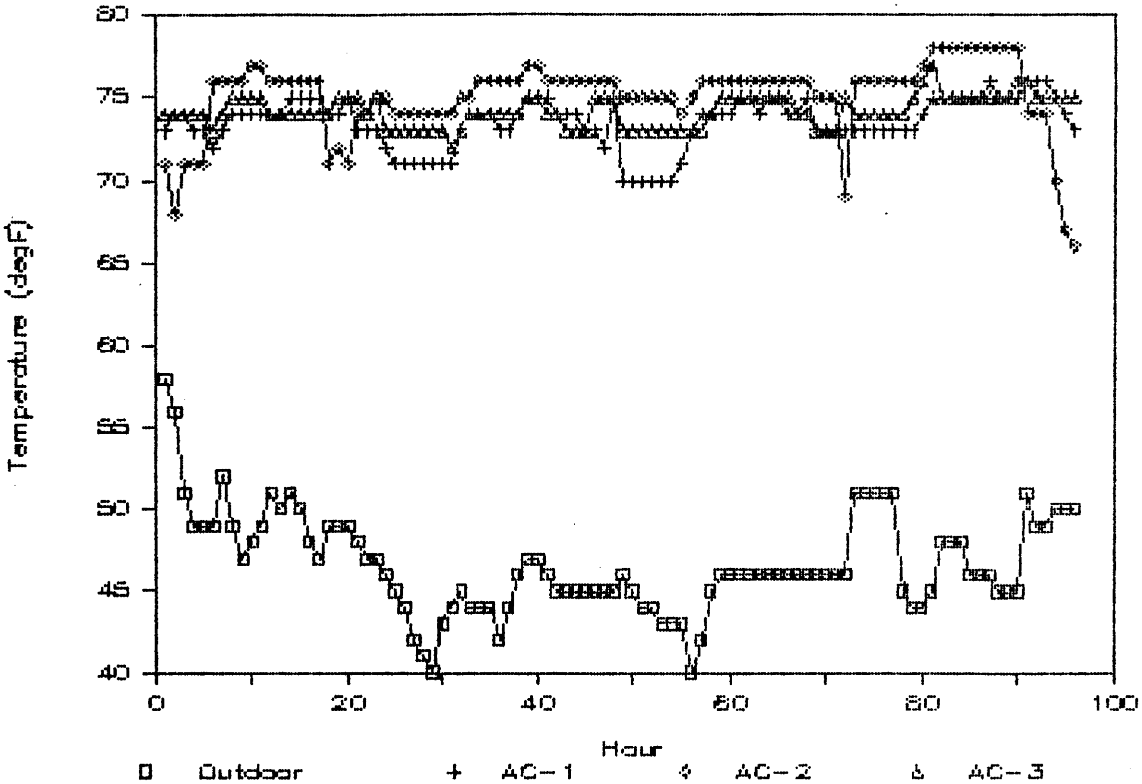
Benefits of Free Cooling. What are the relative cost and energy efficiencies of free cooling versus mechanical cooling? While free cooling or using cool outdoor air as the building cooling supply, the only energy cost is that of operating the fans. While mechanical cooling, energy costs include electric loads from the heat pumps, fans, pumps, and cooling towers. Whether free cooling or mechanical cooling, the net coefficient of performance (COP_{net}) of either operation will vary depending upon the building cooling load and outdoor air enthalpy or temperature.

Figure 4-19 illustrates the relative efficiencies of free cooling versus mechanical cooling during the four day period of October 28-31. This monitored data shows that with outdoor temperatures in the high forties and low fifties (See Figure 4-19(a)), free cooling provided much higher cooling COP_{net} values than mechanical cooling. Figure 4-19(b) graphs the occupied hours COP_{net} values over the four day period. On the first three days, mechanical cooling was used. On the fourth day, free cooling was used exclusively. On the days when mechanical cooling was used, the building COP_{net} was about three or four with the exception of a four hour period on October 28 when free cooling was used along with mechanical cooling. On October 31 when free cooling was used, the hourly building COP_{net} ranged from 15-18.

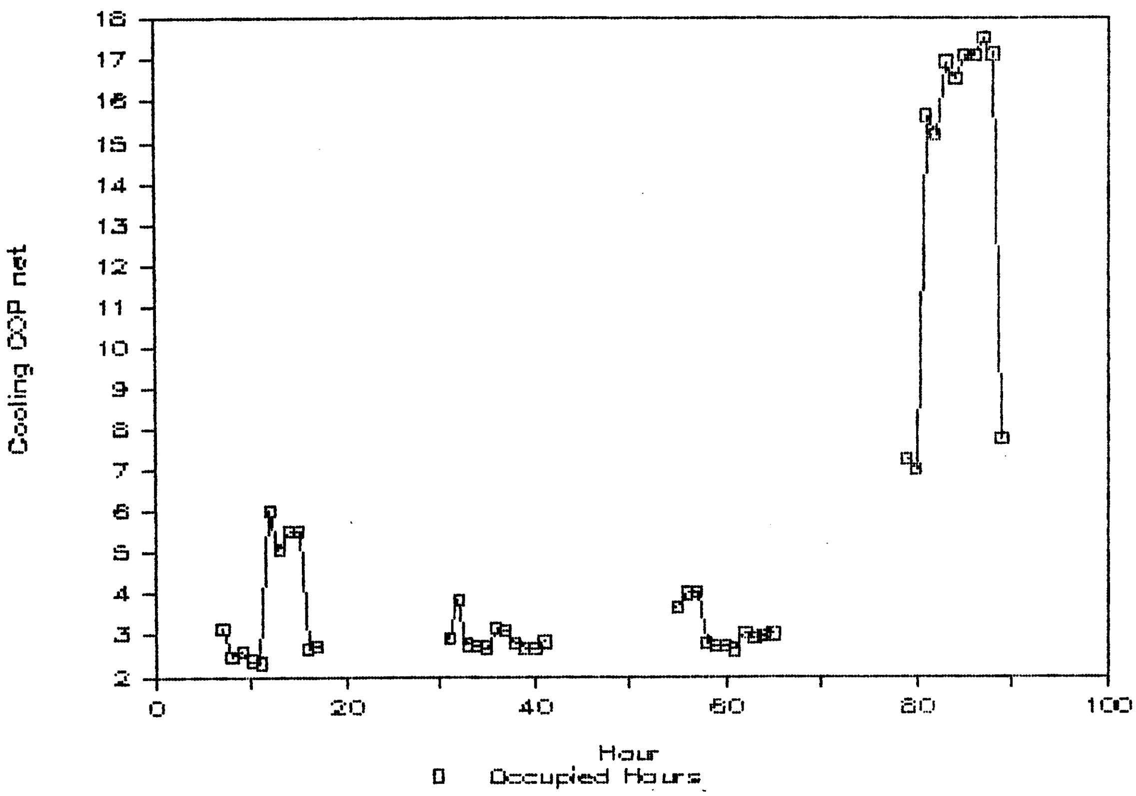
Figure 4-20 illustrates the relative efficiencies of free cooling and mechanical cooling on October 3, 1985. Although mechanical cooling was actually used on this day, a daily computer model simulation was run using free cooling for comparison (See Figure C-4 for the computer model run summary). With average outdoor temperatures in the mid-fifties during occupied hours, mechanical cooling was provided with a COP_{net} of 3 or 4 while free cooling would have provided the same amount of cooling at COP_{net} of 10 to 6. Free cooling would have reduced the total daily building electric use by 5570 kWh at a cost savings of $450.

Free cooling can both provide electric use savings, and also be used in the same way as chilled water storage to reduce peak electric demand. Figure 4-20(b) reveals that free cooling would not only have provided electric energy use savings but also would have reduced the peak daily electric demand by about 500 kW with a potential monthly demand cost savings of $5260 under the current electric utility rates.

(a)



(b)



<u>Figure 4-19: Monitored Building Data - 10/28/85 - 10/31/85</u>
<u>(a) Indoor and Outdoor Temperatures</u>
<u>(b) Occupied Hours Cooling COP_{net}</u>

(a)

(b)

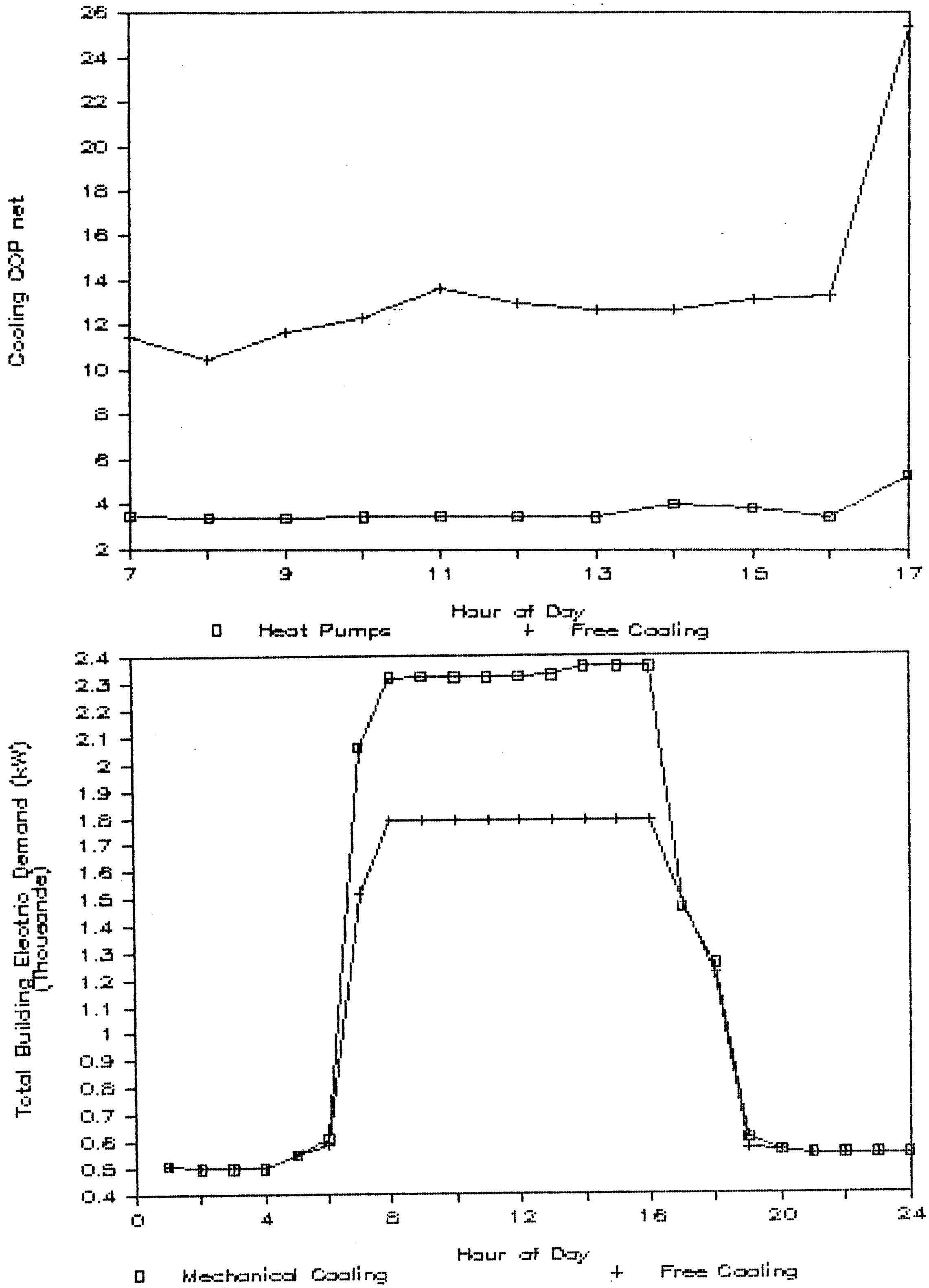


Figure 4-20(a): Comparison of Modeled Free Cooling to Actual Mechanical Cooling COP_{net}

Figure 4-20(b): Comparison of Modeled Free Cooling to Actual Mechanical Cooling Electric Demand Profiles

How do the relative efficiencies of free cooling and mechanical cooling change with variations in building cooling requirements and outdoor air temperatures? Energy system cooling simulations were conducted for a range of outdoor air temperatures and corresponding building cooling loads. Table C-47 summarizes the results using present building cooling requirements. Only sensible cooling loads are included in this analysis since latent loads are usually negligible for the temperature ranges being considered.

Figure 4-21 (a) graphs the data in Table C-47 comparing hourly free cooling and mechanical cooling COPnet values for outdoor air temperatures ranging from 50 to 68 degF. Free cooling COPnet values range from about 80 at outdoor temperatures of 50 degF down to less than 1 at outdoor temperatures of 68 degF. As outdoor temperatures get warmer, more air is required for cooling and more fan power is required. Since fan power is proportional to the cube of the fan flow rate, COPnet is proportional to the cube of the outdoor air temperature. Mechanical cooling COPnet values stay relatively constant at about 3 or 4 throughout the temperature range.

Figure 4-21 (b) shows a close-up of the free cooling and mechanical cooling load COP curves for the 60-68 degF temperature range. Note that above 64-65 degF, mechanical cooling is actually more efficient than free cooling alone because a very large amount of outdoor air is required to meet building cooling requirements at these high temperatures. Lines are drawn on the figures to show the limit of the Transportation Building fan system. Above roughly 67 degF, the 600,000 cfm total capacity of the building's air handlers cannot meet the cooling requirements of the building with free cooling.

This analysis illustrates that for outdoor temperatures below 64-65 degF, exclusive free cooling would more economically meet building

(a)

(b)

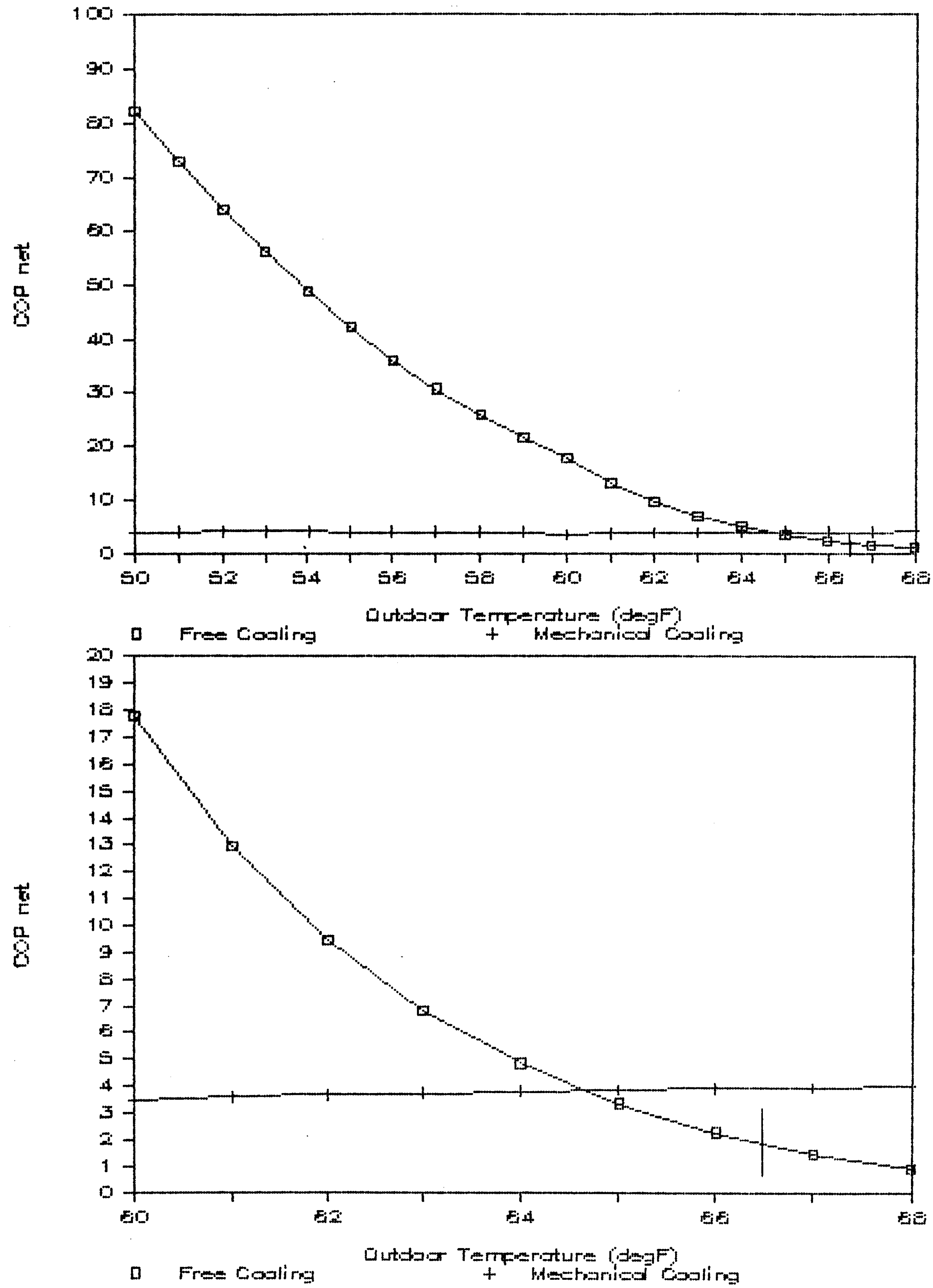


Figure 4-21: Free Cooling vs. Mechanical Cooling COP_{net}
(a) 50 - 68 degF (b) 60-68 degF

cooling requirements than mechanical cooling. This does not mean that for outside air temperatures above 65 degF, free cooling should not be used at all. Even when mechanical cooling is in use, free cooling in conjunction with mechanical cooling will reduce building cooling loads and consequently heat pump electric use and demand as long as outdoor air enthalpies are below indoor air enthalpies.

Cooling Requirements. Figures 4-22 (a) and (b) graph the amount of mechanical cooling required during occupied hours in addition to free cooling on the basis of 1985 weather data. Separate points are plotted assuming either present building cooling loads or projected building cooling loads with retail space occupancy (See Table C-52 for data).

Because the retail space will be served by separate air handlers and only mechanical cooling will be supplied by the central energy system, there are two possible scenarios. Figure 4-22 (a) assumes that when AC-1, 2, 3 are using econonomizer cooling, the air handlers serving the retail spaces will be doing the same. Figure 4-22a shows that mechanical cooling would only be required between April 26 and October 15. Mechanical cooling beyond the capacity of one heat pump, either RU-1 or RU-2, would only be required between June 1 and September 19. Note on the negative side of the figure that there are several days, particularly in the spring and the fall when no mechanical cooling will be required.

However it is conceivable that the scenario in Figure 4-22 (b) might occur. In this figure, it is assumed that the economizer option is not being utilized by the retail space air handlers. Therefore the central energy system would be obliged to supply chilled water throughout the cooling season to the retail area. Although the retail space mechanical systems are required to have an economizing option, the State Transportation Building management will not have control

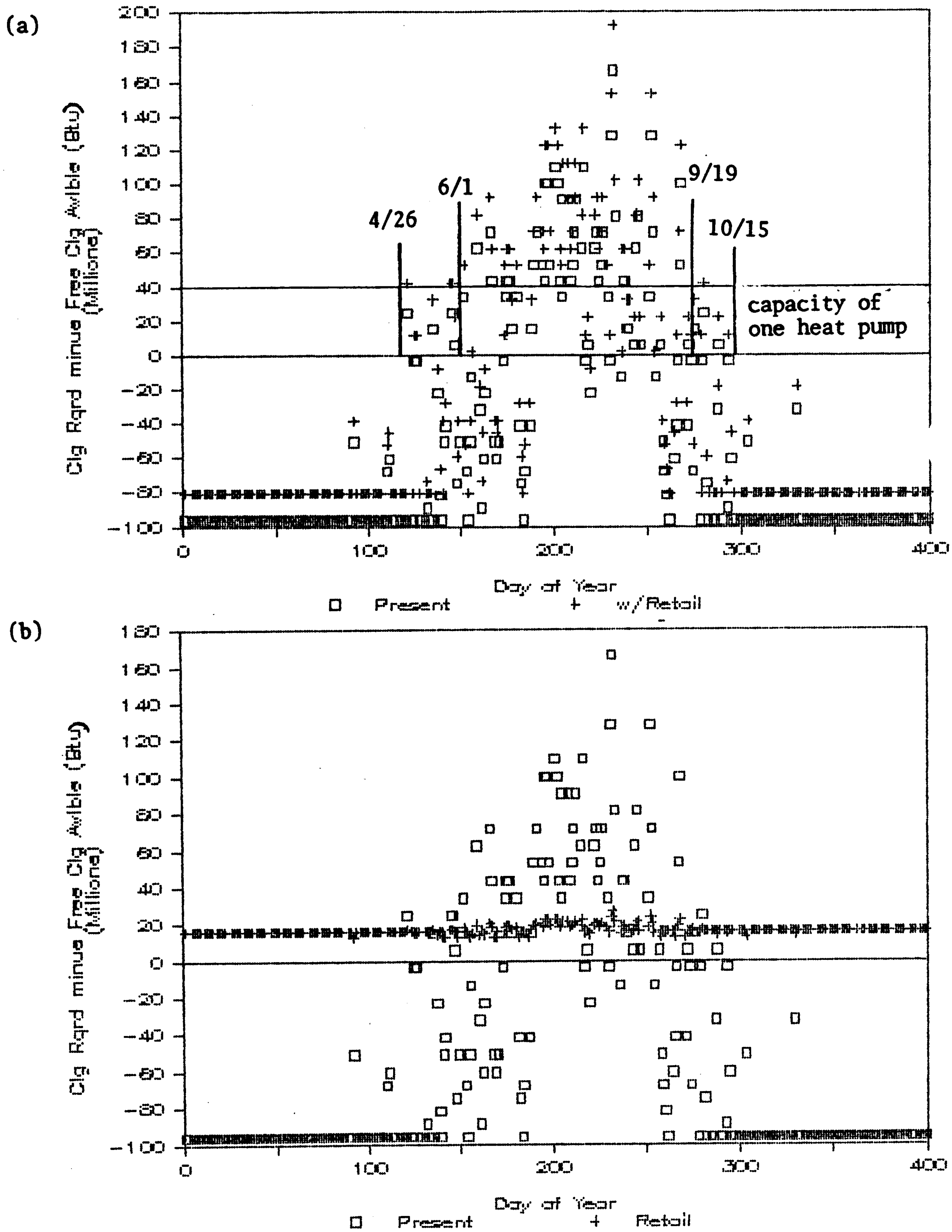


Figure 4-22: Building Cooling Requirement Beyond Available Free Cooling
(a) Total Building Free Cooling
(b) No Retail Free Cooling

over the operation of the retail space handlers. Clearly the first scenario would be preferable with respect to operation cost for both the State Transportation Building management and the retail space tenants.

Heating Requirements. Up until now, we have been looking at the need for mechanical cooling entirely from the perspective of meeting the building's cooling requirements. When is mechanical cooling necessary to meet the heating requirements of the building?

Figure 4-23 (a) plots the daily occupied hours heating requirements. The positive side of the figure indicates days when heating would be required. The negative side of the figure indicates days when heating would not be required. The figure shows that no or very little heating would be needed between July 1 and September 6, that heating would be required for some occupied days between April 26 and October 2, and heating would be required for all occupied days between October 2 and April 26. Note that the results for present building conditions with air handler improvements are roughly the same during occupied hours.

Figure 4-23 (b) plots the amount of heating required in the building during weekday unoccupied hours with present building heating requirements and air handler improvements. With the present building heating loads, no heating would be needed between April 10 and November 12. With air handler improvements, no weekday unoccupied heating would be needed between March 22 and November 26.

During weekends, heating is required later in the season than during weekday unoccupied hours because building internal heat gains are diminished over the two-day period. Figure 4-24 (a) shows that weekend heating is needed for most weekends except between June 1-September 1. See Tables C-53 and C-54 for the data from Figures 4-23 and 4-24.

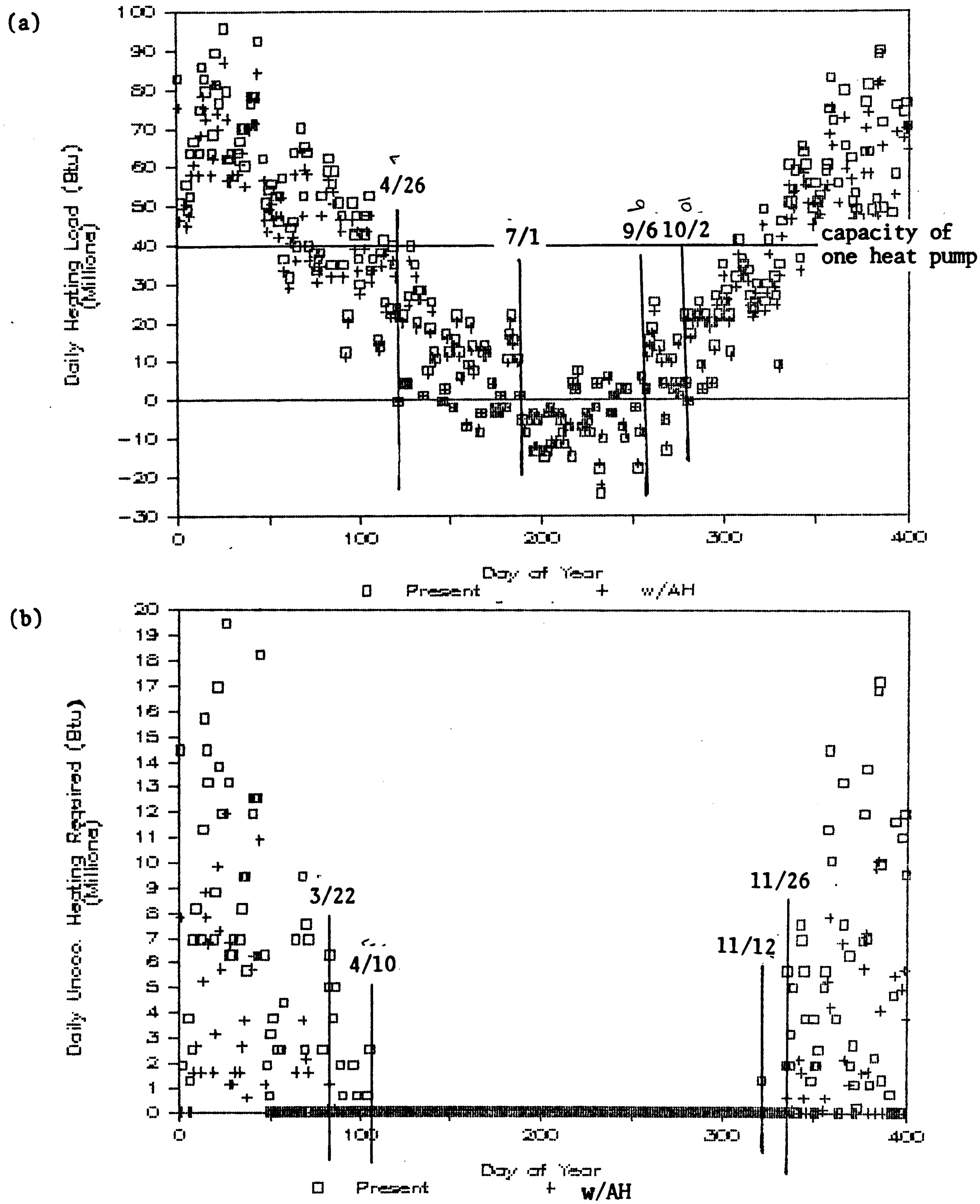


Figure 4-23: 1985 Daily Heating Requirements
(a) Occupied (b) Unoccupied

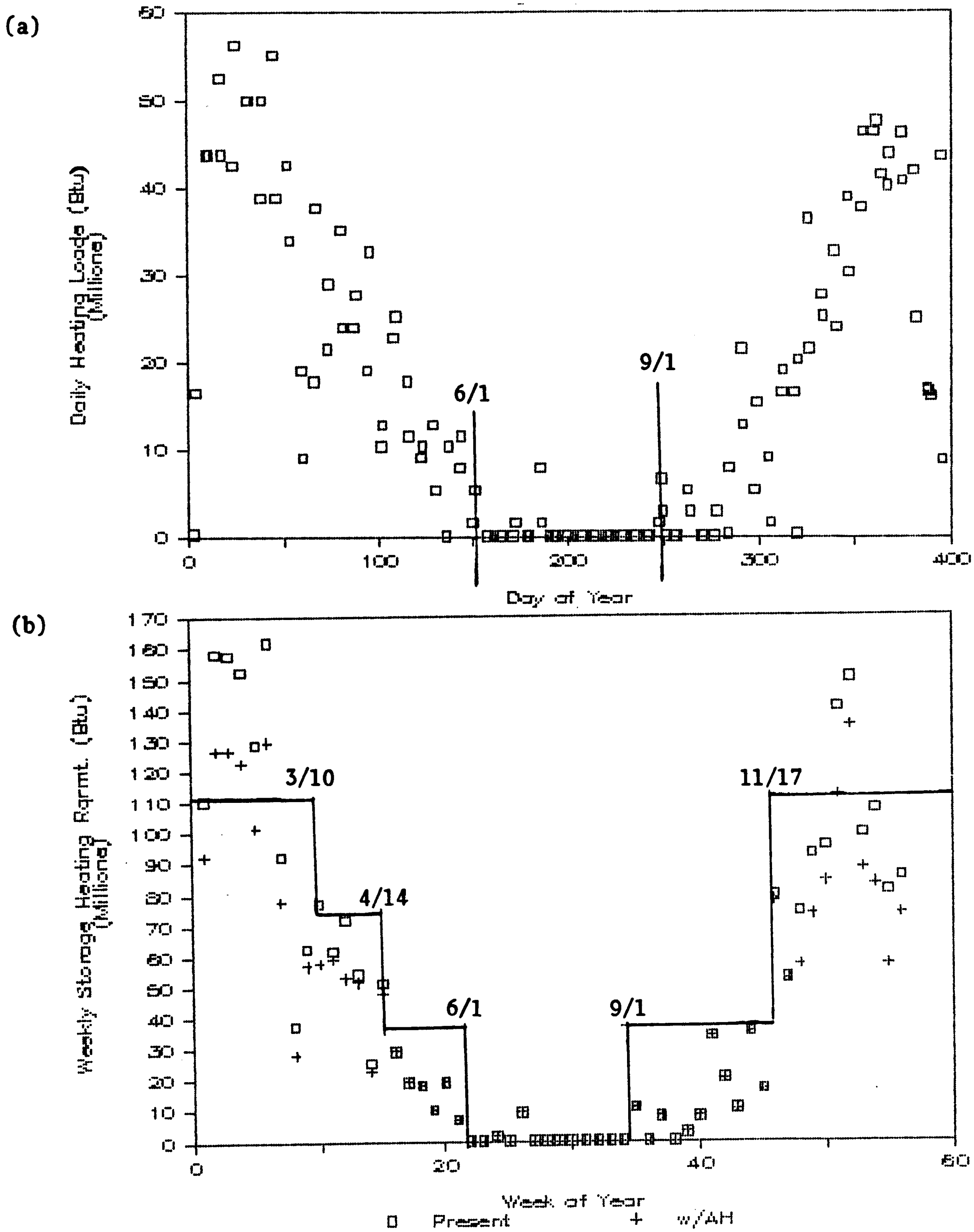


Figure 4-24(a): 1985 Weekend Daily Heating Requirements
Figure 4-24(b): 1985 Weekly Storage Heating Requirements

Storage Management. Assuming that the unoccupied hours heating requirements are met by the excess heat recovered by the heat pumps and stored in the thermal storage system, we then know from the previous analysis that heat storage will be necessary between early November and early April to meet the present unoccupied hours heating load, and between early September and early June to meet weekend heating loads. Stored heat might also be used during occupied hours in the spring and fall in conjunction with free cooling without operating the heat pumps.

How much heat must be stored each week during occupied hours in order to meet the unoccupied hours heating requirements of the building? Figure 4-24(b) graphs the weekly unoccupied hours heating requirements over 1985 including weekdays and weekends (see Table C-55 for data).

How do these weekly heating requirements relate to the thermal capacity of the system? The system designers anticipated a heat storage capacity of 37.8 mmBtu for each storage tank and a cooling storage capacity of 30.2 Btu/degF.[11]

On Figure 4-24(b), areas have been blocked in to designate the designer's projected heat storage capacity of each tank. The diagram indicates that all three storage tanks would be needed until March 10, tow would be needed until April 14, and one would be needed until June 1 for heat storage. One tank would be needed after September 1 and

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[11]The designers anticipated a 20 degF temperature differential between the tanks and the hot water loop in the winter, and a 16 degF temperature differential between the the tanks and the chilled water loop in the summer. This issue is discussed in more depth in Chapter V.

all three would be needed after November 17. Note that the diagram indicates unoccupied heating beyond the designers' projected storage capacity would be needed for some weeks in the winter even with a reduced building heating load resulting from air handler improvements. This suggests that even if enough heat was available to meet unoccupied heating loads, the storage system may not always have sufficient capacity to store it. Obviously, this would be a function of how much heat is stored in and extracted from the tanks each successive day, which would depend upon day-to-day weather conditions.

Figure 4-24(b) indicates that all three storage tanks would be available for chilled water storage from June through August, two would be available from mid-April to mid-November, and one would be available from mid-March until mid-November. Referring to Figure 4-18(a) and (b), this schedule would accommodate the time period within which chilled water storage is required for demand management purposes.

As Figures 4-22(a) and 4-23(a) indicate, there are several days between late April and late October when little or no heating is required and the cooling load cannot be met exclusively by free cooling. Generally, these times occur when average daily outdoor temperatures are in the 55-65 degF range. There are also several days between late April and early June, and again between mid-september and mid-October, when daily occupied heating and cooling loads could be met by operating only one heat pump in conjunction with free cooling.

With spring and fall operation, we encounter enormous difficulty in prescribing specific optimal operating modes because the weather in the Boston area is extremely variable. Daily average temperatures typically have a twenty degree variance from one day to the next. It is therefore difficult to predict how much stored heat will be required for any more than a day or two in advance.

Many thermal storage systems are operated so that the storage is always heated to capacity even if the full capacity is not immediately needed. This conservative operating strategy seems to be especially suited to a system like that of the State Transportation Building with no fossil fuel back-up heating system. If for example a single storage tank has been designated for heating, the system operators can consider alternative operation strategies such as shutting down the heat pumps and free cooling after the tank in use is heated to capacity.

Reheat during the Spring and Fall. Earlier in this chapter, monitored operation data was presented which indicated that reheat was a significant part (up to 50 percent) of the heating and cooling loads during the spring and fall (See Figures 4-2 (b) and 4-5 (b)). Reheat occurs when heat is extracted at the exterior air handler cooling coils and then supplied to the exterior VAV boxes. This problem could be alleviated by having the exterior air handler cooling coil setpoints controlled according to outdoor temperature. For example, exterior cooling coil setpoints could be increased proportionately as outdoor temperatures drop below 60 degF, and decreased as outdoor temperatures rise. This feature would allow the system to meet building heating requirements efficiently without reheat on a cold day while also enabling it to meet building cooling requirements on a warmer day.

Chapter Summary

In this chapter, building operation data for the past year (1985) was presented and analyzed by examining the seasonal trends in the heating and cooling requirements of the State Transportation Building along with the relative energy and cost effectiveness of different operation strategies.

Building heating and cooling requirements for various weather conditions were determined. Estimates were also made of how much these requirements might change with improved air handler performance and retail space occupancy.

It was determined from monitored data that to date, heating and cooling have been principally supplied by the heat pumps, and the storage system has had a minimal impact both in meeting winter heating loads and in meeting summer cooling loads. It was also determined that current winter internal heat gains in the building are insufficient to meet winter heating requirements. Internal heat gains may become sufficient, except for days with average outdoor temperatures below 15 degF, with retail space occupancy and reduced infiltration at the air handlers.

Various back-up heating and false-loading alternatives were evaluated and compared. It was found that the least expensive back-up heating alternatives are direct storage tank heating, storage tank false loading, and direct steam heating. The most expensive alternatives are false loading with steam and leaving the lights of the building on for 24 hours. If direct steam heating had been used as a back-up this winter rather than the more expensive option of leaving the lights on for 24 hours, about $6,340 would have been saved.

Cooling season electric demand management using chilled water storage was evaluated and found to offer a potential electric cost savings of $5145 annually with present building conditions and electric rates. These annual savings could be as high as $25,500 annually with retail space occupancy, new electric rates, and improved storage system efficiency. However, no demand cost savings will be possible until heat pump electric demand is monitored and controlled.

Finally, spring and fall operations were examined to determine when and how much mechanical heating and cooling is required. Exclusive free cooling was found to be an economic alternative to mechanical cooling with outdoor temperatures up to 64 degF. A good correspondence between storage system capacity and sequencing and heating and cooling requirements was found.

Chapters III and IV have presented a large amount of information about energy system performance. In Chapter V these results are more specifically discussed in the context of improving building energy system operation strategies.

Chapter V: Discussion of Operation of the System

In this chapter information presented in Chapter III and IV concerning building system operation, heating and cooling requirements, and the relative efficiencies of different operating strategies are discussed in the context of improving the energy system operation.

Thermal Storage System

Observations of Storage System Performance

In Chapter IV, the monitored energy system operation date indicated that the thermal storage system has been supplying relatively little of the building's heating in the winter and cooling in the summer (see Figures 4-2(a) and 4-5 (a)).

The designers of the system predicted that during the summer, the storage system could absorb heat at the rate of 16.8 mmBtu/hr (1,400 tons) and provide a total of 96.3 mmBtu/day of cooling. They also forecast that during the winter, the storage system could provide heat at a rate of 12.3 mmBtu/hr and a total of 113.3 mmBtu/day.

A closer look at the storage system indicates that it typically stores and supplies less than 20 percent of these capacities on a daily basis. This section of Chapter V explains why the storage system is being underutilized, and proposes a solution.

Summer Operation. Figure 5-1(a) graphs the average storage tank temperatures over the six day period of August 12-17, 1986 which was studied in the summer operation section of Chapter IV. Figure 5-1(b) graphs the amount of heat extracted from (positive) or added to (negative) the storage tanks over the same time period.

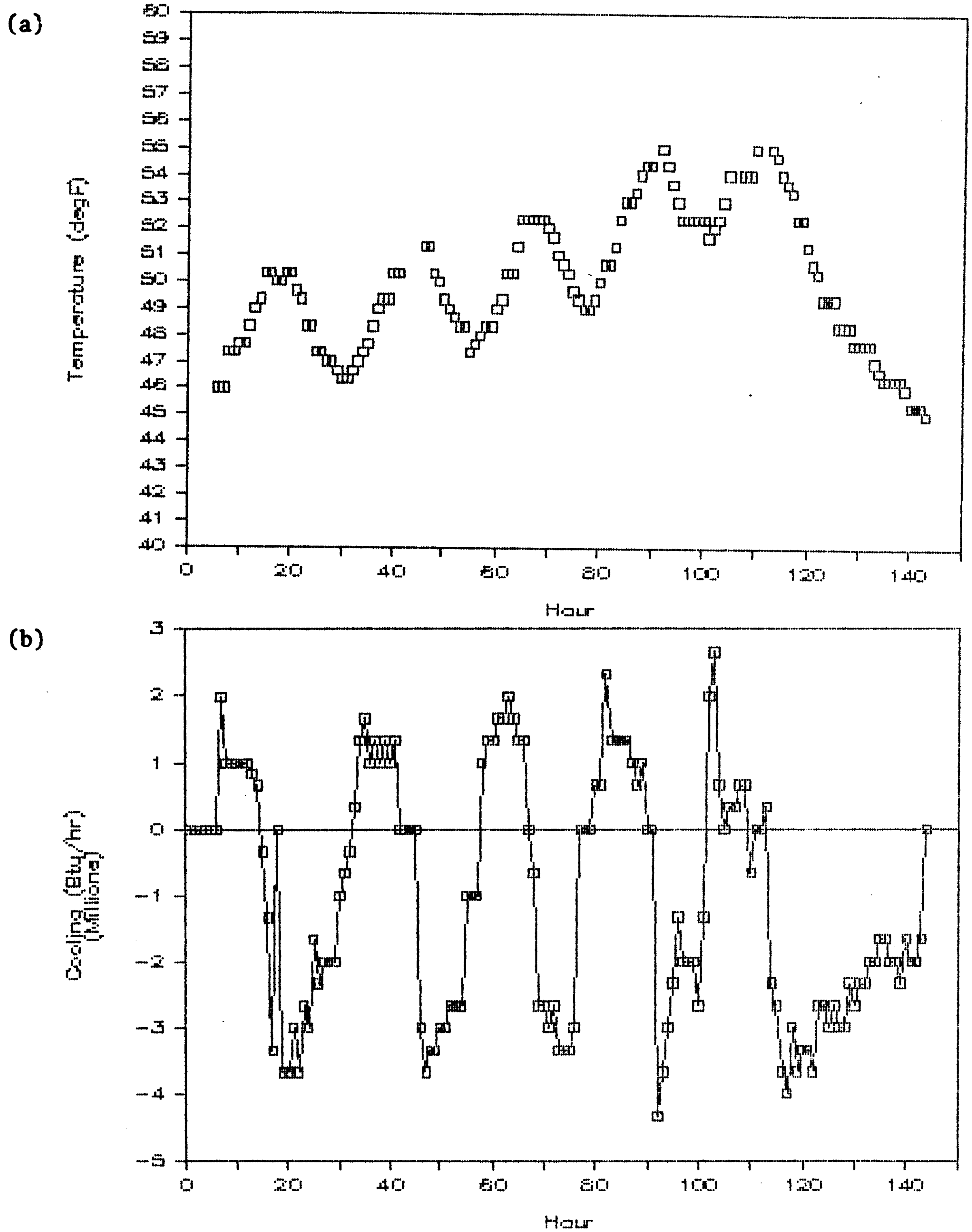

Figure 5-1: Monitored Operation Data - 8/12/85 - 8/17/85
(a) Average Storage Tank Temperatures
(b) Heat Transfer from Storage Tanks

Figure 5-1(a) shows that during weekdays, the tank temperatures would typically rise by 5-6 degrees during occupied hours when the peak chilled water mode was in use, and then would be cooled down again by 4-5 degrees during unoccupied hours. Because more heat was added to the tanks during occupied hours than was extracted from the tanks during unoccupied hours, the minimum temperature was higher on each consecutive day. On Saturday the seventeenth, the tanks were cooled all day, and the tank temperatures were brought down to their initial values from the beginning of the week.

Figure 5-1(b) shows that during each occupied hour, 0.3 -3.0 mmBtu of cooling was usually extracted from the tanks. Integrated over each day, 11 mmBtu or less of cooling was extracted from the tanks on a daily basis. With daily occupied cooling loads of 68-84 mmBtu, the tanks supplied only 7-14 percent of the total building cooling load each day.

<u>Winter Operation</u>. Figure 5-2 presents monitored winter operation data from December 1-4, 1985. Figure 5-2(a) graphs the three storage tank temperatures over the four day period. Note that all three tanks underwent less than 5 degF temperature changes throughout most of the four day period. In Figure 5-2 (b), note that heat was provided or stored to the building at rates of 0.3-2.0 mmBtu/hr. False loading was used at slightly higher rates ranging from 0.3-3.0 mmBtu/hr.

With daily heating loads ranging from 79.4-109.7 mmBtu/day, the storage tank provided only 3-16 percent of the daily building heating loads. False loading use on the second, third, and fourth days of the month, provided only 4 percent of the total building cooling load on the second, 8 percent on the third, and 18 on the fourth.

Eight percent of the heat supplied by the heat pumps was stored on the second and negligible amounts of heat were stored on the other days. Overall throughout the four day period, the storage system stored and supplied less than 20 percent of its designed capacity.

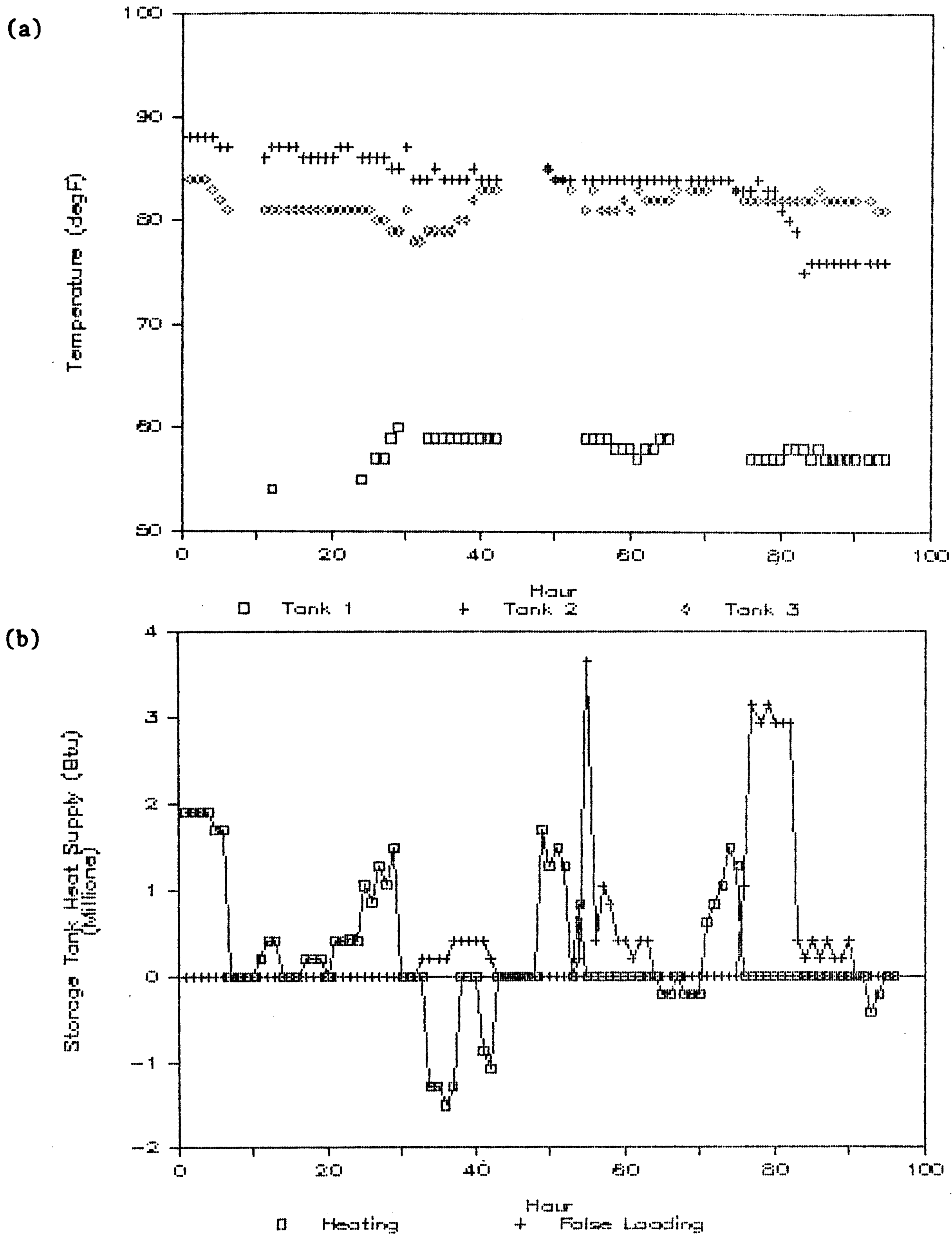

Figure 5-2: Monitored Operation Data - 12/1/85 -12/4/85
(a) Average Storage Tank Temperatures
(b) Storage Tank Heat Supply

Concepts in Hot and Chilled Water Storage

The previous observations of storage system performance raise the question of why the storage system in practice has provided and stored only a fraction of the amount of heating and cooling that the designers of the system had anticipated? To discuss this question, we will first present some basic definitions to describe hot and chilled water storage performance.

The instantaneous rate at which storage absorbs or discharges heat, will be called the instantaneous capacity change. This will be expressed mathematically by the equation:

$$q = \dot{m}\, c_p\, (T_i - T_o) \qquad (5\text{-}1)$$

where T_i is the inlet temperature and T_o is the outlet temperature. This quantity is positive when the inlet temperature is higher than the outlet temperature, meaning that heat is being added to the storage. The instantaneous capacity change is negative when heat is being extracted from the storage. The total amount of heat added to or discharged from storage over a period of time will be called the integrated capacity change. This is simply the instantaneous capacity change integrated over a specified time period:

$$Q = \int \dot{m}\, c_p\, (T_i - T_o)\, dt \qquad (5\text{-}2)$$

When the storage is being charged with heating or with cooling, the instantaneous and integrated capacity changes are subscripted q_c and Q_c respectively. When the storage is discharging heating and cooling, the instantaneous and integrated capacity changes are subscripted q_d and Q_d respectively.

The thermal efficiency of storage is expressed as the ratio of the integrated discharge and charge capacity changes:

$$\eta_{th} = -Q_d/Q_c \qquad (5\text{-}3)$$

When evaluating ηth for a single cycle, care must be taken to ensure that the storage is in the same state at the end of the cycle as it was in the beginning. These definitions are similar to those used by M. Wildin and C. Truman of the University of New Mexico Department of Mechanical Engineering.[1]

Applying these definitions to the State Transportation Building thermal storage system, we can see how the designer's predictions were developed. In order for the energy system to meet the designers' anticipated peak cooling load of 2000 tons, if RU-1 and RU-2 each provide 300 tons of cooling then the storage system must provide an additional 1400 tons or 5.6 mmBtu/hr per tank of cooling. With the designed summer storage tank flow rate of 640 gpm per tank, using equation 5-1, $(T_i - T_o)$ = 17 degF.[2] This quantity is about equal to the temperature difference specified for the storage tank heat exchangers during the cooling system of 16 degF (62 degF - 46 degF). Each storage tank holds roughly 230,000 gallons or 1,888,390 lbm of water. If all of the water in each tank were

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[1]M. Wildin and C. Truman, "A Summary of Experience with Stratified Chilled Water Storage", ASHRAE Transactions, 1985, vol. 91, pp. 957-958.

[2]5.6 mmBtu/hr = (640 gpm)(8.3445 lbm/gal)(60 min/hr)(1 Btu/lbm degF)(17 degF)

cooled by 17 degF, that would amount to a total of 96.3 mmBtu of cooling available per day.[3]

In the wintertime, the designers specified a 410 gpm flow rate of water from each tank and a 20 degF temperature drop (102 degF - 82 degF). Using equation 5-1, this would amount to a heat transfer of 4.1 mmBtu/hr per tank[4], or a total of 12.3 mmBtu/hr. If all of these tanks were heated by 20 degF, that would amount to a total heat storage capacity of 113.3 mmBtu/day.[5]

Examining equation 5-1 again, we see that instantaneous capacity change, the rate at which heat can be transferred to or from the storage, is a function of flow rate and the difference between inlet and outlet temperatures. Assuming a constant flow rate, the maximum instantaneous and integrated capacity change will occur when the maximum temperature difference is maintained between the tank outlet and inlet. For this reason, the literature on thermal storage system design and operation agrees that the maintenance of temperature difference between storage tank inlets and outlets is of primary

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[3] 96.3 mmBtu/day = (3)(1,888,390 lbm)(1 Btu/lbm degF)(17 degF)

[4] 4.1 mmBtu/hr = (410 gpm)(8.3445 lbm/gal)(60 min/hr)(1 Btu/lbm degF)(20 degF)

[5] 113.3 mmBtu/day = (3)(1,888,390 lbm)(1 Btu/lbm degF)(20 degF)

concern.[6] By maintaining temperature difference, the storage system can store and provide heating and cooling at a faster rate and therefore has an increased integrated capacity to store heating or cooling than without the temperature difference.

Mixed and Unmixed Chilled Water Storage. For example, we shall assume summer design conditions where we begin the occupied day with 43 degF water in each tank and chilled water return from the air handler cooling coils of 62 degF. Assuming 100 percent of the return chilled water is passed through the heat exchangers, equal flows through all three heat exchangers, and the design heat exchanger effectiveness of 0.84, the water passing through the heat exchangers will undergo a 16 degF temperature change. The tank return or inlet water will be 59 degF and the return chilled water will be 46 degF, with 426 tons of cooling supplied by each tank.

Assuming that the tank water is perfectly mixed, the tank temperature will rise to 46 degF after the first hour. With the chilled water return temperature maintained at 62 degF, the approach temperature difference between the two streams is reduced. Instead of obtaining 426 tons of cooling from each tank, only 365 tons of cooling is available from each tank by the second hour. As warmer return water is mixed into the tanks, the tank temperature rises every hour, and the amount of cooling available from each tank decreases. After six hours of operation, only 198 tons of cooling can be supplied by each tank and the tank temperature will have risen to 54 degF.

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[6] G. Reeves, Commercial Cool Storage Design Guide, EPRI-EM 3981, May 1985.

What would happen if we began the day with the same operation conditions but prevented the return chilled water from mixing with the 43 degF in the tanks? Rather than having the tank temperature rise each hour, we could maintain the supply of 43 degF water to the heat exchanger, and supply any amount of cooling up to a maximum constant rate of 426 tons of cooling. After six hours of operation at 426 tons, we would have supplied a total of 2,557 tons of cooling as compared to only 1802 tons of cooling with the mixed tanks (30 percent less cooling). Table 5-1 summarizes the hourly temperatures and amount of cooling supplied from both the mixed and unmixed occupied hours operations for these design conditions. This example clearly illustrates how mixing the return water with the tank water reduces the rate at which cooling can be extracted from storage.

The same principles work in reverse at night when the tanks are to be cooled. With mixed tanks, the amount of cooling that each tank can absorb diminishes hourly as the tank temperature falls, and the difference between the tank temperature and the chilled water supply temperature decreases.

Assuming design conditions with 100 percent of the chilled water supplied to the tank heat exchangers, the tanks at 59 degF and the chilled water supply temperature at 40 degF, the tanks would initially be cooled 426 tons each during the first hour. However, with the mixed tanks, by the eleventh hour each tank could only absorb 79 tons of cooling and it would take 12 hours to cool the tanks to 43 degF for the next day.

If the return water was not mixed with the supply water, then the tanks could absorb a constant 426 tons of cooling each hour. It would only take six hours to cool the tanks to 43 degF.[7] This is half of the operation

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[7]6 hrs = (226,303 gal/tank)(640 gpm)(60 min/hr)

Table 5-1: Summer Occupied Operation, Design Conditions

E = 0.84

Mixed Return

Hour	T tank o (degF)	T tank i (degF)	delT (degF)	T chwr (before tank) (degF)	Tchwsup (after tank) (degF)	m cp(delT) (per tank) (Btu/hr)	m cp(delT) (per tank) (tons)
0	43	59	16	62	46	5,114,044	426
1	46	59	14	62	48	4,385,118	365
2	48	60	12	62	50	3,760,089	313
3	50	60	10	62	52	3,224,149	269
4	52	60	9	62	53	2,764,598	230
5	53	61	7	62	55	2,370,548	198
6	54						
					Total	21,618,546	1,802

Unmixed Return

Hour	T tank o (degF)	T tank i (degF)	delT (degF)	T chwr (before tank) (degF)	Tchwsup (after tank) (degF)	m cp(delT) (per tank) (Btu/hr)	m cp(delT) (per tank) (tons)
0	43	59	16	62	46	5,114,044	426
1	43	59	16	62	46	5,114,044	426
2	43	59	16	62	46	5,114,044	426
3	43	59	16	62	46	5,114,044	426
4	43	59	16	62	46	5,114,044	426
5	43	59	16	62	46	5,114,044	426
6	59						
					Total	30,684,262	2,557

Equations:

Given T tank o, T chwret, and E:
T tank i = T tank o + E(T chwret - T tank o)
del T = T tank i - T tank o = T chwret - T chwsup
T chwsup = T chwret + E(T tank o - T chwret)
m cp (del T) = 320,428.8 * (del T)

for mixed calculations: T tank o (t+1) = T tank o (t) + (m cp (delT))/1,888,392
Assumes equal flow rates through heat exchangers.

time with the mixed tanks. Table 5-2 summarizes the hourly temperatures and amounts of cooling supplied for both the mixed and unmixed unoccupied hours operations.

More important than operation time is the fact that with the unmixed tanks, there can be more efficient operation because the storage provides a constant high-temperature cooling load for the heat pumps during unoccupied hours. As an example, we shall begin with the storage tank conditions at the end of the six hour period from Table 5-1. With the mixed tanks, we would be left with three 54 degF tanks. With the unmixed tanks, we would have three tanks at 59 degF. The 54 degF mixed tanks would initially provide a load on the heat pumps of 314 tons per tank. As time went by, the load on the heat pumps would decrease with the mixed tanks so that by the time the tanks were brought down to their initial temperature of 43 degF (eleven hours later), the tanks would only be providing a load of 67 tons per tank on the heat pumps. The 59 degF unmixed tanks would provide a steady 426 ton load on the heat pumps. Table 5-3 summarizes the hourly temperatures and cooling supplied to storage for this operation.

These results help to explain the monitored summer building operation data. Examining Table 5-1 and 5-3 we can see that with mixed tanks and full flow rates, it would take roughly twice as long during unoccupied hours to bring the storage tanks back to their original condition of 43 degF than it took to bring them up to 54 degF during occupied hours. Recalling Figure 5-1(a) we begin to understand why as the week progressed, the operators would tend to be unable to bring the storage down to its original temperature over night.

Examining Tables 5-2 and 5-3 we also begin to understand the reason why the system operators must use the unoccupied building to increase the cooling load on the heat pumps. Recalling Figure 4-16 which graphed

Table 5-2: Summer Unoccupied Operation, Design Conditions

E = 0.84

	Mixed Return							Unmixed Return						
Hour	T tank o (degF)	T tank i (degF)	delT (degF)	Tchwsup (before tank) (degF)	Tchwr (after tank) (degF)	m cp(delT) (per tank) (Btu/hr)	m cp(delT) (per tank) (tons)	T tank o (degF)	T tank i (degF)	delT (degF)	Tchwsup (before tank) (degF)	Tchwr (after tank) (degF)	m cp(delT) (per tank) (Btu/hr)	m cp(delT) (per tank) (tons)
0	59	43	(16)	40	56	(5,114,044)	(426)	59	43	(16)	40	56	(5,114,044)	(426)
1	56	43	(14)	40	54	(4,385,118)	(365)	59	43	(16)	40	56	(5,114,044)	(426)
2	54	42	(12)	40	52	(3,760,089)	(313)	59	43	(16)	40	56	(5,114,044)	(426)
3	52	42	(10)	40	50	(3,224,149)	(269)	59	43	(16)	40	56	(5,114,044)	(426)
4	50	42	(9)	40	49	(2,764,598)	(230)	59	43	(16)	40	56	(5,114,044)	(426)
5	49	41	(7)	40	47	(2,370,548)	(198)	59	43	(16)	40	56	(5,114,044)	(426)
6	48	41	(6)	40	46	(2,032,664)	(169)	43						
7	46	41	(5)	40	45	(1,742,940)	(145)					Total	(30,684,262)	(2,557)
8	46	41	(5)	40	45	(1,494,512)	(125)							
9	45	41	(4)	40	44	(1,281,493)	(107)							
10	44	41	(3)	40	43	(1,098,837)	(92)							
11	44	41	(3)	40	43	(942,215)	(79)							
12	43													
					Total	(30,211,208)	(2,518)							

Equations:

Given T tank o, T chwsup, and E:
T tank i = T tank o + E(T chwsup - T tank o)
del T = T tank i - T tank o = T chwsup - T chwret
T chwret = T chwsup + E(T tank o - T chwsup)
m cp (del T) = 320,428.8 * (del T)

for mixed calculations: T tank o (t+1) = T tank o (t) + (m cp (delT))/1,888,392
Assumes equal flow rates through heat exchangers.

Table 5-3: Summer Unoccupied Operation, Mixed Initial Tank Condition of 54 degF

E = 0.84

	Mixed Return							Unmixed Return						
Hour	T tank o (degF)	T tank i (degF)	delT (degF)	Tchwsup (before tank) (degF)	Tchwr (after tank) (degF)	m cp(delT) (per tank) (Btu/hr)	m cp(delT) (per tank) (tons)	T tank o (degF)	T tank i (degF)	delT (degF)	Tchwsup (before tank) (degF)	Tchwr (after tank) (degF)	m cp(delT) (per tank) (Btu/hr)	m cp(delT) (per tank) (tons)
0	54	42	(12)	40	52	(3,768,243)	(314)	59	43	(16)	40	56	(5,114,044)	(426)
1	52	42	(10)	40	50	(3,231,140)	(269)	59	43	(16)	40	56	(5,114,044)	(426)
2	50	42	(9)	40	49	(2,770,592)	(231)	59	43	(16)	40	56	(5,114,044)	(426)
3	49	41	(7)	40	47	(2,375,688)	(198)	59	43	(16)	40	56	(5,114,044)	(426)
4	48	41	(6)	40	46	(2,037,072)	(170)	59	43	(16)	40	56	(5,114,044)	(426)
5	46	41	(5)	40	45	(1,746,720)	(146)	59	43	(16)	40	56	(5,114,044)	(426)
6	46	41	(5)	40	45	(1,497,753)	(125)	43						
7	45	41	(4)	40	44	(1,284,272)	(107)					Total	(30,684,262)	(2,557)
8	44	41	(3)	40	43	(1,101,219)	(92)							
9	44	41	(3)	40	43	(944,258)	(79)							
10	43	40	(3)	40	43	(809,669)	(67)							
11	43													
					Total	(21,566,626)	(1,797)							

Equations:

Given T tank o, T chwsup, and E:
T tank i = T tank o + E(T chwsup - T tank o)
del T = T tank i - T tank o = T chwsup - T chwret
T chwret = T chwsup + E(T tank o - T chwsup)
m cp (del T) = 320,428.8 * (del T)

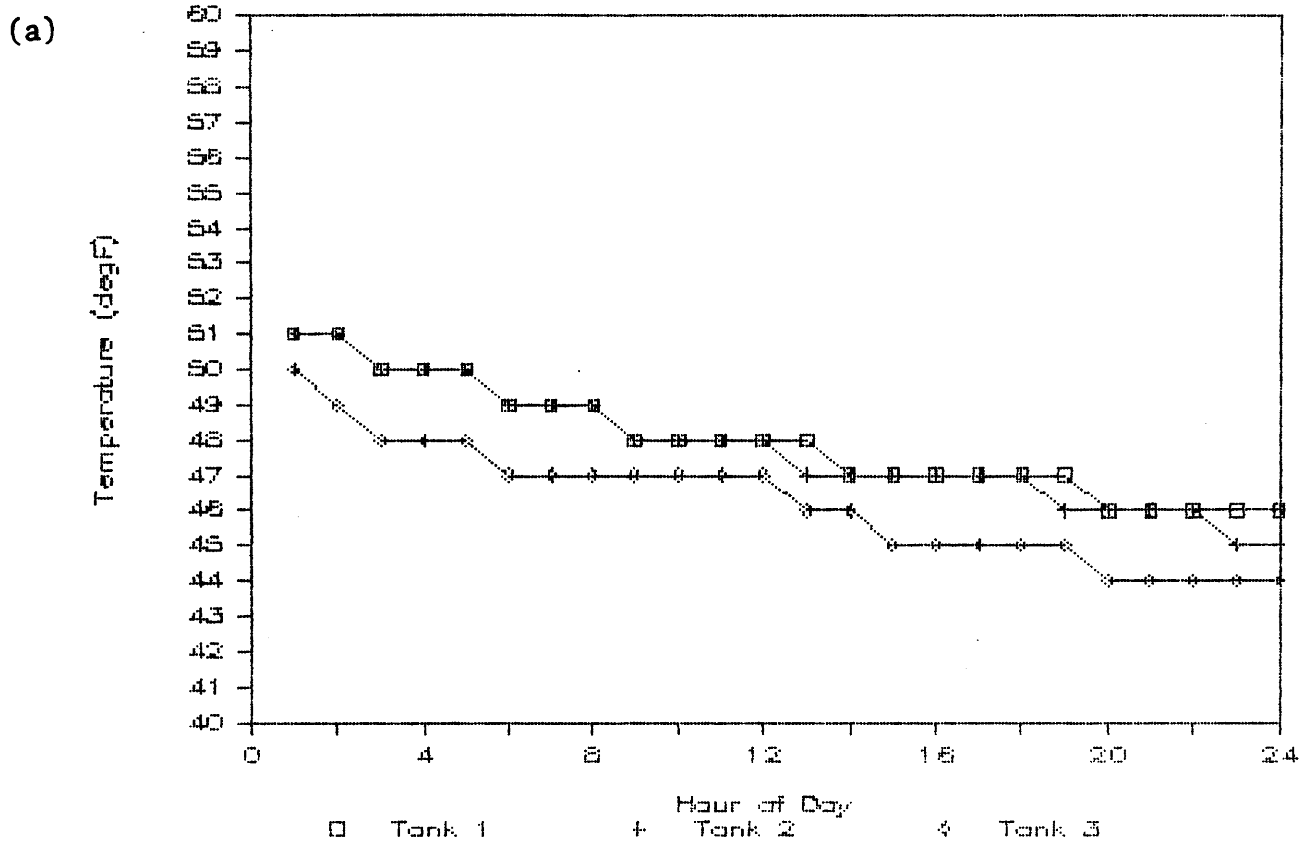
for mixed calculations: T tank o (t+1) = T tank o (t) + (m cp (delT))/1,888,392
Assumes equal flow rates through heat exchangers.

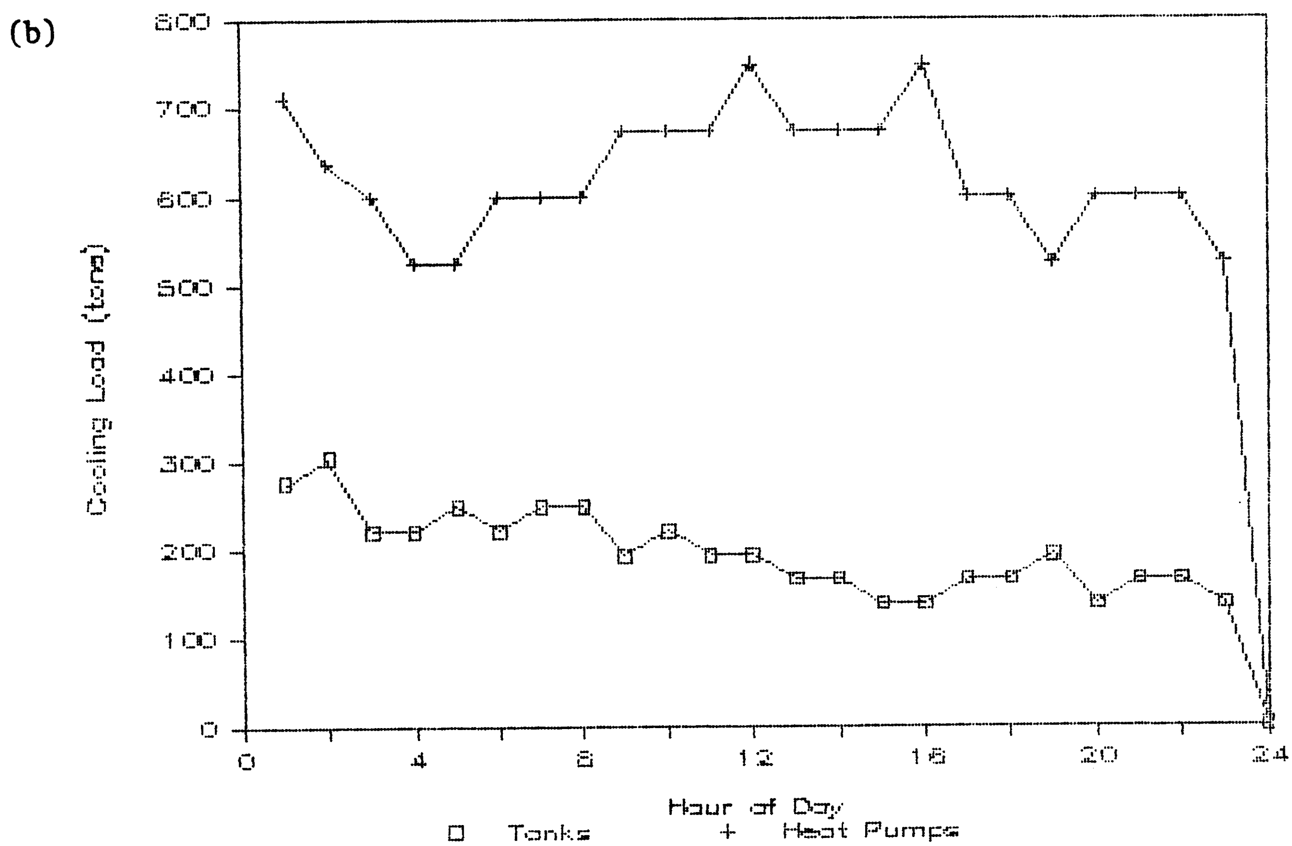
total building cooling supply and storage tank cooling supply over the week of August 12-17, it was observed that when the storage was being cooled at night, the amount of cooling supplied to the tanks decreased with time and the amount of cooling supplied to the building increased.

Figure 5-3 graphs operation data from Saturday August 17, during which the storage tanks were cooled all day. Figure 5-3(a) graphs the tank temperatures over the day, and Figure 5-3(b) graphs the amount of cooling supplied to the storage by the heat pump. Note that the total cooling load upon the heat pump (RU-3) remained fairly constant throughout the day, while the amount of cooling supplied to the storage tanks decreased throughout the day. As the storage tanks were cooled, their ability to absorb cooling decreased, and therefore to maintain the load on RU-3 more cooling had to be absorbed by the building.

However, mixing in the tanks was not the only reason why so much cooling was provided to the building. By operating the air handlers, chilled water was diverted from the storage tanks to the air handlers and therefore the flow rate of water supplied to the storage tanks was reduced. If the system had been operated in the off-peak storage mode rather than the part-chilled water mode, all of the chilled water would have been supplied to the tanks. With two tanks at 51 degF and 50 degF, the tanks alone would have provided a sufficient load (about 583 tons) on RU-3 initially.

A simulation was run assuming mixed storage tanks with the off-peak storage mode using the chilled water supply temperatures from the August 17 monitored data. It was found that although the tanks would have initially provided a sufficient load for the heat pumps, the cooling load from the tanks would be less than 40 percent of the heat pump capacity within three hours, and the heat pump would automatically have shut down (see Table D-1 for data). Consequently





<u>Figure 5-3: Monitored Operation Data - 8/17/85</u>
(a) Storage Tank Temperatures
(b) Heat Pump Cooling Supply and Amount Cooling Transferred to Storage Tanks

even if the off-peak storage mode had been used, within three hours it would have been impossible to cool the storage tanks without using the building to increase the cooling load.

Another simulation was run assuming unmixed storage tanks with the off-peak storage mode and no losses. With the unmixed tanks, it was found that approximately the same amount of storage tank cooling would have been obtained within six hours as was obtained over 24 hours, and no unnecessary cooling would have been supplied to the building (see Table D-2 for data).

Table 5-4 summarizes the comparison between the actual August 17 monitored data, and the simulated data assuming unmixed storage tanks. It was found that with the existing mixed storage tanks, 2.85 kW of mechanical equipment electrical power was required per ton of cooling supplied to the storage. With the unmixed storage tanks only 0.88 kW per ton would be required. This difference results from the fact that with unmixed tanks, the system could store chilled water more efficiently and over a shorter period of time with no excess cooling supplied to the building.

Note that although roughly the same amount of cooling was supplied to the tanks in both cases, the final storage tank temperatures were lower in the unmixed case. These results imply that the actual final storage tank temperatures were lower than 46, 45, and 44 degF, but owing to imperfect mixing higher temperatures were recorded at the storage tank water outlet.

<u>Mixed and Unmixed Hot Water Storage</u>. The same principles and benefits from unmixed chilled water storage would apply to unmixed hot water storage. By maintaining a greater temperature difference between tank inlets and outlets, heat would be transferred into and out of the storage tanks at a higher rate. As a result, the instantaneous and

Table 5-4: Comparison of Actual August 17 Operation to Simulated Operation with Unmixed Storage

	Actual	Unmixed
initial storage tank temperatures (degF)	51 51 50	51 51 50
final storage tank temperatures (degF)	46 45 44	42 42 42
total amount cooling stored (tons)	4,542	4,166
time period (hrs)	24	6
total amount mechanical equip. electricity used (kW)	12,950	3,648
kW/ton stored	2.85	0.88

integrated storage capacities would be greater with an unmixed tank than with a mixed tank. Considering the nature of the building's heat storage system whereby excess heat is stored during occupied hours to be used during unoccupied hours, unmixed storage would be particularly helpful in the winter.

For example, we shall assume that tank #3 is at 80 degF on a relatively warm winter day and excess 105 degF hot water is available to heat the tank for four hours at full flow rate. With a mixed tank, 21.9 mmBtu of heat will have been added to the tank and the tank temperature after four hours will have been elevated to 91.59 degF. Assuming that the tank water can provide useful heat during unoccupied hours with tank temperatures down to 80 degF, then 21.9 mmBtu[8] of heat will be available for heating during unoccupied hours. Below 80 degF, the tank would have to be used for false loading to extract more heat from it.

But if the 105 degF water were available to an unmixed tank at 80 degF, 27.2 mmBtu of heat would have been added to the tank after four hours and 153,600 gallons of the tank's water would be heated to 101.25 with about 72,700 gallons remaining at 80 degF. The 101.25 degF water would be available to provide 27.23 mmBtu[9] of heat before its temperature was reduced to 80 degF. As with the mixed tank, the remaining heat would be available for false loading. See Table 5-5 for temperature and heat transfer data.

This example illustrates how an unmixed storage system would actually

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[8]21.9 mmBtu = (1,888,390 Btu/degF)(91.59-80 degF)

[9]27.23 mmBtu = (153,600 gallons)(1 Btu/lbm degF)(8.3445 lbm/gal)(101.25-80 degF)

Table 5-5: Winter Occupied Operation, Initial Tank Temperature 80 degF, 105 degF Hot Water Supplied to Tank 3 Only

E = 0.85

	Mixed Return						Unmixed Return					
Hour	T tank o (degF)	T tank i (degF)	delT (degF)	T hwsup (before tank) (degF)	Thwret (after tank) (degF)	m cp(delT) (per tank) (Btu/hr)	T tank o (degF)	T tank i (degF)	delT (degF)	T hwsup (before tank) (degF)	Thwret (after tank) (degF)	m cp(delT) (per tank) (Btu/hr)
0	80.00	101	21	105	84	6,809,112	80	101.25	21	105	84	6,809,112
1	83.61	102	18	105	87	5,827,028	80	101.25	21	105	84	6,809,112
2	86.69	102	16	105	89	4,986,590	80	101.25	21	105	84	6,809,112
3	89.33	103	13	105	92	4,267,370	80	101.25	21	105	84	6,809,112
4	91.59						80					
					Total	21,890,100					Total	27,236,448

Equations:

Given T tank o, T hwsup, and E:

T tank i = T tank o + E(T hwsup - T tank o)

del T = T tank i - T tank o = T hwsup - T hwret

T hwret = T hwsup + E(T tank o - T hwsup)

m cp (del T) = 320,428.8 * (del T)

for mixed calculations: T tank o (t+1) = T tank o (t) + (m cp (delT))/1,888,392

Assumes equal flow through heat exchangers.

be able to store more excess heat during occupied hours than mixed storage and in turn provide more heat during unoccupied hours. In this instance, the unmixed tank would have stored 25 percent more heat than the mixed tank.

Table 5-6 summarizes what would happen during unoccupied hours when the heat collected during the day is distributed from the tanks to the spaces. Assuming once again full flow from the tank heat exchangers and a constant hot water supply temperatures of 80 degF, simulations were run for both the mixed and unmixed final conditions from Table 5-5.

The mixed tank with an initial tank temperature of 91.59 degF could supply 3.2 mmBtu/hr for the first hour but its ability to heat would gradually diminish with tank temperature. Even after 26 hours, the tank would not have been able to discharge all of the heat which was stored during the day as a result of the temeprature difference between the tank and the hot water loop.

With the unmixed tank, if all of the 101 degF water was used at full flow rate, a total of 23.1 mmBtu of heat could be recovered with 153,600 gallons of 83.2 degF water remaining.

Note that all of the stored heat could not be recovered owing to the smaller temperature difference between the tank and the hot water loop during heat recovery as opposed to heat storage (See Table 5-5). However considerably more heat would be stored and recovered with the unmixed tank than with the mixed tank.

Control of the Return Water Temperature. A final point concerning the benefits of unmixed storage is that it provides better control during occupied hours in maintaining chilled water and hot water return temperatures to the heat pumps.

Table 5-6: Winter Unoccupied Operation, Mixed Initial Condition of 91.59 degF, Hot Water Loop Temperature of 80 degF

E = 0.85

Mixed Return

Hour	T tank o (degF)	T tank i (degF)	delT (degF)	T hwsup (before tank) (degF)	Thwret (after tank) (degF)	m cp(delT) (per tank) (Btu/hr)
0	91.59	82	(9.85)	80	90	(3,156,704)
1	89.92	81	(8.43)	80	88	(2,701,410)
2	88.49	81	(7.21)	80	87	(2,311,783)
3	87.26	81	(6.17)	80	86	(1,978,353)
4	86.22	81	(5.28)	80	85	(1,693,013)
5	85.32	81	(4.52)	80	85	(1,448,828)
6	84.55	81	(3.87)	80	84	(1,239,862)
7	83.90	81	(3.31)	80	83	(1,061,036)
8	83.33	81	(2.83)	80	83	(908,002)
9	82.85	80	(2.43)	80	82	(777,040)
10	82.44	80	(2.08)	80	82	(664,967)
11	82.09	80	(1.78)	80	82	(569,058)
12	81.79	80	(1.52)	80	82	(486,982)
13	81.53	80	(1.30)	80	81	(416,744)
14	81.31	80	(1.11)	80	81	(356,637)
15	81.12	80	(0.95)	80	81	(305,199)
16	80.96	80	(0.82)	80	81	(261,180)
17	80.82	80	(0.70)	80	81	(223,510)
18	80.70	80	(0.60)	80	81	(191,273)
19	80.60	80	(0.51)	80	81	(163,685)
20	80.51	80	(0.44)	80	80	(140,077)
21	80.44	80	(0.37)	80	80	(119,873)
22	80.38	80	(0.32)	80	80	(102,584)
23	80.32	80	(0.27)	80	80	(87,788)
24	80.28	80	(0.23)	80	80	(75,126)
25	80.24	80	(0.20)	80	80	(64,291)
26	80.20					
					Total	(21,505,005)

Unmixed Return

T tank o (degF)	T tank i (degF)	delT (degF)	T hwsup (before tank) (degF)	Thwret (after tank) (degF)	m cp(delT) (per tank) (Btu/hr)
101	83.19	(18)	80	98	(5,787,745)
101	83.19	(18)	80	98	(5,787,745)
101	83.19	(18)	80	98	(5,787,745)
101	83.19	(18)	80	98	(5,787,745)
				Total	(23,150,981)

Equations:

Given T tank o, T hwsup, and E:

T tank i = T tank o + E(T hwsup - T tank o)

del T = T tank i - T tank o = T hwsup - T hwret

T hwret = T hwsup + E(T tank o - T hwsup)

m cp (del T) = 320,428.8 * (del T)

for mixed calculations: T tank o (t+1) = T tank o (t) + (m cp (delT))/1,888,392

Assumes equal flow through heat exchangers.

During the cooling season when the peak chilled water mode is in use, the storage system is used to pre-cool the return chilled water before it returns to the heat pump evaporators. Note that in Table 5-1 that with the unmixed tanks, the chilled water after the heat exchanger gradually creeps up in temperature. As the storage system becomes less able to absorb heat, the load on the heat pumps increases and they become unable to maintain their chilled water discharge setpoints.

However with the unmixed storage system, the chilled water return temperature is maintained constant throughout the day and the load on the heat pumps consequently remains constant.

During the heating season, the storage system is used in the reduced heating mode to maintain a hot water return temperature setpoint to the heat pumps. This is accomplished by directing to the storage tanks excess hot water which is not required at the perimeter of the building for space heating.

Note in Table 5-5 that as during the cooling season, the mixed tanks would provide an unsteady hot water return temperature while the unmixed tanks would provide a steady hot water return temperature.

In summary, there are several benefits which could be obtained by converting the storage system at the State Transportation Building from a mixed storage system to an unmixed storage system.

1. In the cooling season, unmixed storage would provide and store more cooling at a higher rate than mixed storage. This would offset more of the building cooling load for demand management purposes.

2. With mixed storage, cooling the storage system at night will never be possible even when employing the off-peak storage mode without using the building to increase the load on the heat pumps. But with unmixed storage, the storage system would provide a steady load and consequently cool more efficiently because no cooling would be wasted on the unoccupied building. Cooling of the storage tank during unoccupied hours would also be performed more quickly with unmixed storage.

3. During the heating season, unmixed storage would be able to provide and store more heat at a higher rate and higher temperatures than mixed storage, and thereby offset more of the building heating load.

4. An unmixed storage system would maintain steady chilled water and hot water return temperatures, and as a result provide the heat pumps with more efficient operating conditions.

Methods for Obtaining Unmixed Storage Tanks

Various methods are now being used successfully to prevent mixing in water thermal storage systems similar to that at the State Transportation Building. These systems include multiple tank or empty-tank, baffled, diaphragm, and stratification.

The multiple tank or empty tank method comprises several tanks connected in series which avoids temperature mixing by isolating hot and cold water in separate small tanks When cold water is drawn from a tank and heated, it is stored in a tank with a higher temperature rather than returned to its original cooler tank (See Figure 5-4(a).

(a) (b)

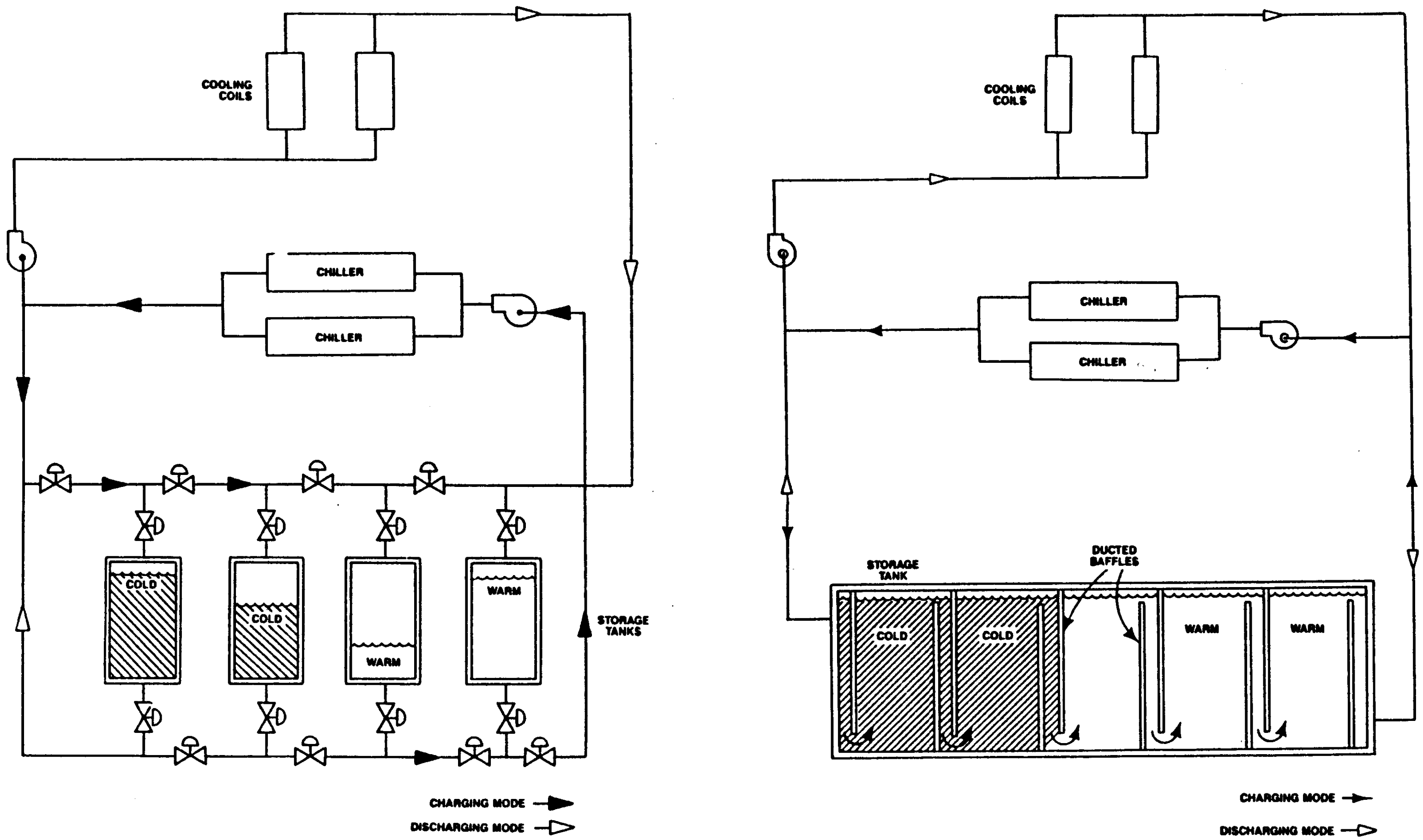

Figure 5-4: Thermal Storage System Designs
(a) Empty Tank Design
(b) Baffled Design

(Source: EPRI EM-3981, Commercial Cool Storage Design Guidelines)

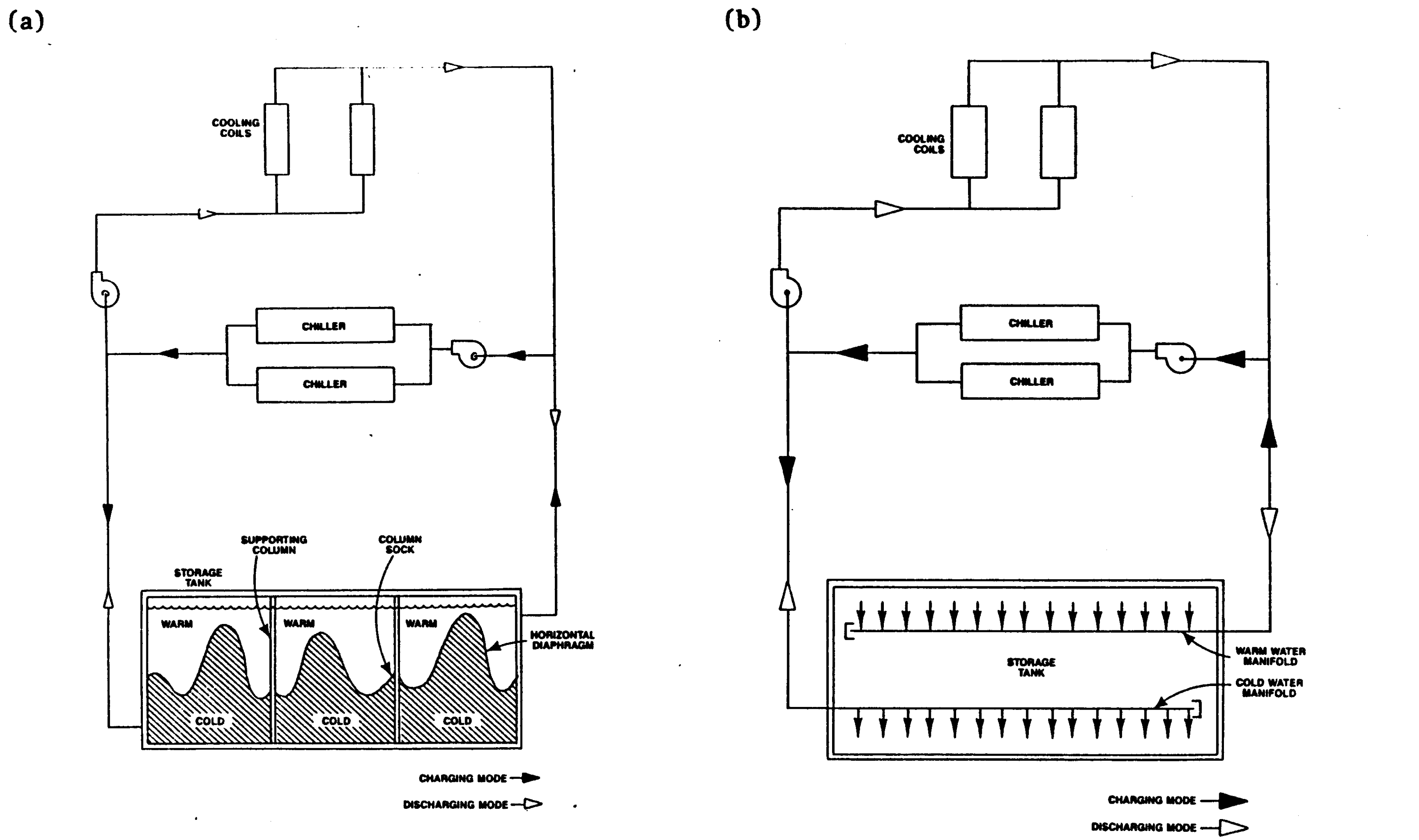

Figure 5-5: Thermal Storage System Designs
(a) Diaphragm Design
(b) Stratification Design

(Source: EPRI EM-3981, Commercial Cool Storage Design Guidelines)

The baffled tank method features vertical partitions which divide the tanks into several cells or compartments (See Figure 5-4(b)). There are several variations on the baffled tank design but generally speaking, they curtail mixing by introducing cold water at the bottom and hot water at the top with baffled separations.

The diaphragm method uses a rubberized fabric to physically separate return and supply water in a tank. The diaphragm physically moves up and down in the tank as water is moved from one side of the diaphragm to the other. (See Figure 5-5 (a)).

The stratification method prevents warm and cool water from mixing by relying upon buoyant or hydrodynamic effects rather than physical separation. When warm water is properly introduced into a cool tank, a thin naturally occuring boundary layer of water called a thermocline separates the warm and the cold water in the tank.

Employing either the multiple tank or baffled tank methods in the State Transportation Building would most likely require very expensive retrofit construction. Due to the large horizontal and vertical structural beams and posts in the existing storage tanks, the installation of a diaphragm system would also be very expensive if not impossible. However the existing storage tank configuration is well-suited to a stratification method and could easily be retrofitted by installing properly designed inlet and outlet diffusers due to the fact that the existing piping has upper tank and lower tank outlets already piped (see Figures 5-6 and 5-7). See Appendix B for details of storage tank dimensions.

A recently published report documenting experiments conducted at the University of New Mexico indicate that properly designed and operated thermocline storage systems can operate with thermal efficiencies (See Equation 5-3) as high as 91 percent.[10]

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[10] M. Wildin and C. Truman, Evaluation of Stratified Chilled-Water Storage Techniques, EPRI EM-3981, December 1985.

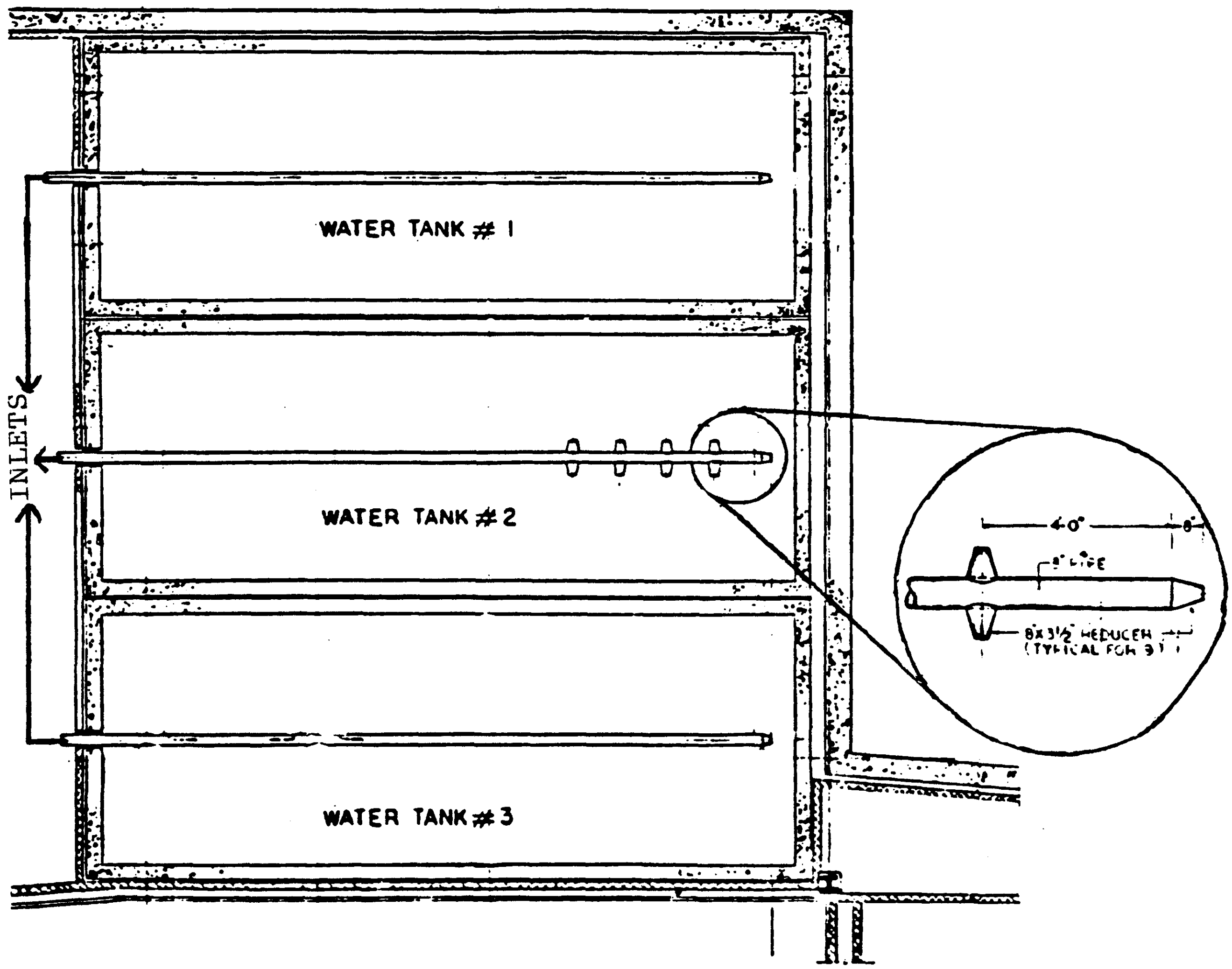

Figure 5-6: Thermal Storage Tank Plan

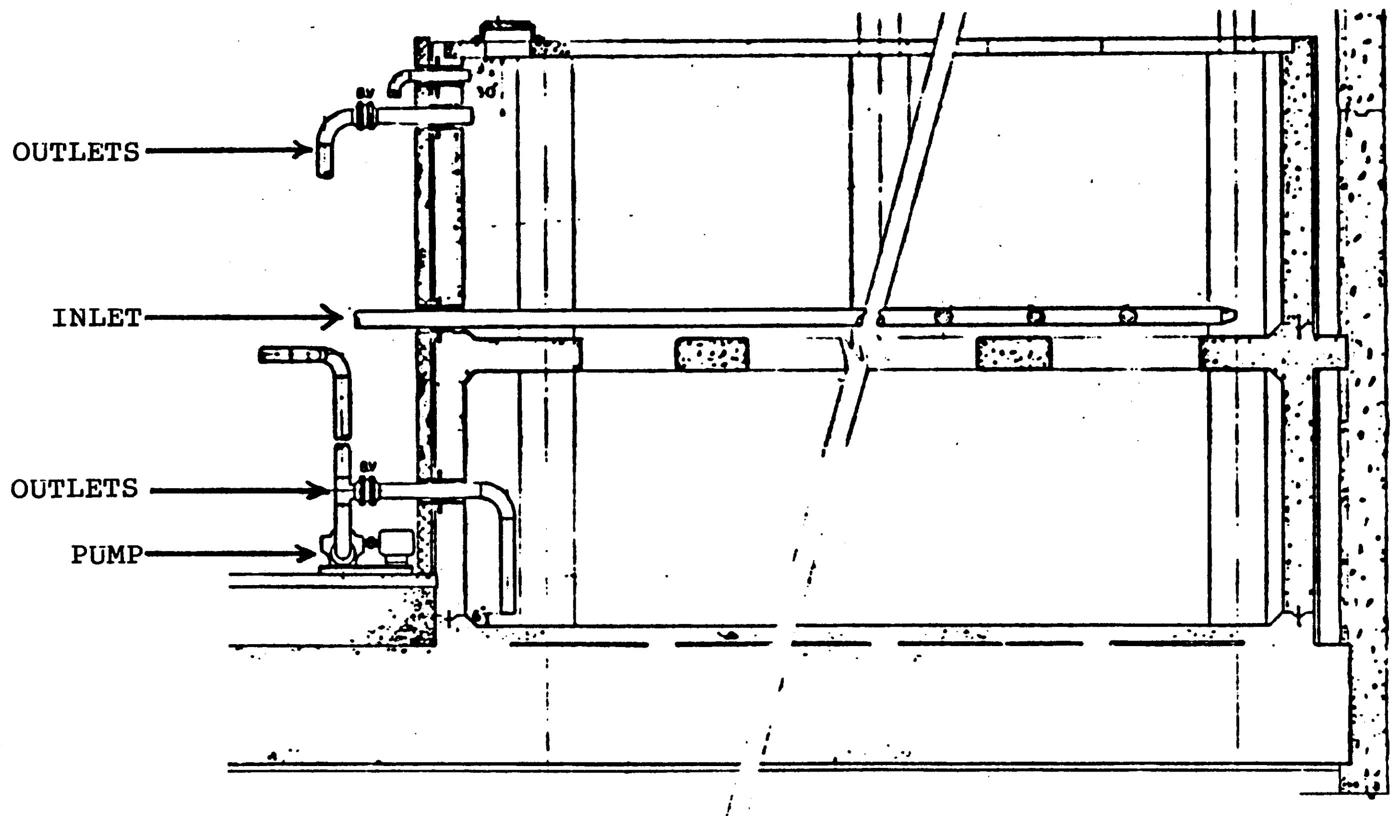

Figure 5-10: Thermal Storage Tank Section

The report recommends the use of low-friction and low-velocity diffusers located at the bottom and top of each tank. When heating the tank, cold water would be removed through the bottom diffusers and hotter return water would be introduced from the top diffusers. When cooling the tank, warm water would be removed through the top diffusers and colder return water would be introduced from the bottom diffusers. Therefore the top and bottom diffusers would need to be designed for low friction flow in both directions.

Good stratification and thermocline formation depend upon the introduction of water into the tanks at a low velocity to prevent mixing. Directing the top diffusers upward and the bottom diffusers downward also aids in the maintenance of stable temperature gradients.

It is more difficult to obtain good stratification with chilled water storage than with hot water storage because hot water has greater density differences and therefore larger buoyancy forces across a specified temperature range. For example, the density difference between 45 degF and 65 degF is only 0.086 lb/ft^3 whereas the density difference between 140 degF and 160 degF is 0.37 lb/ft^3 (See Figure 5-8). Since the strength of the buoyant forces is proportional to temperature differences, the maintenance of temperature differences between the inlets and the outlets is essential to preserving stable temperature gradients.

Theoretical and experimental findings indicate that dynamic forces associated with the jet velocity must be low relative to the buoyant forces associated with the temperature differential between the jet and the still water. A combination of physical parameters which represent the ratio of these two forces is called the densiometric Froude number (Fr):

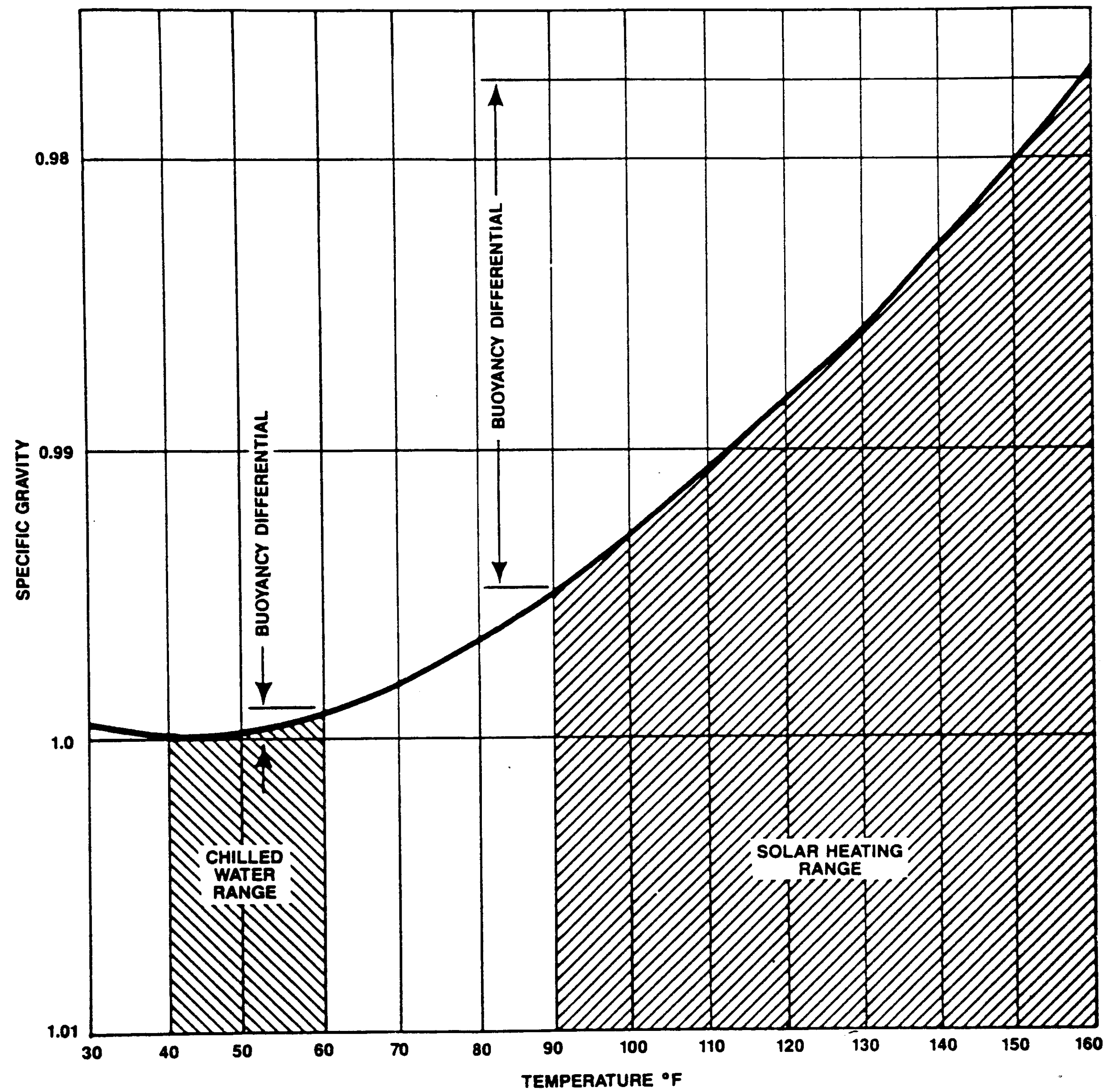

Figure 5-8: Relative Buoyancy Characteristics of Chilled and Hot Water

(Source: EPRI EM-3981, Commercial Cool Storage Design Guidelines)

$$Fr,i = U_1/(g \, B \, \Delta T \, L)^{1/2}$$

where:

U_1 = inlet velocity

g = acceleration due to gravity

B = coefficient of volumetric expansion (density change)

ΔT = temperature difference between cool and hot water

L = characteristic dimension

To minimize mixing, inlet diffusers should be designed so that the densiometric Froude number is less than or equal to one.[11]

Experimenters at the University of New Mexico obtained good results with an H-shaped distribution nozzle configuration which was designed to evenly distribute low-velocity flow throughout the storage tank area (See Figure 5-9). The H-shaped distributed nozzle scheme was originally developed by E.I. Mackie and has been operating in a Vancouver court House for several years. Figure 5-9 (b) is a schematic plan of the Vancouver installation.

Figure 5-9 (a) and 5-9 (c) represent the University of New Mexico experimental apparatus. Figure 5-9 (c) shows how cuts were distributed through the 2" diameter PVC diffusers to ensure equal resistance to flow throughout the storage tank area. Details of the distributed diffuser design and experimental results can be found in the final report of the project: Evaluation of Stratified Chilled-Water Storage Techniques published by the Electric Power Research Institute (EPRI EM-4352, December 1985).

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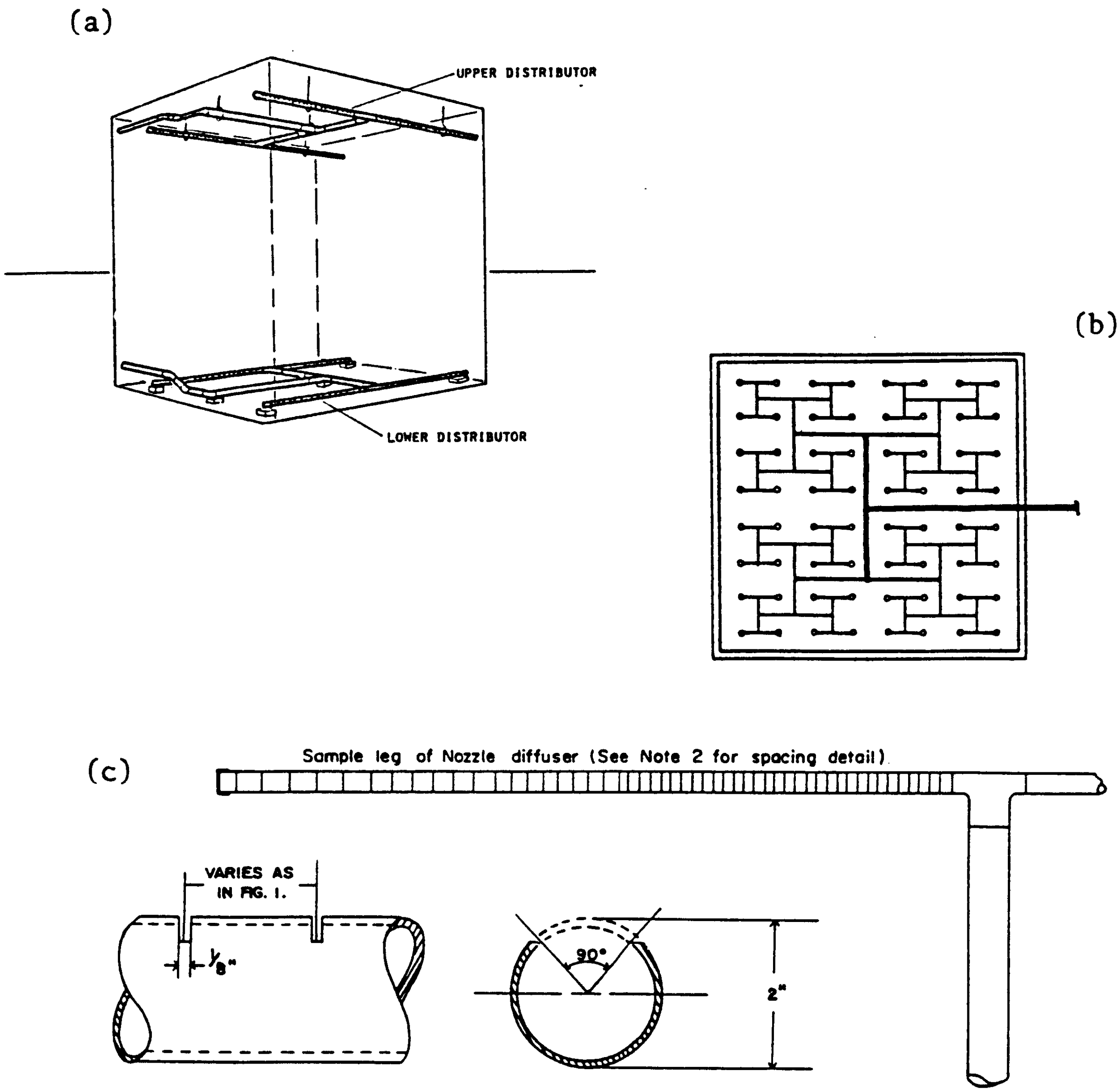
[11] G. Reeves, Commercial Cool Storage Design, EPRI EM-3981, May 1985, pp. 5-15.



Notes: ① Each leg of "H" diffuser is schedule 40 P.V.C. piping, 2" Dia.

② Cuts in each leg of diffuser are made 33@ 1" centers, 8@ 1.5" centers 6@ 2" centers, 5@ 2.5" centers.

Figure 5-9: Distributed Diffuser Stratified Water Storage System Designs
(a) Apparatus used in U. of New Mexico Experiments
(b) Vancouver Courthouse Design
(c) Close up of distributed diffuser design from U. of N. Mexico Experiments

(Source of (a) and (c): EPRI EM-4352, Evaluation of Stratified Chilled Water Storage Techniques)
(Source of (b): Engineering Interface Limited, Commercial Cool Storage Seminar Package)

Losses

So far in this chapter, losses were not considered when dealing with unmixed and mixed storage. However it is important to recognize that with unmixed stratified storage, some losses will occur as a result of convection with the tank surfaces and conduction through the thermocline.

As noted earlier, the University of New Mexico experiments resulted in optimal thermal efficiencies of 91 percent. In other words, 91 percent of the stored cooling could be recovered. This optimal result is equivalent to that obtained by other unmixed storage strategies such as empty tank or diaphragm methods.

The 91 percent efficiency was obtained under conditions where all of the chilled water was stored and recovered in a single cycle. Somewhat lower efficiencies (down to 77 percent) were observed when the storage was only partially used and then recharged. These lower efficiencies can be attributed to the fact that when the storage remains longer in the tanks, more heat transfer and consequently temperature degradation can occur.

Another notable point about a stratified storage system is that the thermocline itself reduces the volume of usable storage space in the tank and should be accounted for when calculating water volumes. Thermoclines up to about a foot in thickness are typically observed. In the State Transportation Building storage tanks, a foot thick thermocline would require 9,840 gallons.[12] or four percent of each storage tanks' volume.

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[12]9840 gallons = (60 x 22 x 1ft^3)(62.2 lbm/ft^3)(1 gal/8.3445 lbm).

Potential Savings from Unmixed Storage

Earlier in this chapter, the potential benefits of unmixed storage were discussed, including increased heating and cooling storage capacity and efficiency. By how much could unmixed storage reduce the operating costs of the State Transportation Building?

Summer Operation. Recalling the analysis in Chapter IV concerning summer operation, potential cost savings were calculated for the case where the chilled water storage system was used for electric demand reduction. Separate calculations were performed assuming present unoccupied cooling conditions (where the building must be used to increase the heat pump load) and ideal unoccupied cooling conditions (where the storage system could be cooled exclusively). Relatively small potential demand demand cost savings were calculated for present building cooling demand loads due to the fact that peak loads above the capacities of RU-1 an RU-2 (600 tons) are rarely encountered. Higher demand cost savings were calculated with retail space occupancy (see Tables 4-3 and 4-4).

The difference between demand cost savings with ideal storage performance versus the present storage tank performance was $17,575 annually (with retail space occupancy). In other words, the increased efficiency of stratified tank cooling during unoccupied hours would save $17,575 annually in operating costs (with either the new or existing G-2 rates).

However the analysis in Chapter IV did not account for the capacity of the storage tanks to meet the peak chilled water demand. For example, Tables 4-3 and 4-4 show that the peak cooling demand beyond the 600 ton capacity was 3 mmBtu/hr during this past summer with current building occupancy and cooling demand. But with retail space occupancy, the peak demand beyond 600 tons is estimated to be 5.6 mmBtu/hr. Would the present mixed storage tanks be able to handle that load?

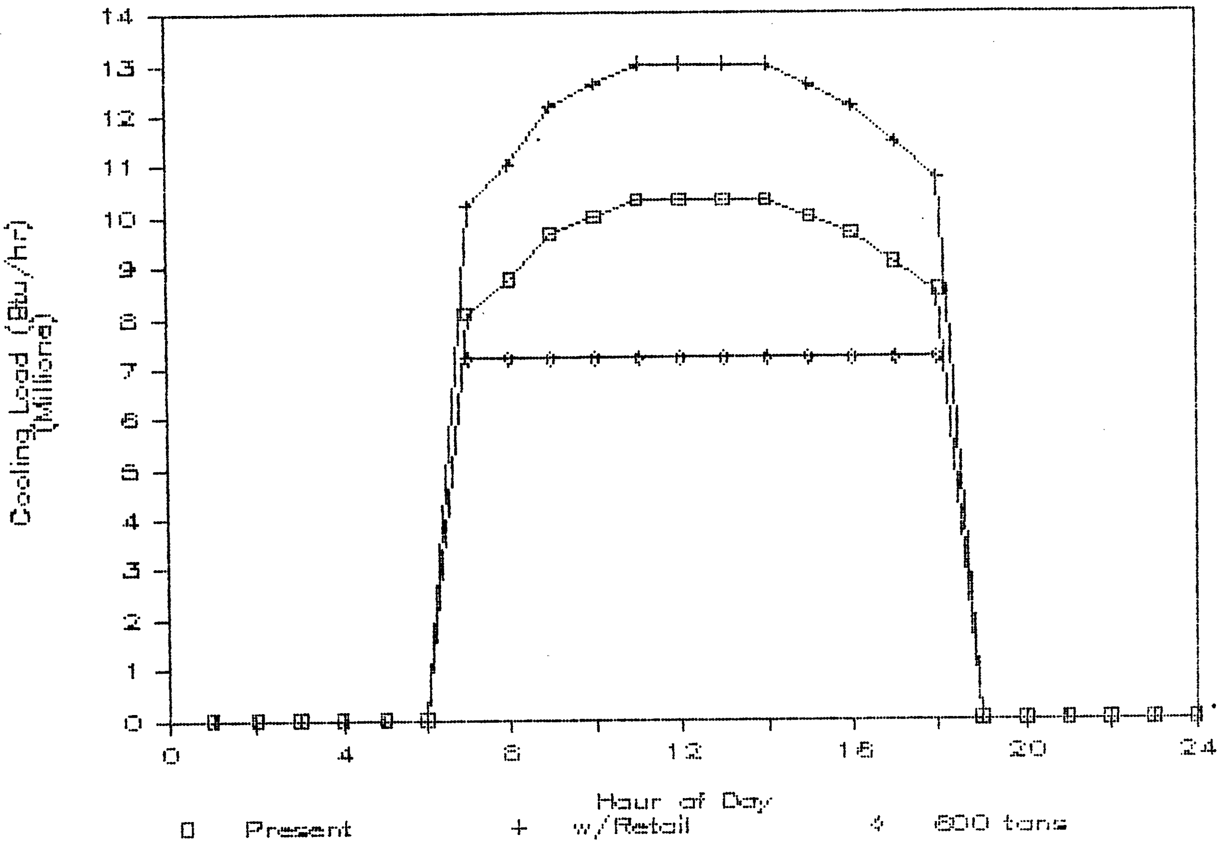
Figure 5-10 graphs the 1985 peak daily cooling load profile for the present building cooling load and projected building cooling load with retail space occupancy. Also shown is the 600 ton capacity of RU-1 and RU-2. For demand load management, the storage system must be capable of meeting the building cooling load beyond the 600 ton limit.

Figure 5-10(b) graphs the peak occupied hourly cooling loads beyond the 600 ton capacity. Integrated over the day, the present daily storage system cooling load is 28.7 mmBtu. With retail space occupancy, the daily load on the storage tanks would increase to 58.6 mmBtu. However assuming that all three storage tanks are initially cooled to 43 degF, the mixed storage system would only be capable of providing at most 29.3 mmBtu over the 11 hour period (See Table D-3). As shown in Figure 5-10(b), when the retail space is occupied, the unmixed storage system would be unable to provide sufficient cooling after six hours of operation on the peak day. As a result, more cooling capacity (RU-3) would have to be brought on line.

But as we found out in our earlier analysis, with stratified storage, the full potential cooling supply from the storage system, 92.1 mmBtu would be available. This cooling could be supplied to the building at rates as high as 15.3 mmBtu/hr depending upon the chilled water return temperature (See Table 5-1).

This analysis indicates that during peak cooling months, demand management as designed may not be possible with the existing storage system once the retail space is occupied. However with stratified storage, the storage tanks would be able to provide sufficient cooling capacity to meet peak loads and demand management would be possible.

(a)



(b)

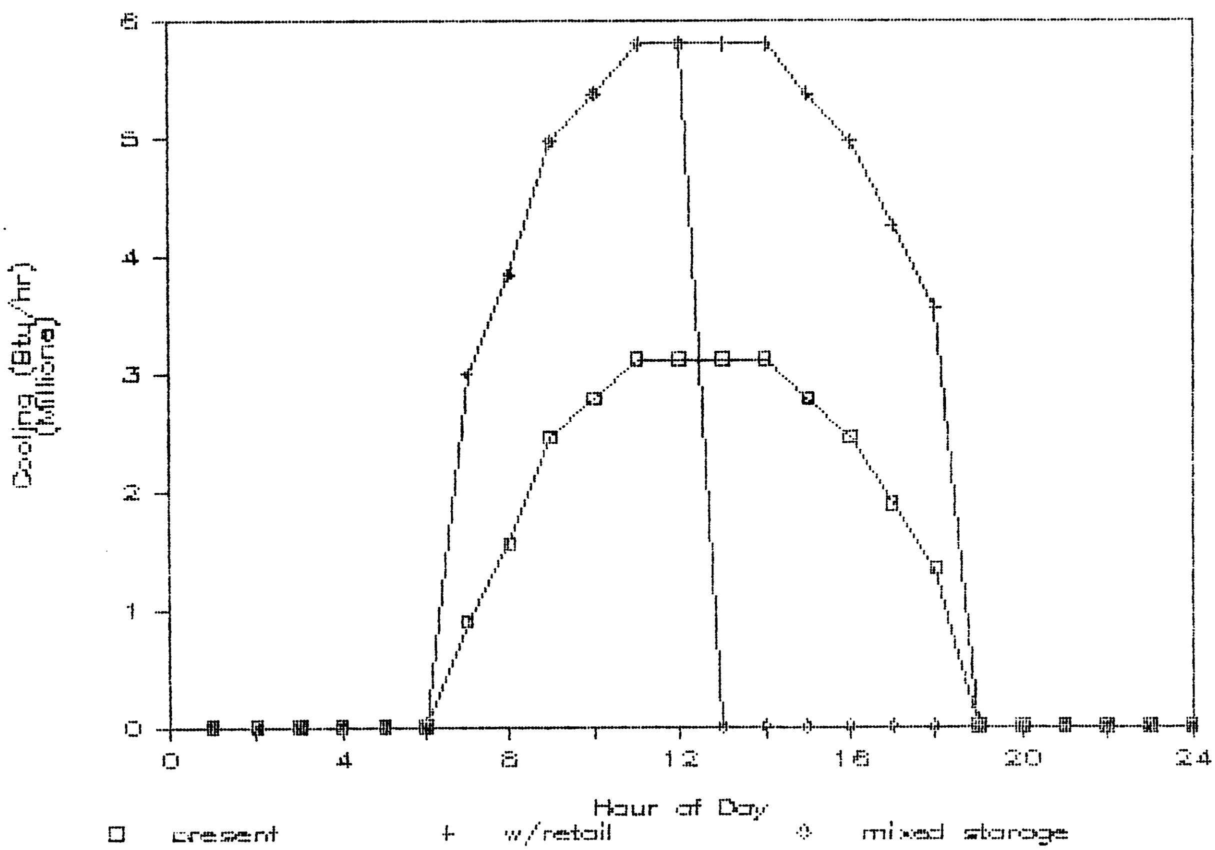


Figure 5-10: Capacity of Storage to Meet Peak Cooling Requirements Beyond 600 Ton Requirement
(a) Peak Day Cooling Load, present and with Retail
(b) Mixed Storage Capability to Meet Peak Loads

Excluding the peak cooling months (July and August) from the analysis in Tables 4-3 and 4-4, we find that stratified storage would allow approximately $18,230 in demand cost savings over unstratified storage once the retail space is occupied.

In addition, the greater cooling capacity of stratified storage would allow for the use of demand limiter settings on the heat pumps throughout the cooling season. This practice could accrue to an additional annual demand cost savings of $16,150 over the cooling season, assuming a 60 percent demand limiter setting and the proposed G-2 rate.

<u>Winter Operation</u>. Recall that in Chapter IV, an analysis was presented indicating that with improved air handler performance and retail space occupancy, enough excess heat would be generated during occupied hours to meet the unoccupied hours heating requirements. However the analysis did not account for any losses in storing and recovering that heat.

The analysis earlier in this chapter indicated that stratified storage could store and supply more heat than unstratified storage. A specific example was presented in which stratified storage was able to store 25 percent more heat than unstratified storage.

It is difficult to estimate exactly how much more heat a stratified storage system could store than the present storage system owing to the nature of the energy system design of the State Transportation Building. The amount of heat stored is not only a function of how much heat is available but also a function of the hot water supply temperature and flow rate, and storage tank water temperature.

Based upon the earlier analysis comparing mixed and unmixed storage, one can conservatively assume that 25 percent more excess hot water available during unoccupied hours could be stored and recovered with an unmixed storage system as compared with a mixed storage system. From our analysis in Chapter IV (See Figure 4-24 b) and Table C-10), this would amount to an annual savings of 698.4 mmBtu with the present building heating requirements and 587.5 mmBtu with improved air handler performance. Assuming that the required heat would be replaced by direct steam heating (which is the least expensive alternative), this would amount to an annual cost savings of $10,040 and $8,440 respectively.

In summary, an unmixed storage system including both heating and cooling operation savings would provide potential annual operation savings of $42,830.

Potential Costs of Converting from Mixed to Unmixed Storage

To estimate the cost of converting the storage of the State Transportation Building to an unmixed system, the operators of a similar system which underwent conversion, were consulted. At the Albuquerque Publishing Company in Albuquerque, New Mexico, a 600,000 gallon water storage system was retrofitted from a mixed to an unmixed configuration using a distributed diffuser design similar to that which was proposed earlier in the chapter. The total cost of the retrofit including replacement water and chemicals from draining down the storage tanks, was $30,000. The design work was done in-house and a local contractor was brought in to do the piping.

The operators at Albuquerque Publishing found that they experienced an immediate 12 percent drop in their electric utility bill which resulted in the complete amortization of their investment within five months. By increasing their storage capacity, the stratified storage also spared them from having to purchase additional chillers when their facilities were expanded.[13]

Assuming that similar retrofit costs would be required for the State Transportation Building storage system, the retrofit costs would yield a complete amortization in less than one year. Considering the many benefits of a stratified storage system including increased heating and cooling storage capacity, more efficient system operation, and a greater potential for electric demand management, retrofitting the existing storage system is strongly recommended.

Lighting Systems

As was noted in Chapter II, lighting is the second largest energy load in the State Transportation Building, accounting for 41.6 percent of the total annual building energy use (See Figure 2-10). Clearly the lighting systems are an obvious consideration for potential energy conservation. While surveying the building lighting systems, it was discovered that the majority of the fixtures use four foot fluorescent lamps (about 18,060 lamps). These fixtures are located mostly in offices and along the corridors. There are many incandescent recessed ceiling 'can' lights (about 1,950), mostly in the corridors and atrium. See Tables A-6 and A-7 for a complete listing of building lamp types, locations, and hours of use.

The fluorescent fixtures in the offices are generally single lamp, single ballast with ballast wattages of 12.63. The lamps which are presently used in the fixtures are standard 40 watt four foot flourescents. Ambient lighting levels are 40-50 footcandles at about 1.6 W/sq. ft. The office lights are generally on from when tenants enter their offices (7-9 a.m.) until the cleaners turn them off, except during the coldest months when they are frequently left on for heating purposes.

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[13]Private communication with Louie Gunther, Albuquerque Publishing House, Albuquerque, NM, May 8, 1986.

The corridor recessed 'can' lights are usually on for 24 hours. Standard 100 watt incandescent lamps are presently used in them.

Five opportunities for lighting energy conservation are presented here: the use of higher efficiency lamps in both fluorescent and incandescent fixtures, turning off corridor lights during unoccupied hours, and daylighting at the atrium abd building perimeter.

Higher Efficiency Lamps

As described in Chapter IV, the use of unnecessary lighting to increase the building's internal gains in effect reduces the heat pump COP since the heat being recovered by the heat pump is no longer 'free' heat. In Chapter IV, it was determined that the use of lights to 'false load' in this manner is less cost effective than storage tank false loading or direct steam heating.

Standard 40 Watt lamps are presently used in the fluorescent fixtures year round rather than higher efficiency lamps in order to increase the building cooling load in the winter. The use of higher efficiency lamps would decrease electric use and reudce the cooling load year-round. Higher efficiency Watt-miser lamps are available which provide slightly lower light levels (2400 lumens per lamp with the wattmizer versus 2700 lumens per lamp with the standard F40) at 34 W per lamp. Using the data in Tables A-6 and A-7, it was determined that the replacement of the existing 40 W lamps with watt-misers would provide total annual cost savings of $38,354.

These calculations include electric use and electric demand cost savings, cooling cost savings, increased heating costs, and additional lamp costs (the wattmizer costs about $1.00 per lamp more). Heating costs assume the use of direct steam heating to compensate for the decreased internal heat gains (See Table 5-7, and Appendix D, Tables D-4 and D-5 for calculations).

Table 5-7: Lighting Conservation Measures

Lighting Conservation Measures

Measure	Potential Use Savings ($/yr)	Potential Demand Savings ($/yr)	Potential Cooling Savings ($/yr)	Potential Heating Cost ($/yr)	Addtnl. Lamp Cost ($/yr)	Total Potential Savings ($/yr)
Watt-miser Flourescents	$36,905	$12,796	$6,235	$13,155	$4,427	$38,354
ER75 Incandescents	$26,795	$5,674	$4,527	$9,551	$9,490	$17,955
Unoccupied Corridor Lights	$28,890	-	$4,881	$10,298	-	$23,473
Atrium Daylighting	$2,560	$1,789	$432	$912	-	$3,869
Perimeter Daylighting	$34,050	$26,436	$5,753	$12,137	-	$54,102
					Total	$137,753

Notes:

Assumes current G-2 rates
Demand Savings assumes high efficiency lamps in use
Cooling Savings assumes $7.92/mmBtu
Heating Cost assumes $16.71/mmBtu (direct steam heat)

75 W ellipsoid-reflector flood incandescent lamps (ER 75) were considered as an alternative to the present 100W standard incandescent lamps. Due to their efficient shape which reflects the light downwards, they provide comparable lighting levels to the 100 watt lamps at three-quarters of the electric use. They also have more than twice as long a lamp life, therefore reducing relamping labor costs (2000 hrs. vs. 750 hrs.). The replacement of the 100 watt lamps with ER-75 lamps throughout the building was determined to potentially provide a $17,955 annual cost savings (see Tables 5-7, D-4 and D-5). These savings account for electric use and demand savings, cooling savings, heating costs, and additional lamp costs (about $2.75 per lamp vs. about $0.50 per lamp). Reduced labor costs were not figured in, and would add to the estimated annual savings.

Unoccupied Corridor Lighting

Both fluorescent and incandescent lamps are used for corridor lighting and are typically on for twenty-four hours. It was determined that if these lights were switched off during weekday nights and weekends, annual cost savings of $23,473 would be incurred (See Table 5-7). See Appendix D for calculations.

Atrium Daylighting

Another lighting conservation measure considered was switching off the corridor lighting in the atrium during daylight hours (this lighting is now on for twenty-four hours). This measure was determined to yield annual savings of $3,869 (see Table 5-7 and Appendix D).

Perimeter Daylighting

By design, the perimeter zone lamp switches are separate from the core lamp switches to provide for the opportunity to utilize daylight exclusively in these areas. If this was done uniformly throughout the building, the potential annual cost savings would be $54,102 (see Table 5-7 and Appendix D).

Note that the potential savings of the last three lighting conservation measures presented here do not account for wiring and switching costs, or any automatic control installation costs which might be incurred. These factors must be investigated before determining final lighting operation cost savings for these measures.

It should be noted that fluorescent low-wattage lamps have already been purchased and are intended for installation. Also money is budgeted for Delta 1000 controls work which may include adding control points for remotely switching some building lighting.

Air Handler Infiltration Problems

As decribed in Chapters II and III excess air handler infiltration has had a significant effect on the building's ability to meet winter heating requirements. This problem is due to a combination of effects including damper leakage, improper fan tracking control, and air handler layout.

Bringing in more than the minimum requirement of outdoor air to meet ventilation requirements and toilet exhaust make-up requirements increases the building cooling load in the summer and the heating load in the winter.

In the winter especially, problems have occurred from bringing in too much outdoor air. Mixing.in too much cold air with the return air may actually bring the mixed air temperature below the cooling coil setpoints. The chilled water supply valves then modulate closed at the air handler cooling coils, reducing the cooling load on the heat pumps, and the heat supply from the heat pumps to the building. Thus, this problem undermines the use of the heat recovery concept upon which the heating system design is based.

Temporary solutions have been used so far to limit air infiltration at the air handlers during the heating season. These solutions have involved disabling the pneumatic damper controls and using blankets or plastic sheeting to seal damper areas. These strategies involve a considerable amount of labor and also limit the operator's flexibility in using and controlling the dampers. Clearly, more permanent and effective solutions are desirable.

Dampers

When commanded closed, the installed damper system has been frequently observed to not close to create a sufficient seal. A solution to this problem, perhaps by replacing the damper installation, is being actively pursued.

Fan Tracking

As described in Chapter I, the three major air handlers in the building were designed to function as VAV systems. In each air handler, as the demand for air flow changes in the building, a static pressure sensor at the second floor will send a signal to vary the pitch of the supply fan blades to maintain a static pressure design setpoint of one inch water. The return fans are then controlled to track the supply fan flow rates.

The delayed vents (minimum outdoor air dampers) are opened during occupied hours to provide fresh air to the building and make-up for toilet exhaust air. When they are commanded open (see Figure 1-7) the return fans are controlled to track the supply fans, maintaining a constant air flow differential setpoint, designed to be 5,000 cfm. When the delayed vents are commanded closed, the return fans are controlled to track the supply fans at the same flow rate.

In practice, during the warm-up cycle, when the outside air dampers are closed and the flow rate differential between the supply and return fans should be zero, usually the return fan flow rate has exceeded the supply fan flow rate. Monitored data from Chapter III indicates that when the dampers are closed the differential between supply and return fan flow rates range from -35,000 cfm to +35,000 cfm for each set of interior or exterior fans. On average, 9,500 cfm of infiltration occurs per fan set, or a total of 76,000 cfm for AC-1, 2, and 3 when the dampers are closed.

This tends to force warm return air out of the exhaust dampers at the air handlers, and causes a negative pressure in the building. These conditions are unfavorable because on one hand heat is exhausted from the building, and on the other hand cold air is forced into the building through doors and cracks.

During occupied hours when the delayed vents are opened the fan tracking control is more accurate, with average ventilation air quantities of 5,500 cfm per fan set, and a total of 44,000 cfm for all three air handlers.

A 2,500 cfm differential between supply and return fan flow rates on each fan is proposed, and would supply a total of 30,000 cfm of fresh air in the building, sufficient to provide make-up air for the approximate 23,000 cfm of toilet exhaust air and still maintain a positive pressure in the building. 30,000 cfm is also approximately 15 cfm per person in the building, meeting the Massachusetts State Code ventilation requirements.[14]

Clearly an improvement in fan tracking controls, especially with delayed vents commanded closed, is necessary to improve building energy system performance.

Air Handler Configuration

Another factor that has encouraged infiltration at the air handlers is their configurations. Figures 5-11 through 5-13 are plan drawings of the AC-1, 2, and 3 air handlers. Note that in both AC-1 and AC-2 return air flow is directed to be in convective contact with both the exhaust dampers and the outside air supply dampers. This configuration encourages air infiltration, especially when the dampers provide a poor seal.

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[14]The Massachusetts State Building Code sites the ASHRAE Standard 62-81 for ventilation standards. Page 7 of ASHRAE Standard 62-81 specifies outdoor air requirements for office spaces of 20 cfm per smoking person, and 5 cfm per non-smoking person.

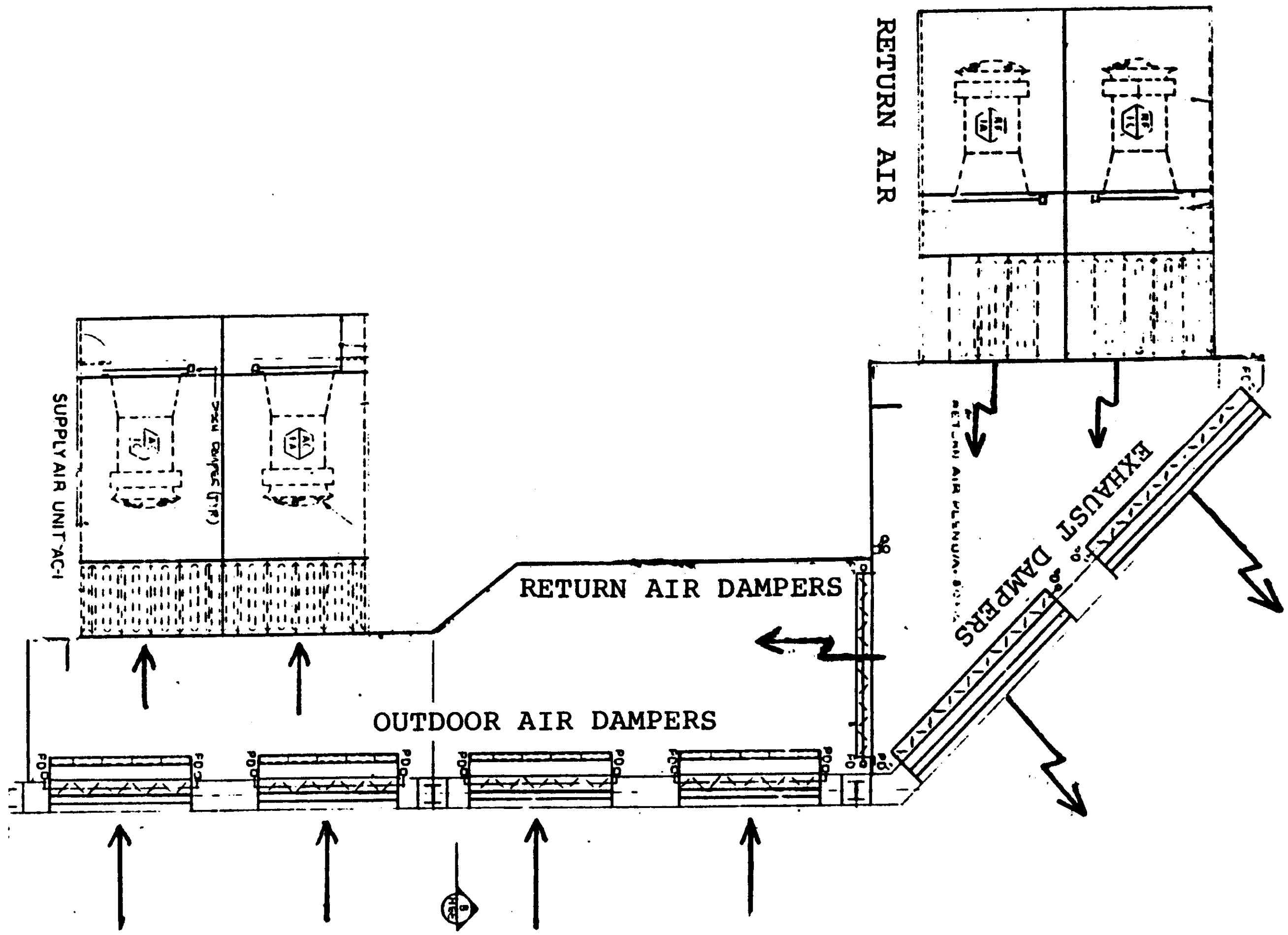

Figure 5-11: Plan of AC-1

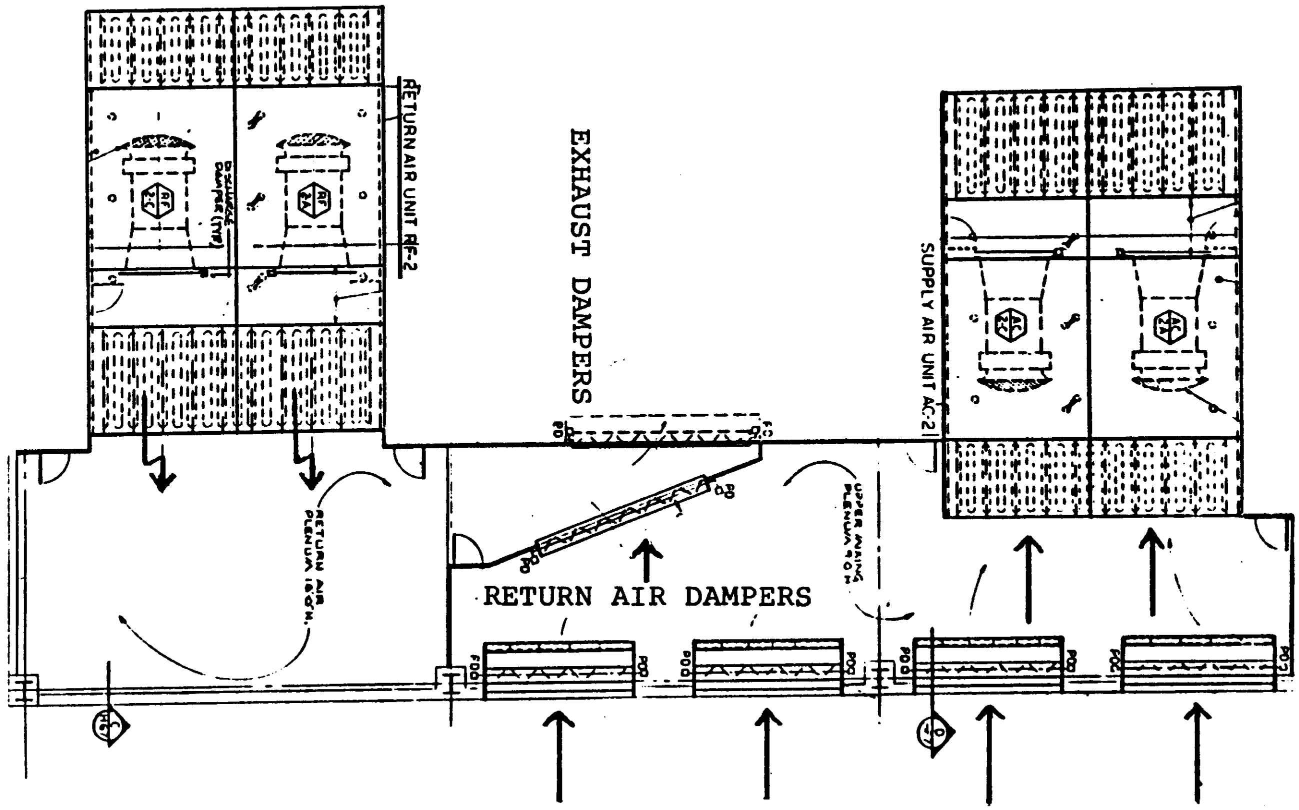

Figure 5-12: Plan of AC-2

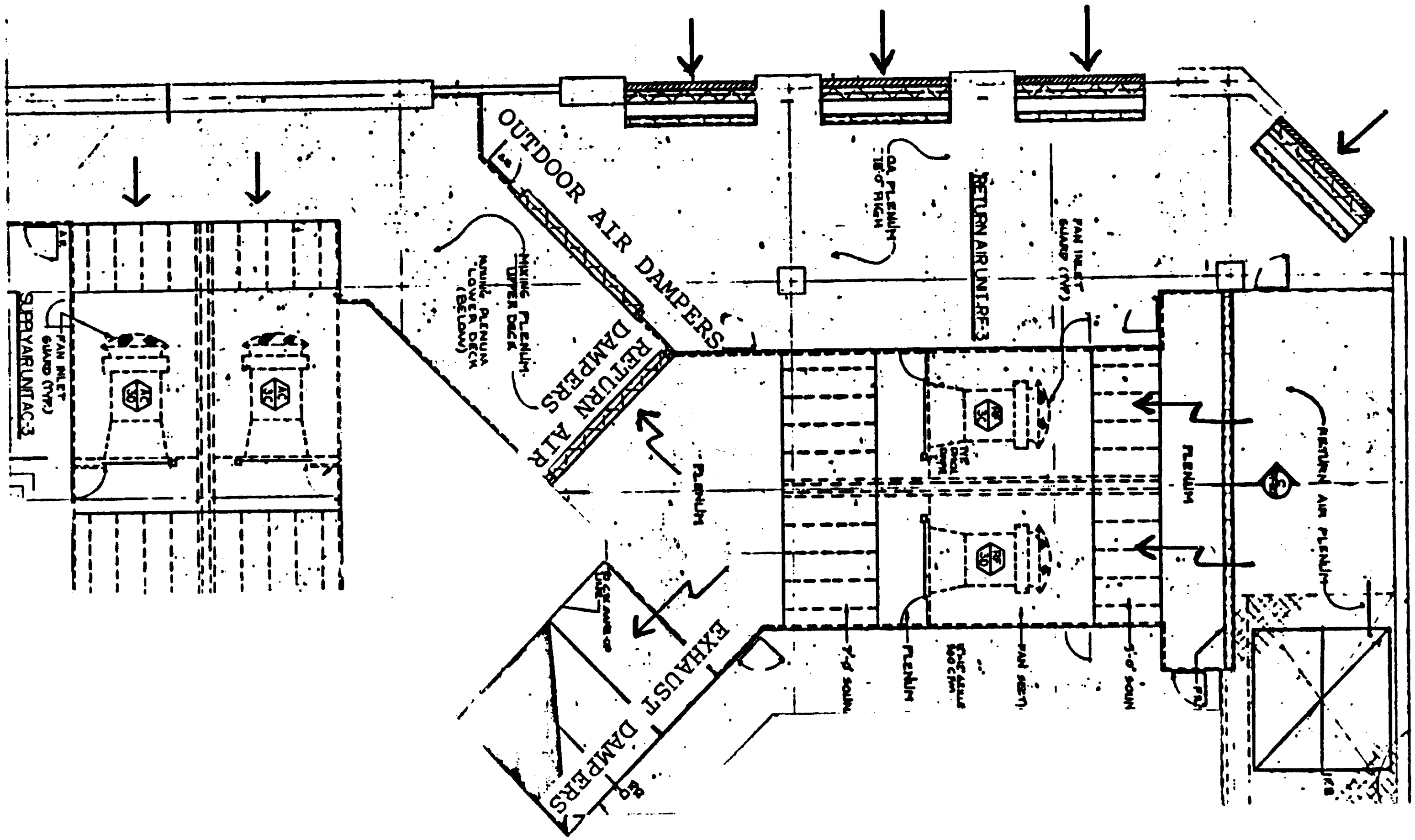

Figure 5-13: Plan of AC-3

By contrast, the AC-3 air handler has the outdoor air dampers located separately from the outside air intakes. It has been observed that this air handler is generally able to maintain higher space temperature levels than AC-1 and 2.

This problem may be improved by constructing barriers in the air handlers to separate the stream of air flow from the dampers.

In conclusion, to improve air handler performance steps must be taken to repair or replace the existing dampers, improve fan tracking control, especially when the delayed vents are closed, and improve the flow configuration of air in the AC-1 and AC-2 air handlers.

Heat Pump Loads

As presented in Chapter IV, monitored data revealed that during the heating season false loading using the storage tanks, steam coils at the air handlers, and auxiliary lighting, made up a considerable portion of the building's cooling load. How much false loading is necessary under different conditions to provide a sufficient load to the heat pumps? How would this change with retail occupancy and reduced air infiltration?

An analysis was conducted comparing the dynamic effects of ventilation upon building cooling loads using the cooling load and ventilation load equations developed in Chapter IV. Although winter cooling loads due to internal gains remain steady, the amount of cooling provided to the building due to a constant amount of ventilation air will increase with decreasing outdoor air temperature. Clearly, this ventilation will reduce the actual cooling load on the heat pumps.

Figure 5-14 graphs the results of this analysis during occupied hours. Two curves are plotted showing the relationship between building mechanical cooling loads and outdoor temperatures, one assuming present building conditions and the other assuming improved air handler performance and retail space occupancy.

With present building cooling loads and ventilation rates, at outdoor temperatures of 50 degF about 275 tons of cooling are required, which is not even enough to load the two 300 ton heat pumps 50 percent. Although the heat pumps are designed to operate efficiently under part-load conditions, they will usually shut down due to low evaporator pressures for loads below about 35 percent of capacity. Figure 5-14 shows that this point is reached at outdoor air temperatures below about 40 degF with present building cooling requirements. Clearly, below this temperature false loading is necessary.

With improved air handler performance and retail space occupancy this situation is predicted to improve. Under these conditions the two 300 ton heat pumps would each be loaded about 57 percent with an outdoor temperature of 40 degF and loaded about 42 percent at an outdoor temperature of 20 degF.

With the present heat pump configuration, RU-1 and RU-2 are operated in parallel, with the chilled water and hot water flows divided between the two heat pumps (see Figures 1-10 and 1-11). Although the system can be operated with only one heat pump, the parallel configuration forces the hot water and chilled water discharge from the two heat pumps to mix, causing temperature degredation of the hot and chilled water being produced by the operating unit. Note that if the two heat pumps did not have to operate in parallel that there would be a sufficient load for one 300 ton unit down to about 20 degF with present building conditions. With the improved conditions one 300 ton heat pump would still have a sufficient cooling load down to about 0 degF.

This retrofit would require a change in hot water and chilled water pump flow rates, either through the use of auxiliary lower flow rate

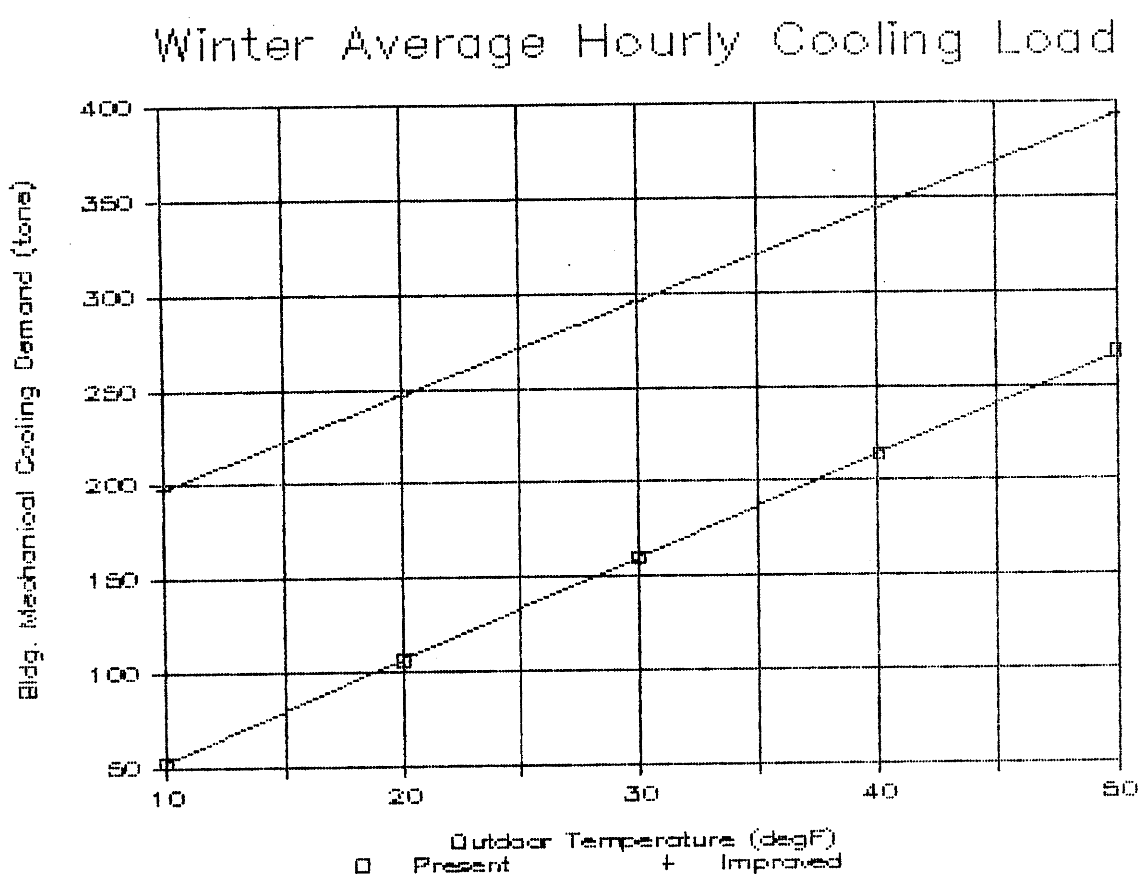

Figure 5-14: Mechanical Cooling Requirement vs. Outdoor Temperature

pumps or through the installation of variable speed pumps. Not only would it reduce the need for false loading in the winter, but also provide for more efficient part-load operation in the spring and fall.

The results of this analysis indicate that while operating RU-1 and RU-2 in parallel false loading is presently necessary to meet heat pump loading requirements below ambient temperatures of 40 degF. With improved air handler performance and retail occupancy, false loading should only be necessary when outdoor temperatures are below 15 degF, except perhaps for early morning start-up. If only one unit could be operated without temperature degredation due to mixing, false loading would not be necessary until considerably lower ambient temperatures were reached (20 degF with present building loads, 0 degF with improved conditions).

Auxiliary Heating

The monitored data on building performance has indicated that the designed system has been unable to meet building heating requirements without auxiliary heating and false loading. The information provided in Chapter IV indicates that the reasons for this include:

- lack of retail space occupancy
- excess infiltration at the air handlers due to damper leakage, inaccurate fan tracking, and air handler layout.
- over-estimation of building cooling requirements and under-estimation of building heating requirements by the system designers.

Even with retail occupancy and improved air handler performance, it was determined in Chapter IV that auxiliary heating will most likely be necessary during the coldest winter conditions.

The result of the lack of an auxiliary heat source is that system operators have been forced to resort to inefficient and expensive methods of heating such as leaving lights on for 24 hours and false loading the heat pumps with steam coils in the interior zone air handlers.

The impact of not having a back-up heating source has also had a effect upon the operation of the storage system. As was discussed in the Thermal Storage Section at the beginning of this Chapter, storage tank temperatures in the winter typically vary only by + or - 5 or 10 degF in a day. It has been observed that system operators are hesitant to use storage tank heat to avoid "depleting the tanks".

If a reliable back-up heating system were available, operators would be able to utilize the storage system heat to its full advantage rather than use it only as a reserve back-up.

It should be noted that a steam heat exchanger has been purchased for the building and will be installed to allow direct heat transfer to the building's hot water loop using district steam. As shown in Chapter IV, this is the least expensive auxiliary option next to direct storage tank heating or storage tank false loading.

Control Improvements

Based upon the analyses in Chapter IV, the following additional energy system controls would be advantageous:

- Demand monitoring and control to allow utilization of the storage system for demand management with chilled water storage.

- Automatic enthalpy control with a manual override so that free cooling is automatically used during the cooling season when beneficial, and automatically disabled during periods when outdoor enthalpy is higher than return air enthalpy. Presently the enthalpy control is manually enabled.

- Cooling coil setpoint adjustment with outside air temperature to minimize reheat at the air handlers.

- Improved tracking between supply and return fans, particularly when the delayed vents are commanded closed.

Note that the enthalpy and cooling coil setpoint controls require accurate temperature and dew point sensor readings. Many of the air and water system temperature and dew point sensors have a history of inaccuracies, and need periodic recalibration or replacement.

It should be noted that a contract has been budgetted and approved to design controls changes, which may include the above items.

Storage System Management

In Chapter IV information about present and predicted building heating and cooling requirements were used to evaluate how much of the thermal storage capacity is required through the spring and fall to meet unoccupied building heating loads and provide for chilled water storage for load management. Based upon these findings, an altered storage tank time of year schedule is proposed (see the Thermal Storage section of Chapter I for the existing Tank Time of Year Schedule).

A premise behind this schedule is that demand management is in use. As discussed in the Summer Operation section of Chapter IV, the storage system is not presently required (nor is it likely to be when the retail space is occupied) to meet the building's peak cooling loads, since the existing mechanical cooling capacity is sufficient. However, if demand management is in use, once the retail space is occupied the storage system must be prepared to meet peak cooling loads beyond the cooling capacities of RU-1 and RU-2 (600 tons) as early as mid-April and as late as mid-October (see Figure 4-18).

Proposed Tank Time of Year Schedule

MONTH	TANK #1	TANK #2	TANK #3
Jan-Feb	Heating	Heating	Heating
Feb-March	Heating	Heating	Heating
March-April	Heating	Heating	Heating
April-May	Cooling	Heating	Heating
May-June	Cooling	Cooling	Cooling
June-July	Cooling	Cooling	Cooling
July-August	Cooling	Cooling	Cooling
August-Sept	Cooling	Cooling	Cooling
Sept-Oct	Cooling	Heating	Heating
Oct-Nov	Cooling	Heating	Heating
Nov-Dec	Heating	Heating	Heating
Dec-Jan	Heating	Heating	Heating

The proposed schedule would change from mid-month to mid-month rather than at the beginning of each month. The mid-month schedule would correspond better with the monitored building heating requirements (see Figure 4-24). It would also be more compatible for demand management purposes since the electric utility bills go from mid-month to mid-month (see Tables 4-3 and 4-4).

Another difference between this schedule and the existing one is that in the proposed schedule the storage tanks do not have month long 'off' periods. As soon as the storage tanks are no longer needed for heating, their storage capacity is available for demand management. This operation would allow for increased utilization of the storage system.

Thesis Summary, Recommendations and Conclusions

The Massachusetts State Transportation Building employs an unconventional internal source heat pump energy system with water thermal storage to provide both heating and cooling to the building. During the heating season, the system recovers internally generated heat due to lights, appliances, and people from the interior zone of the building and provides that heat to the building via the heat pumps. Heat recovered by the heat pumps not immediately needed for heating at the perimeter, is stored in the three 230,000 gallon water thermal storage tanks. The heat is then available as required during unoccupied hours for heating when the heat pumps have been shut down.

During the cooling season, the thermal storage system is used to store chilled water which reduces the cooling load on the heat pumps and therefore electric demand during occupied hours. During unoccupied hours, the heat pumps are used to cool the storage system for the following day.

The energy system was installed without a conventional back-up heating system because the designers predicted that the heat pump and thermal storage system would be able to meet all the building's requirements. However, due to reduced building occupancy and other factors, the system as designed has been unable to meet the building's heating requirements during the coldest winter months (December through February). Building operators have employed a variety of methods to increase the energy system's heat supply during winter months including the reduction of infiltration at the air handlers, the installation of utility-source district steam heating coils in some of the air handlers, and leaving the building lights on during unoccupied hours.

In spite of the heating season difficulties, the 901,000 sq. ft. building is a relatively low energy user compared to other state buildings, energy conscious Boston office buildings, and national building energy use surveys and standards. Annual building energy-use characteristics include:

1985 Building Energy Use Summary

Site Line Total Energy Use	16.02 kWh/sq. ft.
Source Total Energy Use	49.21 kWh/sq. ft.
Peak Electric Demand per sq.ft.	3.1 W/sq. ft.
Annual Total Energy Cost	$1.32/sq. ft.
Peak Electric Demand - total	2,808 kW
Peak Monthly Electric Use(December)	1,330 MWh
Peak Monthly Energy Use(December) (includes steam)	1,689 MWh

Annual Energy Use Breakdown

Lighting - 41.6%	Elevators - 6.2%
Mechanical - 30.1%	Appliances - 5.4%
Steam - 11.2%	Computer Rooms- 5.4%

A simple computer model of the building's energy system was created with algorithms developed from monitored building operation data. This model was then used to determine building heating and cooling demands and electric load profiles for various weather and occupancy conditions, using monitored building operation data and inputs.

The model has also been used to determine the relative efficiencies of different operation strategies. The computer model runs using building operation data resulted in the following findings:

Building Heating and Cooling Requirements

- Linear curves describing building heating and cooling requirements were developed. Daily building perimeter zone heating requirements were determined to range from 112.0 mmBtu/day for average daily outdoor temperatures of 10 degF, to 0 mmBtu/day at average daily outdoor temperatures of 60 degF. Daily building interior zone cooling requirements were found to average 46.2 mmBtu/day for outdoor enthalpies below 20 Btu/lb and temperatures below 60 degF. Cooling loads linearly increased for higher outdoor enthalpies, ranging up to 112.0 mmBtu/day (9,330 ton-hrs) at outdoor enthalpies of 33 Btu/lb.

- Conduction and ventilation account for most of the heating load and are of about the same magnitude. Daily internal gains were determined to be of the same magnitude as the winter cooling load throughout the year. Ventilation air is the primary cooling load in addition to internal gains in the summer.

- Reheat at the exterior air handlers was determined to be significant in the wintertime (typically 10-20 percent of the total heating load). During the spring and fall, reheat was determined to account for as much as 50 percent of the total building heating and cooling loads.

- False loading from storage tanks, lights, and air handler steam coils was determined to account for up to 40 percent of the the winter cooling load. False loading must be used in the winter to make up the difference between the winter heating requirements and the winter cooling requirements, and to provide a sufficient cooling laod for the heat pumps. Without this false loading, the heat pump system would have been unable to meet the winter heating requirements.

- Occupancy of the presently empty first floor retail spaces was predicted to increase the existing building cooling loads by about 15.7 mmBtu/day in the winter and increase the existing building cooling load by 26 percent throughout the cooling season.

  Improved air handler performance through better fan tracking and damper quality was predicted to decrease the daily building heating requirements by 38 percent.

- The existing building heating and cooling requirements curves cross at daily average temperatures of about 40 degF. At temperatures below 40 degF, the heating load exceeds the cooling load. With retail space occupancy and improved air handler performance, the new heating and cooling load curves would cross at about 15 degF.

- The existing building design day cooling demand is about 833 tons. With retail occupancy, it is predicted to increase to about 1,080 tons. This is only 54 percent of the building designers' prediction of 2000 tons.

- The present building design day heating load is 7.35 mmBtu/hr. With air handler improvements, it is expected to drop to 7.0 mmBtu/hr. This is 39 percent higher than the designers' prediction of 5.025 mmBtu/hr.

Heating Operation

- Simulations were run for the 1985 heating season to determine under what conditions, the existing heat pump and thermal storage system would need auxiliary heating, assuming no losses or inefficiencies. It was determined that with existing building heating and cooling requirements, auxiliary heating is needed for average weekly temperatures below 38 degF. With retail occupancy and improved air handlers, this quantity would drop to 20 degF. These results indicate that even with the improved conditions, some auxiliary heating will most likely be necessary during the coldest months.

- Different building heating strategies were examined to compare their relative costs and efficiencies. The following relative net efficiencies and costs were determined for typical winter conditions:

Strategy	COPnet	Net Cost/mmBtu
Occupied Hour heat Pump Operation	2.96	$7.92
Direct Storage Tank Heating	0.89	$12.27
False Loading with Storage Tanks	0.85	$14.96
Direct Steam Heating	0.91	$16.71
False Loading with Steam	0.867	$19.65
Direct Heating with Lights	1.0	$23.44
False Loading with Lights	0.867	$27.04

- Unoccupied auxiliary heating was determined to be required for outdoor temperatures below 35 degF.

- $6,340 would have been saved this past winter if district steam had been used for unoccupied hours heating rather than leaving the lights on for 24 hours.

Cooling Operation

- Due to the fact that building cooling requirements are significantly lower than the system designers anticipated, the installed 1,200 ton cooling capacity, even with retail space occupancy, would be sufficient to meet the building cooling requirements without the storage system.

- Demand reduction is not presently being obtained with the storage system since building electric demand is not being monitored or controlled by the energy management system as specified by the designers.

- Energy system operators must presently cool the unoccupied building in order to cool the storage tanks at night. With this sort of operation the system's full-load cooling COP_{net} is reduced from 3.99 to 1.23.

- Potential chilled water storage demand cost savings with present building conditions and electric rates are $5,000 annually. With retail space occupancy, improved storage system efficiency, use of demand limitter settings, and the proposed Boston Edison utility rates, the potential annual demand reduction savings are $31,000.

Spring/Fall Operation

- Free cooling exclusively was determined to be more cost efficient than mechanical cooling in the Transportation Building for outdoor temperatures below 64 degF (considering only sensible loads). Above 64 degF, the fan power required for free cooling excedes the electric energy requirements of mechanical cooling.

- Additional cooling beyond free cooling is required from late April until mid-October.

- The heat storage capacity of all three storage tanks is required from late November to mid-April to meet unoccupied hour heating loads. Two storage tanks are required for heat storage from mid-March until mid-April. No heat storage is required from June to September.

Unmixed Storage System

It was determined that converting the existing mixed storage system to an unmixed storage system would yield many benefits:

- Unmixed storage would provide and store more cooling at a higher rate than mixed storage, thereby increasing the system's capacity to offset more of the building cooling load for demand purposes.

- With mixed storage, cooling the storage system at night will never be possible without wastefully cooling the unoccupied building as well. But with unmixed storage the storage system could be cooled efficiently and quickly.

- During the heating season unmixed storage could offset more of the building heating load by providing and storing more heat at higher temperatures and at an increased rate.

- Unmixed storage would maintain steady chilled water and hot water return temperatures, resulting in more efficient heat pump operation.

- Stratification of the existing storage tanks would be compatible with the present tank configurations. Potential additional annual operating cost savings from unmixed tanks over mixed tanks were determined to be $42,830. Potential retrofit costs were estimated to be $30,000, resulting in a complete amortization of the investment of conversion in less than one year.

Lighting Systems

Potential annual cost savings were determined for a variety of lighting system improvements, accounting for electric use and demand savings, cooling savings, incremental heating costs, and increased lamp costs. Total annual savings were determined to be:

•	Relamping fluorescent fixtures with higher efficiency lamps	$38,354
•	Relamping incandescent fixtures with higher efficiency lamps	$17,955
•	Switching off corridor lights during unoccupied hours	$23,473
•	Atrium Daylighting	$ 3,869
•	Perimeter Daylighting	$54,102
	total	$137,753/yr.

Conclusions and Recommendations

- The energy system as installed is unable to meet existing building heating requirements without false loading and auxiliary heating. This is due to unoccupancy of the retail spaces, excess infiltration at the air handlers, and an over-estimation of building cooling requirements and under-estimation of building heating requirements by the system designers. With retail space occupancy and reduced infiltration at the air handlers the existing system will be able to meet building heating requirements except when the average weekly outdoor temperature falls below 20 degF.

- Because an auxiliary heating system was not installed the system operators have resorted to inefficient heating and false loading methods. The installation of a steam heat exchanger to supply auxiliary heat will improve this situation.

- Presently only a fraction of the storage system's potential for heat storage and chilled water storage is being utilized due to the fact that the installed storage system is mixed. It is strongly recommended that the existing system be converted to a stratified storage system, which would yield an estimated annual operating cost savings of $42,830 for an initial estimated investment of $30,000.

- The thermal storage system is not presently being used for demand management due to the fact that demand monitoring controls were not installed as originally specified by the designers. With stratified storage, electric demand savings would account for more than 75 percent of potential annual operating cost savings. Therefore, electric demand management in conjunction with stratified storage is strongly recommended.

Other recommended improvements to the existing system include:

- automatic air handler cooling coil setpoint adjustments to reduce reheat during the heating season,
- providing the capability to operated only one 300 ton heat pump without temperature degredation,
- automatic economizer or free cooling control at the air handlers.

A lesson which might be learned by future designers of similar systems from the experience at the State Transportation Building is that: internal gains are dependent upon many factors out of the building designer's control. Design of an internal source heat pump system which depends upon internal gains should allow for maximum flexibility in providing for part-load conditions. These provisions should allow for efficient operation of heat pumps at low internal-gain loads, and also for the supply of relatively inexpensive back-up heating.

The fact that the Massachusetts State Transportation Building, with its internal-source heat pump and thermal storage system, has proved to be a 'low-energy building' by both local and national standards is probably more due to the use of 'bootstrap heating' and a tight thermal envelope than due to the thermal storage system, which is presently providing a relatively low percentage of building heating and cooling requirements. With the implementation of the previously mentioned recommendations, the Transportation Building's energy consumption and operating costs have the potential for even furthur reduction.

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Appendix A

Description of Garage and Retail Space Energy Use

Garage

floor area: 221,830 ft^2
energy use:
lighting: 1,626.057 kWh x 365 days = 593,511 kWh/yr
fans: GMA-1: 54.864 kWh's/day x 365 days = 20,025 kWh/hr
AEF-1: 183.024 kWh/day x 365 days = 66,804 kWh/yr
Total: 680,340 kWh/yr, 3.0669 kWh/sqft/yr, 10.223 kWh/sqft/yr source
Demand: 67.752(lights) + 16.52(fans) = 84.272 kW

Retail

floor area: 53,465 ft^2 (includes first floor of atrium)
energy use:
lighting: 5.121 kW demand, 61.452 kWh use x 365 days = 22,430.2 kWh/yr
plant lights: 106 kWh x 365 days = 38,690 kWh/yr, 11 kW demand
368 flour. x 52.63 W/lamp x 8760 hrs/yr = 169,662.3 kWh/yr
77 inc. x 100 W/lamp x 8760 hrs/yr = 67,452 kWh/yr
4 exit x 9 W x 8760 hrs/yr = 315.4 kWh/yr
unit heaters: .5 kW x 24 hrs. x 2920 hrs/yr = 35,040 kWh/yr
vestibule fans: 1.7 W x 24 x 2920 hrs/yr = 119,136 kWh/yr
steam: assume 80 % of total steam use,
1340 Mlbs = 465,741 kWh/yr
Total: 918,477 kWh/hr, 17.179 kWh/sqft/yr, demand: 45.425 kW

Net Building without garage

floor area: 625,964 ft^2 + 53,465 ft^2 = 679,429 ft^2
energy use: 13,820,020 kWh/yr (20.341 kWh/sqft)
49,055,819 kWh/yr source (72.20 kWh/sqft)
demand: 2724 kW, 4.0 W/sqft

Net Building without retail

floor area: 625,964 + 221,830 = 847,794 ft^2
demand: 2,762.6 kW, 3.3 W/sqft
steam: 1,626,619 kWh
electric: 10,281,386.2 kWh
total: 11,908,005.2 kWh/yr, 14.0459 kWh/sqft, 43,165 kWh/sqft source

Total Building without garage or retail

floor area: 625,964 ft^2
electric: 10,809,183 kWh/yr
steam: 1,626,619 kWh/yr
total: 12,435,802 kWh/yr, 19.87 kWh/sqft/yr, 61.27 kWh/sqft/yr source
demand: 2,694.85 kW, 4.3 W/sqft

Appendix A

Description of Modes of Operation

See Figure A-1 for a general schematic of the energy system, showing valves and system components referred to in the descriptions of the modes of operation. Also refer to the simplified schematics showing the concepts behind the modes of operation in Chapter I.

Maximum Heating Mode. This mode directs all hot water generated by the heat pumps directly to the perimeter coils, bypassing the storage tanks. The maximum heating mode is commanded on manually by the Delta operator. When commanded on, three-way valves V-1H, V-2H, and V-3H at the storage tank heat exchangers close off hot water supply to the heat exchangers, and will direct full hot water supply to the perimeter heating coils.

Reduced Heating Mode. This mode enables an automatic sequence which directs hot water not needed at the perimeter heating coils to the storage tanks. Unless the maximum heating mode is commanded on, the system is automatically in the reduced heating mode whenever the hot water pump and at least one chiller is running. In the reduced heating mode a pneumatic sensor controller modulates valve V-3H which determines how much hot water is diverted from the hot water flow to the perimeter coils and sent to the tank #3 heat exchanger. If the controller senses a return hot water temperature above a setpoint (typically 85 degF) due to a decrease in heating demand at the building perimeter, it will enable the command to modulate valve V-3H toward the heat exchanger position as required to maintain the hot water return temperature setpoint.

When hot water has been directed to the tank #3 heat exchanger while tank #3 is in heating, tank #3 will then switch from the turbulation valve position to the heating position, directing water from the tank through the heat exchanger. As more perimeter heating valves close and the hot water return temperature increases, more hot water will be available to send to the tanks. Once the valves on the tank #3 heat exchanger are fully open, V-2H at tank #2 will begin to modulate open and tank #2 will switch from turbulating to directing tank water into the heat exchanger.

An increase in building heating demand will cause the return hot water temperature to decrease and the reverse sequencing will occur.

Heat Recovery Mode. When the heat pumps are off this mode is used to provide heat to the perimeter of the building from the thermal storage tanks. On shutdown of the refrigeration units electric/pneumatic relay, EP-3 is de-energized and the heat recovery mode is activated. Three-way valve V-1 modulates to its full chiller bypass position. Valves V-1H, V-2H, and V-3H modulate to direct full hot water flow through heat exchangers HE-1, HE-2, and HE-3. If the tank pumps are in the turbulation position, they will automatically take suction from their high-level valves. Otherwise they must be commanded into heating.

On a drop in building heating demand as indicated by an increase in hot water pump head pressure, DPC-2 will modulate three-way valve V-3HR to divert hot water directly to the hot water return, HWR-1. On a further drop in heating demand valves V-2HR and V-1HR will modulate towards their hot water return positions in sequence to maintain hot water pump head pressure.

Stand-by Mode. In the event of failure of RU-1 or RU-2 to operate the stand-by mode is automatically enabled and sounds an alarm at the Delta 1000. In this event back-up chillers must be manually commanded on.

False Loading Mode. False loading mode is used in the heating season when the building cooling load is insuffcent to provide a heat source to the heat pumps. In the false loading mode, heat is taken from the storage tanks and transferred to the chilled water loop to provide a "false load".

The system is designed so that a reduction in the interior mechanical cooling load is detected by DPC-1 across the chilled water pump as the chilled water valves at the AC-units throttle closed. DPC-1 locks out the hot water valves at HE-1, and opens the chilled water valves, V-1C and SV-1C to the heat exchanger. This relieves head pressure on the chilled water pump by providing a place for the chilled water to go. In practice, DPC-1 always keeps the hot water valves locked closed and the chilled water valves locked open on HE #1 as long as the chilled water pump is runnning.

The false loading mode was originally designed to be commanded on automatically when the hot water supply temperature dropped below a 105 degF setpoint. However, this function was disabled early in the system's operation due to the fact that tank temerature is not accounted for in the control sequence. The false loading mode is now only commanded on manually by the Delta operator. When commanded on, EP-5 is enabled, and pump P-7A, tank #1 pump, will automatically take suction from high level valve V1-1SH. Hot water from the tank is passed through HE-1, exchanging heat with the chilled water passing through the heat exchanger.

If the Delta operator wants to use tank #2 or tank #3 for false loading, this is done by commanding the tank into cooling. Suction will be taken from the bottom tank valve and the chilled water valves will open up on the heat exchanger, allowing heat to be transferred from the tank to the chilled water loop.

Peak Chilled Water Mode. The peak chilled water mode is used in the cooling season when the heat pump(s) are running. It pre-cools the chilled water return from the air handlers with chilled water stored in the storage tanks.

The Delta operator manually commands on the peak chilled water mode which energizes EP-4 and enables peak chilled controller, C-3C. PRV-1 will close, diverting full chilled water flow directly to the AC-unit cooling coils. Chilled water valves at HE-1, 2, and 3 will open fully. If the tanks are in the cooling mode, pumps P-7A, B, and C will automatically take suction from their respective low level valves and chilled water from the storage tanks will be passed through the heat exchangers.

On a rise in chilled water return temperature, as sensed by temperature transmitter TT-3C, C-3C will modulate valve V-2 open to divert chilled water return through the heat exchangers for pre-cooling in order to maintain a return chilled water temperature setpoint. On a drop in chilled water return temperature, the reverse will occur.

Part Chilled Water Mode. Part chilled water mode is similar to the reduced heating mode. Part chilled water mode is automatically activated whenever the chilled water pump and a chiller are running. This mode sends excess chilled water not needed at the cooling coils to the storage tanks for cooling.

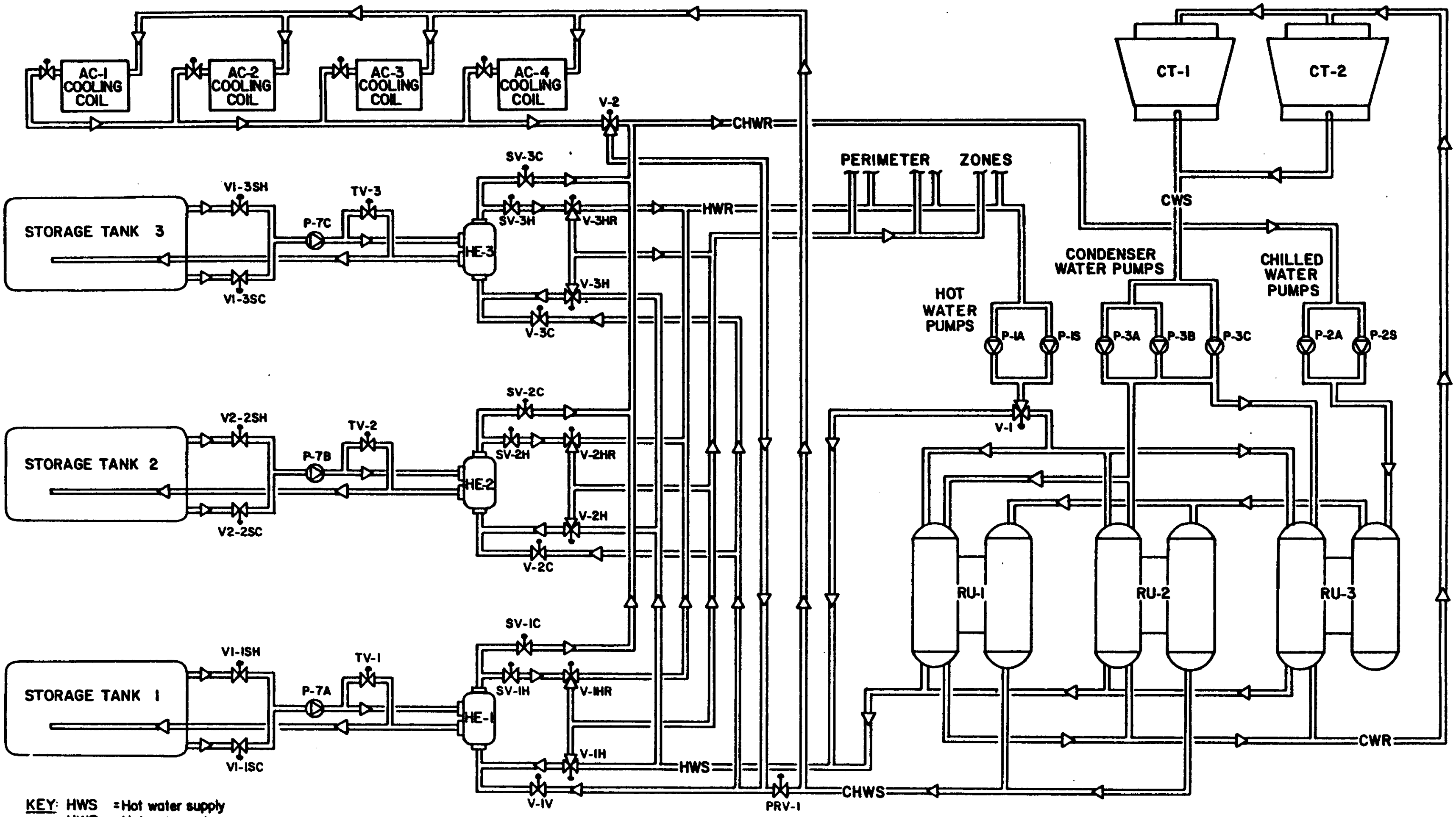
The system was designed so that on a drop in mechanical cooling load, DPC-1 senses the increase in chilled water pump head pressure due to cooling coil valves throttling closed. DPC-1 then modulates PRV-1 open and opens the chilled water valves at HE-1. As the AC coils modulate closed and pressure builds up across the pump, the cooling coils on tank #2 and #3 would then be sequenced open.

As mentioned in the False Loading Mode section, DPC-1 almost always keeps the chilled water valves locked open at HE-1. To provide chilled water to the storage tanks, the tanks are manually commanded into cooling, high tank suction valves open up to send tank water to the heat exchanger, and the chilled water valves on the heat exchanger open.

Off-peak Storage Mode. This mode was originally intended to be a time-based program that would turn on all three heat pumps during off-peak hours to cool the storage tanks, but this was never implemented. This mode is now automatically enabled whenever RU-3 is commanded on.

Economizer Mode. This mode is automatically enabled when the chillers and chilled water pump are manually commanded off while the fans are running because sufficient "free cooling" is available from outside air.

Heat Rejection Mode. This mode is automatically enabled whenever the condenser water pump(s) are commanded on to reject heat from the chillers to the cooling towers. It was originally designed to activate automatically when the hot water return temperature exceeded a setpoint, but this operation was disabled, and this mode is now manually controlled. Because the automatic control sequence did not account for other options to decrease the hot water return temperature, such as manipulating the operation of the storage tanks and the heat pumps, the automatic control of this mode was disabled.



KEY: HWS = Hot water supply
HWR = Hot water return
CWS = Condensed water supply
CWR = Condensed water return
CHWS = Chilled water supply
CHWR = Chilled water return

Figure A-1: Schematic of Energy System, Including Water System Valves

Table A-1: 1985 Daily Electric Use

Month	Day	Year	Day	Daily Elec. Use (MWh)	Ave. Outdoor Temp (degF)	Day #
12	27	84	Thurs	40.24	17	1
12	28	84	Fri	38.02	37	2
12	29	84	Sat	30.08	63	3
12	30	84	Sun	30.71	50	4
12	31	84	Mon	37.61	34	5
1	1	85	Tues		38	6
1	2	85	Wed	36.76	36	7
1	3	85	Thurs	39.80	29	8
1	4	85	Fri	39.39	27	9
1	5	85	Sat	33.29	28	10
1	6	85	Sun	37.42	28	11
1	7	85	Mon	40.23	29	12
1	8	85	Tues		22	13
1	9	85	Wed		15	14
1	10	85	Thurs	43.51	17	15
1	11	85	Fri	43.54	19	16
1	12	85	Sat	38.74	21	17
1	13	85	Sun	40.67	28	18
1	14	85	Mon	45.29	29	19
1	15	85	Tues	42.37	26	20
1	16	85	Wed	45.20	13	21
1	17	85	Thurs	45.59	18	22
1	18	85	Fri	44.51	21	23
1	19	85	Sat	40.88	29	24
1	20	85	Sun	38.91	18	25
1	21	85	Mon	42.34	9	26
1	22	85	Tues	42.37	19	27
1	23	85	Wed	44.02	30	28
1	24	85	Thurs		30	29
1	25	85	Fri	47.63	29	30
1	26	85	Sat	40.28	23	31
1	27	85	Sun	38.62	23	32
1	28	85	Mon	42.79	29	33
1	29	85	Tues	42.69	27	34
1	30	85	Wed	42.66	25	35
1	31	85	Thurs		25	36
2	1	85	Fri	43.61	31	37
2	2	85	Sat		32	38
2	3	85	Sun	32.41	23	39
2	4	85	Mon	45.49	21	40
2	5	85	Tues	45.99	20	41
	6	85	Wed		20	42
	7	85	Thurs		20	43
2	8	85	Fri	43.08	11	44
2	9	85	Sat	42.69	19	45
2	10	85	Sun	38.41	32	46
2	11	85	Mon	38.40	30	47
2	12	85	Tues	41.65	37	48
2	13	85	Wed	42.74	39	49
2	14	85	Thurs		35	50
2	15	85	Fri	37.30	34	51
2	16	85	Sat		29	52
2	17	85	Sun	37.31	36	53
2	18	85	Mon	37.49	36	54
2	19	85	Tues	39.74	40	55
	20		Wed		36	56
2	21	85	Thurs	37.03	33	57
2	22	85	Fri		46	58
	23		Sat	30.01	48	59
2	24		Sun		56	60
2	25	85	Mon	35.10	49	61
2	26	85	Tues	34.63	41	62
2	27	85	Wed	31.55	40	63
	28	85	Thurs	36.70	29	64
3	1	85	Fri	34.89	44	65
3	2	85	Sat	22.70	49	66
3	3	85	Sun	27.29	33	67
3	4	85	Mon		25	68
3	5	85	Tues	37.74	36	69
3	6	85	Wed	36.50	28	70
3	7	85	Thurs	36.34	29	71
3	8	85	Fri	34.79	44	72
	9	85	Sat		46	73
3	10	85	Sun	26.27	40	74
3	11	85	Mon	34.72	45	75
3	12	85	Tues		48	76
3	13	85	Wed	33.53	46	77
3	14	85	Thurs	30.96	45	78
3	15	85	Fri	33.05	36	79
3	16	85	Sat	33.20	35	80
3	17	85	Sun	27.35	44	81
	18	85	Mon		32	82
3	19	85	Tues	35.73	30	83
3	20	85	Wed	22.81	47	84
3	21	85	Thurs	36.82	34	85
3	22	85	Fri	35.08	32	86
3	23	85	Sat	27.92	44	87
3	24	85	Sun	24.22	41	88
3	25	85	Mon		37	89
3	26	85	Tues	34.76	39	90
3	27	85	Wed	32.93	47	91
3	28	85	Thurs	32.52	61	92
3	29	85	Fri		55	93
3	30	85	Sat	23.48	48	94
	31	85	Sun		37	95
4	1	85	Mon	34.65	37	96
4	2	85	Tues	35.37	42	97
4	3	85	Wed	34.15	39	98
4	4	85	Thurs		46	99
4	5	85	Fri	32.57	50	100
4	6	85	Sat	20.61	55	101
4	7	85	Sun	20.23	53	102

Table A-1, continued (p. 2 of 4)

Month	Day	Year	Day	Daily Elec. Use (MWh)	Ave. Outdoor Temp (degF)	Day #
4	8	85	Mon	32.81	42	103
4	9	85	Tues	32.55	39	104
4	10	85	Wed	32.70	36	105
4	11	85	Thurs	32.44	48	106
4	12	85	Fri		46	107
4	13	85	Sat	23.01	45	108
4	14	85	Sun	23.11	43	109
4	15	85	Mon	24.31	59	110
4	16	85	Tues	33.48	60	111
4	17	85	Wed	32.05	45	112
4	18	85	Thurs	32.76	43	113
4	19	85	Fri	32.15	53	114
4	20	85	Sat	22.19	49	115
4	21	85	Sun	21.08	54	116
4	22	85	Mon	32.75	54	117
4	23	85	Tues	31.39	44	118
4	24	85	Wed	33.30	47	119
4	25	85	Thurs		54	120
4	26	85	Fri		69	121
	27	85	Sat		56	122
4	28	85	Sun	20.09	55	123
4	29	85	Mon	34.77	55	124
	30	85	Tues	37.25	66	125
5	1	85	Wed	37.20	66	126
5	2	85	Thurs	34.41	52	127
5	3	85	Fri	37.88	44	128
5	4	85	Sat	27.16	53	129
5	5	85	Sun	23.11	59	130
5	6	85	Mon	36.85	47	131
5	7	85	Tues	36.46	56	132
5	8	85	Wed	30.14	51	133
5	9	85	Thurs	33.34	51	134
5	10	85	Fri		68	135
5	11	85	Sat		76	136
5	12	85	Sun		55	137
5	13	85	Mon		64	138
5	14	85	Tues	35.77	57	139
5	15	85	Wed	34.20	53	140
5	16	85	Thurs	35.73	61	141
5	17	85	Fri	35.67	62	142
5	18	85	Sat		57	143
5	19	85	Sun	23.87	54	144
5	20	85	Mon	36.38	69	145
5	21	85	Tues	36.49	69	146
5	22	85	Wed	35.89	67	147
5	23	85	Thurs	32.27	58	148
5	24	85	Fri	31.83	61	149
5	25	85	Sat	24.10	62	150
5	26	85	Sun	20.23	59	151
5	27	85	Mon	33.46	70	152
5	28	85	Tues	33.16	59	153
5	29	85	Wed		55	154
5	30	85	Thurs		61	155
5	31	85	Fri		65	156
6	1	85	Sat		70	157
6	2	85	Sun	20.11	70	158
6	3	85	Mon	35.72	73	159
6	4	85	Tues	35.68	63	160
6	5	85	Wed		56	161
6	6	85	Thurs	35.07	60	162
6	7	85	Fri		64	163
6	8	85	Sat		64	164
6	9	85	Sun	21.10	66	165
6	10	85	Mon	35.10	74	166
6	11	85	Tues	36.05	71	167
6	12	85	Wed	35.83	61	168
6	13	85	Thurs	35.09	60	169
6	14	85	Fri		61	170
6	15	85	Sat		65	171
6	16	85	Sun	22.97	62	172
6	17	85	Mon		66	173
6	18	85	Tues		70	174
6	19	85	Wed		71	175
6	20	85	Thurs		71	176
6	21	85	Fri		68	177
6	22	85	Sat		71	178
6	23	85	Sun	24.16	71	179
6	24	85	Mon	36.72	70	180
6	25	85	Tues	34.98	62	181
6	26	85	Wed		58	182
6	27	85	Thurs	34.86	55	183
6	28	85	Fri		59	184
6	29	85	Sat		57	185
6	30	85	Sun	22.67	62	186
7	1	85	Mon	33.55	62	187
7	2	85	Tues	36.87	68	188
7	3	85	Wed		72	189
7	4	85	Thurs	27.02	76	190
7	5	85	Fri	36.43	74	191
7	6	85	Sat	28.62	77	192
7	7	85	Sun	23.74	78	193
7	8	85	Mon		72	194
7	9	85	Tues	40.71	71	195
7	10	85	Wed	41.37	77	196
7	11	85	Thurs	41.01	77	197
7	12	85	Fri	38.91	72	198
7	13	85	Sat	26.99	72	199
7	14	85	Sun	21.55	76	200
7	15	85	Mon	41.89	78	201
7	16	85	Tues	42.12	77	202
7	17	85	Wed	39.90	71	203
7	18	85	Thurs	41.26	70	204

Table A-1, continued (p. 3 of 4)

Month	Day	Year	Day	Daily Elec. Use (MWh)	Ave. Outdoor Temp (degF)	Day #
7	19	85	Fri		76	205
7	20	85	Sat		82	206
7	21	85	Sun	23.22	77	207
7	22	85	Mon	38.71	76	208
7	23	85	Tues	33.31	71	209
7	24	85	Wed	38.31	72	210
7	25	85	Thurs		74	211
7	26	85	Fri		76	212
7	27	85	Sat		74	213
7	28	85	Sun		68	214
7	29	85	Mon	38.05	73	215
7	30	85	Tues		78	216
7	31	85	Wed	41.42	66	217
8	1	85	Thurs	41.22	67	218
8	2	85	Fri		64	219
8	3	85	Sat		68	220
8	4	85	Sun	25.47	71	221
8	5	85	Mon	36.54	73	222
8	6	85	Tues	39.57	74	223
8	7	85	Wed	41.40	71	224
8	8	85	Thurs	40.28	72	225
8	9	85	Fri		74	226
8	10	85	Sat		74	227
8	11	85	Sun	23.12	78	228
8	12	85	Mon	39.26	70	229
8	13	85	Tues	37.29	66	230
8	14	85	Wed	43.15	80	231
8	15	85	Thurs	42.85	84	232
8	16	85	Fri	41.87	75	233
8	17	85	Sat		74	234
8	18	85	Sun	23.24	70	235
8	19	85	Mon		65	236
8	20	85	Tues		71	237
8	21	85	Wed	39.43	71	238
8	22	85	Thurs	39.23	68	239
8	23	85	Fri	39.96	68	240
8	24	85	Sat	30.92	70	241
8	25	85	Sun	18.25	67	242
8	26	85	Mon	35.31	67	243
8	27	85	Tues		73	244
8	28	85	Wed	39.16	75	245
8	29	85	Thurs		67	246
8	30	85	Fri	20.41	62	247
8	31	85	Sat	18.52	58	248
9	1	85	Sun	19.65	61	249
9	2	85	Mon	19.72	65	250
9	3	85	Tues		70	251
9	4	85	Wed		80	252
9	5	85	Thurs	38.64	74	253
9	6	85	Fri		65	254
9	7	85	Sat		66	255
9	8	85	Sun	20.32	78	256
9	9	85	Mon		67	257
9	10	85	Tues	38.18	61	258
9	11	85	Wed		59	259
9	12	85	Thurs	31.32	57	260
9	13	85	Fri	31.52	53	261
9	14	85	Sat		59	262
9	15	85	Sun	17.02	61	263
9	16	85	Mon	31.53	60	264
9	17	85	Tues	32.93	62	265
9	18	85	Wed	33.61	66	266
9	19	85	Thurs	37.34	72	267
9	20	85	Fri		77	268
9	21	85	Sat		76	269
9	22	85	Sun	20.72	65	270
9	23	85	Mon		62	271
9	24	85	Tues	36.74	67	272
9	25	85	Wed	34.70	66	273
9	26	85	Thurs		59	274
9	27	85	Fri		68	275
9	28	85	Sat		66	276
9	29	85	Sun	17.17	61	277
9	30	85	Mon		55	278
10	1	85	Tues	35.62	66	279
10	2	85	Wed	35.27	69	280
10	3	85	Thurs	27.11	58	281
10	4	85	Fri		55	282
10	5	85	Sat		63	283
10	6	85	Sun	19.78	57	284
10	7	85	Mon	32.74	55	285
10	8	85	Tues	32.03	53	286
10	9	85	Wed	32.37	63	287
10	10	85	Thurs		67	288
10	11	85	Fri		55	289
10	12	85	Sat		46	290
10	13	85	Sun	23.11	53	291
10	14	85	Mon	33.71	56	292
10	15	85	Tues		66	293
10	16	85	Wed		60	294
10	17	85	Thurs		52	295
10	18	85	Fri		55	296
10	19	85	Sat		59	297
10	20	85	Sun	17.55	51	298
10	21	85	Mon	32.08	47	299
10	22	85	Tues	32.35	53	300
10	23	85	Wed	30.77	51	301
10	24	85	Thurs		55	302
10	25	85	Fri		61	303
10	26	85	Sat		56	304
10	27	85	Sun		62	305
10	28	85	Mon	31.06	49	306

Table A-1, continued (p. 4 of 4)

Month	Day	Year	Day	Daily Elec. Use (MWh)	Ave. Outdoor Temp (degF)	Day #
10	29	85	Tues	32.20	43	307
10	30	85	Wed	32.12	43	308
10	31	85	Thurs	28.28	46	309
11	1	85	Fri		47	310
11	2	85	Sat		50	311
11	3	85	Sun	16.74	48	312
11	4	85	Mon	31.53	48	313
11	5	85	Tues		52	314
11	6	85	Wed		54	315
11	7	85	Thurs	29.89	53	316
11	8	85	Fri		50	317
11	9	85	Sat		50	318
11	10	85	Sun		63	319
11	11	85	Mon	17.30	47	320
11	12	85	Tues		38	321
11	13	85	Wed	32.32	53	322
11	14	85	Thurs		50	323
11	15	85	Fri		43	324
11	16	85	Sat		34	325
11	17	85	Sun		46	326
11	18	85	Mon	31.48	49	327
11	19	85	Tues	31.19	52	328
11	20	85	Wed		63	329
11	21	85	Thurs		47	330
11	22	85	Fri		40	331
11	23	85	Sat		41	332
11	24	85	Sun	18.46	43	333
11	25	85	Mon	32.51	37	334
11	26	85	Tues	33.59	31	335
11	27	85	Wed		37	336
11	28	85	Thurs	23.98	35	337
11	29	85	Fri		32	338
11	30	85	Sat		37	339
12	1	85	Sun	22.30	44	340
12	2	85	Mon	33.31	46	341
12	3	85	Tues		28	342
12	4	85	Wed	37.27	29	343
12	5	85	Thurs		31	344
12	6	85	Fri		34	345
12	7	85	Sat		32	346
12	8	85	Sun	19.73	39	347
12	9	85	Mon	38.18	38	348
12	10	85	Tues	38.02	34	349
12	11	85	Wed	39.81	37	350
12	12	85	Thurs	44.18	37	351
12	13	85	Fri		36	352
12	14	85	Sat		33	353
12	15	85	Sun	40.98	26	354
12	16	85	Mon		32	355
12	17	85	Tues	43.37	31	356
12	18	85	Wed	48.41	22	357

Month	Day	Year	Day	Daily Elec. Use (MWh)	Ave. Outdoor Temp (degF)	Day #
12	19	85	Thurs		17	358
12	20	85	Fri	45.30	24	359
12	21	85	Sat		26	360
12	22	85	Sun	38.75	25	361
12	23	85	Mon	43.38	34	362
12	24	85	Tues	42.84	42	363
12	25	85	Wed	22.80	30	364
12	26	85	Thurs		19	365
12	27	85	Fri		28	366
12	28	85	Sat		31	367
12	29	85	Sun	36.82	28	368
12	30	85	Mon	42.73	30	369
12	31	85	Tues	40.16	37	370
1	1	86	Wed	34.44	36	371
1	2	86	Thurs	41.30	38	372
1	3	86	Fri		40	373
1	4	86	Sat		26	374
1	5	86	Sun	32.23	31	375
1	6	86	Mon	44.31	29	376
1	7	86	Tues	43.65	21	377
1	8	86	Wed	44.71	18	378
1	9	86	Thurs	43.47	29	379
1	10	86	Fri		38	380
1	11	86	Sat	32.56	30	381
1	12	86	Sun	33.79	43	382
1	13	86	Mon	44.73	37	383
1	14	86	Tues	44.57	13	384
1	15	86	Wed	46.73	13	385
1	16	86	Thurs	45.16	24	386
1	17	86	Fri	40.53	38	387
1	18	86	Sat	40.70	50	388
1	19	86	Sun	36.59	50	389
1	20	86	Mon	36.53	50	390
1	21	86	Tues	40.59	39	391
1	22	86	Wed	39.79	43	392
1	23	86	Thurs	40.23	33	393
1	24	86	Fri	41.52	22	394
1	25	86	Sat	35.80	28	395
1	26	86	Sun	30.71	56	396
1	27	86	Mon	41.71	45	397
1	28	86	Tues	43.16	23	398
1	29	86	Wed	43.75	21	399
1	30	86	Thurs	43.09	25	400
1	31	86	Fri	42.85	32	401

Table A-2: Winter Occupied Base Electric Load (24 Hour Lighting)

Base Occupied Electrical Loads Winter	kW	Corr. Fac. Occ.	Corr. Fac. Unoc.	1
Fans				

AC-4	13.7	1	1	
GMA-1	3.81	0.7	0.7	2.667
AEF-1	12.71	0.7	0.7	8.897
EF-1	3.8	1		
EF-2	3.1	1		
EF-6	6.4	0.4		2.56
EF-8	0.9	0.4		0.36
MA-6	7	0.4		2.8
PF-1	0.9	0.4		0.36
Total Fans	52.3			17.6
	Daily fans Total			663.8
Lighting				

Office	742.573	0.8	0.6	445.5438
Corridor/Atrium	205.73	1		205.73
Bathrooms	37.815	0.9	0.7	26.4705
Outdoor	4.6	1		4.6
Miscel. Outdoor	4.93	1		4.93
Garage	67.752	1		67.752
Mechanical	35.099	0.8		28.0792
Retail	10.242	0.5		5.121
Storage	11.361	0.9		10.2249
Conference Rms.	13.905	0.8		11.124
UG offices	5.496	0.9		4.9464
Atrium plant lamps	2	1		2
At. Met.Hal. Lamps	8	1		8
Total Lighting	1,149.5			824.5
	Daily Lighting Total			21,413.1
Pumps				

Comp.Rm.pump	5.8	1		5.8
Solar Tank pump	3.9	1		
Solar Panel pump	5.8	1		
Dom. HW pump	12.49	1		12.49
Sewage pump	8.3	0.5		4.15
Total Pumps	36.3			22.4
	Daily pumps total			664.7
Appliances	346.2	0.80	0.05	17.3
	Daily Appliances Tot.			2,752.1
Computer Rooms				

Computer Rm. units				
base load	56.4	0.9	0.5	28.2
Xtra compressor	27.6	0		0
Computers	68.73	0.9	0.5	34.365
Total Comp.rm.	152.7			62.6
	Daily Total Comp. rms.			2,102.2

Elevators				

Geared	119.7	0.8	0.05	5.985
Gearless	89.7	0.8	0.05	4.485
Geared	59.85	0.8	0.05	2.9925
Hydraulic	36.9	0.8	0.2	7.38
Total	306.2			20.8
	Daily Elev. Total			2,965.1
Miscell. Equipment				

AC-5	4.2	0.5		2.1
Air Compressors	20.7	0.3		6.21
Sprink. Comprssrs.	16	0.15		2.4
LD Unit heaters	4.8	0.9	0.5	2.4
Retail Un.Htrs.	0.5	1		0.5
Vestibule Fans	1.7	1		1.7
Total	47.9			15.3
	Daily Miscel. Total			384.7

Total	2,091			981
Pumps & Mis. Equip	84.2			37.8
Daily Total	30,946			

Table A-3: Winter Unoccupied Base Electric Load (24 Hour Lighting)

Base Unoccupied Electrical Loads Winter	kW	Corr. Fac. Occ.	Corr. Fac. Unoc.	1
Fans				

AC-4	13.7	1	1	
GMA-1	3.81	0.4	0.4	1.524
AEF-1	12.71	0.4	0.4	5.084
EF-1	3.8	0		
EF-2	3.1	0		
EF-6	6.4	0.1		0.64
EF-8	0.9	0.1		0.09
MA-6	7	0.1		0.7
PF-1	0.9	0.1		0.09
Total Fans	52.3			8.1
	Daily fans Total			359.5
Lighting				

Office	742.573	0.8	0.6	445.5438
Corridor/Atrium	205.73	1		205.73
Bathrooms	37.815	0.9	0.7	26.4705
Outdoor	4.6	1		4.6
Miscel. Outdoor	4.93	1		4.93
Garage	67.752	1		67.752
Mechanical	35.099	0.8		28.0792
Retail	10.242	0.5		5.121
Storage	11.361	0.9		10.2249
Conference Rms.	13.905	0.8		11.124
UG offices	5.496	0.9		4.9464
Atrium plant lamps	2	1		2
At. Met.Hal. Lamps	8	1		8
Total Lighting	1,149.5			824.5
	Daily Lighting Total			21,413.1
Pumps				

Comp.Rm.pump	5.8	1		5.8
Solar Tank pump	3.9	1		
Solar Panel pump	5.8	1		
Dom. HW pump	12.49	1		12.49
Sewage pump	8.3	0.5		4.15
Total Pumps	36.3			22.4
	Daily pumps total			664.7
Appliances	346.2	0.05	0.05	17.3
	Daily Appliances Tot.			415.4
Computer Rooms				

Computer Rm. units				
base load	56.4	0.5	0.5	28.2
Xtra compressor	27.6	0		0
Computers	68.73	0.5	0.5	34.365
Total Comp.rm.	152.7			62.6
	Daily Total Comp. rms.			1,501.6

Elevators				

Geared	119.7	0.05	0.05	5.985
Gearless	89.7	0.05	0.05	4.485
Geared	59.85	0.05	0.05	2.9925
Hydraulic	36.9	0.2	0.2	7.38
Total	306.2			20.8
	Daily Elev. Total			500.2
Miscell. Equipment				

AC-5	4.2	0.5		2.1
Air Compressors	20.7	0.3		6.21
Sprink. Comprssrs.	16	0.15		2.4
LD Unit heaters	4.8	0.9	0.5	2.4
Retail Un.Htrs.	0.5	1		0.5
Vestibule Fans	1.7	1		1.7
Total	47.9			15.3
	Daily Miscel. Total			384.7

Total	2,091			971
Pumps & Mis. Equip	84.2			37.8
Daily Total	25,239			

Table A-4: Spring/Summer/Fall Occupied Base Electric Load

Base Occupied Electrical Loads Summer/Sprg/Fall	kW	Corr. Fac. Occ.	Corr. Fac. Unoc.	1
Fans				

AC-4	13.7	1	1	
GMA-1	3.81	0.7	0.7	2.667
AEF-1	12.71	0.7	0.7	8.897
EF-1	3.8	1		
EF-2	3.1	1		
EF-6	6.4	0.4		2.56
EF-8	0.9	0.4		0.36
MA-6	7	0.4		2.8
PF-1	0.9	0.4		0.36
Total Fans	52.3			17.6
	Daily fans Total			663.8
Lighting				

Office	742.573	0.8	0.05	37.12865
Corridor/Atrium	205.73	1		205.73
Bathrooms	37.815	0.9	0.05	1.89075
Outdoor	4.6	1		4.6
Miscel. Outdoor	4.93	1		4.93
Garage	67.752	1		67.752
Mechanical	35.099	0.8	0.4	14.0396
Retail	10.242	0.5		5.121
Storage	11.361	0.9		
Conference Rms.	13.905	0.8	0.05	
UG offices	5.496	0.9	0.1	
Atrium plant lamps	2	1		2
At. Met.Hal. Lamps	8	1		8
Total Lighting	1,149.5			351.2
	Daily Lighting Total			15,784.0
Pumps				

Comp.Rm.pump	5.8	1		5.8
Solar Tank pump	3.9	1		
Solar Panel pump	5.8	1		
Dom. HW pump	12.49	1		12.49
Sewage pump	8.3	0.5		4.15
Total Pumps	36.3			22.4
	Daily pumps total			664.7
Appliances	346.2	0.80	0.05	17.3
	Daily Appliances Tot.			2,752.1
Computer Rooms				

Computer Rm. units base load	56.4	0.9	0.5	28.2
Xtra compressor	27.6	0.05		1.38
Computers	68.73	0.9	0.5	34.365
Total Comp.rm.	152.7			63.9
	Daily Total Comp. rms.			2,135.3

Elevators				

Geared	119.7	0.8	0.05	5.985
Gearless	89.7	0.8	0.05	4.485
Geared	59.85	0.8	0.05	2.9925
Hydraulic	36.9	0.8	0.2	7.38
Total	306.2			20.8
	Daily Elev. Total			2,965.1
Miscell. Equipment				

AC-5	4.2	0.5		2.1
Air Compressors	20.7	0.3		6.21
Sprink. Comprssrs.	16	0.15		2.4
LD Unit heaters	4.8	0	0	0
Retail Un.Htrs.	0.5	0		0
Vestibule Fans	1.7	0		0
Total	47.9			10.7
	Daily Miscel. Total			257.0

Total	2,091			504
Pumps & Mis. Equip	84.2			33.2
Daily Total	25,222			

Table A-5: Spring/Summer/Fall Unoccupied Base Electric Load

Base Unoccupied Electrical Loads Summer/Sprg/Fall	kW	Corr. Fac. Occ.	Corr. Fac. Unoc.	1
Fans				
AC-4	13.7	1	1	
GMA-1	3.81	0.3	0.3	1.143
AEF-1	12.71	0.3	0.3	3.813
EF-1	3.8	0		
EF-2	3.1	0		
EF-6	6.4	0.4		2.56
EF-8	0.9	0.4		0.36
MA-6	7	0.4		2.8
PF-1	0.9	0.4		0.36
Total Fans	52.3			11.0
	Daily fans Total			429.3
Lighting				
Office	742.573	0.2	0.05	37.12865
Corridor/Atrium	205.73	1		205.73
Bathrooms	37.815	0.2	0.05	1.89075
Outdoor	4.6	1		4.6
Miscel. Outdoor	4.93	1		4.93
Garage	67.752	1		67.752
Mechanical	35.099	0.8	0.4	14.0396
Retail	10.242	0.5		5.121
Storage	11.361	0		
Conference Rms.	13.905	0.2	0.05	
UG offices	5.496	0.2	0.1	
Atrium plant lamps	2	1		2
At. Met.Hal. Lamps	8	1		8
Total Lighting	1,149.5			351.2
	Daily Lighting Total			9,850.8
Pumps				
Comp.Rm.pump	5.8	1		5.8
Solar Tank pump	3.9	1		
Solar Panel pump	5.8	1		
Dom. HW pump	12.49	1		12.49
Sewage pump	8.3	0.5		4.15
Total Pumps	36.3			22.4
	Daily pumps total			664.7
Appliances	346.2	0.05	0.05	17.3
	Daily Appliances Tot.			415.4
Computer Rooms				
Computer Rm. units				
base load	56.4	0.9	0.5	28.2
Xtra compressor	27.6	0.05		1.38
Computers	68.73	0.9	0.5	34.365
Total Comp.rm.	152.7			63.9
	Daily Total Comp. rms.			2,135.3
Elevators				
Geared	119.7	0.2	0.05	5.985
Gearless	89.7	0.2	0.05	4.485
Geared	59.85	0.2	0.05	2.9925
Hydraulic	36.9	0.2	0.2	7.38
Total	306.2			20.8
	Daily Elev. Total			944.5
Miscell. Equipment				
AC-5	4.2	0.5		2.1
Air Compressors	20.7	0.3		6.21
Sprink. Comprssrs.	16	0.15		2.4
LD Unit heaters	4.8	0	0	0
Retail Un.Htrs.	0.5	0		0
Vestibule Fans	1.7	0		0
Total	47.9			10.7
	Daily Miscel. Total			257.0
Total	2,091			497
Pumps & Mis. Equip	84.2			33.2
Daily Total	14,697			

Table A-6: Total Building Lamp Summary

LOCATION	FLUORESCENT	INCANDESCENT	EXIT
Lower Garage	465	90	6
Mechanical	23		
Storage	35	1	
Upper Garage	461	99	7
Record Storage	192	12	
Mechanical	80	26	
Offices	124		
First Floor	368	77	4
Outdoor	12	30	
Outdoor Floods (150W)		12	
Outdoor Mercury Vapor(70W)		8	
High Pres. Sodium (70W)		27	
High Pres. Sodium (170W)		4	
Retail		94	
Second Floor			
Office	1,344		
Corridor/Atrium	176	200	8
Atrium Plant lights		2	
Atr. Metal Halide Lamps	8		
Conference Rooms	2	138	
Cafeteria	19		
Library	58	107	
Bathrooms	111		
Third Floor			
Office	2,149	34	
Corridor	281	109	10
Locker Rooms	63	5	
Bathrooms	88	2	
Fourth Floor			
Office	2,212	39	
Corridor	281	109	10
Bathrooms	88	2	
Fifth Floor			
Office	2,212	39	
Corridor	281	109	10
Bathrooms	88	2	
Sixth Floor			
Office	2,212	39	
Corridor	281	109	10
Bathrooms	88	2	
Seventh Floor			
Office	2,212	39	
Corridor	281	109	10
Bathrooms	88	2	

Table A-6, continued (p. 2 of 2)

Eigth Floor				
	Office	1,146		
	Corridor	282	55	6
	Mechanical Rooms	72	139	
	Bathrooms	76		
East Penthouse				
	Mechanical	42	22	
	Outdoor		4	
West Penthouse				
	Mechanical	56	43	
	Outdoor		12	

Table A-7: Building Lighting Electric Use Summary

SUBTOTALS	FLUORESCENT	INCANDESCENT	EXIT	FLUORESCENT Watts/LAMP	INCANDESCENT Watts/LAMP	EXIT Watts/LAMP	PEAK TOTAL WATTs	WEEKDAY HOURS	WKDAY CORR. FACTOR	WEEKEND HOURS	WKEND CORR. FACTOR	TYPICAL WKDAY Watt-hrs	TYPICAL WKEND Watt-hrs
Office	13,545	297	0	52.63	100	0	742,573	16 (7am-10pm)	0.9	16	0.1	10,693,056	1,188,117
Corridor/Atrium	2,231	877	68	52.63	100	9	205,730	24	1.0	24	1.0	4,937,509	4,937,509
Bathrooms	690	15	0	52.63	100	0	37,815	24	0.9	24	0.5	816,798	453,776
Outdoor	12	46	0	0	100	0	4,600	12 (6pm-6am)*	1.0	12	1.0	55,200	55,200
Miscel. Outdoor		51		-	-	-	4,930	12 (6pm-6am)*	1.0	12	1.0	59,160	59,160
Garage	926	189	13	52.63	100	9	67,752	24	1.0	24	1.0	1,626,057	1,626,057
Mechanical	273	230		44.32	100	0	35,099	24	0.8	24	0.5	673,908	421,192
Retail	19	94		44.32	100	0	10,242	24	0.5	24	0.5	122,905	122,905
Storage	227	13		44.32	100	0	11,361	10 (7am-5pm)	0.9	0	0.0	102,246	0
Conference rooms	2	138		52.63	100	0	13,905	16 (7am-10pm)	0.8	16	0.2	177,987	44,497
UG offices	124	0		44.32	0	0	5,496	24	0.9	24	0.5	118,707	65,948
Atrium plant lights		2		0	1000	0	2,000	21 (5am-2am)	1.0	21	1.0	42,000	42,000
At. Metal Halide Lamps	8			1000	0	0	8,000	8 (6pm-2am)	1.0	8	1.0	64,000	64,000
TOTALS			81				1,149,503					19,489,532	9,080,362

* - Outdoor lights controlled by light sensor so hours vary with time of year.

Notes:

1. Exit sign wattage varies with fixture - averaged to 9 W.
2. Lamp counts taken from electrical drawings, therefore task lamps and other additions or changes not accounted for.
3. Floors 4 through 7 were not individually surveyed, but were estimated to be approximately the same as floor 3.
4. Correction factors based on estimated percentage of lamps on at any one time.
5. Fluorescent Lamp wattages - 52.63 watts/lamp: (1)f40 lamp + ballast, 44.32 watts/lamp: 1/2 of (2)f40 + ballast
   Source: lamp and ballast manufacturer's data

Table A-8: Miscellaneous Equipment Electric Use Summary

MISCELLANEOUS EQUIPMENT ELECTRIC LOADS AND SCHEDULES

Item	Quantity	Rated Power (hp)	Measured Power (kW)	----Estimated Daily---- Hours of use --sp/su/fl-! OC	UNOC	---winter--! OC	UNOC	--correction factors--- --sp/su/fl-! OC	UNOC	---winter--! OC	UNOC
Computer Room AC units	6										
fan		5	4.8	24		24		0.9	0.5	0.9	0.5
compressor 1			4.6	24		24		0.9	0.5	0.9	0.5
compressor2			4.6	24		0		0.05			
Total			14								
AC-5 (LG packaged unit)	1		4.2	24		24		0.5	0.5	0.5	0.5
Cooling Tower Fans	1	25	22.3	VAR	VAR						
	1	25	22.3	VAR	VAR						
Air Compressors											
	1	25	20.7	24		24		0.3		0.3	
	2	25	16								
Sprinkler Comprsrs	1	25	16	24		24		0.15		0.15	
	1	25	16								
Unit Heaters	1	5	2.3	0		8	16			0.9	0.5
(Loading Dock)	1	5	2.5	0		8	16			0.9	0.5
Retail Unit Heaters											
	4	1/8	0.075 *			24				1	
	1	1/3	0.2 *			24				1	
Vestibule Fans	3	1.5	1.7			24				1	
Elevators											
Geared	4		29.925	8	16	8	16	0.8	0.05	0.8	0.05
Gearless	4	35	22.425	8	16	8	16	0.8	0.05	0.8	0.05
Geared	2		29.925	8	16	8	16	0.8	0.05	0.8	0.05
Hydraulic	2		18.45	24		24		0.8	0.2	0.8	0.2
RU-1	1		224.4	VAR	VAR	VAR	VAR				
RU-2	1		224.4	VAR	VAR	VAR	VAR				
RU-3	1		224.4	VAR	VAR	VAR	VAR				
MBTA & Massport Computers	1		68.73	24	24	24	24	0.9	0.5	0.9	0.5
Appliances											
UG	1		15.1	8	16	8	16	0.8	0.05	0.8	0.05
Level 2	1		51.48	8	16	8	16	0.8	0.05	0.8	0.05
Level 3	1		46.6	8	16	8	16	0.8	0.05	0.8	0.05
Level 4	1		46.6	8	16	8	16	0.8	0.05	0.8	0.05
Level 5	1		46.6	8	16	8	16	0.8	0.05	0.8	0.05
Level 6	1		46.6	8	16	8	16	0.8	0.05	0.8	0.05
Level 7	1		46.6	8	16	8	16	0.8	0.05	0.8	0.05
Level 8	1		46.6	8	16	8	16	0.8	0.05	0.8	0.05

continued

Table A-8, continued (p. 2 of 2)

Notes:

1. Measured power readings calculated as follows: 3 phase AC circuit:
   3 phase AC circuit: Power(kW)=(Power Factor)*(sqrt(3))*(volts)*(amps)
   Power factor assumed = 0.8

2. Appliance measurements taken from 208V circuits supplying floors.

   No measurements taken on levels 3,4,6,7,8
   assumed to be approx. the same as level 5.
   LG and Level 1 appliance circuits assumed negligible.

3. Correction factors account for percent on.

* - Estimated values.

Table A-9: Pump Summary

	Rated Power (HP)	Design Flow Rate (GPM)	Balancer Flow Rate (GPM)	10/85 Flow Rate (GPM)	Measured Electric Usage (kW)	Hours
Hot Water Pumps						
P-1A, P-1S	40	1240	1250	1280 1200	26.8	VAR
Chilled Water Pumps						
P-2A,P-2S	100	1800	1775	1875 1700	70.1	VAR
Condenser Water Pumps						
P-3A, P-3B	20	1800	1600	1200	14.7	VAR
P-3C	75	3600	3200	3150	48.4	VAR
Tank Pumps						
P-7A, P-7B, P-7C	15	640/410	3650	665/420 665/420 665/430	12.3	VAR
Computer Condenser Water Pumps						
P-8, P-8S	7.5	175	170	170 170	5.8	24
Solar Storage Pumps						
P-9, P-9A	3	75	80		3.9	12
Solar Panel Pumps						
P-10 P-10A	5	75		71	5.8	12
Domestic Hot Water Pumps					12.49	24
Sewage Ejector Pumps (2)	2				8.3	24

Table A-10: Fan Summary

Transportation Building Fan Schedule

Fan	Location	Peak Design Flow (CFM)	Peak Actual Flow (CFM)	Power Rating (HP)	Peak Electric Use (kW)	Average Hours of Operation
AC-1	W. Penthouse					
Fan 1A		50,000	52,500	75	55.5	VAR
1B		50,000	53,000	75	56.1	VAR
1C		50,000	52,500	75	56.1	VAR
1D		50,000	53,000	75	56.1	VAR
RF 1A		45,000	47,600	25	18.5	VAR
1B		45,000	45,500	25	19.1	VAR
1C		45,000	47,000	25	19.1	VAR
1D		45,000	45,450	25	19.1	VAR
	Total	380,000	396,550		300	
AC-2	W. Penthouse					
Fan 2A		50,000	53,000	75	55.5	VAR
2B		50,000	53,250	75	55.5	VAR
2C		50,000	52,900	75	55.7	VAR
2D		50,000	52,750	75	55.5	VAR
RF 2A		45,000	46,500	25	17.8	VAR
2B		45,000	47,100	25	17.2	VAR
2C		45,000	46,500	25	17.8	VAR
2D		45,000	47,000	25	17.8	VAR
	Total	380,000	399,000		293	
AC-3	E. Penthouse					
Fan 3A		50,000	51,500	75	53.5	VAR
3B		50,000	49,750	75	52.3	VAR
3C		50,000	52,600	75	52.3	VAR
3D		50,000	51,000	75	52.3	VAR
RF 3A		45,000	44,700	25	16.6	VAR
3B		45,000	46,500	25	17.2	VAR
3C		45,000	47,000	25	17.2	VAR
3D		45,000	46,500	25	17.2	VAR
	Total	380,000	389,550		279	
AC-4	Loading Dock					
Supply		16,300	17,250	15	10.5	6am-7pm
Return		11,700	12,840	5	3.2	6am-7pm
GMA-1 (Garage Exhaust)	E. Penthouse	67,500	62,745	30	22.9	*24
AEF-1 (Garage Supply)	W. Penthouse	130,000	139,655	100	76.5	*24
EF-1 (West toilets)	W.Penthouse	13,230	12,789	5	3.8	8am-6pm

Table A-10, continued (p. 2 of 2)

EF-2 (East toilets)	E. Penthouse	9,900	9,941	3	3.1	8am-6pm
EF-6 (Electric Rooms)	W. Penthouse	18,000	18,275	10	6.4	**24
EF-8 (L-6 Service)	W. Penthouse	800	791	0.75	0.9	24
MA-6 (Transformer Room)	First Floor	18,000	18,722	10	7	**24
PF-1 (Elevator exhaust)	W. Penthouse		5774	3/4	0.9	**24

Notes:

1. This table lists the major fans in the building. Some small thermostat-controlled exhaust fans in mechanical rooms have been considered negligible, and deleted. There are also many smoke exhaust fans which only operate during fire alarms.

2. * - Garage exhaust fans controlled by CO monitor to maintain less than 50 ppm.
Fans start at 1/3rd capacity, then go to 2/3rds capacity, then go to 100% capacity as needed.
Fans are assumed to run at 1/3rd capacity usually.

3. ** - Electric, elevator and transformer room fans are thermostat controlled.
A 0.5 correction factor is assumed for these fans.

Appendix B

Appendix B

Enthalpy Calculations

The following equations were used to calculate air heating and cooling loads from drybulb temperatures and dewpoint temperatures:

Q(sensible and latent) = $4.5 \cdot cfm \cdot (h_2 - h_1)$

where h, enthalpy, is measured in Btu/lb air

$h = 0.240\ t + W(1061+0.444\ t)$ (Btu/lb air)

where t is temperature, degF and W, relative humidity, is

$W = 0.62198\ P_w/(P-P_w)$ (kg water/kg dry air)

where P_w is partial pressure, and P is atmospheric pressure (Pa)

P = 101,325 Pa

$$\ln P_w = C_1/t_d + C_2 + (C_3 \cdot t_d) + (C_4 \cdot t_d^2) + (C_5 \cdot t_d^3) + (C_6 \cdot \ln(t_d))$$

where:
C_1 = -5800.2206
C_2 = 1.3914993
C_3 = -0.04860239
C_4 = .000041764768
C_5 = -.000000014452093
C_6 = 6.5459673
t_d, dewpoint temperature, in degK

$t_d = (t_{dew} - 32)/1.8 + 273.15$ (degK)

where t_{dew} in degF

(Source: ASHRAE Handbook of Fundamentals, pp. 5.2-5.4)

Discussion of Heat Pump Monitoring

The accuracy of some of the monitored data in Table B-8 comes into question, particularly that from the spring and summer monitoring. Heating and cooling COP's are frequently much higher than the rated full-load COP's. For the winter data the COP's are more consistent, and more in the range of the rated COP's. This could be due to errors in power or temperature readings, or in assumed water flow rates. The power readings are probably accurate, since they were taken with precision, properly calibrated instruments, and, as is shown in Figure 4-21, they correlate fairly well with manufacturer's data.

The spring and summer temperature readings were taken manually by a variety of maintenance personnel at different times of the day, from thermometers installed in the system piping. It is possible that these readings are inaccurate due to human error in reading the thermometers. The winter temperature data, from the Delta 1000, could also be somewhat inaccurate (the sensors have a +/- 1 degF accuracy), but these errors would tend to be more consistent than the human errors.

Water flow rates were not monitored, but were assumed based upon average pump flow rates and upon which heat pumps were operating at the time. Chilled water flow was assumed half of the chilled water pump flow for RU-1 and RU-2 and full flow for RU-3, since chilled water valves to the heat pumps are generally always left open, even to units which are not operating. When one heat pump was running it was assumed that the full hot water flow went through that one unit since the other units are typically valved off in this case. During winter monitoring in all cases both RU-1 and RU-2 were operating, so the chilled water and hot water flows were probably more uniform in relation to pump flow than during spring and summer monitoring when more often than not only one unit was operating.

In practice, all of these flow rates are variable. Changes in system characteristics due to normal operation will cause a variation of the hot water and chilled water system pressures and flow rates, thus varying the operation point on the pump curve. Manual adjustment of the valves into and out of the pumps and the heat pump condensers and evaporators are typically made to regulate pressures, which will also vary flow characteristics. The heat pumps also have their own built-in control mechanisms which will vary water flows to maintain operating setpoints.

Temperature and flow rate errors would effect the accuracy of the heating and cooling effect calculations, which would in turn effect the COP, kW/ton, and percent full-load capacity calculations. The results from the winter monitoring seems to be most reasonable and consistent when compared with the spring and summer results. The heating and cooling COP values are a bit high, but generally close to the rated values. The kW/ton values are consistently in the rated range, and the percent full-load capacity values are quite close to the manufacturer's rating.

Because of the apparent inaccuracy of the spring and summer monitoring results, it was assumed that the winter data was more meaningful, and therefore only the winter data was used in Figures 4-14 through 4-20 and Figure 4-22.

Description of Thermal Storage Tanks, Their Thermal Capacity and Conduction Losses

The Transportation Building has three unpressurized water storage tanks located in an underground mechanical room. These tanks are used for both hot water storage and chilled water storage. Each tank has a holding capacity of approximately 230,000 U.S. gallons. Below is a summary of the characteristics of the tanks, as obtained from the architectural and mechanical design drawings:

Each tank:

Inside dimensions: 60 ft. long, 22 ft. wide, 24 ft. high (18.3 x 6.7 x 7.3 m)
Approximate water height*: 23 ft. (7.2 m)
Water volume: 30,360 ft^3, 230,000 gals. (860 m^2)

Walls: 14 in. concrete, 2 in. rigid insulation, plus 8 in. concrete block covering exposed walls. Walls between tanks are a sandwich of 14 in. concrete, 2 in. rigid insulation, 14 in. concrete
Floor: 8 in. concrete, 2 in. rigid insulation, 5 ft. concrete beam
Top: 8 in pre-cast concrete cover, 2 in. rigid insulation, with manhole

R-values: all units (f^2 hr degF/Btu)
Assumes for concrete R=0.28/inch, for 8 in. concrete block R=0.58, for 2 in. rigid insulation R=10.0

Component	U (1/R)	Area (f^2)	UA (Btu/hr degF)
Floor	.082	1,320	108.24
Top	.082	1,320	108.24
Front Wall	.069	528	36.43
Back Wall	.072	528	37.93
Side Walls (between tanks)	.112	1,440	161.28
Outside Walls	.072	1,440	103.68

Total UA value for end tanks: 555.79
Total UA value for center tank: 613.39

What order of magnitude is thermal conduction loss?

Worst case scenario:
End tank in heating, assume tank temperature 100 degF, other tank temperature 75 degF, ground temperature 55 degF, mechanical room 80 degF.

Heat loss: 18,168 Btu/hr

How does this compare to the tank's thermal capacity?
230,000 gals = 1,888,392 lbm of water
at a specific heat of 1 Btu/lbm degF, it would take 1,888,392 Btu/hr to change the tank temperature by one degF.
Conclusion: thermal conduction is negligible.

* - The tanks are regularly filled with city water to maintain water level.

Energy Balance and CFM Studies

Table B-2 lists the algorithms used to conduct the energy balance and CFM studies. Points referred to are in the computer model, listed in Table B-2.

Internal gains: (levels 2 through 8)

Office lights	668.3 kW
Corridor/atrium lights	205.7 kW
Bathroom lights	37.8 kW
Conference room lights	13.9 kW
Plant lights	2 kW
Total lights	927.8 kW

People: 2000 people @ 100 W/person = 200 kW
Appliances: 331 kW

Total internal gains: 1,459 kW or 4,979,567 Btu/hr

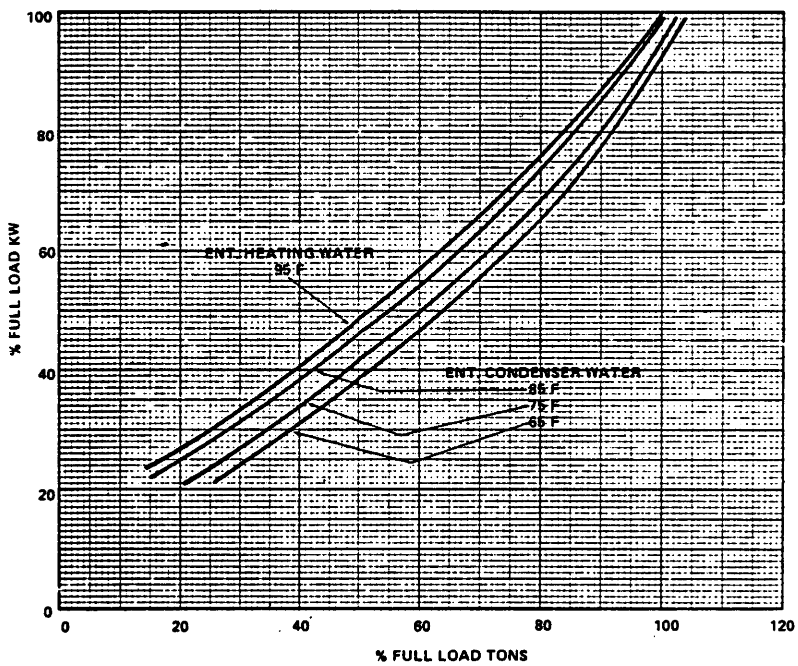
Conduction Heat Loss: (Levels 2 through 8)

Component	U	Area	UA (Btu/degF hr)
Glass	.60	53,505	32,103
Walls	.10	133,155	13,315
Roof	.08	25,670	2,054
Floor	.07	18,840	1,319
Skylights	.83	2771	2,230
Total			51,091

(Source: Shooshanian Engineering's records)

Correction Factors:

The above internal gains due to lights, people, and appliances were multiplied times correction factors from the ASHRAE Handbook of Fundamentals to estimate internal gains for the energy balance calculations. Lights: Table 17E "a"=.65,"b"=C pg. 26.24; People: Table 19 pg. 26.25, Appliances: Table 23, pg. 26.28.



<u>Figure B-1: Part Load Power Use - Trane Heat Recovery Centravac Heat Pumps</u>

(Source: Trane Heat Recovery Centravac Catalog, DS CTV-10/Dec. 78, p. 10)

Table B-1: All Points Listing of Delta 1000 Outputs

```
                    ALL  POINT  LOG          14:34

1-01...STORAGE TANK# 1

  01......OFF TANK MODE                02...+81DEG TANK TEMP                 03......CLO HIGH SUCTION VALVE V1-1
  04......CLO LOW SUCTION VALVE V1-1S  05......CLO TURBULATION VALVE TV- 1   06......OFF PUMP P-7 A STATUS
* 07..+.00IN  PUMP P-7 A DIF PRES      08...+75DEG TSR- 1 RETURN TEMP

1-02...STORAGE TANK# 2

  01......HTG TANK MODE                02...+94DEG TANK TEMP                 03......CLO HIGH SUCTION VALVE V1-2
  04......OPN LOW SUCTION VALVE V1-2S  05......OPN TURBULATION VALVE TV- 2   06......ON  PUMP P-7 B STATUS
* 07.+2.71IN  PUMP P-7 B DIF PRES      08...+92DEG TSR- 2 RETURN TEMP

1-03...STORAGE TANK# 3

  01......HTG TANK MODE                02...+84DEG TANK TEMP                 03......CLO HIGH SUCTION VALVE V1-3
  04......OPN LOW SUCTION VALVE V1-3S  05......OPN TURBULATION VALVE TV- 3   06......ON  PUMP P-7 C STATUS
* 07.+5.25IN  PUMP P-7 C DIF PRES      08...+85DEG TSR- 3 RETURN TEMP

1-04...STORAGE TANK PUMP FLOW

* 01.....0GPM PUMP P-7 A FLOW        * 02+505.8GPM PUMP P-7 B FLOW         * 03+458.2GPM PUMP P-7 C FLOW
  04.....0    SPARE

1-05...HEAT EXCHANGER VALVES

  01......CLO SV-1H VALVE STATUS       02......OPN SV-1SC & V-1 C VALVE ST   03......CLO SV-2H VALVE STATUS
  04......CLO SV-2SC & V-2 C VALVE ST  05......CLO SV-3H VALVE STATUS        06......CLO SV-3SC & V-3 C VALVE ST

1-06...HOT WATER SYSTEM

  01......ON  HOT WATER PUMP P-1A S/S  02......OFF HOT WATER PUMP P-1S S/S * 03......ON  HOT WATER FLOW STATUS
* 04.+2.75IN  HOT WATER DIF PRES       05......OPN VALVE V-1 STATUS          06...+91DEG HOT WATER RETURN TEMP
  07..+100DEG HOT WATER SUPPLY TEMP  * 08..+.00IN  HOT WATER ZONE DIF PRES   09......ON  MAXIMUM HOT WATER MODE
  10......OFF FALSE LOADING MODE - S/  11...+94DEG HOT WATER ZONE SUPPLY T

1-07...HOT WATER SYSTEM FLOW

* 01+392.7GPM HOT WATER PUMP FLOW    * 02..+390GPM HOT WATER ZONE FLOW       03.....0    SPARE
  04.....0    SPARE

1-09...CHILLED WATER SYSTEM

  01......ON  CHILLER RU- 1 S/S        02......ON  CHILLER RU- 2 S/S         03......OFF CHILLER RU- 3 S/S
  04.+48.3DEG CHILLED WATER RETURN TE  05.+47.9DEG RU- 1 CHW DISCH TEMP      06.+48.2DEG RU- 2 CHW DISCH TEMP
  07.+52.5DEG RU- 3 CHW DISCH TEMP     08....-2PCT CHW SUPPLY TEMP - CPA     09......OFF ECONOMIZER SIGNAL
  10......OFF STORAGE MODE STATUS

1-10...CHILLED WATER SYSTEM

  01......ON  CHILLED WATER PUMP P-2A  02......OFF CHILLED WATER PUMP P-2S   03......ON  CHILLED WATER FLOW STAT
* 04.+5.24IN  CHILLED WATER DIF PRES * 05..+728KWH RU- 1 POWER             * 06..+485KWH RU- 2 POWER
* 07..+254KWH RU- 3 POWER              08......OFF PEAK CHILLED WATER MODE   09......OFF STORAGE MODE STATUS

1-11...CHILLED WATER SYSTEM FLOW

* 01+575.2GPM CHILLED WATER PUMP FLOW  02.....0    SPARE                     03.....0    SPARE
  04.....0    SPARE

1-13...CONDENSER WATER SYSTEM

  01......OFF COND WTR PUMP P-3 A S/S  02......OFF COND WTR PUMP P-3 B S/S   03......OFF COND WTR PUMP P-3 C S/S
* 04..+.00IN  COND WTR DIF PRES        05..+119DEG COND WTR RETURN TEMP      06...+78DEG COND WTR SUPPLY TEMP
  07.....0PCT SUPPLY TEMP - CPA        08......DIG SPARE                     09......OFF STORAGE MODE STATUS

1-14...COOLING TOWER & COMPUTER ROOM AC

  01......OFF CLG TWR CT # 1 STATUS    02......OFF CLG TWR CT # 2 STATUS     03......ON  COND WTR P-8 A S/S
  04......OFF COND WTR P-8S S/S        05...+72DEG COMPUTER ROOM SPACE TEM   06...+94DEG COMPUTER ROOM COND WTR

1-15...CONDENSER WATER & SOLAR SYSTEM FLOW

* 01.+1140GPM COND WTR PUMP FLOW     * 02+29.44GPM SOLAR STORAGE PUMP FLOW * 03.+45.6GPM SOLAR ARRAY PUMP FLOW
  04.....0    SPARE

1-18...SOLAR SYSTEM STORAGE LOOP

  01......ON  SOLAR PUMP P-9 S/S       02......OFF SOLAR PUMP P-9 A S/S    * 03.+5.44IN  PUMP P-9 DIF PRES
  04..+107DEG SOLAR STORAGE TANK TEMP

1-19...SOLAR SYSTEM COLLECTOR LOOP

  01......ON  SOLAR PUMP P-10 S/S      02......OFF SOLAR PUMP P-10 A S/S     03..+105DEG SOLAR ARRAY # 1 - TEMP

1-20...AC- 1 INTERIOR SUPPLY DAMPERS

  01...+78DEG AC- 1 SPACE TEMP         02......OPN LVL - 2                   03......OPN LVL - 3
  04......OPN LVL - 4                  05......OPN LVL - 5                   06......OPN LVL - 6
  07......OPN LVL - 7                  08......OPN LVL - 8
```

* - Inaccurate points

Table B-1, continued (p. 2 of 3)

1 . 21...AC- 1 EXTERIOR SUPPLY DAMPERS

01.....0DEG SPARE	02......OPN LVL - 2	03......OPN LVL - 3
04......OPN LVL - 4	05......OPN LVL - 5	06......OPN LVL - 6
07......OPN LVL - 7	08......OPN LVL - 8	

1 . 22...AC- 1 RETURN / EXHAUST DAMPERS

01......SPV ROOM 8 1 5 1 HALON PURG	02......OPN LVL - 2	03......OPN LVL - 3
04......OPN LVL - 4	05......OPN LVL - 5	06......OPN LVL - 6
07......OPN LVL - 7	08......OPN LVL - 8	

1 . 23...AC- 1 EXTERIOR FAN STARTS

01......ON AC- 1A S/S	02......ON RF- 1A S/S	03......ON AC- 1C S/S
04......ON RF- 1C S/S	05......OPN AC- 1 DELAYED VENTILATI	06......OFF AC- 1 SMOKE MODE
07......MEC AC- 1 FREEZE ALARM	08......OPN AC- 1 FAN SYSTEM DAMPER	

1 . 24...AC- 1 INTERIOR FAN STARTS

01......ON AC- 1B S/S	02......ON RF- 1B S/S	03......ON AC- 1D S/S
04......ON RF- 1D S/S	05......CLO AC- 1 ENTHALPY S/S	06...+75DEG AC- 1 RETURN AIR TEMP
07...+45DPT AC- 1 RA DEWPOINT	08......MEC AC- 1 HIGH STATIC ALARM	

1 . 25...AC- 1 EXTERIOR STATIC

* 01..+.55PSI AC- 1 EXTERIOR STATIC

1 . 26...AC- 1 INTERIOR STATIC

* 01..+.72PSI AC- 1 INTERIOR STATIC

1 . 27...AC- 1 EXTERIOR CFM

* 01.+27.5CFM AC- 1A SUPPLY CFM	* 02.+32.1CFM RF- 1A RETURN CFM	* 03.+23.9CFM AC- 1C SUPPLY CFM
* 04.+23.6CFM RF- 1C RETURN CFM		

1 . 28...AC- 1 INTERIOR CFM

* 01.+18.9CFM AC- 1B SUPPLY CFM	* 02.+13.1CFM RF- 1B RETURN CFM	* 03.+15.8CFM AC- 1D SUPPLY CFM
* 04.+16.9CFM RF- 1D RETURN CFM		

1 . 30...AC- 2 INTERIOR SUPPLY DAMPERS

01...+76DEG AC- 2 SPACE TEMP	02......OPN LVL - 2	03......OPN LVL - 3
04......OPN LVL - 4	05......OPN LVL - 5	06......OPN LVL - 6
07......OPN LVL - 7	08......OPN LVL - 8	

1 . 31...AC- 2 EXTERIOR SUPPLY DAMPERS

01......SPV ROOM 8 2 1 1 HALON PURG	02......OPN LVL - 2	03......OPN LVL - 3
04......OPN LVL - 4	05......OPN LVL - 5	06......OPN LVL - 6
07......OPN LVL - 7	08......OPN LVL - 8	

1 . 32...AC- 2 RETURN / EXHAUST DAMPERS

01......SPV ROOM 8 2 3 1 HALON PURG	02......OPN LVL - 2	03......OPN LVL - 3
04......OPN LVL - 4	05......OPN LVL - 5	06......OPN LVL - 6
07......OPN LVL - 7	08......OPN LVL - 8	

1 . 33...AC- 2 EXTERIOR FAN STARTS

01......ON AC- 2A S/S	02......ON RF- 2A S/S	03......ON AC- 2C S/S
04......ON RF- 2C S/S	05......OPN AC- 2 DELAYED VENTILATI	06......OFF AC- 2 SMOKE MODE
07......MEC AC- 2 FREEZE ALARM	08......OPN AC- 2 FAN SYSTEM DAMPER	

1 . 34...AC- 2 INTERIOR FAN STARTS

01......ON AC- 2B S/S	02......ON RF- 2B S/S	03......ON AC- 2D S/S
04......ON RF- 2D S/S	05......CLO AC- 2 ENTHALPY S/S	06...+75DEG AC- 2 RETURN AIR TEMP
07...+46DPT AC- 2 RA DEWPOINT	08......MEC AC- 2 HIGH STATIC ALARM	

1 . 35...AC- 2 EXTERIOR STATIC

* 01..+.67PSI AC- 2 EXTERIOR STATIC

1 . 36...AC- 2 INTERIOR STATIC

* 01..+.00PSI AC- 2 INTERIOR STATIC

1 . 37...AC- 2 EXTERIOR CFM

* 01.+22.3CFM AC- 2A SUPPLY CFM	* 02.+18.1CFM RF- 2A RETURN CFM	* 03.+22.6CFM AC- 2C SUPPLY CFM
* 04.+21.9CFM RF- 2C RETURN CFM		

1 . 38...AC- 2 INTERIOR CFM

* 01.+17.4CFM AC- 2B SUPPLY CFM	* 02.+34.2CFM RF- 2B RETURN CFM	* 03.+23.6CFM AC- 2D SUPPLY CFM
* 04.+35.8CFM RF- 2D RETURN CFM		

1 . 40...LWR GARAGE - FLOOR 7 WEST -FIRE

01......FIR LWR GARAGE ZONES 1 & 2	02......FIR LWR GARAGE ZONES 3 & 4	03......FIR UPR GARAGE ZONES 6 & 7
04......FIR UPR GARAGE ZONES 8 & 9	05......FIR LEVEL 1 ZONES 1 1 & 1 2	06......FIR LEVEL 1 ZONES 1 3 & 1 4
07......FIR LEVEL 2 ZONES 1 7 & 1 9	08......FIR LEVEL 2 ZONES 1 8 & 2 0	09......FIR SPARE
10......FIR LEVEL 2 HVAC CONTROL RO	11......FIR LEVEL 3 ZONES 2 3 & 2 5	12......FIR LEVEL 3 ZONES 2 4 & 2 7

* - Inaccurate points

Table B-1, continued (p. 3 of 3)

13......FIR LEVEL 4 ZONES 3 0 & 3 2	14......FIR LEVEL 4 ZONES 3 1 & 3 3	15......FIR LEVEL 5 ZONES 3 6 & 3 8
16......FIR LEVEL 5 ZONES 3 7 & 3 9	17......FIR LEVEL 6 ZONES 4 2 & 4 4	18......FIR LEVEL 6 ZONES 4 3 & 4 5
19......FIR LEVEL 7 ZONES 4 8 & 5 0	20......FIR LEVEL 7 ZONES 4 9 & 5 1	

1 - 41...PENTHOUSE & 8 TH FLOOR -FIRE

01......FIR LEVEL 8 ZONES 5 4 & 5 6	02......FIR LEVEL 8 ZONES 5 5 & 5 7	03......FIR LEVEL 8 MBTA COMPUTERS
04......FIR LEVEL 8 DPW COMPUTERS	05......FIR WEST PENTHOUSE -FIRE	

1 - 42...LWR GARAGE - 8 TH FLOOR EAST -FIRE

01......FIR LWR GARAGE ZONE 5 -FIRE	02......FIR UPR GARAGE ZONE 1 0 -FI	03......FIR LEVEL 1 ZONES 1 5 & 1 6
04......FIR LEVEL 2 ZONES 2 1 & 2 2	05......FIR LEVEL 3 ZONES 2 8 & 2 9	06......FIR LEVEL 4 ZONES 3 4 & 3 5
07......FIR LEVEL 5 ZONES 4 0 & 4 1	08......FIR LEVEL 6 ZONES 4 6 & 4 7	09......FIR LEVEL 7 ZONES 5 2 & 5 3
10......FIR LEVEL 8 ZONES 5 8 & 5 9		

1 - 43...EAST PENTHOUSE & ATRIUM

01......FIR EAST PENTHOUSE -FIRE	02......FIR ATRIUM FIRE ALARM	03......OFF SUPPLY FAN AC- 1 STATUS
04......ON EXHAUST FAN - 2 S/S	05......OFF STAIR N 1 SMOKE EVAC S/	06......OFF STAIR N 2 SMOKE EVAC S/
* 07.+15.4IN SOLAR ARRAY DIF PRES		

- 45...WEST PENTHOUSE MISC POINTS

01......ON EXHAUST FAN - 1 S/S	02......SPV FIRE DAMPERS EIP 97 INI	03......OFF FUTURE EXHAUST FAN
04......OFF FUTURE EXHAUST FAN		

1 - 46...WEST PENTHOUSE MISC POINTS

01......ON MAIN ELEC RM EXHAUST FA	02...+25DEG OUTSIDE AIR TEMP	03...+21DPT OUTSIDE AIR DEWPOINT
04......DIG SPARE		

1 - 47...WEST PENTHOUSE SMOKE SYSTEM

01......OFF ATRIUM SMOKE EXHAUST	02......OFF STAIR N 3 SMOKE EVAC S/	03......OFF STAIR N 4 SMOKE EVAC S/
04......OFF STAIR N 5 SMOKE EVAC S/		

1 - 50...AC- 3 INTERIOR SUPPLY DAMPERS

01...+74DEG AC- 3 SPACE TEMP	02......OPN LVL - 2	03......OPN LVL - 3
04......OPN LVL - 4	05......OPN LVL - 5	06......OPN LVL - 6
07......OPN LVL - 7	08......OPN LVL - 8	

1 - 51...AC- 3 EXTERIOR SUPPLY DAMPERS

01......SPV HVAC CONTROL ROOM HALON	02......OPN LVL - 2	03......OPN LVL - 3
04......OPN LVL - 4	05......OPN LVL - 5	06......OPN LVL - 6
07......OPN LVL - 7	08......OPN LVL - 8	

1 - 52...AC- 3 RETURN / EXHAUST DAMPERS

01......OFF EMERGENCY POWER	02......DIG SPARE	03......OPN LVL - 3
04......CLO LVL - 4	05......OPN LVL - 5	06......OPN LVL - 6
07......OPN LVL - 7	08......OPN LVL - 8	

1 - 53...AC- 3 EXTERIOR FAN STARTS

01......ON AC- 3A S/S	02......ON RF- 3A S/S	03......OFF AC- 3C S/S
04......ON RF- 3C S/S	05......OPN AC- 3 DELAYED VENTILATI	06......OFF AC- 3 SMOKE MODE
07......MEC AC- 3 FREEZE ALARM	08......OPN AC- 3 FAN SYSTEM DAMPER	

1 - 54...AC- 3 INTERIOR FAN STARTS

01......ON AC- 3B S/S	02......ON RF- 3B S/S	03......ON AC- 3D S/S
04......ON RF- 3D S/S	05......CLO AC- 3 ENTHALPY S/S	06...+74DEG AC- 3 RETURN AIR TEMP
07...+44DPT AC- 3 RA DEWPOINT	08......MNT AC- 3 HIGH STATIC ALARM	

1 - 55...AC- 3 EXTERIOR STATIC

* 01..+.75PSI AC- 3 EXTERIOR STATIC	02.....0 SPARE	03.....0 SPARE
04.....0 SPARE		

1 - 56...AC- 3 INTERIOR STATIC

* 01..+.72PSI AC- 3 INTERIOR STATIC	02.....0 SPARE	03.....0 SPARE
04.....0 SPARE		

1 - 57...AC- 3 EXTERIOR CFM

* 01.+21.7CFM AC- 3A SUPPLY CFM	* 02.+20.4CFM RF- 3A RETURN CFM	* 03.+23.6CFM AC- 3C SUPPLY CFM
* 04.+20.0CFM RF- 3C RETURN CFM	* 05..+.75PSI AC- 3 EXTERIOR STATIC	06.....0ANA SPARE
07.....0ANA SPARE	08.....0ANA SPARE	09.....0ANA SPARE
10.....0ANA SPARE		

1 - 58...AC- 3 INTERIOR CFM

* 01.+14.8CFM AC- 3B SUPPLY CFM	* 02.+17.1CFM RF- 3B RETURN CFM	* 03.+17.8CFM AC- 3D SUPPLY CFM
* 04.+19.8CFM RF- 3D RETURN CFM	* 05..+.72PSI AC- 3 INTERIOR STATIC	

1 - 60...AC- 4

01......ON AC- 4 S/S	02......ON RF- 4 S/S	03...+69DEG AC- 4 SPACE TEMP
04......OPN AC- 4 FAN SYSTEM DAMPER	05...+67DEG AC- 4 RETURN AIR TEMP	06...+15DPT AC- 4 RA DEWPOINT
07......CLO AC- 4 ENTHALPY S/S	08......OFF AC- 4 SMOKE MODE	09......MEC AC- 4 FREEZE ALARM
10......OFF FALSE LOADING S/S	11.....0TOT ...NO DESCRIPTOR FILE	12..+141TOT ...NO DESCRIPTOR FILE

1 - 61...ELECTRICAL USAGE

01.+34.4	02...+26MWH CALCULATION	03+418.6KWH CALCULATION
04.....0		

1 - 62...ELECTRICAL USAGE

01+26.42MWH CALCULATION	02.....0	03.....0
04.....0		

* - Inaccurate points

Table B-2: Listing of Computer Model Output Algorithms

```
A60: 'OUTPUTS                   C61: (,2) (0.24*C8)+(C98*(1061+0.444*C8))
A61: 'OA enthalpy(Btu/lb)       C62: (,2) (0.24*((C51+C49+C53)/3)+(C99*(1061+0.444*((C49+C53+C51)/3))))
A62: 'RA enthalpy(Btu/lb)       C63: (,0) @IF(C26=1,+C22*499.77*(C25-C24),0)
A63: 'HP Htg supply             C64: (,0) @IF(C11=1#AND#C57=0,+C10*499.77*(C12-C13),0)
A64: 'Tank 1 Htg supply         C65: (,0) @IF(C15=1#AND#C57=0,+C14*499.77*(C16-C17),0)
A65: 'Tank 2 Htg supply         C66: (,0) @IF(C19=1#AND#C57=0,+C18*499.77*(C20-C21),0)
A66: 'Tank 3 Htg supply         C67: (,0) +C64+C65+C66
A67: 'Tank Htg supply           C68: (,0) ((C36*$B$36)+(C37*$B$37)+(C38*$B$38))*499.77*(C40-C39)
A68: 'Clg Twr Heat Disch        C69: (,0) +C63+C67
A69: 'Bldg. Htg Demand          C70: (,0) @IF(C27=1,+(C34/2)*499.77*(C31-C33),0)
A70: 'RU-1 clg supply           C71: (,0) @IF(C28=1,+(C34/2)*499.77*(C32-C33),0)
A71: 'RU-2 clg supply           C72: (,0) @IF(C29=1,+C34*499.77*(C33-C30),0)
A72: 'RU-3 clg supply           C73: (,0) +C70+C71+C72
A73: 'HP Clg supply             C74: (,0) @IF(C11=2,+C10*499.77*(C12-C13),0)
A74: 'Tank 1 Clg supply         C75: (,0) @IF(C15=2,+C14*499.77*(C16-C17),0)
A75: 'Tank 2 Clg supply         C76: (,0) @IF(C19=2,+C18*499.77*(C20-C21),0)
A76: 'Tank 3 Clg supply         C77: (,0) +C74+C75+C76
A77: 'Tank Clg supply           C78: (,0) (30.483+(C8*0.1777))*1000*C43/2*(1-((C58*5)/7))
A78: 'AC-1 int cfm              C79: (,0) @IF(C8>60,+(-4.3321+(C8*0.9133))*1000*C44/2,+(104.0297+(C8*-0.9088))*1000*C44/2)*(1-((C58*5)/7))
A79: 'AC-1 ext cfm              C80: (,0) (35.432+(C8*0.1988))*1000*C45/2*(1-((C58*5)/7))
A80: 'AC-2 int cfm              C81: (,0) @IF(C8>51,+(31.6953+(C8*0.2957))*1000*C46/2,+(71.506+(C8*-0.4047))*1000*C46/2)*(1-((C58*5)/7))
A81: 'AC-2 ext cfm              C82: (,0) (23.3247+(C8*0.3946))*1000*C47/2*(1-((C58*5)/7))
A82: 'AC-3 int cfm              C83: (,0) @IF(C8>46,+(15.2487+(C8*0.5276))*1000*C48/2,+(69.4535+(C8*-0.7714))*1000*C48/2)*(1-((C58*5)/7))
A83: 'AC-3 ext cfm              C84: (,0) @IF((C62-C61)>0#AND#C8>C41,C59*C78*4.5*(C61-C62),+C59*((C41-C49)/(C8-C49))*C78*4.5*(C61-C62))
A84: 'AC-1 int free clg         C85: (,0) @IF((C62-C61)>0#AND#C8>C42,+C59*C79*4.5*(C61-C62),+C59*((C42-C49)/(C8-C49))*C79*4.5*(C61-C62))
A85: 'AC-1 ext free clg         C86: (,0) @IF((C62-C61)>0#AND#C8>C41,+C59*C80*4.5*(C61-C62),+C59*((C41-C51)/(C8-C51))*C80*4.5*(C61-C62))
A86: 'AC-2 int free clg         C87: (,0) @IF((C62-C61)>0#AND#C8>C42,+C59*C81*4.5*(C61-C62),+C59*((C42-C51)/(C8-C51))*C81*4.5*(C61-C62))
A87: 'AC-2 ext free clg         C88: (,0) @IF((C62-C61)>0#AND#C8>C41,+C59*C82*4.5*(C61-C62),+C59*((C41-C53)/(C8-C53))*C82*4.5*(C61-C62))
A88: 'AC-3 int free clg         C89: (,0) @IF((C62-C61)>0#AND#C8>C42,+C59*C83*4.5*(C61-C62),+C59*((C42-C53)/(C8-C53))*C83*4.5*(C61-C62))
A89: 'AC-3 ext free clg         C90: (,0) +C84+C85+C86+C87+C88+C89
A90: 'free cooling (Btu/hr)     C91: (,0) @IF(C55=1#AND#C56=0,(C43+C44+C45+C46+C47+C48)*2750*4.5*(C61-C62),0)
A91: 'Ventilation (Btu/hr)      C92: (,0) @IF(C55+C56=0,(C43+C44+C45+C46+C47+C48)*4750*4.5*(C61-C62),0)
A92: 'Infiltration (Btu/hr)     C93: (,0) +C73+C77+C90+C91+C92
A93: 'Bldg. Clg Demand          C94: (,0) ((C9-32)/1.8)+273.15
A94: 'OA dewpoint(K)            C95: (,0) ((((C52+C54)/2)-32)/1.8)+273.15
A95: 'RA dewpoint(K)            C96: (,0) @EXP((-5800.2206/C94)+1.3914993+(C94*-0.04860239)+(0.0000417648*C94*C94)
A96: 'OA partial pressure                 +(C94*C94*C94*-0.0000000145)+(6.5459673*@LN(C94)))
A97: 'RA partial pressure       C97: (,0) @EXP((-5800.2206/C95)+1.3914993+(C95*-0.04860239)+(0.0000417648*C95*C95)
A98: 'OA Humidity ratio                   +(C95*C95*C95*-0.0000000145)+(6.5459673*@LN(C95)))
A99: 'RA Humidity ratio         C98: (,4) 0.62198*(C96/(101325-C96))
A101: 'Daily Bldg.Htg. Demand   C99: (,4) 0.62198*(C97/(101325-C97))
A102: \-                        C101: (,0) @SUM(C69..Z69)
A103: 'Daily HP Htg. Supply     C103: (,0) @SUM(C63..Z63)
A104: 'Dly Tank Htg. Sup        C104: (,0) @SUM(C67..Z67)
A105: 'Daily Clg.Twr. Disch.    C105: (,0) @SUM(C68..Z68)
A107: 'Daily Bldg.Clg. Demand   C107: (,0) @SUM(C93..Z93)
A108: \-                        C109: (,0) @SUM(C73..Z73)
A109: 'Daily HP Clg. Supply     C110: (,0) @SUM(C77..Z77)
A110: 'Dly Tank Clg. Sup        C111: (,0) @SUM(C90..Z90)
A111: 'Daily Free cooling       C112: (,0) @SUM(C91..Z91)
A112: 'Daily Ventilation        C113: (,0) @SUM(C92..Z92)
A113: 'Daily Infiltration
```

Table B-2, continued (p. 2 of 3)

```
A115: 'Electrical Loads
B115: 'kW
A116: \-
A117: 'AC-1 int fans
A118: 'AC-1 ext fans
A119: 'AC-2 int fans
A120: 'AC-2 ext fans
A121: 'AC-3 int fans
A122: 'AC-3 ext fans
A123: 'Total fans
A125: 'Pumps
A126: 'Miscel. pumps
A127: 'Tank1
B127: 12.3
A128: 'Tank2
B128: 12.3
A129: 'Tank3
B129: 12.3
A130: 'Pumps total
A132: 'Cooling Towers
B132: 22.3
B133: 22.3
A134: 'Total Cooling Towers
B134: @SUM(B132..B133)
A136: 'Heat Pumps
A137: 'RU-1
B137: 258
A138: 'RU-2
B138: 258
A139: 'RU-3
B139: 430
A140: 'Total Heat Pumps
A142: 'Total electric load
A144: 'Total Var.Dly. Elec. Load
A145: \-
A146: 'Daily Fans
A147: 'Daily Pumps
A148: 'Daily Cooling Towers
A149: 'Daily Heat Pumps
A151: 'COP's
A152: \-
A153: 'Heat Pump Htg. COP
A154: 'RU-1 Clg COP
A155: 'RU-2 Clg COP
A156: 'RU-3 Clg COP
A157: 'Bldg. Htg. COP
A158: 'Bldg. Clg. COP
A159: 'Bldg. Overall COP
```

```
C117: (,2) (((C78*C78*C78)/8)/(52500*52500*52500)*56.091)+(((C78*C78*C78)/8)/(47600*47600*47600)*18.484)
C118: (,2) (((C79*C79*C79)/8)/(52500*52500*52500)*56.091)+(((C79*C79*C79)/8)/(47600*47600*47600)*18.484)
C119: (,2) (((C80*C80*C80)/8)/(52500*52500*52500)*56.091)+(((C80*C80*C80)/8)/(47600*47600*47600)*18.484)
C120: (,2) (((C81*C81*C81)/8)/(52500*52500*52500)*56.091)+(((C81*C81*C81)/8)/(47600*47600*47600)*18.484)
C121: (,2) (((C82*C82*C82)/8)/(52500*52500*52500)*56.091)+(((C82*C82*C82)/8)/(47600*47600*47600)*18.484)
C122: (,2) (((C83*C83*C83)/8)/(52500*52500*52500)*56.091)+(((C83*C83*C83)/8)/(47600*47600*47600)*18.484)
C123: (,2) @SUM(C117..C122)
C126: (C23*26.8)+(C35*70.1)+((C36+C37)*14.7)+(C38*48.4)
C127: (,0) @IF(C11>0,$B$127,0)
C128: (,0) @IF(C15>0,$B$128,0)
C129: (,0) @IF(C19>0,$B$129,0)
C130: (,0) @SUM(C129..C126)
C132: (,0) @IF((C37+C36+C38)>0,$B$132,0)
C133: (,0) @IF(C40>88#AND#C132>0,$B$133,0)
C134: (,0) @SUM(C132..C133)
C137: (,0) @IF(C68<0,2.57*C27*((0.185408*C40)-1.7440018)*@EXP(0.02*((-C70/12000)/3)),2.58*C27
          *((0.185408*C24)-1.7440018)*@EXP(0.02*((-C70/12000)/2.98)))
C138: (,0) @IF(C68<0,2.57*C28*((0.185408*C40)-1.7440018)*@EXP(0.02*((-C71/12000)/3)),2.58*C28
          *((0.185408*C24)-1.7440018)*@EXP(0.02*((-C71/12000)/2.88)))
C139: (,0) @IF(C68<0,4.16*C29*((0.185408*C40)-1.7440018)*@EXP(0.02*((-C72/12000)/6)),4.3*C29
          *((0.185408*C24)-1.7440018)*@EXP(0.02*((-C72/12000)/5.97)))
C140: (,0) @SUM(C137..C139)
C142: (,0) +C123+C130+C134+C140
C144: (,0) @SUM(C142..Z142)
C146: (,0) @SUM(C123..Z123)
C147: (,0) @SUM(C130..Z130)
C148: (,0) @SUM(C134..Z134)
C149: (,0) @SUM(C140..Z140)
C153: (,2) @IF(C23=1#AND#@SUM(C27..C29)>0,(C63*0.293)/(C140*1000),0)
C154: (,2) @IF(C27=1,(-C70*0.293)/(C137*1000),0)
C155: (,2) @IF(C28=1,(-C71*0.293)/(C138*1000),0)
C156: (,2) @IF(C29=1,(-C72*0.293)/(C139*1000),0)
C157: (,2) @IF(C69>0,(C69*0.293)/(C142*1000),0)
C158: (,2) @IF(C73<0,(-C73*0.293)/(C142*1000),0)
C159: (,2) @IF((C69-C73)>0,((C69-C73)*0.293)/(C142*1000),0)
C163: (,0) @IF(C55+C56=0,(@SUM(C43..C48)/2)*9500,0)
C164: (,0) @IF(C55=1#AND#C56=0,+(@SUM(C43..C48)/2)*5500,0)
C165: (,0) @IF(C56=1#AND#C8<C42,((C42-C51)/(C8-C51))*(+C79+C81+C83),+C56*(+C79+C81+C83))
C166: (,0) @IF(C56=1#AND#C8<C41,((C41-C51)/(C8-C51))*(+C80+C78+C82),+C56*(+C80+C82+C78))
C167: (,0) (C163+C164)/2+C165
C168: (,0) (C163+C164)/2+C166
C169: (,2) @IF(C79+C81+C83>0,((C61*C167)+(C62*((C79+C81+C83)-C167)))/(C79+C81+C83),0)
C170: (,2) @IF(C80+C82+C78>0,((C61*C168)+(C62*((C80+C82+C78)-C168)))/(C80+C82+C78),0)
C171: (,2) @IF(C81+C83+C79>0,((C8*C167)+(C51*((C81+C83+C79)-C167)))/(C81+C83+C79),0)
C172: (,2) @IF(C82+C78+C80>0,((C8*C168)+(C51*((C82+C78+C80)-C168)))/(C82+C78+C80),0)
C173: (,3) (C169-(0.24*C171))/(1061+(0.444*C171))
C174: (,3) (C170-(0.24*C172))/(1061+(0.444*C172))
C175: (,2) (0.24*C42)+(C173*(1061+(0.444*C42)))
C176: (,2) (0.24*C41)+(C174*(1061+(0.444*C41)))
C177: (,0) @IF(C79+C81+C83>0#AND#C26=1,4.5*(C79+C81+C83)*(C175-C169),0)
C178: (,0) @IF(C80+C78+C82>0#AND#C26=1,4.5*(C80+C82+C78)*(C176-C170),0)
C179: (,0) +C177+C178
C180: +C73+C77
C181: (,0) +C73+C77-C179
```

```
A161: 'CFM study
A162: \-
A163: 'Amount OA - infil(cfm)        C163: (,0) @IF(C55+C56=0,(@SUM(C43..C48)/2)*9500,0)
A164: 'Amount OA - ventil(cfm)       C164: (,0) @IF(C55=1#AND#C56=0,+(@SUM(C43..C48)/2)*5500,0)
A165: 'Amount OA-free clg.(ext)      C165: (,0) @IF(C56=1#AND#C8<C42,((C42-C51)/(C8-C51))*(+C79+C81+C83),+C56*(+C79+C81+C83))
A166: 'Amount OA-free clg.(int)      C166: (,0) @IF(C56=1#AND#C8<C41,((C41-C51)/(C8-C51))*(+C80+C78+C82),+C56*(+C80+C82+C78))
A167: 'Amount OA (ext)(cfm)          C167: (,0) (C163+C164)/2+C165
A168: 'Amount OA (int)(cfm)          C168: (,0) (C163+C164)/2+C166
A169: 'MA enthalpy(ext)(Btu/lb)      C169: (,2) @IF(C79+C81+C83>0,((C61*C167)+(C62*((C79+C81+C83)-C167)))/(C79+C81+C83),0)
A170: 'MA enthalpy(int)(Btu/lb)      C170: (,2) @IF(C80+C82+C78>0,((C61*C168)+(C62*((C80+C82+C78)-C168)))/(C80+C82+C78),0)
A171: 'MA temp(ext)                  C171: (,2) @IF(C81+C83+C79>0,((C8*C167)+(C51*((C81+C83+C79)-C167)))/(C81+C83+C79),0)
A172: 'MA temp(int)                  C172: (,2) @IF(C82+C78+C80>0,((C8*C168)+(C51*((C82+C78+C80)-C168)))/(C82+C78+C80),0)
A173: 'MA humidity ratio(ext)        C173: (,3) (C169-(0.24*C171))/(1061+(0.444*C171))
A174: 'MA humidity ratio(int)        C174: (,3) (C170-(0.24*C172))/(1061+(0.444*C172))
A175: 'SA enthalpy(ext)(Btu/lb)      C175: (,2) (0.24*C42)+(C173*(1061+(0.444*C42)))
A176: 'SA enthalpy(int)(Btu/lb)      C176: (,2) (0.24*C41)+(C174*(1061+(0.444*C41)))
A177: 'Q(calc.) (ext)(Btu/hr)        C177: (,0) @IF(C79+C81+C83>0#AND#C26=1,4.5*(C79+C81+C83)*(C175-C169),0)
A178: 'Q(calc.) (int)(Btu/hr)        C178: (,0) @IF(C80+C78+C82>0#AND#C26=1,4.5*(C80+C82+C78)*(C176-C170),0)
A179: 'Q(calc.) total(Btu/hr)        C179: (,0) +C177+C178
A180: 'Q(act.) total (Btu/hr)        C180: +C73+C77
A181: 'diff. (act - calc) (Btu/hr)   C181: (,0) +C73+C77-C179
A183: 'Energy Balance Study
A184: \-
A185: 'Building Htg Demand (Btu/hr)     C185: (,0) +C69
A186: 'Building Clg Demand (Btu/hr)     C186: (,0) +C73+C77
A187: 'Ventilation (Btu/hr)             C187: (,0) +C91+C92+C90
A188: 'Heat Conduction (Btu/hr)         C188: (,0) (C8-C51)*51091
A189: 'Internal Gains (Btu/hr)          C189: (,0) 4979567
A190: 'Total (Btu/hr)                   C190: (,0) @SUM(C189..C185)
```

Table B-3: Sample of Computer Model Inputs and Outputs

Energy Use and Loads Calculations

For output go to A60

Date:	7/24/85	Wednesday Day1 1	Day1 2	Day1 3	Day1 4	Day1 5	Day1 6	Day1 7	Day1 8	Day1 9	Day1 10	Day1 11	Day1 12	Day1 13
INPUTS	Ave.													
T out	72	69	69	66	65	64	61	67	73	74	74	73	73	73
Dew T out	44	44	44	44	43	43	42	44	45	41	40	40	42	43
Tank 1 gpm		665	665	665	665	665	665	665	665	665	665	665	665	665
Tank 1 Status		2	2	2	2	2	2	2	2	0	2	2	2	2
Tank 1 Supply T		45	45	44	44	45	44	44	45	0	45	45	45	45
Tank 1 Return T		45	45	45	45	45	49	46	47	0	47	46	47	46
Tank 2 gpm		665	665	665	665	665	665	665	665	665	665	665	665	665
Tank 2 Status		2	2	2	2	2	2	2	2	0	2	2	2	2
Tank 2 Supply T		45	44	44	44	44	44	44	44	0	45	45	45	45
Tank 2 Return T		45	45	44	44	44	44	46	46	0	45	46	45	46
Tank 3 gpm		665	665	665	665	665	665	665	665	665	665	665	665	665
Tank 3 Status		2	2	2	2	2	2	2	2	0	2	2	2	2
Tank 3 Supply T		45	44	44	45	44	44	44	45	0	45	45	45	45
Tank 3 Return T		44	44	44	44	44	45	46	46	0	45	45	45	46
HW gpm		1,240	1,240	1,240	1,240	1,240	1,240	1,240	1,240	1,240	1,240	1,240	1,240	1,240
HW pump on?		0	0	0	0	0	0	0	0	0	0	0	0	0
HW Return T		0	0	0	0	0	0	0	0	0	0	0	0	0
HW Supply T		0	0	0	0	0	0	0	0	0	0	0	0	0
Chiller on?		1	1	1	1	1	1	1	1	1	1	1	1	1
RU-1 on?		0	0	0	0	0	1	0	0	0	0	0	0	1
RU-2 on?		1	1	1	1	1	0	1	1	1	0	0	0	0
RU-3 on?		1	1	1	1	1	0	0	0	0	1	1	1	1
CHW return T		49	49	51	50	50	57	49	50	57	51	51	51	51
CHW supply T-RU-1		42	41	43	42	43	53	55	57	0	47	47	47	43
CHW supply T-RU-2		41	40	41	41	41	53	47	47	58	47	47	48	0
CHW supply T-RU-3		45	44	45	45	45	57	52	53	60	47	47	47	49
CHW gpm		1,875	1,875	1,875	1,875	1,875	1,875	1,875	1,875	1,875	1,875	1,875	1,875	1,875
CHW pump on?		1	1	1	1	1	1	1	1	1	1	1	1	1
P-3A on?	1200	0	0	0	0	0	0	0	1	1	0	0	0	0
P-3B on?	1200	1	1	1	1	1	1	1	0	1	0	0	0	0
P-3C on?	3150	1	1	1	1	1	1	1	0	0	1	1	1	1
CW return T		84	82	85	85	85	79	84	88	84	86	86	86	85
CW supply T		81	79	82	82	82	75	80	82	82	81	80	80	80
int coil T		55	55	55	55	55	55	55	55	55	55	55	55	55
ext coil T		55	55	55	55	55	55	55	55	55	55	55	55	55
# AC-1 int. fans		0	1	1	1	1	2	2	2	2	2	2	2	2
# AC-1 ext. fans		0	0	1	1	2	2	2	2	2	2	2	2	2
# AC-2 int. fans		1	1	1	1	1	2	2	2	2	2	2	2	2
# AC-2 ext. fans		0	0	0	0	2	2	2	2	2	2	2	2	2
# AC-3 int. fans		1	1	1	1	1	2	2	2	2	2	2	2	2

Table B-3, continued (p. 2 of 4)

Energy Use and Loads Calculations

For output go to A60														
Date:	7/24/85	Wednesday												
		Day1	Day1	Day1	Day1	Day1	Day1	Day1	Day1	Day1	Day1	Day1	Day1	Day1
		1	2	3	4	5	6	7	8	9	10	11	12	13
# AC-3 ext. fans		0	0	0	0	2	2	2	2	2	2	2	2	2
AC-1 RA T		76	76	74	73	72	73	73	74	74	74	75	75	75
AC-1 RA dew T		52	52	52	52	51	52	52	53	51	50	49	50	51
AC-2 RA T		74	73	73	72	72	71	71	72	72	72	73	73	73
AC-2 RA dew T		41	40	41	41	41	41	40	41	40	39	39	49	39
AC-3 RA T		75	74	74	73	73	72	72	73	73	73	74	74	74
AC-3 RA dew T		39	39	39	39	39	39	39	39	39	38	38	38	39
Delayed vents open?											1	1	1	1
Enthalpy open?		0	0	0	0	0	0	0	1	1	1	1	1	1
Maximum Heating?		0	0	0	0	0	0	0	0	0	0	0	0	0
Floor dampers?		1	1	0	0	0	0	0	0	0	0	0	0	0
		0	0	0	0	0	0	0	0	0	0	0	1	0
OUTPUTS														
OA enthalpy(Btu/lb)		23.26	23.26	22.53	22.03	21.79	20.82	22.77	24.49	23.73	23.50	23.26	23.73	23.97
RA enthalpy(Btu/lb)		23.75	23.47	23.42	23.18	23.10	23.02	22.91	23.26	23.15	22.93	23.17	24.34	23.28
HP Htg supply		0	0	0	0	0	0	0	0	0	0	0	0	0
Tank 1 Htg supply		0	0	0	0	0	0	0	0	0	0	0	0	0
Tank 2 Htg supply		0	0	0	0	0	0	0	0	0	0	0	0	0
Tank 3 Htg supply		0	0	0	0	0	0	0	0	0	0	0	0	0
Tank Htg supply		0	0	0	0	0	0	0	0	0	0	0	0	0
Clg Twr Heat Disch		(6,521,999)	(6,521,999)	(6,521,999)	(6,521,999)	(6,521,999)	(8,695,998)	(8,695,998)	(3,598,344)	(2,398,896)	(7,871,378)	(9,445,653)	(9,445,653)	(7,871,378)
Bldg. Htg Demand		0	0	0	0	0	0	0	0	0	0	0	0	0
RU-1 clg supply		0	0	0	0	0	(1,874,138)	0	0	0	0	0	0	(2,811,206)
RU-2 clg supply		(1,874,138)	(1,874,138)	(1,874,138)	(1,874,138)	(1,874,138)	0	(2,342,672)	(2,811,206)	(937,069)	0	0	0	0
RU-3 clg supply		(3,748,275)	(4,685,344)	(5,622,413)	(4,685,344)	(4,685,344)	0	0	0	0	(3,748,275)	(3,748,275)	(3,748,275)	(1,874,138)
HP Clg supply		(5,622,413)	(6,559,481)	(7,496,550)	(6,559,481)	(6,559,481)	(1,874,138)	(2,342,672)	(2,811,206)	(937,069)	(3,748,275)	(3,748,275)	(3,748,275)	(4,685,344)
Tank 1 Clg supply		0	0	(332,347)	(332,347)	0	(1,661,735)	(664,694)	(664,694)	0	(664,694)	(332,347)	(664,694)	(332,347)
Tank 2 Clg supply		0	(332,347)	0	0	0	0	(664,694)	(664,694)	0	0	(332,347)	0	(332,347)
Tank 3 Clg supply		332,347	0	0	332,347	0	(332,347)	(664,694)	(332,347)	0	0	0	0	(332,347)
Tank Clg supply		332,347	(332,347)	(332,347)	0	0	(1,994,082)	(1,994,082)	(1,661,735)	0	(664,694)	(664,694)	(664,694)	(997,041)
AC-1 int cfm		0	6,106	21,106	21,017	20,928	41,323	42,389	43,455	43,633	43,633	43,455	43,455	43,455
AC-1 ext cfm		0	0	27,973	27,516	54,119	51,379	56,859	62,339	63,252	63,252	62,339	62,339	62,339
AC-2 int cfm		7,021	7,021	24,276	24,177	24,078	47,559	48,752	49,944	50,143	50,143	49,944	49,944	49,944
AC-2 ext cfm		0	0	0	0	50,620	49,733	51,507	53,281	53,577	53,577	53,281	53,281	53,281
AC-3 int cfm		7,222	7,222	24,684	24,487	24,290	47,395	49,763	52,131	52,525	52,525	52,131	52,131	52,131
AC-3 ext cfm		0	0	0	0	49,015	47,432	50,598	53,764	54,291	54,291	53,764	53,764	53,764
AC-1 int free clg		0	0	0	0	0	0	0	0	0	0	0	0	0
AC-1 ext free clg		0	0	0	0	0	0	0	0	0	0	0	0	0
AC-2 int free clg		0	0	0	0	0	0	0	0	0	0	0	(138,204)	0
AC-2 ext free clg		0	0	0	0	0	0	0	0	0	0	0	(147,438)	0
AC-3 int free clg		0	0	0	0	0	0	0	0	0	0	0	0	0

Table B-3, continued (p. 3 of 4)

Energy Use and Loads Calculations

For output go to A60

Date:	7/24/85	Wednesday Day1	Day1	Day1	Day1	Day1	Day1	Day1	Day1	Day1	Day1	Day1	Day1	Day1
		1	2	3	4	5	6	7	8	9	10	11	12	13
AC-3 ext free clg		0	0	0	0	0	0	0	0	0	0	0	0	0
free cooling (Btu/hr)		0	0	0	0	0	0	0	0	0	0	0	0	0
Ventilation (Btu/hr)		0	0	0	0	0	0	0	0	0	0	0	0	0
Infiltration (Btu/hr)		(20,855)	(13,754)	(76,343)	(98,082)	(251,819)	(564,530)	(34,527)	0	0	0	0	0	0
Bldg. Clg Demand		(5,310,921)	(6,905,583)	(7,905,240)	(6,657,563)	(6,811,300)	(4,432,749)	(4,371,281)	(4,472,942)	(937,069)	(4,412,969)	(4,412,969)	(4,412,969)	(5,682,385)
OA dewpoint(K)		280	280	280	279	279	279	280	280	278	278	278	279	279
RA dewpoint(K)		278	277	278	278	278	278	277	278	277	277	277	280	277
OA partial pressure		990	990	990	952	952	916	990	1,028	882	848	848	916	952
RA partial pressure		848	832	848	848	848	848	832	848	832	800	800	971	816
OA Humidity ratio		0.0061	0.0061	0.0061	0.0059	0.0059	0.0057	0.0061	0.0064	0.0055	0.0053	0.0053	0.0057	0.0059
RA Humidity ratio		0.0053	0.0051	0.0053	0.0053	0.0053	0.0053	0.0051	0.0053	0.0051	0.0049	0.0049	0.0060	0.0050

Daily Bldg.Htg. Demand	0	(Btu/hr)
Daily HP Htg. Supply	0	
Dly Tank Htg. Sup	0	
Daily Clg.Twr. Disch.	(138,761,141)	
Daily Bldg.Clg. Demand	(107,191,603)	(Btu/hr)
Daily HP Clg. Supply	(95,581,013)	
Dly Tank Clg. Sup	(10,967,453)	
Daily Free cooling	0	
Daily Ventilation	366,921	
Daily Infiltration	(1,010,059)	

Electrical Loads	kW	1	2	3	4	5	6	7	8	9	10	11	12	13
AC-1 int fans		0.00	0.02	0.66	0.65	0.64	4.93	5.32	5.73	5.80	5.80	5.73	5.73	5.73
AC-1 ext fans		0.00	0.00	1.53	1.46	11.08	9.48	12.84	16.93	17.68	17.68	16.93	16.93	16.93
AC-2 int fans		0.02	0.02	1.00	0.99	0.98	7.52	8.10	8.71	8.81	8.81	8.71	8.71	8.71
AC-2 ext fans		0.00	0.00	0.00	0.00	9.06	8.60	9.55	10.57	10.75	10.75	10.57	10.57	10.57
AC-3 int fans		0.03	0.03	1.05	1.03	1.00	7.44	8.61	9.90	10.13	10.13	9.90	9.90	9.90
AC-3 ext fans		0.00	0.00	0.00	0.00	8.23	7.46	9.05	10.86	11.18	11.18	10.86	10.86	10.86
Total fans		0.05	0.07	4.24	4.12	30.99	45.42	53.47	62.70	64.35	64.35	62.70	62.70	62.70
Pumps														
Miscel. pumps		133.2	133.2	133.2	133.2	133.2	133.2	133.2	84.8	99.5	118.5	118.5	118.5	118.5
Tank1	12.3	12	12	12	12	12	12	12	12	0	12	12	12	12
Tank2	12.3	12	12	12	12	12	12	12	12	0	12	12	12	12
Tank3	12.3	12	12	12	12	12	12	12	12	0	12	12	12	12

Table B-3, continued (p. 4 of 4)

Energy Use and Loads Calculations

For output go to A60														
Date:	7/24/85	Wednesday												
		Day1	Day1	Day1	Day1	Day1	Day1	Day1	Day1	Day1	Day1	Day1	Day1	Day1
		1	2	3	4	5	6	7	8	9	10	11	12	13
Pumps total		170	170	170	170	170	170	170	122	100	155	155	155	155
Cooling Towers	22.3	22	22	22	22	22	22	22	22	22	22	22	22	22
	22.3	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Cooling Towers	44.6	22	22	22	22	22	22	22	22	22	22	22	22	22
Heat Pumps														
RU-1	258	0	0	0	0	0	89	0	0	0	0	0	0	160
RU-2	258	97	94	98	98	98	0	124	165	58	0	0	0	0
RU-3	430	156	197	267	206	206	0	0	0	0	156	154	154	92
Total Heat Pumps		253	291	365	304	304	89	124	165	58	156	154	154	252
Total electric load		445	484	562	500	527	326	349	372	244	398	395	395	492

Total Var.Dly. Elec. Load	9,558 (kWh)

Daily Fans	734
Daily Pumps	3,288
Daily Cooling Towers	513
Daily Heat Pumps	5,022

COP's

Heat Pump Htg. COP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RU-1 Clg COP	0.00	0.00	0.00	0.00	0.00	6.20	0.00	0.00	0.00	0.00	0.00	0.00	5.14
RU-2 Clg COP	5.68	5.85	5.60	5.60	5.60	0.00	5.55	4.99	4.72	0.00	0.00	0.00	0.00
RU-3 Clg COP	7.02	6.96	6.17	6.67	6.67	0.00	0.00	0.00	0.00	7.02	7.12	7.12	5.99
Bldg. Htg. COP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bldg. Clg. COP	3.70	3.97	3.91	3.84	3.65	1.68	1.86	2.22	1.12	2.76	2.78	2.78	2.79
Bldg. Overall COP	3.70	3.97	3.91	3.84	3.65	1.68	1.86	2.22	1.12	2.76	2.78	2.78	2.79

Table B-4: Monitored Air Handler Performance Data

Date	Time	Outdoor Air Temp (degF)	AC-1 Interior S.P. (in.H2O)	AC-1 Exterior S.P. (in.H2O)	AC-1 Ret.Air Temp (degF)	AC-1 Mix.Air Temp (degF)	AC-1 Dampers	CAMBRDG AC-1A CFM (X1000)	CAMBRDG RF-1A CFM (X1000)	CAMBRDG AC-1C CFM (X1000)	CAMBRDG RF-1C CFM (X1000)	CAMBRDG AC-1B CFM (X1000)	CAMBRDG RF-1B CFM (X1000)	CAMBRDG AC-1D CFM (X1000)	CAMBRDG RF-1D CFM (X1000)	EXT. SUPPLY CFM (X1000)	INT. SUPPLY CFM (X1000)	EXT. RETURN CFM (X1000)	INT. RETURN CFM (X1000)	AC-1 EXT. DIFF. CFM (X1000)
3/28/85		70 *	0.90	1.00			C	30	18	26	20	20	14	19	15	56	39	38	29	18
3/29/85	16.00	50	1.00	0.90			E	32	30	28	30	19	20	19	20	60	38	60	40	0
4/2/85		46 *	1.00	0.95			C	29	26	26	27	20	20	20	20	55	40	53	40	2
4/5/85		44	1.00	0.95	74	68	C	30	16	26	18	20	15	19	16	56	39	34	31	22
4/11/85		53 *	1.00	0.95			E	32.5	23	30	25	20	15	18	15	62.5	38	48	30	14.5
4/18/85		43	1.05	0.90	74	67	D	31	31	29	31	20	22	19	22	60	39	62	44	-2
4/26/85	16.30	75	1.00	0.55			D	37	38	36	38	20	16	20	16	73	40	76	32	-3
4/30/85		72	1.00	0.50	75	75	D	32	26	29	27	22	17	20	18	61	42	53	35	8
4/30/85		72	1.00	0.50	76	76	E	34	28	28	28	22	18	20	18	62	42	56	36	6
4/30/85		72	1.00	0.55	76	76	C	33	35.5	29	35	22	23	20	23	62	42	70.5	46	-8.5
5/9/85		52	1.00	0.50			E	34	33	31	32	20	16	20	16	65	40	65	32	0
10/24/85		53	1.30	0.60	76		D	28	21	22	21	26	21	22	23	50	48	42	44	8
11/8/85	4:00	52	1.25	0.60	76	62	D	27	10	22	14	26	21	22	23	49	48	24	44	25
11/12/85	11:30	40	1.35	0.55			C	41	55	37	55	22	26	20	26	78	42	110	52	-32
11/12/85	11:35	40	1.30	0.60			D	41	43	37	43	22	18	20	20	78	42	86	38	-8
11/12/85	13:00	40	1.35	0.60			D	39	40	36	41	22	18	19	20	75	41	81	38	-6
11/12/85	14:30	40	1.35	0.60			C	40	55	35	55	22	23	20	26	75	42	110	49	-35
11/12/85	15:35	44	1.35	0.60			D	39	40	36	41	22	19	20	20	75	42	81	39	-6
11/12/85	16:35	44	1.35	0.60			D	40	40	36	40	23	19	19	20	76	42	80	39	-4
11/22/85	15:05	40	1.30	0.60			C	36	33	36	31	22	28	20	28	72	42	64	56	8
12/3/85		29	1.35	0.60	71	66	C	40	38	41	38	20	18	25	26	81	45	76	44	5
12/12/85		34	1.00	0.45	66		D	33	30	33	30	18	10	16	14	66	34	60	24	6
12/13/85		32	1.00	0.45	75	65	D	32	31	30	31	18	14	16	16	62	34	62	30	0
12/20/85		26 *	1.00	0.45			D	33	29	32.5	31	18	10	16	10	65.5	34	60	20	5.5
12/27/85		29	1.00	0.20	73	67	C	20	10	14	14	18	22	16	24	34	34	24	46	10
12/27/85		35	1.00	0.45	74	66	D	35	29	33	30	17	15	16	17	68	33	59	32	9
1/7/86	10:00	20	1.00	0.50			D	36	29	36	30	17	14	16	18	72	33	59	32	13
1/8/86		20	1.05	0.80	73	66	D	48	47	45	48	18	14	16	18	93	34	95	32	-2
1/12/85		44 *	1.00	0.75			D	45	42.5	42	43	18	12	16	16	87	34	85.5	28	1.5
1/16/86	10:00	24	0.80	1.05	73	69	D	47	47	44	47	16	16	16	18	91	32	94	34	-3
1/16/86	14:00	30			74		D	42	38	40	39	19	14	16	17	82	35	77	31	5
1/18/86	13:00	59	1.00	0.15	74		C	19	13	15	18	18	10	16	14	34	34	31	24	3

Notes:
1. AC-1 & AC-2, A&C exterior, B&D interior. AC-3, A&C interior, B&D exterior.
2. Dampers: E-enthalpy dampers, D-delayed vents, C-all closed
3. Amount OA (TEMP)= (T(mixed)-T(return))/(T(out)-T(ret)) * Supply cfm
4. Amount OA (CFM) = supply cfm - return cfm
5. * - Approx. outside air temperature
6. **- Note that amount OA calculated from supply and return fan flow rates is inaccurate when enthalpy dampers are open.

Table B-4, continued (p. 2 of 4)

Date	AC-1 INT. DIFF. CFM (X1000)	AC-1 AMT. OA. (from temp) (X1000)	AC-1 AMT. OA.** (from cfm) (X1000)	AC-2 Interior S.P. (in.H2O)	AC-2 Exterior S.P. (in.H2O)	AC-2 Ret.Air Temp (degF)	AC-2 Mix.Air Temp (degF)	AC-2 Dampers	CAMBRDG AC-2A CFM (X1000)	CAMBRDG RF-2A CFM (X1000)	CAMBRDG AC-2C CFM (X1000)	CAMBRDG RF-2C CFM (X1000)	CAMBRDG AC-2B CFM (X1000)	CAMBRDG RF-2B CFM (X1000)	CAMBRDG AC-2D CFM (X1000)	CAMBRDG RF-2D CFM (X1000)	EXT. SUPPLY CFM (X1000)	INT. SUPPLY CFM (X1000)	EXT. RETURN CFM (X1000)	INT. RETURN CFM (X1000)	AC-2 EXT. DIFF. CFM (X1000)
3/28/85	10	0.00	28.00	1.05	1.00			C	26	25	26	24	28	18	26	20	52	54	49	38	3
3/29/85	-2	0.00	2.00	1.00	1.00			E	21	12	22	13	24	22	26	25	43	50	25	47	18
4/2/85	0	0.00	2.00	1.00	1.00			C	23	17	23	19	19	19	23.5	20	46	42.5	36	39	10
4/5/85	8	19.00	30.00	1.00	1.00	74	66	C	22	5	23	5	22	16	24	15	45	46	10	31	35
4/11/85	8	0.00	22.50	1.00	1.05			E	22	10	22	10	22	16	22	16	44	44	20	32	24
4/18/85	-5	22.35	7.00	1.00	1.05	73	67	D	20	13	20	13	19	19	24	21	40	43	26	40	14
4/26/85	8	0.00	11.00	1.00	1.00			D	26	28	27	27	22	19	24	21.5	53	46	55	40.5	-2
4/30/85	7	0.00	15.00	1.00	1.00	75	75	D	25	26	27	27	21	20	24	18	52	45	53	38	-1
4/30/85	6	0.00	12.00	1.00	1.00	75	75	E	26	28	26	28	22	21	24	19	52	46	56	40	-4
4/30/85	-4	0.00	12.50	1.00	1.00	75	75	C	26	32	26	32	22	26	25	24	52	47	64	50	-12
5/9/85	8	0.00	8.00	1.00	1.00			E	28.5	31	28	31	22	21	24	19	56.5	46	62	40	-5.5
10/24/85	4	ERR	12.00	0.60	0.95	74		D	28	26	28	27	20	19	24	17	56	44	53	36	3
11/8/85	4	56.58	29.00	0.55	1.00	78	65	D	31	30	30	30	22	21	25	18	61	47	60	39	1
11/12/85	-10	0.00	42.00	0.60	0.95			C	30	36	31	44	18	21	24	24	61	42	80	45	-19
11/12/85	4	0.00	12.00	0.60	1.00			D	30	33	31	33	18	16	24	18	61	42	66	34	-5
11/12/85	3	0.00	9.00	0.60	0.95			D	30	32	30	33	18	16	23	18	60	41	65	34	-5
11/12/85	-7	0.00	42.00	0.60	0.95			C	30	36	31	39	18	20	23	23	61	41	75	43	-14
11/12/85	3	0.00	9.00	0.60	1.00			C	30	35	30	37	18	20	24	23	60	42	72	43	-12
11/12/85	3	0.00	7.00	0.60	0.95			C	30	38	30	41	17	21	24	24	60	41	79	45	-19
11/22/85	-14	0.00	22.00	0.60	0.95			C	29	34	29	37	20	22	24	24	58	44	71	46	-13
12/3/85	1	15.00	6.00	0.60	0.95	70	65	C	29	37	31	36	16	21	22	23	60	38	73	44	-13
12/12/85	10	ERR	16.00	1.00	0.95	75	70	D	29	28	30	29	22	20	26	22	59	48	57	42	2
12/13/85	4	22.33	4.00	1.00	0.93	72		D	28	29	26	27	23	21	26	23	54	49	56	44	-2
12/20/85	14	0.00	19.50	1.00	0.95			D	29	26	31	27	22	20	25	21	60	47	53	41	7
12/27/85	-12	9.27	22.00	0.90	1.00	73	68.5	C	28	30	30	30	21	23	24	27	58	45	60	50	-2
12/27/85	1	20.72	10.00	0.95	0.95	74		D	28	25	30	26	21	18	25	20	58	46	51	38	7
1/7/86	1	0.00	14.00	1.00	1.00			D	29	28	32	28	20	19	24	20	61	44	56	39	5
1/8/86	2	16.77	4.00	1.00	1.00			D	29	28	31	28	20	19	24	21	60	44	56	40	4
1/12/85	6	0.00	7.50	1.00	0.95			D	28	24	29	25	22	19	24	22	57	46	49	41	8
1/16/86	-2	10.04	5.00	1.00	1.00	73	64	D	28	27	30	28	20	19	24	21	58	44	55	40	3
1/16/86	4	ERR	9.00	1.00	1.00	74		D	28	26	30	27	21	18	24	24	58	45	53	42	5
1/18/86	10	ERR	13.00	1.00	0.90	75		C	26	28	29	28	23	22	25	27	55	48	56	49	-1

Notes:

1. AC-1 & AC-2, A&C exterior, B&D interior. AC-3, A&C interior, B&D exterior.
2. Dampers: E-enthalpy dampers, D-delayed vents, C-all closed
3. Amount OA (TEMP)= (T(mixed)-T(return))/(T(out)-T(ret)) * Supply cfm
4. Amount OA (CFM) = supply cfm - return cfm
5. * - Approx. outside air temperature
6. **- Note that amount OA calculated from supply and return fan flow rates is inaccurate when enthalpy dampers are open.

Table B-4, continued (p. 3 of 4)

Date	AC-2 INT. DIFF. CFM (X1000)	AC-2 AMT. OA. (from temp) (X1000)	AC-2 AMT. OA.** (from cfm) (X1000)	AC-3 Interior S.P. (in.H2O)	AC-3 Exterior S.P. (in.H2O)	AC-3 Ret.Air Temp (degF)	AC-3 Mix.Air Temp (degF)	AC-3 Dampers	CAMBRDG AC-3A CFM (X1000)	CAMBRDG RF-3A CFM (X1000)	CAMBRDG AC-3C CFM (X1000)	CAMBRDG RF-3C CFM (X1000)	CAMBRDG AC-3B CFM (X1000)	CAMBRDG RF-3B CFM (X1000)	CAMBRDG AC-3D CFM (X1000)	CAMBRDG RF-3D CFM (X1000)	EXT. SUPPLY CFM (X1000)	INT. SUPPLY CFM (X1000)	EXT. RETURN CFM (X1000)	INT. RETURN CFM (X1000)	AC-3 EXT. DIFF. CFM (X1000)
3/28/85	16	ERR	19.00	0.90	1.00			C	24	16	24	18	26	16	26	16	48	52	34	32	14
3/29/85	3	ERR	21.00	1.15	1.20			E	19	12	19	12	24	17	25	18	38	49	24	35	14
4/2/85	3.5	ERR	13.50	1.25	1.20			C	19	18	20	18	20	19	22	18	39	42	36	37	3
4/5/85	15	13.24	50.00	1.20	1.20	74	66	C	18	12	18	12	26	16	26	18	36	52	24	34	12
4/11/85	12	ERR	36.00	1.25	1.15			E	20	16	18	17	23	16	26	17	38	49	33	33	5
4/18/85	3	9.83	17.00	1.30	1.15	73	73	D	22	22	19	23	18	18	21	19	41	39	45	37	-4
4/26/85	5.5	ERR	7.50	1.15	1.10			D	28	22	26	24	20	18	23	20	54	43	46	38	8
4/30/85	7	0.00	8.00	1.25	1.10	74.5	74	D	31	26	27	27	18	18	22	20	58	40	53	38	5
4/30/85	6	0.00	10.00	1.25	1.10	74.5	73	E	31.5	28	26	26.5	20	18	22	21	57.5	42	54.5	39	3
4/30/85	-3	0.00	15.00	1.25	1.00	75	75	C	22	29	24	29	19	30	22	28	46	41	58	58	-12
5/9/85	6	ERR	11.50	1.25	1.15	73	56	E	18	17	18	21	34	29	28	27	36	62	38	56	-2
10/24/85	8	ERR	11.00	0.80	0.80	75		D	22	20	24	21	28	23	22	22	46	50	41	45	5
11/8/85	8	65.56	9.00	0.80	0.80	76	69	D	26	21	25	23	24	20	24	22	51	48	44	42	7
11/12/85	-3	ERR	22.00	0.85	0.80			C	30	29	26	30	18	22	18	24	56	36	59	46	-3
11/12/85	8	ERR	13.00	0.80	0.80			D	29	26	26	26	18	19	18	22	55	36	52	41	3
11/12/85	7	ERR	12.00	0.85	0.80			D	29	26	26	26	18	19	18	21	55	36	52	40	3
11/12/85	-2	ERR	16.00	0.85	0.80			C	31	30	26	30	18	21	18	23	57	36	60	44	-3
11/12/85	-1	ERR	13.00	0.85	0.80			C	31	30	26	30	19	21	19	24	57	38	60	45	-3
11/12/85	-4	ERR	23.00	0.85	0.80			C	30	29	25	29	18	20	18	24	55	36	58	44	-3
11/22/85	-2	ERR	15.00														0	0	0	0	0
12/3/85	-6	8.91	19.00	0.85	0.80	72	72	C	28	29	26	30	16	20	15	23	54	31	59	43	-5
12/12/85	6	ERR	8.00	0.80	1.00	74	64	D	29	19	26	17	18	10	18	8	55	36	36	18	19
12/13/85	5	ERR	7.00	0.95	1.00	73	72	D	30	28	29	28	16	14	16	14	59	32	56	28	3
12/20/85	6	ERR	13.00	0.95	1.00			D	33	28	26	26	18	12	20	12	59	38	54	24	5
12/27/85	-5	7.27	7.00	0.95	1.00	73	72.5	C	32	32	29	30	17	16	16	18	61	33	62	34	-1
12/27/85	8	ERR	15.00	0.95	1.00	73	70	D	31	27	28	25	17	13	17	15	59	34	52	28	7
1/7/86	5	ERR	10.00														0	0	0	0	0
1/8/86	4	0.00	8.00	1.00	1.00	73	69	D	28	26	29	26	18	16	18	16	57	36	52	32	5
1/12/85	5	ERR	13.00	0.85	1.00			C	28	28	30	28	20	28	20	32	58	40	56	60	2
1/16/86	4	14.58	7.00	1.00	1.00	73	69	D	29	27	29	26	18	16	17	17	58	35	53	33	5
1/16/86	3	ERR	8.00			73		D	28	26	26	25	18	16	18	18	54	36	51	34	3
1/18/86	-1	ERR	2.00	0.85	1.00	73		C	26	26	28	25	18	26	18	30	54	36	51	56	3

Notes:

1. AC-1 & AC-2, A&C exterior, B&D interior. AC-3, A&C interior, B&D exterior.
2. Dampers: E-enthalpy dampers, D-delayed vents, C-all closed
3. Amount OA (TEMP)= (T(mixed)-T(return))/(T(out)-T(ret)) * Supply cfm
4. Amount OA (CFM) = supply cfm - return cfm
5. * - Approx. outside air temperature
6. **- Note that amount OA calculated from supply and return fan flow rates is inaccurate when enthalpy dampers are open.

Table B-4, continued (p. 4 of 4)

Date	AC-3 INT. DIFF. CFM (X1000)	AC-3 AMT. OA. (from temp) (X1000)	AC-3 AMT. OA.** (from cfm) (X1000)	NOTES:
3/28/85	20	ERR	34.00	
3/29/85	14	ERR	28.00	
4/2/85	5	ERR	8.00	
4/5/85	18	11.59	30.00	
4/11/85	16	ERR	21.00	
4/18/85	2	0.00	6.00	
4/26/85	5	ERR	13.00	55-int/60-ext
4/30/85	2	0.66	7.00	
4/30/85	3	2.00	6.00	
4/30/85	-17	0.00	29.00	
5/9/85	6	ERR	8.00	
10/24/85	5	ERR	10.00	
11/8/85	6	66.36	13.00	
11/12/85	-10	ERR	13.00	
11/12/85	-5	ERR	8.00	
11/12/85	-4	ERR	7.00	
11/12/85	-8	ERR	11.00	
11/12/85	-7	ERR	10.00	
11/12/85	-8	ERR	11.00	
11/22/85	0	ERR	0.00	
12/3/85	-12	0.00	17.00	
12/12/85	18	ERR	37.00	OAdamps.adj.AC1,2
12/13/85	4	ERR	7.00	prehts.AC-1,2
12/20/85	14	ERR	19.00	
12/27/85	-1	0.72	2.00	
12/27/85	6	ERR	13.00	ext-65/int-55
1/7/86	0	ERR	0.00	Camb.man calib.
1/8/86	4	5.10	9.00	
1/12/85	-20	ERR	22.00	
1/16/86	2	6.37	7.00	
1/16/86	2	ERR	5.00	
1/18/86	-20	ERR	23.00	

Notes:

1. AC-1 & AC-2, A&C exterior, B&D interior. AC-3, A&C interior, B&D exterior.
2. Dampers: E-enthalpy dampers, D-delayed vents, C-all closed
3. Amount OA (TEMP)= (T(mixed)-T(return))/(T(out)-T(ret)) * Supply cfm
4. Amount OA (CFM) = supply cfm - return cfm
5. * - Approx. outside air temperature
6. **- Note that amount OA calculated from supply and return fan flow rates is inaccurate when enthalpy dampers are open.

Table B-5: Observed Fan Tracking Distribution

(A) Supply-Return	(B) Dampers Closed	(A)*(B)	(C) Delayed Dampers	(A)*(C)
-35	1	-35	0	0
-34	0	0	0	0
-33	0	0	0	0
-32	1	-32	0	0
-31	0	0	0	0
-30	0	0	0	0
-29	0	0	0	0
-28	0	0	0	0
-27	0	0	0	0
-26	0	0	0	0
-25	0	0	0	0
-24	0	0	0	0
-23	0	0	0	0
-22	0	0	0	0
-21	0	0	0	0
-20	2	-40	0	0
-19	2	-38	0	0
-18	0	0	0	0
-17	1	-17	0	0
-16	0	0	0	0
-15	0	0	0	0
-14	2	-28	0	0
-13	2	-26	0	0
-12	5	-60	0	0
-11	0	0	0	0
-10	2	-20	0	0
-9	0	0	0	0
-8	3	-24	1	-8
-7	2	-14	0	0
-6	1	-6	2	-12
-5	2	-10	4	-20
-4	2	-8	3	-12
-3	6	-18	2	-6
-2	3	-6	5	-10
-1	5	-5	1	-1
0	1	0	1	0
1	1	1	4	4
2	2	4	7	14
3	4	12	11	33
4	1	4	10	40
5	2	10	13	65
6	0	0	9	54
7	0	0	7	49
8	2	16	9	72
9	0	0	1	9
10	4	40	1	10
11	0	0	0	0
12	1	12	0	0
13	0	0	1	13
14	1	14	3	42
15	1	15	0	0
16	1	16	0	0
17	0	0	0	0
18	2	36	1	18
19	0	0	1	19
20	1	20	0	0
21	0	0	0	0
22	1	22	0	0
23	0	0	0	0
24	0	0	0	0
25	0	0	1	25
26	0	0	0	0
27	0	0	0	0
28	0	0	0	0
29	0	0	0	0
30	0	0	0	0
31	0	0	0	0
32	0	0	0	0
33	0	0	0	0
34	0	0	0	0
35	1	35	0	0
Average:		(1.9)		4.1

Table B-5(a): Linear Equations for Air Handler Supply Fan Flow Rate Curves

SUMMARY OF FAN FLOW RATES

Fan flow rate = (slope * outside temperature) + intercept

AC Unit	Intercept	Slope	Correlation Coefficient
AC-1 interior	30.4830	0.1777	0.64
AC-2 interior	35.4320	0.1988	0.64
AC-3 interior	23.3247	0.3946	0.71
AC-1 exterior (T<=60 degF)	104.0297	(0.9088)	(0.73)
AC-1 exterior (T>60 degF)	(4.3321)	0.9133	0.77
AC-2 exterior (T<=51 degF)	71.5060	(0.4047)	(0.62)
AC-2 exterior (T>51 degF)	31.6953	0.2957	0.70
AC-3 exterior (T<=46 degF)	69.4535	(0.7714)	(0.77)
AC-3 exterior (T>46 degF)	15.2487	0.5276	0.68

Note: numbers in parantheses are negative

Table B-6: Observed Fan Tracking Distribution - All Positive

(A) Supply-Return	(B) Dampers Closed	(A)*(B)	(C) Delayed Dampers	(A)*(C)
0	1	0	1	0
1	6	6	5	5
2	5	10	12	24
3	10	30	13	39
4	3	12	13	52
5	4	20	17	85
6	1	6	11	66
7	2	14	7	49
8	5	40	10	80
9	0	0	1	9
10	6	60	1	10
11	0	0	0	0
12	6	72	0	0
13	2	26	1	13
14	3	42	3	42
15	1	15	0	0
16	1	16	0	0
17	1	17	0	0
18	2	36	1	18
19	2	38	1	19
20	3	60	0	0
21	0	0	0	0
22	1	22	0	0
23	0	0	0	0
24	0	0	0	0
25	0	0	1	25
26	0	0	0	0
27	0	0	0	0
28	0	0	0	0
29	0	0	0	0
30	0	0	0	0
31	0	0	0	0
32	1	32	0	0
33	0	0	0	0
34	0	0	0	0
35	2	70	0	0
Average:		9.5		5.5

Table B-7: Monitored Heat Pump Performance Data

Date	Time	Heat Pump	Current (Amps)	Power (kW)	Evaporator Pressure (in. Hg)	Condenser Pressure (psi)	Chilled Water Supply (degF)	Chilled Water Discharge (degF)	Chilled Water Delta T	Condenser Water Supply (degF)	Condenser Water Discharge (degF)	Condenser Water Delta T	Hot Water Supply (degF)	Hot Water Discharge (degF)	Hot Water Delta T	Hot-Cold Cold Delta T	Demand Limiter Setting (percent)	CPA	Heating Effect (kW)
4/11/85	9:17	RU-1	310	197.59	14	9	57	46	11				92	97	5	51			908
4/11/85	12:05	RU-1	310	197.59	14	9.3	56	47.5	8.5				93	98	5	50.5			908
4/12/85	7:00	RU-1	310	197.59	14	8	60	50	10				90	94	4	44	100		726
4/16/85	7:00	RU-2	320	203.96	14	9	60	50	10				87	95	8	45	100		1,453
4/17/85	7:00	RU-2	330	210.33	15	11	55	48	7				87	95	8	47	100		1,453
4/18/85	7:00	RU-2	260	165.72	15	9	56	47	9				83	90	7	43	100		1,271
4/18/85	9:45	RU-2	320	203.96	14	11	56	50	6				91	97.5	6.5	47.5	100	-2	1,180
4/18/85	12:10	RU-2	300	191.21	15	10	53.5	48	5.5				91	96.5	5.5	48.5	100	-3	999
4/18/85	2:08	RU-2	260	165.72	15	7	53.5	47	6.5				88	90	2	43	100	-3	363
4/19/85	7:00	RU-1	310	197.59	14	8	60	49	11				86	94	8	45	100		1,453
4/12/85	3:00	RU-2	330	210.33			53	41	12	81	90	9	90	91	1	50	80		
4/17/85	3:00	RU-2	260	165.72	15	9	54	49	5	90	95	5	86	97	11	48	100		
7/23/85	3:56	RU-2	240	152.97	16	9	48	43	5	83	90	7				47	100	0	
7/23/85	7:30	RU-2	160	101.98	16	7	44	41	3	81	85	4				44	100		
7/24/85	4:10	RU-2	320	203.96	12.5	10	62	54	8	84	93	9				39	80	-2	
7/25/85	9:30	RU-2	280	178.47	13	8	54	45	9	78	87	9				42	100	0	
7/25/85	2:23	RU-2	300	191.21	16	10	53	45	8	83	91	8				46	100	0	
7/25/85	3:21	RU-2	300	191.21	16	10	53	45	8	84	95	11				50	100		
7/25/85	4:40	RU-2	300	191.21	16	10	54	46	8	83	92	9				46	100	0	
7/29/85	3:15	RU-2	320	203.96	16.5	10.5	52	44	8	81	90	9				46	100	0	
7/29/85	4:00	RU-2	310	197.59	16	10	52	44	8	82	90	8				46	100		
7/29/85	5:20	RU-2	300	191.21	16	10.5	55	44	11	85	98	13				54	100	0	
7/30/85	11:05	RU-2	320	203.96	17	9	52	43.5	8.5	80	87	7				43.5	100	0	
7/30/85	3:25	RU-2	320	203.96	16.5	9	53	44	9	81	90	9				46	100	0	
7/30/85	5:28	RU-2	320	203.96	16	11	56	44	12	83	94	11				50	100	0	
7/30/85	6:20	RU-2	220	140.22	15	7	54	43	11	81	90	9				47	100	0	
7/30/85	8:45	RU-2	200	127.48	16	7	53	43	10	80	92	12				49	100	0	
7/31/85	10:45	RU-2	360	229.46	16.5	11	52	44	8	81	90	9				46	100	0	
7/31/85	3:05	RU-2	360	229.46	16	11.5	52.5	45	7.5	85	94	9				49	100		
7/31/85	4:00	RU-2	350	223.08	16.5	9.5	52	44.5	7.5	80	89	9				44.5	100		
8/3/85	7:12	RU-2	390	248.58	16	11.5	51	46	5	87	98	11				52	100		
8/3/85	7:15	RU-2	380	242.20	16	11.5	51	46	5	82	96	14				50	100		
8/3/85	10:05	RU-2	390	248.58	15.5	10	50	43	7	84	94	10				51	100		
8/5/85	3:17	RU-2	300	191.21	16	11.5	50	44	6	88	100	12				56	100		
7/26/85	3:00	RU-3	390	248.58	13	8	52	50	2	82	89	7				39	100		
7/30/85	6:20	RU-3	300	191.21	13	7.5	56	46	10	80	90	10				44	100	0	
7/30/85	8:45	RU-3	240	152.97	13	8	54	47	7	80	92	12				45	100	0	
8/4/85	3:10	RU-3	450	286.82	16	11.5	53	46	7	83	96	13				50	100		
8/4/85	3:27	RU-3	450	286.82	16	11.5	50	44	6	86	97	11				53	100		
8/5/85	10:00	RU-3	480	305.94	12	10	60	53	7	89	96	7				43	100	-6	
8/5/85	10:28	RU-3	480	305.94	15	10	52	44	8	89	96	7				52	100	-6	

Table B-7, continued (p. 2 of 6)

Date	Time	Heat Pump	Current (Amps)	Power (kW)	Evaporator Pressure (in. Hg)	Condenser Pressure (psi)	Chilled Water Supply (degF)	Chilled Water Discharge (degF)	Chilled Water Delta T	Condenser Water Supply (degF)	Condenser Water Discharge (degF)	Condenser Water Delta T	Hot Water Supply (degF)	Hot Water Discharge (degF)	Hot Water Delta T	Hot-Cold Cold Delta T	Demand Limiter Setting (percent)	CPA	Heating Effect (kW)
1/13/86	16:24	RU-2	264	168.27			53.2	47.7	5.5				91	104	13	56.3		-3	1,180
1/13/86	16:54	RU-2	258	164.44			53	47.5	5.5				90	104	14	56.5		-3	1,271
1/13/86	17:24	RU-2	260	165.72			53	47.5	5.5				90	103	13	55.5		-3	1,180
1/13/86	17:54	RU-2	294	187.39			53.3	47.7	5.6				90	103	13	55.3		-3	1,180
1/14/86	6:54	RU-2	318	202.69			53.4	46.8	6.6				91	100	9	53.2		-3	817
1/14/86	7:24	RU-2	232	147.87			61.6	55.6	6				96	106	10	50.4		0	908
1/14/86	7:54	RU-2	230	146.60			62.4	57.4	5				95	104	9	46.6		0	817
1/14/86	8:24	RU-2	230	146.60			62.7	57.6	5.1				94	102	8	44.4		0	726
1/14/86	8:54	RU-2	230	146.60			62.6	57.4	5.2				93	103	10	45.6		0	908
1/14/86	9:24	RU-2	228	145.32			62.2	57.5	4.7				95	104	9	46.5		0	817
1/14/86	9:54	RU-2	230	146.60			61.9	57.1	4.8				95	104	9	46.9		0	817
1/14/86	10:24	RU-2	228	145.32			61.3	56.6	4.7				96	105	9	48.4		0	817
1/14/86	10:54	RU-2	228	145.32			61.3	56.6	4.7				96	106	10	49.4		0	908
1/14/86	11:24	RU-2	180	114.73			55.2	51.2	4				96	104	8	52.8		0	726
1/14/86	11:54	RU-2	174	110.90			54.6	51	3.6				94	101	7	50		-1	636
1/14/86	12:24	RU-2	180	114.73			54.3	51.1	3.2				92	100	8	48.9		-1	726
1/15/86	9:54	RU-2	228	145.32			58.2	53.2	5				93	103	10	49.8		0	908
1/15/86	10:24	RU-2	224	142.77			58.5	53.4	5.1				92	102	10	48.6		0	908
1/15/86	10:54	RU-2	222	141.50			57.6	52.5	5.1				94	105	11	52.5		0	999
1/15/86	11:24	RU-2	220	140.22			57.5	52.6	4.9				95	106	11	53.4		0	999
1/15/86	11:54	RU-2	212	135.12			57.6	53	4.6				96	106	10	53		0	908
1/15/86	12:24	RU-2	214	136.40			57.6	53	4.6				96	106	10	53		0	908
1/15/86	12:54	RU-2	210	133.85			57.6	53	4.6				96	106	10	53		0	908
1/15/86	13:24	RU-2	214	136.40			57.4	52.9	4.5				96	107	11	54.1		0	999
1/15/86	13:54	RU-2	214	136.40			57.6	53	4.6				96	107	11	54		0	999
1/15/86	14:24	RU-2	224	142.77			58.2	53.2	5				96	105	9	51.8		0	817
1/15/86	15:24	RU-2	314	200.14			54.2	48.2	6				93	104	11	55.8		-4	999
1/15/86	15:54	RU-2	254	161.89			49.9	44.4	5.5				95	104	9	59.6		-4	817
1/15/86	16:24	RU-2	240	152.97			49.9	44.6	5.3				92	102	10	57.4		-4	908
1/15/86	16:54	RU-2	228	145.32			49.6	44.1	5.5				90	99	9	54.9		-4	817
1/15/86	17:24	RU-2	158	100.71			47	43.2	3.8				85	91	6	47.8		-4	545
1/15/86	17:54	RU-2	178	113.45			48.8	43.9	4.9				84	89	5	45.1		-4	454
1/16/86	14:13	RU-2	250	159.34			53.1	47.4	5.7				97	103	6	55.6		-2	545
1/16/86	14:43	RU-2	220	140.22			52.3	47.3	5				92	101	9	53.7		-2	817
1/16/86	15:13	RU-2	206	131.30			52	47.1	4.9				90	99	9	51.9		-2	817
1/16/86	15:43	RU-2	200	127.48			51.8	47.3	4.5				91	99	8	51.7		-2	726
1/16/86	16:13	RU-2	202	128.75			52.2	47.4	4.8				91	99	8	51.6		-2	726
1/16/86	16:43	RU-2	196	124.93			51.7	47	4.7				90	98	8	51		-2	726
1/16/86	17:13	RU-2	200	127.48			52.2	47.5	4.7				89	97	8	49.5		-2	726
1/20/86	9:01	RU-2	252	160.62			53.3	47.9	5.4				88	101	13	53.1		-2	1,180
1/20/86	9:31	RU-2	250	159.34			53.2	48	5.2				87	101	14	53		-2	1,271

Table B-7, continued (p. 3 of 6)

Date	Time	Heat Pump	Current (Amps)	Power (kW)	Evaporator Pressure (in. Hg)	Condenser Pressure (psi)	Chilled Water Supply (degF)	Chilled Water Discharge (degF)	Chilled Water Delta T	Condenser Water Supply (degF)	Condenser Water Discharge (degF)	Condenser Water Delta T	Hot Water Supply (degF)	Hot Water Discharge (degF)	Hot Water Delta T	Hot-Cold Cold Delta T	Demand Limiter Setting (percent)	CPA	Heating Effect (kW)
1/20/86	10:01	RU-2	250	159.34			53.1	48	5.1				88	101	13	53		-2	1,180
1/20/86	10:31	RU-2	248	158.07			52.9	47.8	5.1				88	101	13	53.2		-2	1,180
1/20/86	11:01	RU-2	252	160.62			53.6	48.4	5.2				88	101	13	52.6		-2	1,180
1/20/86	11:46	RU-2	258	164.44			53.7	48.3	5.4				88	102	14	53.7		-2	1,271

Equations:

Power=Sqrt(3)*460volts*amps*0.8(powerfactor)

Heating Effect=gpm*499.77*(HWD-HWS)

Cooling Effect=gpm*499.77*(ChWS-ChWD)

Heating COP=Heating effect/Power

Cooling COP=Cooling effect/Power

Carnot Heating COP=HWD/(HWD-ChWD)

Carnot Cooling COP=ChWD/(HWD or CWD - ChWD)

% Full-load Capacity(tons)=Cooling Effect/RU capacity

% Full-load Capacity(kW)=Power/RU rated capacity

Calculated % Full-load Capacity(kW)=((0.2417*HWD)-2.2735)*exp(.02*%FLtons)

Rated COP's:

RU-1 and RU-2 rated COP's: heating: 4.94, cooling: 4.10, heat recovery cooling: 3.94

RU-3 rated COP's: heating: 5.89, cooling: 5.07, heat recovery cooling: 4.88

Table B-7, continued (p. 4 of 6)

Date	Cooling Effect (kW)	Heating COP	Cooling COP	Carnot Heating COP	Carnot Cooling COP	KW/Ton	% Full-load Capacity (tons)	% Full-load Capacity (kW)	Calculated % Full-load Capacity (kW)	Calculated Power (kW)	Calculated Divided by Actual Power (kW)
4/11/85	1,430	4.59	7.24	1.90	0.90	0.49	141.26	76.58	336.63	969.50	4.91
4/11/85	1,105	4.59	5.59	1.94	0.94	0.63	109.15	76.58	179.28	516.33	2.61
4/12/85	1,300	3.68	6.58	2.14	1.14	0.53	128.41	76.58	254.08	731.75	3.70
4/16/85	1,300	7.12	6.38	2.11	1.11	0.55	128.41	79.05	244.62	704.51	3.45
4/17/85	910	6.91	4.33	2.02	1.02	0.81	89.89	81.52	113.21	326.04	1.55
4/18/85	1,170	7.67	7.06	2.09	1.09	0.50	115.57	64.23	179.46	516.85	3.12
4/18/85	780	5.79	3.83	2.05	1.05	0.92	77.05	79.05	92.08	265.19	1.30
4/16/85	715	5.22	3.74	1.99	0.99	0.94	70.63	74.11	80.98	233.23	1.22
4/18/85	845	2.19	5.10	2.09	1.09	0.69	83.47	64.23	100.85	290.44	1.75
4/19/85	1,430	7.35	7.24	2.09	1.09	0.49	141.26	76.58	312.18	1,009.90	5.11
4/12/85	1,560		7.42		0.84	0.47	154.10	81.52	377.24	537.84	2.56
4/17/85	650		3.92		1.07	0.90	64.21	64.23	70.35	762.24	4.60
7/23/85	650		4.25		0.91	0.83	64.21	59.29	64.24	733.87	4.80
7/23/85	390		3.83		0.93	0.92	38.52	39.53	37.39	339.62	3.33
7/24/85	1,040		5.10		1.38	0.69	102.73	79.05	140.70	538.38	2.64
7/25/85	1,170		6.56		1.07	0.54	115.57	69.17	167.27	276.24	1.55
7/25/85	1,040		5.44		0.98	0.65	102.73	74.11	138.81	242.95	1.27
7/25/85	1,040		5.44		0.90	0.65	102.73	74.11	140.70	302.55	1.58
7/25/85	1,040		5.44		1.00	0.65	102.73	74.11	138.81	936.53	4.90
7/29/85	1,040		5.10		0.96	0.69	102.73	79.05	135.04	1,131.73	5.55
7/29/85	1,040		5.26		0.96	0.67	102.73	76.58	136.93	211.05	1.07
7/29/85	1,430		7.48		0.81	0.47	141.26	74.11	308.10	192.72	1.01
7/30/85	1,105		5.42		1.00	0.65	109.15	79.05	151.40	112.17	0.55
7/30/85	1,170		5.74		0.96	0.61	115.57	79.05	174.58	422.10	2.07
7/30/85	1,560		7.65		0.88	0.46	154.10	79.05	387.78	501.81	2.46
7/30/85	1,430		10.20		0.91	0.34	141.26	54.35	291.80	416.44	2.97
7/30/85	1,300		10.20		0.88	0.34	128.41	49.41	222.55	422.10	3.31
7/31/85	1,040		4.53		0.96	0.78	102.73	88.94	135.04	416.44	1.81
7/31/85	975		4.25		0.92	0.83	96.31	88.94	125.40	405.12	1.77
7/31/85	975		4.37		1.00	0.80	96.31	86.47	117.11	410.78	1.84
8/3/85	650		2.62		0.88	1.34	64.21	96.35	67.73	924.30	3.72
8/3/85	650		2.68		0.92	1.31	64.21	93.88	63.37	454.20	1.88
8/3/85	910		3.66		0.84	0.96	89.89	96.35	108.83	523.75	2.11
8/5/85	780		4.08		0.79	0.86	77.05	74.11	88.70	1,163.35	6.08
7/26/85	520		2.09		1.28	1.68	24.77	57.81	28.79	2,019.79	8.13
7/30/85	2,599		13.59		1.05	0.26	123.83	44.47	203.05	1,075.68	5.63
7/30/85	1,819		11.89		1.04	0.30	86.68	35.57	96.59	1,524.48	9.97
8/4/85	1,819		6.34		0.92	0.55	86.68	66.70	100.69	1,467.73	5.12
8/4/85	1,560		5.44		0.83	0.65	74.30	66.70	81.81	679.25	2.37
8/5/85	1,819		5.95		1.23	0.59	86.68	71.15	108.90	1,076.77	3.52
8/5/85	2,079		6.80		0.85	0.52	99.06	71.15	139.51	552.48	1.81

Table B-7, continued (p. 5 of 6)

Date	Cooling Effect (kW)	Heating COP	Cooling COP	Carnot Heating COP	Carnot Cooling COP	KW/Ton	% Full-load Capacity (tons)	% Full-load Capacity (kW)	Calculated % Full-load Capacity (kW)	Calculated Power (kW)	Calculated Divided by Actual Power (kW)
1/13/86	725	7.01	4.31	1.85	0.85	0.82	71.58	65.22	63.32	182.36	1.08
1/13/86	725	7.73	4.41	1.84	0.84	0.80	71.58	63.74	62.54	180.13	1.10
1/13/86	725	7.12	4.37	1.86	0.86	0.80	71.58	64.23	62.54	180.13	1.09
1/13/86	738	6.30	3.94	1.86	0.86	0.89	72.88	72.63	64.19	184.88	0.99
1/14/86	870	4.03	4.29	1.88	0.88	0.82	85.90	78.56	84.31	242.82	1.20
1/14/86	791	6.14	5.35	2.10	1.10	0.66	78.09	57.31	76.54	220.44	1.49
1/14/86	659	5.57	4.49	2.23	1.23	0.78	65.07	56.82	58.32	167.96	1.15
1/14/86	672	4.95	4.58	2.30	1.30	0.77	66.38	56.82	59.16	170.37	1.16
1/14/86	685	6.19	4.67	2.26	1.26	0.75	67.68	56.82	60.00	172.80	1.18
1/14/86	619	5.62	4.26	2.24	1.24	0.82	61.17	56.33	53.94	155.34	1.07
1/14/86	633	5.57	4.32	2.22	1.22	0.81	62.47	56.82	55.36	159.44	1.09
1/14/86	619	5.62	4.26	2.17	1.17	0.82	61.17	56.33	54.57	157.15	1.08
1/14/86	619	6.25	4.26	2.15	1.15	0.82	61.17	56.33	54.57	157.15	1.08
1/14/86	527	6.33	4.59	1.97	0.97	0.77	52.06	44.47	45.48	130.98	1.14
1/14/86	474	5.73	4.28	2.02	1.02	0.82	46.85	42.99	40.03	115.30	1.04
1/14/86	422	6.33	3.68	2.04	1.04	0.96	41.65	44.47	35.22	101.44	0.88
1/15/86	659	6.25	4.53	2.07	1.07	0.78	65.07	56.33	56.96	164.03	1.13
1/15/86	672	6.36	4.71	2.10	1.10	0.75	66.38	55.34	57.76	166.34	1.17
1/15/86	672	7.06	4.75	2.00	1.00	0.74	66.38	54.84	59.16	170.37	1.20
1/15/86	646	7.12	4.61	1.99	0.99	0.76	63.77	54.35	56.82	163.64	1.17
1/15/86	606	6.72	4.49	2.00	1.00	0.78	59.87	52.37	53.17	153.12	1.13
1/15/86	606	6.66	4.44	2.00	1.00	0.79	59.87	52.87	53.17	153.12	1.12
1/15/86	606	6.78	4.53	2.00	1.00	0.78	59.87	51.88	53.17	153.12	1.14
1/15/86	593	7.32	4.35	1.98	0.98	0.81	58.57	52.87	51.80	149.18	1.09
1/15/86	606	7.32	4.44	1.98	0.98	0.79	59.87	52.87	53.17	153.12	1.12
1/15/86	659	5.72	4.62	2.03	1.03	0.76	65.07	55.34	59.00	169.92	1.19
1/15/86	791	4.99	3.95	1.86	0.86	0.89	78.09	77.57	73.89	212.80	1.06
1/15/86	725	5.05	4.48	1.74	0.74	0.79	71.58	62.75	66.42	191.30	1.18
1/15/86	698	5.94	4.57	1.78	0.78	0.77	68.98	59.29	60.84	175.23	1.15
1/15/86	725	5.62	4.99	1.80	0.80	0.70	71.58	56.33	62.54	180.13	1.24
1/15/86	501	5.41	4.97	1.90	0.90	0.71	49.46	39.03	37.69	108.54	1.08
1/15/86	646	4.00	5.69	1.97	0.97	0.62	63.77	43.97	49.52	142.61	1.26
1/16/86	751	3.42	4.71	1.85	0.85	0.75	74.19	61.76	71.61	206.23	1.29
1/16/86	659	5.83	4.70	1.88	0.88	0.75	65.07	54.35	56.27	162.07	1.16
1/16/86	646	6.22	4.92	1.91	0.91	0.71	63.77	50.89	53.50	154.08	1.17
1/16/86	593	5.70	4.65	1.91	0.91	0.76	58.57	49.41	48.81	140.57	1.10
1/16/86	633	5.64	4.91	1.92	0.92	0.72	62.47	49.90	52.77	151.99	1.18
1/16/86	619	5.81	4.96	1.92	0.92	0.71	61.17	48.42	50.79	146.27	1.17
1/16/86	619	5.70	4.86	1.96	0.96	0.72	61.17	49.41	50.16	144.45	1.13
1/20/86	712	7.35	4.43	1.90	0.90	0.79	70.28	62.26	59.42	171.14	1.07
1/20/86	685	7.98	4.30	1.91	0.91	0.82	67.68	61.76	55.69	160.39	1.01

Table B-7, continued (p. 6 of 6)

Date	Cooling Effect (kW)	Heating COP	Cooling COP	Carnot Heating COP	Carnot Cooling COP	KW/Ton	% Full-load Capacity (tons)	% Full-load Capacity (kW)	Calculated % Full-load Capacity (kW)	Calculated Power (kW)	Calculated Divided by Actual Power (kW)
1/20/86	672	7.41	4.22	1.91	0.91	0.83	66.38	61.76	54.96	158.29	0.99
1/20/86	672	7.47	4.25	1.90	0.90	0.83	66.38	61.27	54.96	158.29	1.00
1/20/86	685	7.35	4.27	1.92	0.92	0.82	67.68	62.26	56.41	162.46	1.01
1/20/86	712	7.73	4.33	1.90	0.90	0.81	70.28	63.74	59.42	171.14	1.04

Equations:

Power=Sqrt(3)*460volts*amps*0.8(powerfactor)
Heating Effect=gpm*499.77*(HWD-HWS)
Cooling Effect=gpm*499.77*(ChWS-ChWD)
Heating COP=Heating effect/Power
Cooling COP=Cooling effect/Power
Carnot Heating COP=HWD/(HWD-ChWD)
Carnot Cooling COP=ChWD/(HWD or CWD - ChWD)
% Full-load Capacity(tons)=Cooling Effect/RU capacity
% Full-load Capacity(kW)=Power/RU rated capacity
Calculated % Full-load Capacity(kW)=((0.2417*HWD)-2.2735)*exp(.02*%FLtons)

Rated COP's:

RU-1 and RU-2 rated COP's: heating: 4.94, cooling: 4.10, heat recovery cooling: 3.94
RU-3 rated COP's: heating: 5.89, cooling: 5.07, heat recovery cooling: 4.88

Table B-8: Equations for Computer Model Summary Sheet

A236: 'Storage Tank Htg Supply	C236: (,0) +C67
A237: 'Heat Pump Htg Supply	C237: (,0) +C63
A238: 'Heat Pump Clg Supply	C238: (,0) +C73
A239: 'Storage Tank Clg Supply	C239: (,0) +C77
A240: 'Infiltration	C240: (,0) +C92
A241: 'Ventilation	C241: (,0) +C91
A242: 'Free Cooling	C242: (,0) +C90
A243: 'Heat Conduction (Btu/hr)	C243: (,0) +C188
A244: 'Internal Gains (Btu/hr)	C244: (,0) +C189
A245: 'Balance (Btu/hr)	C245: (,0) @SUM(C236..C244)
A246: \-	
A247: 'Reheat	C247: (,0) @IF(C185>=-C177,-C177,0)
A248: 'Building Heating Demand	C248: (,0) @SUM(C236+C237-C247)
A249: 'Building Cooling Demand	C249: (,0) @MIN(C93,C180)+C247
A253: 'Outdoor Air Temperature	C253: +C8
A254: 'AC-1 Space Temperature	C254: +C49
A255: 'AC-2 Space Temperature	C255: +C51
A256: 'AC-3 Space Temperature	C256: +C53
A257: 'Tank 1 Temperature	C257: +C12
A258: 'Tank 2 Temperature	C258: +C16
A259: 'Tank 3 Temperature	C259: +C20
A260: 'Hot Water Return Temp	C260: +C24
A261: 'Chilled Water Return Temp	C261: @IF(C29=1,C30,C33)
A265: 'Heat Pumps	C265: (,0) +C140
A266: 'Pumps and Miscellaneous	C266: (,0) +C130+C294+C298
A267: 'Fans and Cooling Towers	C267: (,0) +C123+C134+C292
A268: 'Computer Rooms	C268: (,0) +C296
A269: 'Appliances and Elevators	C269: (,0) +C297+C295
A270: 'Lights	C270: (,0) +C293
A274: 'Heat Pump Htg. COP	C274: (,2) +C153
A275: 'RU-1 Clg COP	C275: (,2) +C154
A276: 'RU-2 Clg COP	C276: (,2) +C155
A277: 'RU-3 Clg COP	C277: (,2) +C156
A278: 'Bldg. Htg. COP	C278: (,2) +C157
A279: 'Bldg. Clg. COP	C279: (,2) -C249*0.000293/C142
A280: 'Bldg. Overall COP	C280: (,2) +C278+C279

A284: 'Q(calc.) (ext)(Btu/hr)	C284: (,0) +C177
A285: 'Q(calc.) (int)(Btu/hr)	C285: (,0) +C178
A286: 'Q(calc.) total(Btu/hr)	C286: (,0) +C179
A287: 'Q(act.) total (Btu/hr)	C287: (,0) +C180
A288: 'diff. (act - calc)(Btu/hr)	C288: (,0) +C181
A305: 'Tank 1 Clg or FlsLdg Pot.	C305: (,0) @IF(C35=1#AND#C11>=1,+1888392*(C12-C261),0)
A306: 'Tank 2 Clg or FlsLdg Pot.	C306: (,0) @IF(C35=1#AND#C15>=1,+1888392*(C16-C261),0)
A307: 'Tank 3 Clg or FlsLdg Pot.	C307: (,0) @IF(C35=1#AND#C19>=1,+1888392*(C20-C261),0)
A308: 'Tank 1 Heating Potential	C308: (,0) @IF((C23+C11)=2#AND#C12>C302,+1888392*(C12-C260),0)
A309: 'Tank 2 Heating Potential	C309: (,0) @IF((C23+C15)=2#AND#C16>C302,+1888392*(C16-C260),0)
A310: 'Tank 3 Heating Potential	C310: (,0) @IF((C23+C19)=2#AND#C20>C302,+1888392*(C20-C260),0)
A311: 'Tank 1 Space Htg/Clg Pot.	C311: (,0) @IF(C11>0,+1888392*(C12-@AVG(C254..C256)),0)
A312: 'Tank 2 Space Htg/Clg Pot.	C312: (,0) @IF(C15>0,+1888392*(C16-@AVG(C254..C256)),0)
A313: 'Tank 3 Space Htg/Clg Pot.	C313: (,0) @IF(C19>0,+1888392*(C20-@AVG(C254..C256)),0)
A317: 'Tank 1 Clg or FlsLdg Pot.	C317: (,0) @IF(C11>=1#AND#C35=1,+499.97*C10*0.85*(C12-C261),0)
A318: 'Tank 2 Clg or FlsLdg Pot.	C318: (,0) @IF(C15>=1#AND#C35=1,+499.97*C14*0.85*(C16-C261),0)
A319: 'Tank 3 Clg or FlsLdg Pot.	C319: (,0) @IF(C19>=1#AND#C35=1,+499.97*C18*0.85*(C20-C261),0)
A320: 'Tank 1 Heating Potential	C320: (,0) @IF(C11>=1#AND#C23=1,+499.97*C10*0.85*(C12-C260),0)
A321: 'Tank 2 Heating Potential	C321: (,0) @IF(C15>=1#AND#C23=1,+499.97*C14*0.85*(C16-C260),0)
A322: 'Tank 3 Heating Potential	C322: (,0) @IF(C19>=1#AND#C23=1,+499.97*C18*0.85*(C20-C260),0)
A326: 'Storage Tank 1	C326: (,0) +C64+C74
A327: 'Storage Tank 2	C327: (,0) +C65+C75
A328: 'Storage Tank 3	C328: (,0) +C66+C76

Appendix C

Estimate of Retail Space Heat Gain to Building

Winter Peak Heating Load Estimate (Shooshanian): 1,978,200 Btu/hr
heat loss due to : conduction ventilation
conduction UA (Shooshanian): 11,200 Btu/hr .F
2.5 % htg. load: Delta T = 65, construction load - 728,000 Btu/hr
Ventilation Load = 1,978,200 - 728,00 = 1,250,200 Btu/hr
cfm = 17,809 for ventilation

Peak cooling load (Summer Schein): 2,664,000 Btu/hr
subtract conduction and ventilation to get internal gains
(2.5 %): conduction: 11,200 (90 - 76) = 156,800
ventilation: 17,809 (4.5) (34 - 26 Btu/lb) = 641,124

internal gains: 1,854,876 Btu/hr
approx. ,855,000 Btu/hr

occupied gain: 11 x 77 x 1,855,000 = 15,712,000 Btu/hr
unocc. 13 x 65 x 1,855,000 = 15,677,000 Btu/hr

For cooling loads above 60 degF:

Assume 26 percent increase of actual since 22 tons would represent a 26 percent increase over the present peak cooling load.

Table 4-1 Auxiliary Heating Calculations

From Figure 5-3, average daily cooling load = 46.228 mmBtu/day

Averaged over 11 hours 2.101 mmBtu/hr (61 percent of full load)
Equation 4-7: assume Thws = 95 degF
% FLKW = 54% 139 kW
COP = 5.42
Q = 2.575 mmBtu/hr

Auxiliary Equipment Costs

If heat pumps are being operated

Hot Water Pump:	26.8 kW
Chilled Water Pump:	70.1
Fans:	135 kW
	231.9 kW

If storage tanks are in use:
Storage tank pumps = 3 x 12.3 = 36.9 kW

If heat pumps are off:

only exterior fans on:	114 kW
only hot water pump:	26.8 kW
	150.8 kW

Cost of Electricity: $0.08/kWh
Steam $14.37/mmBtu

<u>Standard Heat Pump Operation</u>

Gross cost per mmBtu
139kW x 2 x $0.08/2.575 x 2 mmBtu = $4.32/mmBtu

COPnet:

2.575 x 2 mmBtu / (231.9 + 2(139)) 3413 = 2.96

Net cost per mmBtu:
(231.9 + (139 x 2)) x $0.08 ? 2 / 2.575 = $7.92/mmBtu

<u>False Loading with Storage Tanks</u>

Gross cost per mmBTU
(139kW x 2 x $0.08) + (2 x 2.101 x $4.32) / 2.575 x 2 = $7.84/mmBtu

COPnet: 2.575 x 2 mmBtu / (231.9 + 2(139) + 36.9) 3413 + (2 x 2.101) = .85
546.8

Net cost per mmBtu:
(546.8) (.08) + (2 x 2.101 x $7.92) / 2 x 2.575 $14.96

<u>False Loading with Steam</u>

Gross Cost per mmBtu
2(139 x .08) + (2 x 2.101 x $14.37) / 2 x 2.575 = $16.04/mmBtu

COPnet: 2,575,000 x 2 / (231.9 = 2(139)) 3413 + (2.101 x 2) = .867

Net cost per mmBtu:
((2 x 139 + 231.9) .08 + (2 x 2.101 x 14.37 / 2 x 2.575 = $19.65 / mmBtu

<u>False Loading with Lights</u>
Gross Cost per mmBtu
2(139 x .08) + (2 x 2.101,000 / 3413 x $.08) / 2 x 2.575 = $23.44

COPnet: 2,575,000 x 2 / (231.9 = 2(139))3413 + (2.101 x 2) = .867

Net cost per mmBtu
((2 x 139) + 231.9) (.08) = (2 x 2,101,000 / 3413 x .08) / 2 x 2.575
= $27.04

<u>Direct Steam Heating</u>

Gross Cost per mmBtu = $14.37/mmBtu

COP net = 2.575 x 2 / (150.8 x 3413) + (2 x 2.575) = .91
Net cost per mmBtu = (2 x 2.575 x $14.37) + (150.8 x .08) / 2 x 2.575 = 16.71

Direct Storage Tank Heating

Gross cost per mmBtu: $4.32/mmBtu

COPnet: 2.575 x 2 / ((36.9 + 150.8) x 3413 / 1,000,000) + (2 x 2.575) = .89

Net cost per mmBtu = (2 x 2,575 x 7.92) + (36.9 + 150.8) .08 / 2 x 2.575 = $12.24

Direct Lights Heating

Gross Cost per mmBtu: $0.08 / kWh x 1 kWh / 3413 Btu x 1,000,000 = $23.44

Calculations for Use of Storage System for Partial Cooling

Savings = Demand savings and operation cost savings - operation costs

Demand Savings = Demand x .857 kW/ton / 12,000 Btu/hr/ton x incremental demand cost

Operation Cost Savings and Costs = Cost of on-peak operation - Cost of off-peak operation

=(Clg Supply * incremental use cost (peak) / 3413 Btu/hr / kW * COPnet (peak)

- (Clg Supply * incremental use cost (off peak) / 3413 Btu/hr / kW * COPnet (off-peak))

= Clg Supply / 3413 8 (IUC (Peak) / COPnet(peak) - IUC (off-peak) / COPnet (off-peak))

This operation cost savings and costs analysis assumes that only the amount of cooling necessary to make up for the monthly demand for cooling has been provided, and that no losses have occurred.

COPnet (peak) = 3.99 during occupied hours with both chillers (RU-1 and RU-2) fully loaded.

COPnet (off-peak) = 1.23 during unoccupied hours if only cooling supplied to tanks is considered useful.

(These COPs were averaged from summer monitored data.)

Incremental demand and use costs were taken from table 5-3.

G-2 rates

Operation cost savings = Clg Supply * 0.08 / 3413 (1 / 3.99 - 1/1.23)
= Clg Supply * 0.08 / 3413 * (-1.78)

T-2 rate : (November-June)

Operation cost savings = Clg Supply / 3413 (.0719/3.99 - .0561/1.23)
= clg supply / 3413 (-36.24)

T-2 rate (July-October)

Operation cost savings = clg supply / 3413 (.0756 / 3.99 - .0576 / 1.23)
= clg supply / 3413 (-35.89)

Under Ideal Conditions

G-2 rate: Cost of on-peak operation - Cost of off-peak operation = 0

T-2 rate: Cost of on-peak operation - Cost of off-peak operation
= Clg Supply / 3413 (3.99) (ICU (peak) - ICU (off-peak))

(November-June) = Clg Supply / 3413 (3.99) (.0158)
(July-October) = Clg Supply / 3413 (3.99) (.0180)

Boston Edison Company
800 Boylston Street, Boston

M.D.P.U. No. 689
Sheet No. 1 Cancels M.D.P.U. No. 673

GENERAL SERVICE RATE G-2

Available for all use at a single location where the service voltage is less than 5000 volts and the monthly demand is equal to or greater than 20 kilowatts. Not available for resale.

Rate:

Demand Charge

During the Billing Months of:

November - June	July - October	
$184.20	$184.20	for the first 20 kilowatts of demand or any portion thereof in each month.
$6.05	$7.29	for each additional kilowatt.

Energy Charge - Cents Per Kilowatthour

During the Billing Months of:

November - June	July - October	
4.0866 cents	4.8608 cents	for each kilowatthour in the first 300 hours' use of the demand each month.
3.0112 cents	3.7854 cents	for each additional kilowatthour.

Minimum Charge: The demand charge for 20 kilowatts.

Fuel and Purchased Power Adjustment as provided in "Fuel and Purchased Power Adjustment," applicable to all kilowatthours on this rate.

Conservation Service Charge as provided in the "Conservation Service Charge," applicable to all bills rendered under this rate.

Additional DC Energy Charge as provided in "Direct Current Rate", applicable to all DC kilowatthours on this rate.

Determination of Demand: The billing demand will be the maximum fifteen-minute demand (either kilowatts or 80 percent of the kilovolt-amperes) as determined by meter during the monthly billing period, except any demand recorded during off-peak hours will be reduced by 70 percent.* In no case will the billing demand be less than the higher of the following: (1) 20 kilowatts and (2) if Auxiliary Service is supplied, the Auxiliary Service

(Continued)

Date Filed,
December 11, 1984
Pursuant to Amended Order in
DPU 1720 dated July 7, 1984

Date Effective,
January 1, 1985

Figure C-1: Present G-2 Boston Edison Electric Rate

GENERAL SERVICE RATE G-2 (Continued)

Capacity. Demands established prior to the application of this rate shall be considered as having been established under this rate.

Billing Periods:

Daily: Two daily time periods are included in this rate as follows:

(1) Peak hours shall be the hours between 8 a.m. and 9 p.m. EST and 9 a.m. and 10 p.m. EDT weekdays.
(2) All other hours shall be off-peak.

*Additional Meter Charge: The customer shall be responsible for the cost of all special metering equipment, including the cost of installation, to ascertain the necessary billing determinants under this rate.

Primary Credit: If only alternating current service is supplied, a credit of two percent of the total bill (not including the Fuel and Purchased Power Adjustment and other Miscellaneous Charges and before deduction of the Transformer Ownership Allowance) will be made when energy is metered at the nominal voltage of 2400 volts single phase or 4160 volts three phase.

Transformer Ownership Allowance: If only alternating current service is supplied and if a customer furnishes, installs, owns and maintains at his expense all the protective devices, transformers, and other equipment required, as specified by the Company upon request, the electricity so supplied will be metered by the Company at line voltage and the monthly demand charges will be reduced by 15 cents per kilowatt of demand when the demand is 75 kilowatts or more and the nominal voltage is 2400 volts single phase or 4160 volts three phase.

Terms of Contract: Customer may terminate service at any time by giving ten days' notice in writing, provided that such termination is not made for the purpose of obtaining the advantage of this rate for periods of less than one year.

Auxiliary Service Charge, Emergency Service Charge and Welding Machine Charge: These Charges as shown on the schedule of Miscellaneous Charges shall apply to service under this rate.

Terms and Conditions: The schedule of Terms and Conditions, as in effect from time to time, shall apply to service under this rate to the extent that they are not inconsistent with the specific provisions of this rate.

Date Filed,
December 11, 1984
Pursuant to Amended Order in
DPU 1720 dated July 7, 1984

Date Effective,
January 1, 1985

Figure C-1, continued (p. 2 of 2)

Boston Edison Company
800 Boylston Street, Boston

Sheet No. 1 Cancels M.D.P.U. No. 689

M.D.P.U. No. 714

GENERAL SERVICE RATE G-2

Available for all use at a single location where the service voltage is less than 5000 volts and the monthly demand is equal to or greater than 10 kilowatts. Rate T-2 must be used by customers whose usage characteristics would normally be served under Rate G-2 if they are required to have a time of use rate by the DPU.

Rate:

Demand Charge

During the Billing Months of:

November - June	July - October	
$101.69	$101.69	for the first 10 kilowatts of demand or any portion thereof in each month.
$7.00	$13.00	for each additional kilowatt.

Energy Charge - Cents Per Kilowatthour

During the Billing Months of:

November - June	July - October	
4.425¢	4.795¢	for each kilowatthour in the first 180 hours' use of the demand in each month.
2.846¢	2.994¢	for each additional kilowatthour.

Minimum Charge: The demand charge for 10 kilowatts.

Fuel and Purchased Power Adjustment as provided in "Fuel and Purchased Power Adjustment," applicable to all kilowatthours on this rate.

Conservation Service Charge as provided in the "Conservation Service Charge," applicable to all bills rendered under this rate.

Additional DC Energy Charge as provided in "Direct Current Charge", applicable to all DC kilowatthours on this rate.

Determination of Demand: The billing demand will be the maximum fifteen-minute demand (either kilowatts or 90 percent of the kilovolt-amperes) as determined by meter during the monthly billing period, except any demand recorded during off-peak hours will be reduced by 70 percent.* In no case will the billing demand be less than the higher of the following: (1) 10 kilowatts and (2) if Auxiliary Service is supplied, the Auxiliary Service

(Continued)

Date Filed,
December 17, 1985

Date Effective,
January 1, 1986

Figure C-2: Proposed G-2 Boston Edison Electric Rate

GENERAL SERVICE RATE G-2 (Continued)

Capacity. Demands established prior to the application of this rate shall be considered as having been established under this rate.

Billing Periods:

Daily: Two daily time periods are included in this rate as follows:

(1) Peak hours shall be the hours between 8 a.m. and 9 p.m. EST and 9 a.m. and 10 p.m. EDT weekdays.
(2) All other hours shall be off-peak.

*Additional Meter Charge: The customer shall be responsible for the cost of all special metering equipment, including the cost of installation, to ascertain the necessary billing determinants under this rate.

Primary Credit: If only alternating current service is supplied, a credit of two percent of the total bill (not including the Fuel and Purchased Power Adjustment and other Miscellaneous Charges and before deduction of the Transformer Ownership Allowance) will be made when energy is metered at the nominal voltage of 2400 volts single phase or 4160 volts three phase.

Transformer Ownership Allowance: If only alternating current service is supplied and if a customer furnishes, installs, owns and maintains at his expense all the protective devices, transformers, and other equipment required, as specified by the Company upon request, the electricity so supplied will be metered by the Company at line voltage and the monthly demand charges will be reduced by 15 cents per kilowatt of demand when the demand is 75 kilowatts or more and the nominal voltage is 2400 volts single phase or 4160 volts three phase.

Terms of Contract: Customer may terminate service at any time by giving ten days' notice in writing, provided that such termination is not made for the purpose of obtaining the advantage of this rate for periods of less than one year.

Auxiliary Service Rate, Duplicate Service Charge, Welding Machine Charge and Master-Metered Multiple Occupant Building Losses Charge: The charges as shown on the Auxiliary Service Rate or on the schedule of Miscellaneous Charges, as applicable, shall apply to service under this rate.

Terms and Conditions: The schedule of Terms and Conditions, as in effect from time to time, shall apply to service under this rate to the extent that they are not inconsistent with the specific provisions of this rate.

Date Filed,
December 17, 1985

Date Effective,
January 1, 1986

Figure C-2, continued (p. 2 of 2)

Boston Edison Company
800 Boylston Street, Boston

M.D.P.U. No. 718
Sheet No. 1 Cancels M.D.P.U. No. 698

TIME OF USE RATE T-2

Available for all use at a single location where the service voltage is less than 5000 volts and the monthly demand is greater than or equal to 10 kW. Not available for resale.

Rate:

Monthly Service Charge $107.55

Demand Charge

During the Billing Months of:

November - June	July - October	
$7.00	$13.00	for each kilowatt.

Energy Charge - Cents Per Kilowatthour

During the Billing Months of:

November - June Peak Hours	November - June Off-Peak Hours	July - October Peak Hours	July - October Off-Peak Hours	
4.425¢	2.846¢	4.795¢	2.994¢	for each kilowatthour.

Minimum Charge: The minimum charge per month is the Service Charge.

Fuel and Purchased Power Adjustment as provided in "Fuel and Purchased Power Adjustment," applicable to all kilowatthours on this rate.

Conservation Service Charge as provided in the "Conservation Service Charge," applicable to all bills rendered under this rate.

Primary Credit: A credit of two percent of the total bill not including the Fuel and Purchased Power Adjustment and other Miscellaneous Charges and before deduction of the Transformer Ownership Allowance, will be made when energy is metered at the nominal voltage of 2400 volts single phase or 4160 volts three phase.

Transformer Ownership Allowance: If a customer furnishes, installs, owns and maintains at his expense all the protective devices, transformers, and other equipment required, as specified by the Company upon request, the electricity so supplied will be metered by the Company at line voltage and the monthly demand charges will be reduced by 15 cents per kilowatt of demand when the demand is 75 kilowatts or more and the nominal voltage is 2400 volts single phase or 4160 three phase.

(Continued)

Date Filed,
December 17, 1985

Date Effective,
January 1, 1986

Figure C-3: Proposed T-2 Boston Edison Electric Rate

Boston Edison Company
800 Boylston Street, Boston

Sheet No. 2

M.D.P.U. No. 718
Cancels M.D.P.U. No. 698

TIME OF USE RATE T-2 (Continued)

Determination of Demand: The billing demand will be the maximum fifteen-minute demand (either kilowatts or 90 percent of the kilovolt-amperes) as determined by meter during the monthly billing period, except any demand recorded during off-peak hours will be reduced by 70 percent. In no case will the billing demand be less than the higher of the following: (1) 10 kilowatts or (2) if Auxiliary Service is supplied, the Auxiliary Service Capacity. Demands established prior to the application of this rate shall be considered as having been established under this rate.

Billing Periods:

Daily: Two daily time periods are included in this rate as follows:

(1) Peak hours shall be the hours between 8 a.m. and 9 p.m. EST and 9 a.m. and 10 p.m. EDT weekdays.
(2) All other hours shall be off-peak.

Term of Contract: One year from installation date after which the customer may terminate service at any time by giving ten days' notice in writing, provided that such termination is not made for the purpose of obtaining the advantage of this rate for periods of less than one year.

Auxiliary Service Charge, Duplicate Service Charge and Welding Machine Charge and Master-Metered Multiple Occupant Building Losses Charge: The charges as shown on the Auxiliary Service Rate or on the schedule of Miscellaneous Charges, as applicable, shall apply to service under this rate.

Terms and Conditions: The schedule of Terms and Conditions, as in effect from time to time, shall apply to service under this rate to the extent that they are not inconsistent with the specific provisions of this rate.

Date Filed,
December 17, 1985

Date Effective,
January 1, 1986

Figure C-3, continued (p. 2 of 2)

Transportation Building Daily Energy System Summary Sheet

Dates:	10/3/85 Thursday (Free Cooling)
Ave. outdoor Temp (degF)	56
Ave. outdoor Dewpt. (degF)	40
Ave. Outdoor Enthalpy (Btu/lb	19.16
Ave. Indoor Enthalpy (Btu/lb)	23.88

Storage Capacity Change	Tank 1	Tank 2	Tank 3
Hour 1-6 (Btu/hr)	0	0	0
Hour 7-17 (Btu/hr)	0	0	0
Hour 18-24 (Btu/hr)	0	0	0

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	0	0	0	0	0	0	0
Stor. Tank Htg. Sup	0	0	0	0	0	0	0
Reheat	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Clg.Twr. Disch.	0	0	0	0	0	0	0
Totals:	0	0	0	0	0	0	0
Clg. Use Summary (Btu/hr)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
HP Clg. Supply	0	0	0	0	0	0	0
Stor. Tank Clg. Sup	0	0	0	0	0	0	0
Free cooling	(49,947,124)	0	(49,947,124)	0	0	(4,540,648)	0
Ventilation	(6,105,824)	(629,877)	0	(5,475,947)	(104,979)	0	(782,278)
Infiltration	(1,248,611)	(1,248,611)	0	0	(208,102)	0	0
Reheat	0	0	0	0	0	0	0
Totals	(57,301,558)	(1,878,487)	(49,947,124)	(5,475,947)	(313,081)	(4,540,648)	(782,278)
Daily Energy Balance (Btu/hr)	(17,177,421)	(1,013,535)	(21,919,149)	5,755,264	(168,923)	(1,992,650)	822,181
Electric Use Summary (kW)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
Heat Pumps	0	0	0	0	0	0	0
Pumps and Miscellaneous	1,571	199	1,121	251	33	102	36
Fans and Cooling Towers	1,524	211	883	429	35	80	61
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	15,784	2,092	10,594	3,098	349	963	443
Totals	26,731	3,115	19,073	4,544	132	296	168

Figure C-4: Daily Energy System Summary Sheet for Free Cooling Simulation, 10/3/85

Energy Use Summary (Btu/hr)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Storage Tank Htg Supply	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Heat Pump Htg Supply	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Heat Pump Clg Supply	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Storage Tank Clg Supply	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Infiltration	(166,477)	(133,321)	(124,464)	(108,786)	(715,561)	0	0	0	0	0	0	0	0	0	0	0
Ventilation	0	0	0	0	0	(629,877)	0	0	0	0	0	0	0	0	0	0
Free Cooling	0	0	0	0	0	0	(4,174,948)	(3,803,426)	(4,241,297)	(4,472,038)	(4,943,734)	(4,715,214)	(4,609,182)	(4,609,182)	(4,784,252)	(4,836,464)
Heat Conduction (Btu/hr)	(766,365)	(510,910)	(459,819)	(408,728)	(408,728)	(766,365)	(1,072,911)	(817,456)	(868,547)	(919,638)	(970,729)	(1,021,820)	(970,729)	(970,729)	(970,729)	(919,638)
Internal Gains (Btu/hr)	912,848	801,434	721,686	641,938	593,855	514,107	482,441	402,693	3,803,208	4,039,777	4,201,608	4,335,725	4,464,723	4,539,461	4,646,922	4,199,471
Balance (Btu/hr)	(19,994)	157,202	137,402	124,423	(530,434)	(882,135)	(4,765,418)	(4,218,189)	(1,306,636)	(1,351,899)	(1,712,856)	(1,401,309)	(1,115,189)	(1,040,451)	(1,108,058)	(1,556,631)
Reheat	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Building Heating Demand	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Building Cooling Demand	(166,477)	(133,321)	(124,464)	(108,786)	(715,561)	(629,877)	(4,174,948)	(3,803,426)	(4,241,297)	(4,472,038)	(4,943,734)	(4,715,214)	(4,609,182)	(4,609,182)	(4,784,252)	(4,836,464)

Temperature Summary (degF)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Outdoor Air Temperature	60	62	62	63	63	59	52	57	56	55	55	54	54	54	54	55
AC-1 Space Temperature	75	76	76	76	76	73	73	73	74	74	74	74	74	74	74	74
AC-2 Space Temperature	75	72	71	71	71	74	73	73	73	73	74	74	73	73	73	73
AC-3 Space Temperature	75	75	75	75	75	74	74	74	75	75	75	75	75	75	75	75
Tank 1 Temperature	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tank 2 Temperature	0	0	0	0	0	76	75	77	78	80	82	83	85	86	87	88
Tank 3 Temperature	0	0	0	0	0	90	88	89	89	90	91	91	91	92	92	93
Hot Water Return Temp	0	0	0	0	0	0	85	83	84	84	84	85	86	86	85	87
Chilled Water Return Temp	0	0	0	0	0	0	50	50	51	51	51	51	51	50	50	50

Total Electric Summary (kW)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Heat Pumps	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pumps and Miscellaneous	33	33	33	33	33	33	107	107	107	107	107	107	107	107	107	107
Fans and Cooling Towers	18	18	18	18	66	75	74	81	81	81	81	81	81	81	81	81
Computer Rooms	64	64	64	64	64	64	114	114	114	114	114	114	114	114	114	114
Appliances and Elevators	38	38	38	38	38	38	262	522	522	522	522	522	522	522	522	522
Lights	351	341	341	341	343	374	963	963	963	963	963	963	963	963	963	963

COP's	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Heat Pump Htg. COP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RU-1 Clg COP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RU-2 Clg COP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RU-3 Clg COP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bldg. Htg. COP	0.00	0.00	0.00	0.00	0.00	0.00	15.31	19.79	18.67	19.84	21.00	19.31	19.31	18.73	21.02	19.29
Bldg. Clg. COP	1,139.86	879.29	820.87	704.26	4.37	4.25	11.52	10.44	11.66	12.31	13.61	13.00	12.70	12.70	13.19	13.32
Bldg. Overall COP	1,139.86	879.29	820.87	704.26	4.37	4.25	26.83	30.23	30.33	32.16	34.61	32.31	32.02	31.44	34.21	32.61

CFM study	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Q(calc.) (ext)(Btu/hr)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Q(calc.) (int)(Btu/hr)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Q(calc.) total(Btu/hr)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Q(act.) total (Btu/hr)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
diff. (act - calc)(Btu/hr)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure C-4, continued (p. 2 of 3)

Energy Use Summary (Btu/hr)	17	18	19	20	21	22	23	24
Storage Tank Htg Supply	0	0	0	0	0	0	0	0
Heat Pump Htg Supply	0	0	0	0	0	0	0	0
Heat Pump Clg Supply	0	0	0	0	0	0	0	0
Storage Tank Clg Supply	0	0	0	0	0	0	0	0
Infiltration	0	0	0	0	0	0	0	0
Ventilation	0	(836,428)	(859,459)	(823,499)	(823,499)	(701,494)	(759,299)	(672,267)
Free Cooling	(4,757,386)	0	0	0	0	0	0	0
Heat Conduction (Btu/hr)	(970,729)	(970,729)	(1,072,911)	(1,021,820)	(1,021,820)	(970,729)	(1,021,820)	(970,729)
Internal Gains (Btu/hr)	3,385,600	3,297,231	3,246,814	3,224,111	3,206,527	3,200,240	1,109,129	997,715
Balance (Btu/hr)	(2,342,514)	1,490,074	1,314,444	1,378,792	1,361,208	1,528,017	(671,990)	(645,281)
Reheat	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Building Heating Demand	0	0	0	0	0	0	0	0
Building Cooling Demand	(4,757,386)	(836,428)	(859,459)	(823,499)	(823,499)	(701,494)	(759,299)	(672,267)
Temperature Summary (degF)	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Outdoor Air Temperature	55	55	54	55	55	55	54	55
AC-1 Space Temperature	74	74	73	73	73	72	72	72
AC-2 Space Temperature	74	74	75	75	75	74	74	74
AC-3 Space Temperature	75	76	76	76	76	76	75	75
Tank 1 Temperature	0	0	0	0	0	0	0	0
Tank 2 Temperature	0	0	0	0	0	0	0	0
Tank 3 Temperature	0	0	0	0	0	0	0	0
Hot Water Return Temp	0	0	0	0	0	0	0	0
Chilled Water Return Temp	0	0	0	0	0	0	0	0
Total Electric Summary (kW)	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Heat Pumps	0	0	0	0	0	0	0	0
Pumps and Miscellaneous	55	43	43	33	33	33	33	33
Fans and Cooling Towers	81	67	60	60	60	60	60	60
Computer Rooms	114	114	64	64	64	64	64	64
Appliances and Elevators	262	38	38	38	38	38	38	38
Lights	963	956	366	366	352	352	352	352
COP's	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Heat Pump Htg. COP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RU-1 Clg COP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RU-2 Clg COP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RU-3 Clg COP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bldg. Htg. COP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bldg. Clg. COP	25.34	5.74	5.91	5.65	5.65	4.81	5.22	4.61
Bldg. Overall COP	25.34	5.74	5.91	5.65	5.65	4.81	5.22	4.61
CFM study	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Q(calc.) (ext)(Btu/hr)	0	0	0	0	0	0	0	0
Q(calc.) (int)(Btu/hr)	0	0	0	0	0	0	0	0
Q(calc.) total(Btu/hr)	0	0	0	0	0	0	0	0
Q(act.) total (Btu/hr)	0	0	0	0	0	0	0	0
diff. (act - calc)(Btu/hr)	0	0	0	0	0	0	0	0

Figure C-4, continued (p. 3 of 3)

Table C-1: Daily Energy System Summary Sheet - 7/22/85

Transportation Building Daily Energy System Summary Sheet

Date: 7/22/85	Monday	Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)	76	Hour 1-6 (Btu/hr)	0	0	0
Ave. outdoor Dewpt. (degF)	54	Hour 7-17 (Btu/hr)	1,994,082	10,967,453	8,308,676
Ave. Outdoor Enthalpy (Btu/lb	28.15	Hour 18-24 (Btu/hr)	(8,308,676)	(0)	(3,988,165)
Ave. Indoor Enthalpy (Btu/lb)	24.24				

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	0	0	0	0	0	0	0
Stor. Tank Htg. Sup	0	0	0	0	0	0	0
Reheat	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Clg.Twr. Disch.	(188,388,302)	0	(99,479,219)	(88,909,083)	0	(9,043,565)	(12,701,298)
Totals*	0	0	0	0	0	(9,043,565)	(12,701,298)

Clg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Clg. Supply	(133,532,297)	0	(84,804,722)	(48,727,575)	0	(7,709,520)	(6,961,082)
Stor. Tank Clg. Sup	(8,973,370)	0	(21,270,211)	12,296,841	0	(1,933,656)	1,756,692
Free cooling	(243,831)	0	0	(243,831)	0	0	(34,833)
Ventilation	710,483	0	710,483	0	0	64,589	0
Infiltration	10,384,877	0	9,111,113	1,273,764	0	828,283	181,966
Reheat	0	0	0	0	0	0	0
Totals	(131,654,138)	0	(96,253,337)	(35,400,801)	0	(8,750,303)	(5,057,257)

Daily Energy Balance (Btu/hr)	(72,176,692)	270,336	(56,145,452)	(16,301,576)	45,056	(5,104,132)	(2,328,797)

Electric Use Summary (kW)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
Heat Pumps	6,818	0	4,501	2,316	0	409	331
Pumps and Miscellaneous	3,524	236	1,947	1,341	39	177	192
Fans and Cooling Towers	1,779	120	1,371	289	20	125	41
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	15,784	2,092	10,594	3,098	349	963	443
Totals	35,757	3,060	24,888	7,809	123	825	635

Table C-2: Daily Energy System Summary Sheet - 7/23/85

Transportation Building Daily Energy System Summary Sheet

Date:	7/23/85	Tuesday	Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)		70	Hour 1-6 (Btu/hr)	(7,643,982)	(332,347)	(4,965,206)
Ave. outdoor Dewpt. (degF)		42	Hour 7-17 (Btu/hr)	(8,641,023)	2,326,429	(4,652,859)
Ave. Outdoor Enthalpy (Btu/lb		22.94	Hour 18-24 (Btu/hr)	997,041	0	(1,661,735)
Ave. Indoor Enthalpy (Btu/lb)		23.55				

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	0	0	0	0	0	0	0
Stor. Tank Htg. Sup	0	0	0	0	0	0	0
Reheat	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Clg.Twr. Disch.	(252,708,701)	(65,219,985)	(132,613,970)	(54,874,746)	(10,869,998)	(12,055,815)	(7,839,249)
Totals*	0	0	0	0	(10,869,998)	(12,055,815)	(7,839,249)

Clg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Clg. Supply	(149,931,000)	(37,951,284)	(73,091,363)	(38,888,353)	(6,325,214)	(6,644,669)	(5,555,479)
Stor. Tank Clg. Sup	24,593,682	12,961,535	10,967,453	664,694	2,160,256	997,041	94,956
Free cooling	4,050,633	0	4,050,633	0	0	368,239	0
Ventilation	(553,969)	(286,971)	(266,998)	0	(47,828)	(24,273)	0
Infiltration	(1,101,819)	(805,518)	0	(296,301)	(134,253)	0	(42,329)
Reheat	0	0	0	0	0	0	0
Totals	(122,942,474)	(26,082,238)	(58,340,275)	(38,519,960)	(4,347,040)	(5,303,661)	(5,502,851)
Daily Energy Balance (Btu/hr)	(67,031,217)	(23,531,283)	(20,605,011)	(22,894,924)	(3,921,881)	(1,873,183)	(3,270,703)

Electric Use Summary (kW)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
Heat Pumps	6,996	1,778	3,481	1,737	296	316	248
Pumps and Miscellaneous	4,948	1,220	2,330	1,398	203	212	200
Fans and Cooling Towers	1,852	303	1,262	287	51	115	41
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	15,784	2,092	10,594	3,098	349	963	443
Totals	37,432	6,005	24,143	7,285	614	757	560

Table C-3: Daily Energy System Summary Sheet - 7/24/85

Transportation Building Daily Energy System Summary Sheet

Date:	7/24/85 Wednesday	Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)	72	Hour 1-6 (Btu/hr)	2,326,429	332,347	(332,347)
Ave. outdoor Dewpt. (degF)	44	Hour 7-17 (Btu/hr)	4,320,512	2,326,429	1,661,735
Ave. Outdoor Enthalpy (Btu/lb	24.01	Hour 18-24 (Btu/hr)	332,347	0	0
Ave. Indoor Enthalpy (Btu/lb)	23.74				

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	0	0	0	0	0	0	0
Stor. Tank Htg. Sup	0	0	0	0	0	0	0
Reheat	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Clg.Twr. Disch.	(138,761,141)	(41,305,991)	(79,463,430)	(17,991,720)	(6,884,332)	(7,223,948)	(2,570,246)
Totals*	0	0	0	0	(6,884,332)	(7,223,948)	(2,570,246)

Clg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Clg. Supply	(95,581,013)	(34,671,544)	(40,762,491)	(20,146,978)	(5,778,591)	(3,705,681)	(2,878,140)
Stor. Tank Clg. Sup	(10,967,453)	(2,326,429)	(8,308,676)	(332,347)	(387,738)	(755,334)	(47,478)
Free cooling	8,538,018	0	8,538,018	0	0	776,183	0
Ventilation	366,521	0	310,399	56,523	0	28,218	8,075
Infiltration	(1,010,059)	(1,025,383)	(34,527)	49,851	(170,897)	(3,139)	7,122
Reheat	0	0	0	0	0	0	0
Totals	(98,653,584)	(38,023,356)	(40,257,277)	(20,372,951)	(6,337,226)	(3,659,752)	(2,910,422)
Daily Energy Balance (Btu/hr)	(39,727,959)	(35,932,220)	(836,009)	(2,959,730)	(5,988,703)	(76,001)	(422,819)

Electric Use Summary (kW)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
Heat Pumps	5,006	1,605	2,230	1,171	268	203	167
Pumps and Miscellaneous	4,210	1,220	1,994	997	203	181	142
Fans and Cooling Towers	1,911	338	1,308	265	56	119	38
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	15,784	2,092	10,594	3,098	349	963	443
Totals	34,764	5,867	22,601	6,295	591	617	419

Table C-4: Daily Energy System Summary Sheet - 7/25/85

Transportation Building Daily Energy System Summary Sheet

Date:	7/25/85	Thursday	Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)	76		Hour 1-6 (Btu/hr)	0	0	0
Ave. outdoor Dewpt. (degF)	52		Hour 7-17 (Btu/hr)	11,964,494	9,970,412	9,970,412
Ave. Outdoor Enthalpy (Btu/lb	27.53		Hour 18-24 (Btu/hr)	(332,347)	(664,694)	(2,326,429)
Ave. Indoor Enthalpy (Btu/lb)	25.39					

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	0	0	0	0	0	0	0
Stor. Tank Htg. Sup	0	0	0	0	0	0	0
Reheat	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Clg.Twr. Disch.	(163,199,894)	0	(95,955,840)	(67,244,054)	0	(8,723,258)	(9,606,293)
Totals*	0	0	0	0	0	(8,723,258)	(9,606,293)
Clg. Use Summary (Btu/hr)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
HP Clg. Supply	(136,287,279)	0	(97,605,081)	(38,682,198)	0	(8,873,189)	(5,526,028)
Stor. Tank Clg. Sup	(28,581,846)	0	(31,905,317)	3,323,471	0	(2,900,483)	474,782
Free cooling	(352,836)	(4,879,731)	4,526,895	0	(813,289)	411,536	0
Ventilation	5,578,279	0	5,373,522	204,757	0	488,502	29,251
Infiltration	568,291	0	0	568,291	0	0	81,184
Reheat	0	0	0	0	0	0	0
Totals	(159,075,392)	(4,879,731)	(119,609,980)	(34,585,680)	(813,289)	(10,873,635)	(4,940,811)
Daily Energy Balance (Btu/hr)	(96,828,851)	(3,095,141)	(77,940,709)	(15,793,001)	(515,857)	(7,085,519)	(2,256,143)
Electric Use Summary (kW)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
Heat Pumps	7,295	0	5,475	1,820	0	498	260
Pumps and Miscellaneous	3,431	236	1,972	1,224	39	179	175
Fans and Cooling Towers	1,942	182	1,478	282	30	134	40
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	15,784	2,092	10,594	3,098	349	963	443
Totals	36,304	3,122	25,993	7,189	134	925	546

Table C-5: Daily Energy System Summary Sheet - 7/26/85

Transportation Building Daily Energy System Summary Sheet

Date: 7/26/85	Friday				Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)	75				Hour 1-6 (Btu/hr)	(997,041)	(997,041)	(2,326,429)
Ave. outdoor Dewpt. (degF)	59				Hour 7-17 (Btu/hr)	332,347	664,694	(664,694)
Ave. Outdoor Enthalpy (Btu/lb	30.05				Hour 18-24 (Btu/hr)	0	0	(1,661,735)
Ave. Indoor Enthalpy (Btu/lb)	26.23							

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	0	0	0	0	0	0	0
Stor. Tank Htg. Sup	0	0	0	0	0	0	0
Reheat	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Clg.Twr. Disch.	(278,271,936)	(69,567,984)	(165,223,962)	(43,479,990)	(11,594,664)	(15,020,360)	(6,211,427)
Totals*	0	0	0	0	(11,594,664)	(15,020,360)	(6,211,427)

Clg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Clg. Supply	(131,189,625)	(47,790,506)	(58,566,797)	(24,832,322)	(7,965,084)	(5,324,254)	(3,547,475)
Stor. Tank Clg. Sup	5,649,900	4,320,512	(332,347)	1,661,735	720,085	(30,213)	237,391
Free cooling	0	0	0	0	0	0	0
Ventilation	0	0	0	0	0	0	0
Infiltration	16,361,283	3,110,572	12,430,111	820,600	518,429	1,130,010	117,229
Reheat	0	0	0	0	0	0	0
Totals	(109,178,442)	(40,359,423)	(46,469,033)	(22,349,986)	(6,726,570)	(4,224,458)	(3,192,855)
Daily Energy Balance (Btu/hr)	(48,311,358)	(36,531,192)	(6,996,674)	(4,783,492)	(6,088,532)	(636,061)	(683,356)

Electric Use Summary (kW)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
Heat Pumps	7,205	2,342	3,550	1,313	390	323	188
Pumps and Miscellaneous	4,664	1,220	2,342	1,102	203	213	157
Fans and Cooling Towers	1,959	382	1,334	242	64	121	35
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	15,784	2,092	10,594	3,098	349	963	443
Totals	37,464	6,648	24,296	6,520	721	771	451

Table C-6: Daily Energy System Summary Sheet - 7/27/85

Transportation Building Daily Energy System Summary Sheet

Date:	7/27/85	Saturday	Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)	75		Hour 1-6 (Btu/hr)	0	0	0
Ave. outdoor Dewpt. (degF)	51		Hour 7-17 (Btu/hr)	(664,694)	(1,329,388)	(2,658,776)
Ave. Outdoor Enthalpy (Btu/lb	26.67		Hour 18-24 (Btu/hr)	(1,661,735)	(1,661,735)	(1,661,735)
Ave. Indoor Enthalpy (Btu/lb)	23.09					

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	0	0	0	0	0	0	0
Stor. Tank Htg. Sup	0	0	0	0	0	0	0
Reheat	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Clg.Twr. Disch.	(149,856,035)	0	(110,724,044)	(39,131,991)	0	(10,065,822)	(5,590,284)
Totals*	0	0	0	0	0	(10,065,822)	(5,590,284)

Clg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Clg. Supply	(72,622,828)	0	(50,133,178)	(22,489,650)	0	(4,557,562)	(3,212,807)
Stor. Tank Clg. Sup	9,638,064	0	4,652,859	4,985,206	0	422,987	712,172
Free cooling	11,314,454	0	11,314,454	0	0	1,028,587	0
Ventilation	0	0	0	0	0	0	0
Infiltration	2,291,291	0	1,893,140	398,151	0	172,104	56,879
Reheat	0	0	0	0	0	0	0
Totals	(49,379,019)	0	(32,272,726)	(17,106,293)	0	(2,933,884)	(2,443,756)
Daily Energy Balance (Btu/hr)	(41,247,115)	117,063	(27,230,010)	(14,134,169)	19,511	(2,475,455)	(2,019,167)

Electric Use Summary (kW)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
Heat Pumps	3,925	0	2,720	1,205	0	247	172
Pumps and Miscellaneous	3,200	199	1,899	1,102	33	173	157
Fans and Cooling Towers	1,369	80	1,083	206	13	98	29
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	1,360	229	864	267	38	79	38
Lights	9,851	2,070	5,155	2,626	345	469	375
Totals	21,840	2,961	12,975	5,904	110	632	430

Table C-7: Daily Energy System Summary Sheet - 7/28/85

Transportation Building Daily Energy System Summary Sheet

Date:	7/28/85	Sunday	Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)	71		Hour 1-6 (Btu/hr)	0	0	0
Ave. outdoor Dewpt. (degF)	48		Hour 7-17 (Btu/hr)	(997,041)	(997,041)	(997,041)
Ave. Outdoor Enthalpy (Btu/lb	24.89		Hour 18-24 (Btu/hr)	(1,329,388)	(664,694)	(664,694)
Ave. Indoor Enthalpy (Btu/lb)	24.96					

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	0	0	0	0	0	0	0
Stor. Tank Htg. Sup	0	0	0	0	0	0	0
Reheat	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Clg.Twr. Disch.	(91,158,048)	0	(70,767,432)	(20,390,616)	0	(6,433,403)	(2,912,945)
Totals*	0	0	0	0	0	(6,433,403)	(2,912,945)
Clg. Use Summary (Btu/hr)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
HP Clg. Supply	(72,154,294)	0	(54,818,522)	(17,335,772)	0	(4,983,502)	(2,476,539)
Stor. Tank Clg. Sup	5,649,900	0	2,991,123	2,658,776	0	271,920	379,825
Free cooling	170,864	0	134,163	36,701	0	12,197	5,243
Ventilation	241,488	0	241,488	0	0	21,953	0
Infiltration	(316,713)	(337,902)	186,534	(165,345)	(56,317)	16,958	(23,621)
Reheat	0	0	0	0	0	0	0
Totals	(66,408,754)	(337,902)	(51,265,213)	(14,805,640)	(56,317)	(4,660,474)	(2,115,091)
Daily Energy Balance (Btu/hr)	(59,298,671)	443,345	(46,477,953)	(13,264,063)	73,891	(4,225,268)	(1,894,866)
Electric Use Summary (kW)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
Heat Pumps	4,414	0	3,364	1,050	0	306	150
Pumps and Miscellaneous	2,474	199	1,478	797	33	134	114
Fans and Cooling Towers	722	80	475	167	13	43	24
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	1,360	229	864	267	38	79	38
Lights	9,851	2,070	5,155	2,626	345	469	375
Totals	20,955	2,961	12,589	5,405	110	597	359

Table C-8: Daily Energy System Summary Sheet - 8/12/85

Transportation Building Daily Energy System Summary Sheet

Date:	8/12/85	Monday
Ave. outdoor Temp (degF)	72	
Ave. outdoor Dewpt. (degF)	48	
Ave. Outdoor Enthalpy (Btu/lb	25.23	
Ave. Indoor Enthalpy (Btu/lb)	25.91	

Storage Capacity Change	Tank 1	Tank 2	Tank 3
Hour 1-6 (Btu/hr)	0	0	0
Hour 7-17 (Btu/hr)	1,329,388	(1,661,735)	6,979,288
Hour 18-24 (Btu/hr)	(6,979,288)	(7,311,635)	(5,317,553)

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	0	0	0	0	0	0	0
Stor. Tank Htg. Sup	0	0	0	0	0	0	0
Reheat	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Clg.Twr. Disch.	(165,074,031)	0	(116,271,491)	(48,802,541)	0	(10,570,136)	(6,971,792)
Totals*	0	0	0	0	0	(10,570,136)	(6,971,792)

Clg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Clg. Supply	(116,496,387)	0	(76,914,603)	(39,581,784)	0	(6,992,237)	(5,654,541)
Stor. Tank Clg. Sup	12,961,535	0	(6,646,941)	19,608,476	0	(604,267)	2,801,211
Free cooling	(139,299)	(139,299)	0	0	(23,216)	0	0
Ventilation	219,130	0	219,130	0	0	19,921	0
Infiltration	(913,226)	(329,452)	(183,223)	(400,551)	(54,909)	(16,657)	(57,222)
Reheat	0	0	0	0	0	0	0
Totals	(104,368,246)	(468,751)	(83,525,637)	(20,373,859)	(78,125)	(7,593,240)	(2,910,551)

Daily Energy Balance (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
Daily Energy Balance (Btu/hr)	(50,919,539)	261,405	(46,840,849)	(4,340,094)	43,567	(4,258,259)	(620,013)

Electric Use Summary (kW)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
Heat Pumps	7,631	0	5,017	2,614	0	456	373
Pumps and Miscellaneous	3,580	236	2,124	1,221	39	193	174
Fans and Cooling Towers	1,762	157	1,341	265	26	122	38
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	15,784	2,092	10,594	3,098	349	963	443
Totals	36,610	3,097	25,551	7,962	129	885	657

Table C-9: Daily Energy System Summary Sheet - 8/13/85

Transportation Building Daily Energy System Summary Sheet

Date:	8/13/85	Tuesday
Ave. outdoor Temp (degF)		69
Ave. outdoor Dewpt. (degF)		44
Ave. Outdoor Enthalpy (Btu/lb		23.42
Ave. Indoor Enthalpy (Btu/lb)		24.49

Storage Capacity Change	Tank 1	Tank 2	Tank 3
Hour 1-6 (Btu/hr)	(3,323,471)	(4,652,859)	(2,991,123)
Hour 7-17 (Btu/hr)	3,655,818	(664,694)	6,314,594
Hour 18-24 (Btu/hr)	(3,323,471)	(3,655,818)	(2,991,123)

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	0	0	0	0	0	0	0
Stor. Tank Htg. Sup	0	0	0	0	0	0	0
Reheat	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Clg.Twr. Disch.	(125,117,420)	(51,951,092)	(40,781,232)	(32,385,096)	(8,658,515)	(3,707,385)	(4,626,442)
Totals*	0	0	0	0	(8,658,515)	(3,707,385)	(4,626,442)
Clg. Use Summary (Btu/hr)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
HP Clg. Supply	(112,898,043)	(39,131,991)	(49,477,230)	(24,288,822)	(6,521,999)	(4,497,930)	(3,469,832)
Stor. Tank Clg. Sup	11,632,147	10,967,453	(9,305,717)	9,970,412	1,827,909	(845,974)	1,424,345
Free cooling	(9,398,568)	0	(8,508,824)	(889,744)	0	(773,529)	(127,106)
Ventilation	0	0	0	0	0	0	0
Infiltration	(1,626,266)	(1,219,238)	(407,028)	0	(203,206)	(37,003)	0
Reheat	0	0	0	0	0	0	0
Totals	(112,290,730)	(29,383,776)	(67,698,600)	(15,208,154)	(4,897,296)	(6,154,436)	(2,172,593)
Daily Energy Balance (Btu/hr)	(57,707,840)	(27,956,823)	(31,138,628)	1,387,611	(4,659,471)	(2,830,784)	198,230
Electric Use Summary (kW)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
Heat Pumps	6,632	2,468	2,655	1,489	415	241	213
Pumps and Miscellaneous	3,602	1,131	1,810	661	189	165	94
Fans and Cooling Towers	1,826	330	1,292	204	55	117	29
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	15,784	2,092	10,594	3,098	349	963	443
Totals	35,697	6,653	22,827	6,217	722	637	407

Table C-10: Daily Energy System Summary Sheet - 8/14/85

Transportation Building Daily Energy System Summary Sheet

Date:	8/14/85 Wednesday
Ave. outdoor Temp (degF)	80
Ave. outdoor Dewpt. (degF)	55
Ave. Outdoor Enthalpy (Btu/lb	29.76
Ave. Indoor Enthalpy (Btu/lb)	25.69

Storage Capacity Change	Tank 1	Tank 2	Tank 3
Hour 1-6 (Btu/hr)	(6,314,594)	(6,979,288)	(3,988,165)
Hour 7-17 (Btu/hr)	3,323,471	(664,694)	6,314,594
Hour 18-24 (Btu/hr)	(3,655,818)	(3,988,165)	(2,658,776)

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	0	0	0	0	0	0	0
Stor. Tank Htg. Sup	0	0	0	0	0	0	0
Reheat	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Clg.Twr. Disch.	(254,357,942)	(57,573,504)	(125,942,040)	(70,842,398)	(9,595,584)	(11,449,276)	(10,120,343)
Totals*	0	0	0	0	(9,595,584)	(11,449,276)	(10,120,343)

Clg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Clg. Supply	(171,820,926)	(40,481,370)	(84,561,084)	(46,778,472)	(6,746,895)	(7,687,371)	(6,682,639)
Stor. Tank Clg. Sup	18,611,435	17,282,047	(8,973,370)	10,302,759	2,880,341	(815,761)	1,471,823
Free cooling	0	0	0	0	0	0	0
Ventilation	4,718,338	(248,548)	4,817,481	149,405	(41,425)	437,953	21,344
Infiltration	9,465,188	0	7,859,758	1,605,430	0	714,523	229,347
Reheat	0	0	0	0	0	0	0
Totals	(139,025,966)	(23,447,872)	(80,857,215)	(34,720,879)	(3,907,979)	(7,350,656)	(4,960,126)
Daily Energy Balance (Btu/hr)	(71,210,507)	(20,896,917)	(37,399,758)	(12,913,832)	(3,482,819)	(3,399,978)	(1,844,833)

Electric Use Summary (kW)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
Heat Pumps	11,250	2,681	5,473	3,096	447	498	442
Pumps and Miscellaneous	4,382	1,017	2,181	1,184	170	198	169
Fans and Cooling Towers	2,140	314	1,561	265	52	142	38
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	15,784	2,092	10,594	3,098	349	963	443
Totals	41,408	6,717	26,284	8,407	733	952	720

Table C-11: Daily Energy System Summary Sheet - 8/15/85

Transportation Building Daily Energy System Summary Sheet

Date:	8/15/85	Thursday	Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)	84		Hour 1-6 (Btu/hr)	(4,652,859)	(5,317,553)	(2,991,123)
Ave. outdoor Dewpt. (degF)	60		Hour 7-17 (Btu/hr)	4,652,859	997,041	5,982,247
Ave. Outdoor Enthalpy (Btu/lb	32.68		Hour 18-24 (Btu/hr)	(5,649,900)	(4,985,206)	(3,988,165)
Ave. Indoor Enthalpy (Btu/lb)	26.49					

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	0	0	0	0	0	0	0
Stor. Tank Htg. Sup	0	0	0	0	0	0	0
Reheat	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Clg.Twr. Disch.	(220,023,743)	(37,782,612)	(113,347,836)	(68,893,295)	(6,297,102)	(10,304,349)	(9,841,899)
Totals*	0	0	0	0	(6,297,102)	(10,304,349)	(9,841,899)

Clg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Clg. Supply	(165,074,031)	(30,585,924)	(90,408,393)	(44,079,714)	(5,097,654)	(8,218,945)	(6,297,102)
Stor. Tank Clg. Sup	15,952,658	12,961,535	(11,632,147)	14,623,270	2,160,256	(1,057,468)	2,089,039
Free cooling	0	0	0	0	0	0	0
Ventilation	0	0	0	0	0	0	0
Infiltration	27,988,026	1,074,999	20,538,285	6,374,743	179,166	1,867,117	910,678
Reheat	0	0	0	0	0	0	0
Totals	(121,133,346)	(16,549,390)	(81,502,255)	(23,081,701)	(2,758,232)	(7,409,296)	(3,297,386)
Daily Energy Balance (Btu/hr)	(50,916,610)	(12,005,886)	(36,052,249)	(2,858,474)	(2,000,981)	(3,277,477)	(408,353)

Electric Use Summary (kW)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
Heat Pumps	10,256	2,005	5,413	2,838	334	492	405
Pumps and Miscellaneous	4,318	894	2,181	1,243	149	198	178
Fans and Cooling Towers	2,232	212	1,658	362	35	151	52
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	15,784	2,092	10,594	3,098	349	963	443
Totals	40,442	5,816	26,320	8,306	583	955	706

Table C-12: Daily Energy System Summary Sheet - 8/16/85

Transportation Building Daily Energy System Summary Sheet

Date:	8/16/85	Friday
Ave. outdoor Temp (degF)	76	
Ave. outdoor Dewpt. (degF)	53	
Ave. Outdoor Enthalpy (Btu/lb	27.68	
Ave. Indoor Enthalpy (Btu/lb)	25.84	

Storage Capacity Change	Tank 1	Tank 2	Tank 3
Hour 1-6 (Btu/hr)	(2,991,123)	(4,652,859)	(332,347)
Hour 7-17 (Btu/hr)	664,694	332,347	3,988,165
Hour 18-24 (Btu/hr)	(7,643,982)	(8,973,370)	(5,982,247)

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	0	0	0	0	0	0	0
Stor. Tank Htg. Sup	0	0	0	0	0	0	0
Reheat	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Clg.Twr. Disch.	(223,397,190)	(39,057,026)	(116,571,353)	(67,768,812)	(6,509,504)	(10,597,396)	(9,681,259)
Totals*	0	0	0	0	(6,509,504)	(10,597,396)	(9,681,259)
Clg. Use Summary (Btu/hr)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
HP Clg. Supply	(146,182,725)	(23,839,029)	(70,617,501)	(51,726,195)	(3,973,172)	(6,419,773)	(7,389,456)
Stor. Tank Clg. Sup	25,590,723	7,976,329	(4,985,206)	22,599,599	1,329,388	(453,201)	3,228,514
Free cooling	0	0	0	0	0	0	0
Ventilation	0	0	0	0	0	0	0
Infiltration	9,172,858	2,070,266	7,100,343	2,249	345,044	645,486	321
Reheat	0	0	0	0	0	0	0
Totals	(111,419,144)	(13,792,433)	(68,502,364)	(29,124,347)	(2,298,739)	(6,227,488)	(4,160,621)
Daily Energy Balance (Btu/hr)	(51,318,426)	(10,117,476)	(28,927,823)	(12,273,126)	(1,686,246)	(2,629,802)	(1,753,304)
Electric Use Summary (kW)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
Heat Pumps	8,481	1,545	4,388	2,547	258	399	364
Pumps and Miscellaneous	4,617	1,175	2,087	1,354	196	190	193
Fans and Cooling Towers	2,099	387	1,425	287	65	130	41
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	15,784	2,092	10,594	3,098	349	963	443
Totals	38,833	5,813	24,969	8,051	582	832	669

Table C-13: Daily Energy System Summary Sheet - 8/17/85

Transportation Building Daily Energy System Summary Sheet

Date:	8/17/85 Saturday	Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)	74	Hour 1-6 (Btu/hr)	(6,314,594)	(7,311,635)	(4,320,512)
Ave. outdoor Dewpt. (degF)	46	Hour 7-17 (Btu/hr)	(7,976,329)	(9,638,064)	(7,311,635)
Ave. Outdoor Enthalpy (Btu/lb	25.02	Hour 18-24 (Btu/hr)	(4,320,512)	(4,985,206)	(2,326,429)
Ave. Indoor Enthalpy (Btu/lb)	24.96				

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	0	0	0	0	0	0	0
Stor. Tank Htg. Sup	0	0	0	0	0	0	0
Reheat	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Clg.Twr. Disch.	(170,021,754)	(45,653,990)	(83,436,602)	(40,931,163)	(7,608,998)	(7,585,146)	(5,847,309)
Totals*	0	0	0	0	(7,608,998)	(7,585,146)	(5,847,309)

Clg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Clg. Supply	(172,720,512)	(43,180,128)	(88,159,428)	(41,380,956)	(7,196,688)	(8,014,493)	(5,911,565)
Stor. Tank Clg. Sup	54,504,916	17,946,741	24,926,029	11,632,147	2,991,123	2,266,003	1,661,735
Free cooling	0	0	0	0	0	0	0
Ventilation	0	0	0	0	0	0	0
Infiltration	569,968	(301,825)	831,484	40,310	(50,304)	75,589	5,759
Reheat	0	0	0	0	0	0	0
Totals	(117,645,628)	(25,535,213)	(62,401,916)	(29,708,499)	(4,255,869)	(5,672,901)	(4,244,071)
Daily Energy Balance (Btu/hr)	(110,167,727)	(23,699,532)	(58,250,181)	(28,218,014)	(3,949,922)	(5,295,471)	(4,031,145)

Electric Use Summary (kW)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
Heat Pumps	8,858	2,124	4,583	2,150	354	417	307
Pumps and Miscellaneous	4,496	1,131	2,181	1,184	189	198	169
Fans and Cooling Towers	947	214	520	213	36	47	30
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	1,360	229	864	267	38	79	38
Lights	9,851	2,070	5,155	2,626	345	469	375
Totals	27,647	6,152	14,557	6,938	642	776	578

Table C-14: Daily Energy System Summary Sheet - 9/11/85

Transportation Building Daily Energy System Summary Sheet

Date:	9/11/85 Wednesday	Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)	60	Hour 1-6 (Btu/hr)	(3,988,165)	(4,985,206)	0
Ave. outdoor Dewpt. (degF)	37	Hour 7-17 (Btu/hr)	(332,347)	(997,041)	0
Ave. Outdoor Enthalpy (Btu/lb	19.63	Hour 18-24 (Btu/hr)	0	0	3,323,471
Ave. Indoor Enthalpy (Btu/lb)	23.00				

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	14,253,440	0	14,253,440	0	0	1,295,767	0
Stor. Tank Htg. Sup	0	0	0	0	0	0	0
Reheat	(7,409,969)	(0)	(7,409,969)	(0)	(0)	(673,634)	(0)
Clg.Twr. Disch.	(58,173,228)	(40,931,163)	(17,242,065)	0	(6,821,861)	(1,567,460)	0
Totals*	6,843,472	0	6,843,472	0	(6,821,861)	(945,327)	0

Clg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Clg. Supply	(50,826,609)	(35,983,440)	(14,843,169)	0	(5,997,240)	(1,349,379)	0
Stor. Tank Clg. Sup	6,979,288	8,973,370	1,329,388	(3,323,471)	1,495,562	120,853	(474,782)
Free cooling	(9,598,391)	0	(8,796,715)	(801,675)	0	(799,701)	(114,525)
Ventilation	(4,055,248)	0	(4,055,248)	0	0	(368,659)	0
Infiltration	(1,187,214)	(756,984)	0	(430,230)	(126,164)	0	(61,461)
Reheat	7,409,969	0	7,409,969	0	0	673,634	0
Totals	(51,278,205)	(27,767,054)	(18,955,775)	(4,555,376)	(4,627,842)	(1,723,252)	(650,768)
Daily Energy Balance (Btu/hr)	1,053,959	(27,770,649)	19,747,496	9,077,112	(4,628,441)	1,795,227	1,296,730

Electric Use Summary (kW)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
Heat Pumps	2,982	2,134	848	0	356	77	0
Pumps and Miscellaneous	2,750	1,058	1,029	663	176	94	95
Fans and Cooling Towers	1,279	264	885	131	44	80	19
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	15,784	2,092	10,594	3,098	349	963	443
Totals	30,648	6,160	19,831	4,657	640	365	185

Table C-15: Daily Energy System Summary Sheet - 9/12/85

Transportation Building Daily Energy System Summary Sheet

Date:	9/12/85	Thursday	Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)	60		Hour 1-6 (Btu/hr)	(332,347)	(997,041)	2,658,776
Ave. outdoor Dewpt. (degF)	34		Hour 7-17 (Btu/hr)	0	0	15,620,311
Ave. Outdoor Enthalpy (Btu/lb	18.79		Hour 18-24 (Btu/hr)	0	0	0
Ave. Indoor Enthalpy (Btu/lb)	22.35					

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	30,366,025	0	30,366,025	0	0	2,760,548	0
Stor. Tank Htg. Sup	(15,620,311)	0	(15,620,311)	0	0	(1,420,028)	0
Reheat	(4,757,872)	(0)	(4,757,872)	(0)	(0)	(432,534)	(0)
Clg.Twr. Disch.	0	0	0	0	0	0	0
Totals*	9,987,842	0	9,987,842	0	0	907,986	0

Clg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Clg. Supply	(21,590,064)	0	(21,590,064)	0	0	(1,962,733)	0
Stor. Tank Clg. Sup	(1,329,388)	(1,329,388)	0	0	(221,565)	0	0
Free cooling	(26,655,065)	(5,416,608)	(20,995,569)	(242,888)	(902,768)	(1,908,688)	(34,698)
Ventilation	(3,398,446)	0	(3,398,446)	0	0	(308,950)	0
Infiltration	(1,574,512)	(833,843)	0	(740,669)	(138,974)	0	(105,810)
Reheat	4,757,872	0	4,757,872	0	0	432,534	0
Totals	(49,789,603)	(7,579,839)	(41,226,208)	(983,557)	(1,263,307)	(3,747,837)	(140,508)

Daily Energy Balance (Btu/hr)	5,380,385	(8,605,254)	(93,840)	14,079,479	(1,434,209)	(8,531)	2,011,354

Electric Use Summary (kW)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
Heat Pumps	1,446	0	1,446	0	0	131	0
Pumps and Miscellaneous	2,193	706	1,236	251	118	112	36
Fans and Cooling Towers	1,213	162	920	131	27	84	19
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	15,784	2,092	10,594	3,098	349	963	443
Totals	28,488	3,572	20,671	4,245	209	441	126

Table C-16: Daily Energy System Summary Sheet - 9/13/85

Transportation Building Daily Energy System Summary Sheet

Dates	9/13/85	Friday			Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)		52			Hour 1-6 (Btu/hr)	0	0	0
Ave. outdoor Dewpt. (degF)		35			Hour 7-17 (Btu/hr)	0	0	17,282,047
Ave. Outdoor Enthalpy (Btu/lb		17.11			Hour 18-24 (Btu/hr)	0	0	0
Ave. Indoor Enthalpy (Btu/lb)		22.52						

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	26,647,736	0	26,647,736	0	0	2,422,521	0
Stor. Tank Htg. Sup	(17,282,047)	0	(17,282,047)	0	0	(1,571,095)	0
Reheat	(2,193,262)	(0)	(2,193,262)	(0)	(0)	(199,387)	(0)
Clg.Twr. Disch.	0	0	0	0	0	0	0
Totals*	7,172,428	0	7,172,428	0	0	652,039	0
Clg. Use Summary (Btu/hr)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
HP Clg. Supply	(13,943,583)	0	(13,943,583)	0	0	(1,267,598)	0
Stor. Tank Clg. Sup	0	0	0	0	0	0	0
Free cooling	(37,512,255)	0	(37,512,255)	0	0	(3,410,205)	0
Ventilation	(2,708,853)	0	(2,708,853)	0	0	(246,259)	0
Infiltration	(5,371,254)	(501,059)	(3,076,469)	(1,793,726)	(83,510)	(279,679)	(256,247)
Reheat	2,193,262	0	2,193,262	0	0	199,387	0
Totals	(57,342,684)	(501,059)	(55,047,898)	(1,793,726)	(83,510)	(5,004,354)	(256,247)
Daily Energy Balance (Btu/hr)	(13,111,578)	1,028,076	(22,657,500)	8,517,846	171,346	(2,059,773)	1,216,835
Electric Use Summary (kW)	**Daily Total**	**Hours 1-6**	**H[illegible]**	**[illegible]**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
Heat Pumps	910	0	910	0	0	83	0
Pumps and Miscellaneous	1,468	199	1,017	251	33	92	36
Fans and Cooling Towers	1,164	1[illegible]	897	141	21	82	20
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	15,784	2,092	10,594	3,098	349	963	443
Totals	27,178	3,029	19,893	4,255	118	371	127

Table C-17: Daily Energy System Summary Sheet - 10/3/85

Transportation Building Daily Energy System Summary Sheet

Date:	10/3/85	Thursday
Ave. outdoor Temp (degF)		56
Ave. outdoor Dewpt. (degF)		40
Ave. Outdoor Enthalpy (Btu/lb		19.16
Ave. Indoor Enthalpy (Btu/lb)		23.88

Storage Capacity Change	Tank 1	Tank 2	Tank 3
Hour 1-6 (Btu/hr)	0	0	0
Hour 7-17 (Btu/hr)	0	6,926,812	6,297,102
Hour 18-24 (Btu/hr)	0	0	0

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	83,041,783	0	83,041,783	0	0	7,549,253	0
Stor. Tank Htg. Sup	(13,223,914)	0	(13,223,914)	0	0	(1,202,174)	0
Reheat	(25,702,140)	(0)	(25,702,140)	(0)	(0)	(2,336,558)	(0)
Clg.Twr. Disch.	0	0	0	0	0	0	0
Totals*	44,115,729	0	44,115,729	0	0	4,010,521	0

Clg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Clg. Supply	(71,067,294)	0	(71,067,294)	0	0	(6,460,663)	0
Stor. Tank Clg. Sup	0	0	0	0	0	0	0
Free cooling	0	0	0	0	0	0	0
Ventilation	(14,571,671)	(629,877)	(8,465,847)	(5,475,947)	(104,979)	(769,622)	(782,278)
Infiltration	(1,248,611)	(1,248,611)	0	0	(208,102)	0	0
Reheat	25,702,140	0	25,702,140	0	0	2,336,558	0
Totals	(61,185,436)	(1,878,487)	(53,831,002)	(5,475,947)	(313,081)	(4,893,727)	(782,278)

Daily Energy Balance (Btu/hr)	23,054,431	(1,013,535)	18,312,702	5,755,264	(168,923)	1,664,791	822,181

Electric Use Summary (kW)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
Heat Pumps	4,908	0	4,908	0	0	446	0
Pumps and Miscellaneous	2,191	224	1,686	281	37	153	40
Fans and Cooling Towers	1,568	211	883	474	35	80	68
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	15,784	2,092	10,594	3,098	349	963	443
Totals	32,303	3,139	24,546	4,618	136	794	179

Table C-18: Daily Energy System Summary Sheet - 10/4/85

Transportation Building Daily Energy System Summary Sheet

Date:	10/4/85	Friday	Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)		54	Hour 1-6 (Btu/hr)	0	0	0
Ave. outdoor Dewpt. (degF)		40	Hour 7-17 (Btu/hr)	(1,661,735)	997,041	(2,658,776)
Ave. Outdoor Enthalpy (Btu/lb		18.72	Hour 18-24 (Btu/hr)	0	0	0
Ave. Indoor Enthalpy (Btu/lb)		24.10				

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	76,844,635	0	76,844,635	0	0	6,985,876	0
Stor. Tank Htg. Sup	1,661,735	0	1,661,735	0	0	151,067	0
Reheat	(28,506,636)	(0)	(28,506,636)	(0)	(0)	(2,591,512)	(0)
Clg.Twr. Disch.	(16,192,548)	0	(16,192,548)	0	0	(1,472,050)	0
Totals*	49,999,735	0	49,999,735	0	0	3,073,381	0
Clg. Use Summary (Btu/hr)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
HP Clg. Supply	(73,559,897)	0	(73,559,897)	0	0	(6,687,263)	0
Stor. Tank Clg. Sup	1,661,735	0	1,661,735	0	0	151,067	0
Free cooling	0	0	0	0	0	0	0
Ventilation	(10,479,797)	(760,900)	(8,742,424)	(976,472)	(126,817)	(794,766)	(139,496)
Infiltration	0	0	0	0	0	0	0
Reheat	28,506,636	0	28,506,636	0	0	2,591,512	0
Totals	(53,871,323)	(760,900)	(52,133,950)	(976,472)	(126,817)	(4,739,450)	(139,496)
Daily Energy Balance (Btu/hr)	30,887,995	(3,165,772)	25,229,577	8,824,190	(527,629)	2,293,598	1,260,599
Electric Use Summary (kW)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
Heat Pumps	4,958	0	4,958	0	0	451	0
Pumps and Miscellaneous	2,386	199	1,935	251	33	176	36
Fans and Cooling Towers	1,434	120	1,172	142	20	107	20
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	15,784	2,092	10,594	3,098	349	963	443
Totals	32,414	3,023	25,135	4,256	117	847	127

Table C-19: Daily Energy System Summary Sheet - 10/5/85

Transportation Building Daily Energy System Summary Sheet

Date: 10/5/85	Saturday
Ave. outdoor Temp (degF)	61
Ave. outdoor Dewpt. (degF)	46
Ave. Outdoor Enthalpy (Btu/lb	21.99
Ave. Indoor Enthalpy (Btu/lb)	25.09

Storage Capacity Change	Tank 1	Tank 2	Tank 3
Hour 1-6 (Btu/hr)	0	0	0
Hour 7-17 (Btu/hr)	0	0	0
Hour 18-24 (Btu/hr)	0	0	0

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	0	0	0	0	0	0	0
Stor. Tank Htg. Sup	0	0	0	0	0	0	0
Reheat	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Clg.Twr. Disch.	0	0	0	0	0	0	0
Totals*	0	0	0	0	0	0	0

Clg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Clg. Supply	0	0	0	0	0	0	0
Stor. Tank Clg. Sup	0	0	0	0	0	0	0
Free cooling	(780,236)	0	(780,236)	0	0	(70,931)	0
Ventilation	(1,750,531)	(598,806)	(550,427)	(601,297)	(99,801)	(50,039)	(85,900)
Infiltration	0	0	0	0	0	0	0
Reheat	0	0	0	0	0	0	0
Totals	(2,530,767)	(598,806)	(1,330,663)	(601,297)	(99,801)	(120,969)	(85,900)
Daily Energy Balance (Btu/hr)	(8,908,708)	(3,445,021)	(3,338,506)	(2,125,181)	(574,170)	(303,501)	(303,597)

Electric Use Summary (kW)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
Heat Pumps	0	0	0	0	0	0	0
Pumps and Miscellaneous	922	199	471	251	33	43	36
Fans and Cooling Towers	475	90	294	91	15	27	13
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	1,360	229	864	267	38	79	38
Lights	9,851	2,070	5,155	2,626	345	469	375
Totals	14,742	2,971	8,038	3,733	112	184	120

Table C-20: Daily Energy System Summary Sheet - 10/6/85

Transportation Building Daily Energy System Summary Sheet

Date:	10/6/85	Sunday	Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)		58	Hour 1-6 (Btu/hr)	0	0	0
Ave. outdoor Dewpt. (degF)		39	Hour 7-17 (Btu/hr)	8,641,023	(7,976,329)	(4,407,971)
Ave. Outdoor Enthalpy (Btu/lb		19.53	Hour 18-24 (Btu/hr)	2,326,429	(4,198,068)	(629,710)
Ave. Indoor Enthalpy (Btu/lb)		23.26				

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	0	0	0	0	0	0	0
Stor. Tank Htg. Sup	6,244,626	0	3,743,277	2,501,349	0	340,298	357,336
Reheat	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Clg.Twr. Disch.	0	0	0	0	0	0	0
Totals*	6,244,626	0	3,743,277	2,501,349	0	340,298	357,336

Clg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Clg. Supply	0	0	0	0	0	0	0
Stor. Tank Clg. Sup	0	0	0	0	0	0	0
Free cooling	(8,301,793)	0	(7,097,665)	(1,204,129)	0	(645,242)	(172,018)
Ventilation	(1,822,266)	(1,319,015)	0	(503,251)	(219,836)	0	(71,893)
Infiltration	(765,995)	0	(765,995)	0	0	(69,636)	0
Reheat	0	0	0	0	0	0	0
Totals	(10,890,053)	(1,319,015)	(7,863,659)	(1,707,379)	(219,836)	(714,878)	(243,911)
Daily Energy Balance (Btu/hr)	(14,191,010)	(4,778,322)	(8,376,228)	(1,036,460)	(796,387)	(761,475)	(148,066)

Electric Use Summary (kW)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
Heat Pumps	0	0	0	0	0	0	0
Pumps and Miscellaneous	1,814	199	1,045	570	33	95	81
Fans and Cooling Towers	486	93	298	95	16	27	14
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	1,360	229	864	267	38	79	38
Lights	9,851	2,070	5,155	2,626	345	469	375
Totals	15,646	2,974	8,615	4,056	113	236	166

Table C-21: Daily Energy System Summary Sheet - 10/7/85

Transportation Building Daily Energy System Summary Sheet

Date:	10/7/85	Monday	Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)	58		Hour 1-6 (Btu/hr)	664,694	(997,041)	(332,347)
Ave. outdoor Dewpt. (degF)	34		Hour 7-17 (Btu/hr)	0	1,661,735	11,299,800
Ave. Outdoor Enthalpy (Btu/lb	18.37		Hour 18-24 (Btu/hr)	0	0	0
Ave. Indoor Enthalpy (Btu/lb)	22.48					

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	57,013,762	0	57,013,762	0	0	5,183,069	0
Stor. Tank Htg. Sup	(12,296,841)	664,694	(12,961,535)	0	110,782	(1,178,321)	0
Reheat	(17,257,558)	(0)	(17,257,558)	(0)	(0)	(1,568,869)	(0)
Clg.Twr. Disch.	0	0	0	0	0	0	0
Totals*	27,459,363	664,694	26,794,669	0	110,782	2,435,879	0
Clg. Use Summary (Btu/hr)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
HP Clg. Supply	(28,112,063)	0	(28,112,063)	0	0	(2,555,642)	0
Stor. Tank Clg. Sup	0	0	0	0	0	0	0
Free cooling	(21,519,925)	0	(18,160,266)	(3,359,659)	0	(1,650,933)	(479,951)
Ventilation	(1,905,674)	0	(1,267,503)	(638,171)	0	(115,228)	(91,167)
Infiltration	(9,756,099)	(3,908,079)	(5,848,020)	0	(651,347)	(531,638)	0
Reheat	17,257,558	0	17,257,558	0	0	1,568,869	0
Totals	(44,036,203)	(3,908,079)	(36,130,293)	(3,997,830)	(651,347)	(3,284,572)	(571,119)
Daily Energy Balance (Btu/hr)	24,824,[illegible]	(4,575,346)	20,940,354	8,459,565	(762,558)	1,903,669	1,208,509
Electric Use Summary (kW)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
Heat Pumps	1,791	0	1,791	0	0	163	0
Pumps and Miscellaneous	2,064	275	1,538	251	46	140	36
Fans and Cooling Towers	1,300	245	907	147	41	82	21
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	15,784	2,092	10,594	3,098	349	963	443
	28,791	3,224	21,305	4,262	151	499	128

Table C-22: Daily Energy System Summary Sheet - 10/8/85

Transportation Building Daily Energy System Summary Sheet

Date:	10/8/85	Tuesday	Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)		58	Hour 1-6 (Btu/hr)	0	0	0
Ave. outdoor Dewpt. (degF)		34	Hour 7-17 (Btu/hr)	0	3,148,551	4,407,971
Ave. Outdoor Enthalpy (Btu/lb		18.28	Hour 18-24 (Btu/hr)	0	0	0
Ave. Indoor Enthalpy (Btu/lb)		22.51				

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	31,295,597	0	31,295,597	0	0	2,845,054	0
Stor. Tank Htg. Sup	(7,556,522)	0	(7,556,522)	0	0	(686,957)	0
Reheat	(6,193,195)	(0)	(6,193,195)	(0)	(0)	(563,018)	(0)
Clg.Twr. Disch.	(5,397,516)	0	(5,397,516)	0	0	(490,683)	0
Totals*	17,545,880	0	17,545,880	0	0	1,104,397	0

Clg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Clg. Supply	(25,188,408)	0	(25,188,408)	0	0	(2,289,855)	0
Stor. Tank Clg. Sup	0	0	0	0	0	0	0
Free cooling	(77,612,885)	0	(52,440,039)	(25,172,845)	0	(4,767,276)	(3,596,121)
Ventilation	(1,722,177)	0	(734,320)	(987,856)	0	(66,756)	(141,122)
Infiltration	(1,818,555)	(1,818,555)	0	0	(303,092)	0	0
Reheat	6,193,195	0	6,193,195	0	0	563,018	0
Totals	(100,148,829)	(1,818,555)	(72,169,573)	(26,160,702)	(303,092)	(6,560,870)	(3,737,243)
Daily Energy Balance (Btu/hr)	(41,456,992)	(3,559,244)	(24,960,806)	(12,936,942)	(593,207)	(2,269,164)	(1,848,135)

Electric Use Summary (kW)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
Heat Pumps	1,643	0	1,643	0	0	149	0
Pumps and Miscellaneous	1,953	224	1,448	281	37	132	40
Fans and Cooling Towers	1,557	139	937	481	23	85	69
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	15,784	2,092	10,594	3,098	349	963	443
Totals	28,789	3,067	21,097	4,625	124	480	180

Table C-23: Daily Energy System Summary Sheet - 10/9/85

Transportation Building Daily Energy System Summary Sheet

Date:	10/9/85 Wednesday	Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)	64	Hour 1-6 (Btu/hr)	0	0	0
Ave. outdoor Dewpt. (degF)	42	Hour 7-17 (Btu/hr)	1,994,082	(5,457,488)	0
Ave. Outdoor Enthalpy (Btu/lb	21.52	Hour 18-24 (Btu/hr)	2,658,776	(3,568,358)	(1,259,420)
Ave. Indoor Enthalpy (Btu/lb)	24.19				

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	25,718,164	0	25,718,164	0	0	2,338,015	0
Stor. Tank Htg. Sup	5,632,408	0	3,463,406	2,169,002	0	314,855	309,857
Reheat	(12,374,601)	(0)	(12,374,601)	(0)	(0)	(1,124,964)	(0)
Clg.Twr. Disch.	(34,184,268)	0	(34,184,268)	0	0	(3,107,661)	0
Totals*	18,975,971	0	16,806,969	2,169,002	0	(1,579,754)	309,857

Clg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Clg. Supply	(24,288,822)	0	(24,288,822)	0	0	(2,208,075)	0
Stor. Tank Clg. Sup	0	0	0	0	0	0	0
Free cooling	(33,681,070)	0	(28,322,817)	(5,358,253)	0	(2,574,802)	(765,465)
Ventilation	(168,208)	0	0	(168,208)	0	0	(24,030)
Infiltration	(2,729,938)	(1,777,754)	0	(952,184)	(296,292)	0	(136,026)
Reheat	12,374,601	0	12,374,601	0	0	1,124,964	0
Totals	(48,493,437)	(1,777,754)	(40,237,038)	(6,478,644)	(296,292)	(3,657,913)	(925,521)
Daily Energy Balance (Btu/hr)	18,832,323	(2,598,805)	10,166,825	11,264,303	(433,134)	924,257	1,609,186

Electric Use Summary (kW)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
Heat Pumps	1,000	0	1,000	0	0	91	0
Pumps and Miscellaneous	2,595	236	1,752	607	39	159	87
Fans and Cooling Towers	1,608	159	1,161	287	27	106	41
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	15,784	2,092	10,594	3,098	349	963	443
Totals	28,839	3,100	20,982	4,757	130	470	199

Table C-24: Daily Energy System Summary Sheet - 10/28/85

Transportation Building Daily Energy System Summary Sheet

Date:	10/28/85	Monday
Ave. outdoor Temp (degF)		50
Ave. outdoor Dewpt. (degF)		35
Ave. Outdoor Enthalpy (Btu/lb)		16.52
Ave. Indoor Enthalpy (Btu/lb)		23.20

Storage Capacity Change	Tank 1	Tank 2	Tank 3
Hour 1-6 (Btu/hr)	0	(1,049,517)	(209,903)
Hour 7-17 (Btu/hr)	0	(6,297,102)	0
Hour 18-24 (Btu/hr)	0	0	0

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	49,577,184	0	49,577,184	0	0	4,507,017	0
Stor. Tank Htg. Sup	7,556,522	1,259,420	6,297,102	0	209,903	572,464	0
Reheat	(5,280,090)	(0)	(5,280,090)	(0)	(0)	(480,008)	(0)
Clg.Twr. Disch.	(13,793,652)	0	(13,793,652)	0	0	(1,253,968)	0
Totals*	51,853,616	1,259,420	50,594,196	0	209,903	3,345,504	0

Clg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Clg. Supply	(30,136,131)	0	(30,136,131)	0	0	(2,739,648)	0
Stor. Tank Clg. Sup	0	0	0	0	0	0	0
Free cooling	(18,253,193)	(864,625)	(17,388,569)	0	(144,104)	(1,580,779)	0
Ventilation	(7,038,335)	0	(7,038,335)	0	0	(639,849)	0
Infiltration	(4,992,923)	(1,566,032)	(842,641)	(2,584,249)	(261,005)	(76,604)	(369,178)
Reheat	5,280,090	0	5,280,090	0	0	480,008	0
Totals	(55,140,491)	(2,430,656)	(50,125,586)	(2,584,249)	(405,109)	(4,556,871)	(369,178)
Daily Energy Balance (Btu/hr)	27,589,791	(2,911,925)	23,847,304	6,654,412	(485,321)	2,167,937	950,630

Electric Use Summary (kW)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
Heat Pumps	1,969	0	1,969	0	0	179	0
Pumps and Miscellaneous	2,328	250	1,826	251	42	166	36
Fans and Cooling Towers	1,330	156	1,027	148	26	93	21
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	15,784	2,092	10,594	3,098	349	963	443
Totals	29,264	3,110	21,891	4,262	132	552	128

Table C-25: Daily Energy System Summary Sheet - 10/29/85

Transportation Building Daily Energy System Summary Sheet

Date:	10/29/85	Tuesday	Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)	44		Hour 1-6 (Btu/hr)	0	(1,049,517)	(419,807)
Ave. outdoor Dewpt. (degF)	31		Hour 7-17 (Btu/hr)	0	629,710	5,037,682
Ave. Outdoor Enthalpy (Btu/lb)	14.66		Hour 18-24 (Btu/hr)	0	419,807	629,710
Ave. Indoor Enthalpy (Btu/lb)	22.55					

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	57,013,762	0	50,816,614	6,197,148	0	4,619,692	885,307
Stor. Tank Htg. Sup	(5,247,585)	1,469,324	(5,667,392)	(1,049,517)	244,887	(515,217)	(149,931)
Reheat	(8,540,511)	(0)	(7,781,503)	(759,008)	(0)	(707,409)	(108,430)
Clg.Twr. Disch.	0	0	0	0	0	0	0
Totals*	43,225,666	1,469,324	37,367,719	4,388,623	244,887	3,397,065	626,946

Clg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Clg. Supply	(40,931,163)	0	(36,883,026)	(4,048,137)	0	(3,353,002)	(578,305)
Stor. Tank Clg. Sup	0	0	0	0	0	0	0
Free cooling	0	0	0	0	0	0	0
Ventilation	(13,308,159)	0	(12,043,512)	(1,264,646)	0	(1,094,865)	(180,664)
Infiltration	(2,547,416)	(643,099)	(1,904,317)	0	(107,183)	(173,120)	0
Reheat	8,540,511	0	7,781,503	759,008	0	707,409	108,430
Totals	(48,246,228)	(643,099)	(43,049,353)	(4,553,775)	(107,183)	(3,913,578)	(650,539)
Daily Energy Balance (Btu/hr)	17,783,727	(4,644,107)	15,397,965	7,029,869	(774,018)	1,399,815	1,004,267

Electric Use Summary (kW)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
Heat Pumps	2,760	0	2,502	258	0	227	37
Pumps and Miscellaneous	2,431	250	1,808	373	42	164	53
Fans and Cooling Towers	1,245	142	926	176	24	84	25
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	15,784	2,092	10,594	3,098	349	963	443
Totals	30,072	3,097	22,305	4,670	129	590	186

Table C-26: Daily Energy System Summary Sheet - 10/30/85

Transportation Building Daily Energy System Summary Sheet

Date:	10/30/85 Wednesday	Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)	45	Hour 1-6 (Btu/hr)	0	(839,614)	(629,710)
Ave. outdoor Dewpt. (degF)	37	Hour 7-17 (Btu/hr)	0	2,308,937	4,198,068
Ave. Outdoor Enthalpy (Btu/lb)	15.83	Hour 18-24 (Btu/hr)	0	209,903	419,807
Ave. Indoor Enthalpy (Btu/lb)	23.80				

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	66,929,198	0	61,351,765	5,577,433	0	5,577,433	796,776
Stor. Tank Htg. Sup	(5,667,392)	1,469,324	(6,507,005)	(629,710)	244,887	(591,546)	(89,959)
Reheat	(7,367,394)	(0)	(6,604,819)	(762,575)	(0)	(600,438)	(108,939)
Clg.Twr. Disch.	0	0	0	0	0	0	0
Totals*	53,894,413	1,469,324	48,239,941	4,185,148	244,887	4,385,449	597,878

Clg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Clg. Supply	(34,184,268)	0	(31,485,510)	(2,698,758)	0	(2,862,319)	(385,537)
Stor. Tank Clg. Sup	0	0	0	0	0	0	0
Free cooling	0	0	0	0	0	0	0
Ventilation	(12,311,693)	0	(10,829,296)	(1,482,398)	0	(984,481)	(211,771)
Infiltration	(11,092,324)	(1,132,453)	(6,455,246)	(3,504,624)	(188,742)	(586,841)	(500,661)
Reheat	7,367,394	0	6,604,819	762,575	0	600,438	108,939
Totals	(50,220,892)	(1,132,453)	(42,165,233)	(6,923,205)	(188,742)	(3,833,203)	(989,029)
Daily Energy Balance (Btu/hr)	27,550,721	(4,929,098)	27,154,307	5,325,512	(821,516)	2,468,573	760,787

Electric Use Summary (kW)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
Heat Pumps	2,242	0	2,072	170	0	188	24
Pumps and Miscellaneous	2,431	250	1,808	373	42	164	53
Fans and Cooling Towers	1,334	172	924	238	29	84	34
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	15,784	2,092	10,594	3,098	349	963	443
Totals	[illegible]	3,127	21,872	4,644	134	551	183

Table C-27: Daily Energy System Summary Sheet - 10/31/85

Transportation Building Daily Energy System Summary Sheet

Date:	10/31/85	Thursday	Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)	48		Hour 1-6 (Btu/hr)	0	(839,614)	0
Ave. outdoor Dewpt. (degF)	42		Hour 7-17 (Btu/hr)	(1,329,388)	(9,655,556)	(4,407,971)
Ave. Outdoor Enthalpy (Btu/lb)	17.74		Hour 18-24 (Btu/hr)	0	0	0
Ave. Indoor Enthalpy (Btu/lb)	26.19					

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	0	0	0	0	0	0	0
Stor. Tank Htg. Sup	16,232,530	839,614	15,392,916	0	139,936	1,399,356	0
Reheat	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Clg.Twr. Disch.	0	0	0	0	0	0	0
Totals*	16,232,530	839,614	15,392,916	0	139,936	1,399,356	0

Clg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Clg. Supply	0	0	0	0	0	0	0
Stor. Tank Clg. Sup	0	0	0	0	0	0	0
Free cooling	(45,334,969)	0	(45,334,969)	0	0	(4,121,361)	0
Ventilation	0	0	0	0	0	0	0
Infiltration	(8,790,387)	(1,130,401)	(7,659,986)	0	(188,400)	(696,362)	0
Reheat	0	0	0	0	0	0	0
Totals	(54,125,356)	(1,130,401)	(52,994,955)	0	(188,400)	(4,817,723)	0
Daily Energy Balance (Btu/hr)	(10,899,076)	(4,075,116)	(16,982,259)	10,158,300	(679,186)	(1,543,842)	1,451,186

Electric Use Summary (kW)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
Heat Pumps	0	0	0	0	0	0	0
Pumps and Miscellaneous	1,575	250	1,074	251	42	98	36
Fans and Cooling Towers	1,199	151	918	130	25	83	19
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	15,784	2,092	10,594	3,098	349	963	443
Totals	26,411	3,105	19,061	4,245	131	295	126

Table C-28: Daily Energy System Summary Sheet - 11/27/85

Transportation Building Daily Energy System Summary Sheet

Date:	11/27/85 Wednesday	Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)	40	Hour 1-6 (Btu/hr)	0	(839,614)	(419,807)
Ave. outdoor Dewpt. (degF)	40	Hour 7-17 (Btu/hr)	(1,259,420)	(419,807)	2,938,648
Ave. Outdoor Enthalpy (Btu/lb)	15.36	Hour 18-24 (Btu/hr)	(2,099,034)	(3,988,165)	(1,259,420)
Ave. Indoor Enthalpy (Btu/lb)	24.14				

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	73,126,346	0	66,309,484	6,816,863	0	6,028,135	973,838
Stor. Tank Htg. Sup	3,148,551	1,259,420	(2,938,648)	4,827,778	209,903	(267,150)	689,683
Reheat	(7,330,470)	(0)	(6,662,627)	(667,843)	(0)	(605,693)	(95,406)
Clg.Twr. Disch.	0	0	0	0	0	0	0
Totals*	68,944,427	1,259,420	56,708,209	10,976,798	209,903	5,155,292	1,568,114
Clg. Use Summary (Btu/hr)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
HP Clg. Supply	(72,191,777)	0	(66,839,240)	(5,352,537)	0	(6,076,295)	(764,648)
Stor. Tank Clg. Sup	4,198,068	0	1,679,227	2,518,841	0	152,657	359,834
Free cooling	0	0	0	0	0	0	0
Ventilation	0	0	0	0	0	0	0
Infiltration	(40,493,552)	(2,402,198)	(31,768,455)	(6,322,898)	(400,366)	(2,888,041)	(903,271)
Reheat	7,330,470	0	6,662,627	667,843	0	605,693	95,406
Totals	(101,156,790)	(2,402,198)	(90,265,841)	(8,488,751)	(400,366)	(8,205,986)	(1,212,679)
Daily Energy Balance (Btu/hr)	(13,239,899)	(7,175,111)	(15,645,675)	9,580,887	(1,195,852)	(1,422,334)	1,368,698
Electric Use Summary (kW)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
Heat Pumps	4,644	0	2,838	1,806	0	258	258
Pumps and Miscellaneous	2,723	250	1,832	640	42	167	91
Fans and Cooling Towers	1,381	172	1,002	208	29	91	30
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	15,784	2,092	10,594	3,098	349	963	443
Totals	32,384	3,127	22,741	6,517	134	630	450

Table C-29: Daily Energy System Summary Sheet - 11/28/85

Transportation Building Daily Energy System Summary Sheet

Date:	11/28/85Thursday (Thanksgiving!)	Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)	36	Hour 1-6 (Btu/hr)	0	(1,049,517)	(1,259,420)
Ave. outdoor Dewpt. (degF)	35	Hour 7-17 (Btu/hr)	(2,099,034)	0	(839,614)
Ave. Outdoor Enthalpy (Btu/lb)	13.37	Hour 18-24 (Btu/hr)	0	(5,247,585)	(3,778,261)
Ave. Indoor Enthalpy (Btu/lb)	24.53				

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	50,196,899	0	50,196,899	0	0	4,563,354	0
Stor. Tank Htg. Sup	12,174,397	2,308,937	839,614	9,025,846	384,823	76,329	1,289,407
Reheat	(1,696,714)	(0)	(1,696,714)	(0)	(0)	(154,247)	(0)
Clg.Twr. Disch.	0	0	0	0	0	0	0
Totals*	60,674,582	2,308,937	49,339,798	9,025,846	384,823	4,485,436	1,289,407
Clg. Use Summary (Btu/hr)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
HP Clg. Supply	(51,321,381)	0	(51,321,381)	0	0	(4,665,580)	0
Stor. Tank Clg. Sup	2,099,034	0	2,099,034	0	0	190,821	0
Free cooling	0	0	0	0	0	0	0
Ventilation	0	0	0	0	0	0	0
Infiltration	(36,864,608)	(4,105,377)	(27,022,690)	(5,736,541)	(684,229)	(2,456,608)	(819,506)
Reheat	1,696,714	0	1,696,714	0	0	154,247	0
Totals	(84,390,240)	(4,105,377)	(74,548,323)	(5,736,541)	(684,229)	(6,777,120)	(819,506)
Daily Energy Balance (Btu/hr)	(58,500,196)	(9,956,118)	(40,244,572)	(8,299,505)	(1,659,353)	(3,658,597)	(1,185,644)
Electric Use Summary (kW)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
Heat Pumps	2,580	0	2,580	0	0	235	0
Pumps and Miscellaneous	2,526	250	1,738	537	42	158	77
Fans and Cooling Towers	1,050	109	819	122	18	74	17
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	1,360	229	864	267	38	79	39
Lights	9,851	2,070	5,155	2,626	345	469	375
Totals	19,501	3,041	12,410	4,050	124	581	165

Table C-30: Daily Energy System Summary Sheet - 11/29/85

Transportation Building Daily Energy System Summary Sheet

Date:	11/29/85	Friday	Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)	33		Hour 1-6 (Btu/hr)	214,901	(1,889,131)	(2,938,648)
Ave. outdoor Dewpt. (degF)	32		Hour 7-17 (Btu/hr)	(10,315,253)	0	0
Ave. Outdoor Enthalpy (Btu/lb)	11.91		Hour 18-24 (Btu/hr)	0	0	(5,037,682)
Ave. Indoor Enthalpy (Btu/lb)	23.58					

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	63,830,624	0	63,830,624	0	0	5,802,784	0
Stor. Tank Htg. Sup	9,650,559	4,612,877	0	5,037,682	768,813	0	719,669
Reheat	(5,135,257)	(0)	(5,135,257)	(0)	(0)	(466,842)	(0)
Clg.Twr. Disch.	0	0	0	0	0	0	0
Totals*	68,345,926	4,612,877	58,695,368	5,037,682	768,813	5,335,943	719,669

Clg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Clg. Supply	(51,726,195)	0	(51,726,195)	0	0	(4,702,381)	0
Stor. Tank Clg. Sup	10,315,253	0	10,315,253	0	0	937,750	0
Free cooling	0	0	0	0	0	0	0
Ventilation	(9,948,499)	0	(9,948,499)	0	0	(904,409)	0
Infiltration	(34,442,039)	(3,843,641)	(19,092,352)	(11,506,047)	(640,607)	(1,735,668)	(1,643,721)
Reheat	5,135,257	0	5,135,257	0	0	466,842	0
Totals	(80,666,224)	(3,843,641)	(65,316,537)	(11,506,047)	(640,607)	(5,937,867)	(1,643,721)

Daily Energy Balance (Btu/hr)	(51,703,025)	(8,718,808)	(24,875,950)	(18,108,267)	(1,453,135)	(2,261,450)	(2,586,895)

Electric Use Summary (kW)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
Heat Pumps	2,580	0	2,580	0	0	235	0
Pumps and Miscellaneous	2,727	493	1,748	486	32	159	69
Fans and Cooling Towers	1,523	154	944	425	26	86	61
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	1,360	229	864	267	38	79	38
Lights	9,851	2,070	5,155	2,626	345	469	375
Totals	20,176	3,329	12,545	4,302	172	593	201

Table C-31: Daily Energy System Summary Sheet - 11/30/85

Transportation Building Daily Energy System Summary Sheet

Date:	11/30/85	Saturday
Ave. outdoor Temp (degF)		37
Ave. outdoor Dewpt. (degF)		37
Ave. Outdoor Enthalpy (Btu/lb)		13.93
Ave. Indoor Enthalpy (Btu/lb)		24.18

Storage Capacity Change	Tank 1	Tank 2	Tank 3
Hour 1-6 (Btu/hr)	(17,841,789)	419,807	9,865,460
Hour 7-17 (Btu/hr)	(12,594,204)	(419,807)	8,815,943
Hour 18-24 (Btu/hr)	0	(2,099,034)	(6,716,909)

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	105,351,516	44,619,466	60,732,050	0	7,436,578	5,521,095	0
Stor. Tank Htg. Sup	(9,445,653)	(10,285,267)	(7,976,329)	8,815,943	(1,714,211)	(725,121)	1,259,420
Reheat	(2,741,059)	(694,734)	(2,046,325)	(0)	(115,789)	(186,030)	(0)
Clg.Twr. Disch.	0	0	0	0	0	0	0
Totals*	93,164,804	33,639,465	50,709,396	8,815,943	5,606,578	4,609,945	1,259,420

Clg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Clg. Supply	(143,753,843)	(48,397,727)	(95,356,116)	0	(8,066,288)	(8,668,738)	0
Stor. Tank Clg. Sup	30,016,186	17,841,789	12,174,397	0	2,973,632	1,106,763	0
Free cooling	0	0	0	0	0	0	0
Ventilation	0	0	0	0	0	0	0
Infiltration	(47,300,067)	(14,604,060)	(26,795,354)	(5,900,653)	(2,434,010)	(2,435,941)	(842,950)
Reheat	2,741,059	694,734	2,046,325	0	115,789	186,030	0
Totals	(158,296,664)	(44,465,264)	(107,930,747)	(5,900,653)	(7,410,877)	(9,811,886)	(842,950)
Daily Energy Balance (Btu/hr)	(97,923,849)	(19,189,841)	(72,615,036)	(6,118,971)	(3,198,307)	(6,601,367)	(874,139)

Electric Use Summary (kW)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
Heat Pumps	6,450	2,150	4,300	0	358	391	0
Pumps and Miscellaneous	3,309	907	1,803	599	151	164	86
Fans and Cooling Towers	1,433	400	822	210	67	75	30
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	1,360	229	864	267	38	79	38
Lights	9,851	2,070	5,155	2,626	345	469	375
Totals	24,537	6,139	14,198	4,200	640	744	187

Table C-32: Daily Energy System Summary Sheet - 12/1/85

Transportation Building Daily Energy System Summary Sheet

Date:	12/1/85	Sunday	Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)		44	Hour 1-6 (Btu/hr)	0	(6,297,102)	(4,727,624)
Ave. outdoor Dewpt. (degF)		43	Hour 7-17 (Btu/hr)	0	(2,099,034)	859,604
Ave. Outdoor Enthalpy (Btu/lb		16.90	Hour 18-24 (Btu/hr)	(209,903)	(2,728,744)	859,604
Ave. Indoor Enthalpy (Btu/lb)		24.49				

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	79,943,209	0	41,520,892	38,422,318	0	3,774,627	5,488,903
Stor. Tank Htg. Sup	14,343,399	11,024,926	1,239,430	2,079,043	1,837,488	112,675	297,006
Reheat	(4,562,988)	(0)	(1,983,223)	(2,579,764)	(0)	(180,293)	(368,538)
Clg.Twr. Disch.	0	0	0	0	0	0	0
Totals*	89,723,621	11,024,926	40,777,098	37,921,596	1,837,488	3,707,009	5,417,371

Clg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Clg. Supply	(43,667,404)	0	(23,707,839)	(19,959,564)	0	(2,155,258)	(2,851,366)
Stor. Tank Clg. Sup	0	0	0	0	0	0	0
Free cooling	0	0	0	0	0	0	0
Ventilation	0	0	0	0	0	0	0
Infiltration	(23,424,135)	(4,972,222)	(11,063,081)	(7,388,832)	(828,704)	(1,005,735)	(1,055,547)
Reheat	4,562,988	0	1,983,223	2,579,764	0	180,293	368,538
Totals	(62,528,551)	(4,972,222)	(32,787,697)	(24,768,632)	(828,704)	(2,980,700)	(3,538,376)

Daily Energy Balance (Btu/hr)	2,475,459	(1,289,519)	(3,112,640)	6,877,618	(214,920)	(282,967)	982,517

Electric Use Summary (kW)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
Heat Pumps	2,735	0	1,445	1,290	0	131	184
Pumps and Miscellaneous	2,680	507	1,237	935	85	112	134
Fans and Cooling Towers	1,050	229	551	271	38	50	39
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	1,360	229	864	267	38	79	38
Lights	9,851	2,070	5,155	2,626	345	469	375
Totals	19,811	3,418	10,506	5,886	187	408	428

Table C-33: Daily Energy System Summary Sheet - 12/2/85

Transportation Building Daily Energy System Summary Sheet

Date: 12/2/85	Monday	Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)	47	Hour 1-6 (Btu/hr)	3,568,358	(5,877,295)	(3,438,418)
Ave. outdoor Dewpt. (degF)	43	Hour 7-17 (Btu/hr)	(2,938,648)	0	6,232,132
Ave. Outdoor Enthalpy (Btu/lb	18.19	Hour 18-24 (Btu/hr)	(209,903)	0	1,074,506
Ave. Indoor Enthalpy (Btu/lb)	26.15				

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	91,098,076	0	86,140,357	4,957,718	0	7,830,942	708,245
Stor. Tank Htg. Sup	(1,559,282)	5,747,355	(6,232,132)	(1,074,506)	957,893	(566,557)	(153,501)
Reheat	(10,126,440)	(0)	(9,458,246)	(668,195)	(0)	(859,841)	(95,456)
Clg.Twr. Disch.	0	0	0	0	0	0	0
Totals*	79,412,353	5,747,355	70,449,980	3,215,018	957,893	6,404,544	459,288
Clg. Use Summary (Btu/hr)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
HP Clg. Supply	(58,238,823)	0	(53,084,945)	(5,153,878)	0	(4,825,904)	(736,268)
Stor. Tank Clg. Sup	3,148,551	0	2,938,648	209,903	0	267,150	29,986
Free cooling	0	0	0	0	0	0	0
Ventilation	0	0	0	0	0	0	0
Infiltration	(34,245,448)	(193,055)	(20,194,513)	(13,857,879)	(32,176)	(1,835,865)	(1,979,697)
Reheat	10,126,440	0	9,458,246	668,195	0	859,841	95,456
Totals	(79,209,279)	(193,055)	(60,882,565)	(18,133,659)	(32,176)	(5,534,779)	(2,590,523)
Daily Energy Balance (Btu/hr)	25,756,095	1,941,720	34,603,454	(10,789,079)	323,620	3,145,769	(1,541,297)
Electric Use Summary (kW)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
Heat Pumps	3,096	0	2,838	258	0	258	37
Pumps and Miscellaneous	2,836	532	1,919	385	89	174	55
Fans and Cooling Towers	1,531	163	910	459	27	83	66
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	15,784	2,092	10,594	3,098	349	963	443
Totals	31,099	3,399	22,735	4,965	180	629	229

Table C-34: Daily Energy System Summary Sheet - 12/3/85

Transportation Building Daily Energy System Summary Sheet

Date: 12/3/85		Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)	32	Hour 1-6 (Btu/hr)	(209,903)	(3,568,358)	(3,008,615)
Ave. outdoor Dewpt. (degF)	23	Hour 7-17 (Btu/hr)	(5,247,585)	0	(3,223,517)
Ave. Outdoor Enthalpy (Btu/lb	10.43	Hour 18-24 (Btu/hr)	0	(1,469,324)	859,604
Ave. Indoor Enthalpy (Btu/lb)	24.10				

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	97,914,938	0	73,746,061	24,168,877	0	6,704,187	3,452,697
Stor. Tank Htg. Sup	6,971,792	6,576,973	(214,901)	609,719	1,096,162	(19,536)	87,103
Reheat	(7,803,770)	(0)	(4,786,803)	(3,016,967)	(0)	(435,164)	(430,995)
Clg.Twr. Disch.	0	0	0	0	0	0	0
Totals*	97,082,960	6,576,973	68,744,357	21,761,630	1,096,162	6,249,487	3,108,804
Clg. Use Summary (Btu/hr)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
HP Clg. Supply	(67,468,950)	0	(50,273,738)	(17,195,212)	0	(4,570,340)	(2,456,459)
Stor. Tank Clg. Sup	8,895,906	209,903	8,686,003	0	34,984	789,637	0
Free cooling	0	0	0	0	0	0	0
Ventilation	0	0	0	0	0	0	0
Infiltration	(65,122,638)	(13,044,284)	(38,541,455)	(13,536,899)	(2,174,047)	(3,503,769)	(1,933,843)
Reheat	7,803,770	0	4,786,803	3,016,967	0	435,164	430,995
Totals	(115,891,912)	(12,834,381)	(75,342,388)	(27,715,144)	(2,139,063)	(6,849,308)	(3,959,306)
Daily Energy Balance (Btu/hr)	(9,083,960)	(15,457,383)	8,708,285	(2,334,862)	(2,576,230)	791,662	(333,552)

Electric Use Summary (kW)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
Heat Pumps	3,831	0	2,817	1,014	0	256	145
Pumps and Miscellaneous	3,215	456	1,943	816	76	177	117
Fans and Cooling Towers	2,032	459	1,079	493	77	98	70
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	15,784	2,092	10,594	3,098	349	963	443
Totals	32,714	3,620	22,908	6,186	216	645	403

Table C-35: Daily Energy System Summary Sheet - 12/4/85

Transportation Building Daily Energy System Summary Sheet

Date:	12/4/85 Wednesday	Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)	32	Hour 1-6 (Btu/hr)	(1,049,517)	(8,396,136)	(1,504,308)
Ave. outdoor Dewpt. (degF)	25	Hour 7-17 (Btu/hr)	(2,518,841)	(11,544,687)	0
Ave. Outdoor Enthalpy (Btu/lb	10.78	Hour 18-24 (Btu/hr)	(419,807)	0	644,703
Ave. Indoor Enthalpy (Btu/lb)	23.87				

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	118,365,527	21,690,018	70,027,772	26,647,736	3,615,003	6,366,161	3,806,819
Stor. Tank Htg. Sup	3,168,542	3,813,245	0	(644,703)	635,541	0	(92,100)
Reheat	(11,744,166)	(1,048,110)	(6,319,037)	(4,377,019)	(174,685)	(574,458)	(625,288)
Clg.Twr. Disch.	0	0	0	0	0	0	0
Totals*	109,789,902	24,455,153	63,708,735	21,626,014	4,075,859	5,791,703	3,089,431

Clg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Clg. Supply	(103,639,804)	(11,713,359)	(59,035,331)	(32,891,113)	(1,952,227)	(5,366,848)	(4,698,730)
Stor. Tank Clg. Sup	21,620,050	7,136,716	14,063,528	419,807	1,189,453	1,278,503	59,972
Free cooling	0	0	0	0	0	0	0
Ventilation	(15,599,987)	0	(7,734,671)	(7,865,316)	0	(703,152)	(1,123,617)
Infiltration	(34,479,745)	(12,076,385)	(22,403,360)	0	(2,012,731)	(2,036,669)	0
Reheat	11,744,166	1,048,110	6,319,037	4,377,019	174,685	574,458	625,288
Totals	(120,355,319)	(15,604,918)	(68,790,797)	(35,959,603)	(2,600,820)	(6,253,709)	(5,137,086)

Daily Energy Balance (Btu/hr)	947,761	(145,377)	11,705,893	(10,612,755)	(24,229)	1,064,172	(1,516,108)

Electric Use Summary (kW)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
Heat Pumps	5,160	774	2,838	1,548	129	258	221
Pumps and Miscellaneous	3,569	742	1,943	884	124	177	126
Fans and Cooling Towers	2,007	470	1,047	490	78	95	70
Computer Rooms	2,135	384	1,254	498	64	114	71
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	15,784	2,092	10,594	3,098	349	963	443
Totals	34,373	4,691	22,897	6,785	395	644	488

Table C-36: Daily Energy System Summary Sheet - 1/14/86

Transportation Building Daily Energy System Summary Sheet

Date: 1/14/86	Tuesday	Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)	13	Hour 1-6 (Btu/hr)	(629,710)	(5,667,392)	(6,926,812)
Ave. outdoor Dewpt. (degF)	12	Hour 7-17 (Btu/hr)	(8,606,039)	(209,903)	839,614
Ave. Outdoor Enthalpy (Btu/lb	4.85	Hour 18-24 (Btu/hr)	0	(12,384,301)	(1,469,324)
Ave. Indoor Enthalpy (Btu/lb)	24.40				

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	101,633,227	0	59,492,621	42,140,606	0	5,408,420	6,020,087
Stor. Tank Htg. Sup	9,445,653	12,594,204	(629,710)	(2,518,841)	2,099,034	(57,246)	(359,834)
Reheat	(4,045,509)	(0)	(4,045,509)	(0)	(0)	(367,774)	(0)
Clg.Twr. Disch.	0	0	0	0	0	0	0
Totals*	107,033,371	12,594,204	54,817,402	39,621,766	2,099,034	4,983,400	5,660,252

Clg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Clg. Supply	(74,575,679)	0	(49,387,271)	(25,188,408)	0	(4,489,752)	(3,598,344)
Stor. Tank Clg. Sup	25,608,215	629,710	8,606,039	16,372,465	104,952	782,367	2,338,924
Free cooling	0	0	0	0	0	0	0
Ventilation	(26,348,655)	0	(26,348,655)	0	0	(2,395,332)	0
Infiltration	(49,956,275)	(14,678,638)	(9,910,532)	(25,367,105)	(2,446,440)	(900,957)	(3,623,872)
Reheat	4,045,509	0	4,045,509	0	0	367,774	0
Totals	(121,226,885)	(14,048,928)	(72,994,910)	(34,183,048)	(2,341,488)	(6,635,901)	(4,883,293)
Daily Energy Balance (Btu/hr)	3,860,946	384,967	(3,929,189)	7,405,168	64,161	(357,199)	1,057,881

Electric Use Summary (kW)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
Heat Pumps	4,837	0	3,262	1,576	0	297	225
Pumps and Miscellaneous	4,039	968	1,937	1,134	161	176	162
Fans and Cooling Towers	2,920	617	1,496	808	103	136	115
Computer Rooms	2,102	375	1,239	488	63	113	70
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	21,413	4,892	10,594	5,928	815	963	847
Totals	41,029	7,081	23,749	10,200	327	721	572

Table C-37: Daily Energy System Summary Sheet - 1/15/86

Transportation Building Daily Energy System Summary Sheet

Date:	1/15/86 Wednesday	Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)	12	Hour 1-6 (Btu/hr)	(419,807)	(14,693,238)	(5,037,682)
Ave. outdoor Dewpt. (degF)	12	Hour 7-17 (Btu/hr)	(10,075,363)	0	1,259,420
Ave. Outdoor Enthalpy (Btu/lb	4.74	Hour 18-24 (Btu/hr)	0	0	2,518,841
Ave. Indoor Enthalpy (Btu/lb)	23.86				

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	146,252,693	43,999,751	72,506,632	29,746,310	7,333,292	6,591,512	4,249,473
Stor. Tank Htg. Sup	(3,358,454)	419,807	(1,259,420)	(2,518,841)	69,968	(114,493)	(359,834)
Reheat	(1,872,045)	(0)	(1,872,045)	(0)	(0)	(170,186)	(0)
Clg.Twr. Disch.	0	0	0	0	0	0	0
Totals*	141,022,194	44,419,558	69,375,166	27,227,470	7,403,260	6,306,833	3,889,639

Clg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Clg. Supply	(93,646,903)	(21,590,064)	(50,466,775)	(21,590,064)	(3,598,344)	(4,587,889)	(3,084,295)
Stor. Tank Clg. Sup	29,806,283	19,730,920	10,075,363	0	3,288,487	915,942	0
Free cooling	0	0	0	0	0	0	0
Ventilation	(27,301,371)	0	(27,301,371)	0	0	(2,481,943)	0
Infiltration	(48,855,024)	(21,911,707)	(4,562,202)	(22,381,116)	(3,651,951)	(414,746)	(3,197,302)
Reheat	1,872,045	0	1,872,045	0	0	170,186	0
Totals	(138,124,970)	(23,770,851)	(70,382,939)	(43,971,180)	(3,961,809)	(6,398,449)	(6,281,597)
Daily Energy Balance (Btu/hr)	21,718,049	19,371,847	14,262,366	(11,916,164)	3,228,641	1,296,579	(1,702,309)

Electric Use Summary (kW)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
Heat Pumps	6,531	1,548	3,537	1,447	258	322	207
Pumps and Miscellaneous	4,088	980	1,974	1,134	163	179	162
Fans and Cooling Towers	2,975	804	1,480	692	134	135	99
Computer Rooms	2,102	375	1,239	488	63	113	70
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	21,413	4,892	10,594	5,928	815	963	847
Totals	42,827	8,828	24,044	9,955	618	748	537

Table C-38: Daily Energy System Summary Sheet - 1/16/86

Transportation Building Daily Energy System Summary Sheet

Date:	1/16/86	Thursday	Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)	24		Hour 1-6 (Btu/hr)	0	(16,162,562)	0
Ave. outdoor Dewpt. (degF)	20		Hour 7-17 (Btu/hr)	(7,136,716)	629,710	4,617,875
Ave. Outdoor Enthalpy (Btu/lb	8.28		Hour 18-24 (Btu/hr)	0	(2,308,937)	419,807
Ave. Indoor Enthalpy (Btu/lb)	24.50					

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	124,562,675	37,182,888	60,732,050	26,647,736	6,197,148	5,521,095	3,806,819
Stor. Tank Htg. Sup	(5,667,392)	0	(5,247,585)	(419,807)	0	(477,053)	(59,972)
Reheat	(3,374,493)	(60,089)	(2,774,657)	(539,747)	(10,015)	(252,242)	(77,107)
Clg.Twr. Disch.	0	0	0	0	0	0	0
Totals*	115,520,790	37,122,799	52,709,808	25,688,182	6,187,133	4,791,801	3,669,740

Clg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Clg. Supply	(91,532,876)	(22,039,857)	(47,498,141)	(21,994,878)	(3,673,310)	(4,318,013)	(3,142,125)
Stor. Tank Clg. Sup	25,608,215	16,162,562	7,136,716	2,308,937	2,693,760	648,792	329,848
Free cooling	0	0	0	0	0	0	0
Ventilation	(29,584,948)	(3,552,667)	(26,032,280)	0	(592,111)	(2,366,571)	0
Infiltration	(31,769,014)	(12,256,312)	0	(19,512,702)	(2,042,719)	0	(2,787,529)
Reheat	3,374,493	60,089	2,774,657	539,747	10,015	252,242	77,107
Totals	(123,904,128)	(21,626,185)	(63,619,049)	(38,658,895)	(3,604,364)	(5,783,550)	(5,522,699)
Daily Energy Balance (Btu/hr)	24,845,148	18,102,670	11,462,548	(4,720,069)	3,017,112	1,042,050	(674,296)

Electric Use Summary (kW)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
Heat Pumps	6,154	1,428	3,222	1,504	238	293	215
Pumps and Miscellaneous	4,076	956	1,986	1,134	159	181	162
Fans and Cooling Towers	2,358	623	1,197	538	104	109	77
Computer Rooms	2,102	375	1,239	488	63	113	70
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	21,413	4,892	10,594	5,928	815	963	847
Totals	41,820	8,502	23,459	9,859	564	695	523

Table C-39: Daily Energy System Summary Sheet - 1/22/86

Transportation Building Daily Energy System Summary Sheet

Date:	1/22/86 Wednesday
Ave. outdoor Temp (degF)	43
Ave. outdoor Dewpt. (degF)	40
Ave. Outdoor Enthalpy (Btu/lb	16.04
Ave. Indoor Enthalpy (Btu/lb)	24.97

Storage Capacity Change	Tank 1	Tank 2	Tank 3
Hour 1-6 (Btu/hr)	0	(1,049,517)	(6,232,132)
Hour 7-17 (Btu/hr)	0	2,938,648	8,166,242
Hour 18-24 (Btu/hr)	0	209,903	859,604

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	87,379,787	0	79,323,494	8,056,292	0	7,211,227	1,150,899
Stor. Tank Htg. Sup	(4,892,748)	7,281,649	(11,104,889)	(1,069,508)	1,213,608	(1,009,535)	(152,787)
Reheat	(18,277,558)	(0)	(16,797,206)	(1,480,352)	(0)	(1,527,019)	(211,479)
Clg.Twr. Disch.	0	0	0	0	0	0	0
Totals*	64,209,480	7,281,649	51,421,399	5,506,432	1,213,608	4,674,673	786,633

Clg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Clg. Supply	(41,793,266)	0	(38,419,819)	(3,373,448)	0	(3,492,711)	(481,921)
Stor. Tank Clg. Sup	0	0	0	0	0	0	0
Free cooling	0	0	0	0	0	0	0
Ventilation	(16,894,808)	0	(15,508,084)	(1,386,724)	0	(1,409,826)	(198,103)
Infiltration	(15,248,968)	(11,520,001)	(3,728,967)	0	(1,920,000)	(338,997)	0
Reheat	18,277,558	0	16,797,206	1,480,352	0	1,527,019	211,479
Totals	(55,659,484)	(11,520,001)	(40,859,663)	(3,279,820)	(1,920,000)	(3,714,515)	(468,546)

Daily Energy Balance (Btu/hr)	58,536,331	1,228,800	39,984,082	17,323,450	204,800	3,634,917	2,474,779

Electric Use Summary (kW)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
Heat Pumps	3,096	0	2,838	258	0	258	37
Pumps and Miscellaneous	3,175	894	1,876	405	149	171	58
Fans and Cooling Towers	1,553	411	966	177	69	88	25
Computer Rooms	2,102	375	1,239	488	63	113	70
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	21,413	4,892	10,594	5,928	815	963	847
Totals	37,057	6,801	22,733	7,523	280	629	190

Table C-40: Daily Energy System Summary Sheet - 1/23/86

Transportation Building Daily Energy System Summary Sheet

Date:	1/23/86	Thursday	Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)	30		Hour 1-6 (Btu/hr)	0	(839,614)	(1,074,506)
Ave. outdoor Dewpt. (degF)	22		Hour 7-17 (Btu/hr)	0	(419,807)	0
Ave. Outdoor Enthalpy (Btu/lb	9.88		Hour 18-24 (Btu/hr)	0	0	0
Ave. Indoor Enthalpy (Btu/lb)	22.27					

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	86,760,072	0	86,760,072	0	0	7,887,279	0
Stor. Tank Htg. Sup	2,333,926	1,914,119	419,807	0	319,020	38,164	0
Reheat	(15,530,443)	(0)	(15,530,443)	(0)	(0)	(1,411,858)	(0)
Clg.Twr. Disch.	0	0	0	0	0	0	0
Totals*	73,563,555	1,914,119	71,649,436	0	319,020	6,513,585	0
Clg. Use Summary (Btu/hr)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
HP Clg. Supply	(56,270,978)	0	(56,270,978)	0	0	(5,115,543)	0
Stor. Tank Clg. Sup	0	0	0	0	0	0	0
Free cooling	0	0	0	0	0	0	0
Ventilation	(23,724,291)	0	(23,329,213)	(395,078)	0	(2,120,838)	(56,440)
Infiltration	(8,084,148)	(4,023,371)	(4,060,778)	0	(670,562)	(369,162)	0
Reheat	15,530,443	0	15,530,443	0	0	1,411,858	0
Totals	(72,548,976)	(4,023,371)	(68,130,526)	(395,078)	(670,562)	(6,193,684)	(56,440)
Daily Energy Balance (Btu/hr)	34,191,976	2,846,990	26,095,062	5,249,924	474,498	2,372,278	749,989
Electric Use Summary (kW)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
Heat Pumps	4,015	0	4,015	0	0	365	0
Pumps and Miscellaneous	2,425	278	1,863	284	46	169	41
Fans and Cooling Towers	1,370	181	1,053	135	30	96	19
Computer Rooms	2,102	375	1,239	488	63	113	70
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	21,413	4,892	10,594	5,928	815	963	847
Totals	37,042	5,955	23,986	7,102	139	743	130

Table C-41: Daily Energy System Summary Sheet - 1/24/86

Transportation Building Daily Energy System Summary Sheet

Date:	1/24/86	Friday	Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)	21		Hour 1-6 (Btu/hr)	0	(1,049,517)	(859,604)
Ave. outdoor Dewpt. (degF)	10		Hour 7-17 (Btu/hr)	0	0	0
Ave. Outdoor Enthalpy (Btu/lb	6.73		Hour 18-24 (Btu/hr)	0	0	0
Ave. Indoor Enthalpy (Btu/lb)	23.42					

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	68,168,628	0	57,013,762	11,154,866	0	5,183,069	1,593,552
Stor. Tank Htg. Sup	1,909,121	1,909,121	0	0	318,187	0	0
Reheat	(16,958,326)	(0)	(15,402,224)	(1,556,102)	(0)	(1,400,202)	(222,300)
Clg.Twr. Disch.	0	0	0	0	0	0	0
Totals*	53,119,424	1,909,121	41,611,538	9,598,765	318,187	3,782,867	1,371,252
Clg. Use Summary (Btu/hr)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
HP Clg. Supply	(54,959,082)	0	(44,604,473)	(10,354,610)	0	(4,054,952)	(1,479,230)
Stor. Tank Clg. Sup	0	0	0	0	0	0	0
Free cooling	0	0	0	0	0	0	0
Ventilation	(28,070,089)	0	(28,070,089)	0	0	(2,551,826)	0
Infiltration	(15,756,709)	(2,354,106)	0	(13,402,602)	(392,351)	0	(1,914,657)
Reheat	16,958,326	0	15,402,224	1,556,102	0	1,400,202	222,300
Totals	(81,827,554)	(2,354,106)	(57,272,338)	(22,201,110)	(392,351)	(5,206,576)	(3,171,587)
Daily Energy Balance (Btu/hr)	(3,449,840)	934,887	2,879,163	(7,263,890)	155,815	261,742	(1,037,699)
Electric Use Summary (kW)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
Heat Pumps	3,668	0	2,947	721	0	268	103
Pumps and Miscellaneous	3,503	699	1,876	929	116	171	133
Fans and Cooling Towers	1,847	199	1,278	369	33	116	53
Computer Rooms	2,102	375	1,239	488	63	113	70
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	21,413	4,892	10,594	5,928	815	963	847
Totals	38,250	6,394	23,155	8,701	212	667	358

Table C-42: Daily Energy System Summary Sheet - 2/4/86

Transportation Building Daily Energy System Summary Sheet

Date:	2/4/86	Tuesday
Ave. outdoor Temp (degF)	28	
Ave. outdoor Dewpt. (degF)	27	
Ave. Outdoor Enthalpy (Btu/lb	10.28	
Ave. Indoor Enthalpy (Btu/lb)	25.22	

Storage Capacity Change	Tank 1	Tank 2	Tank 3
Hour 1-6 (Btu/hr)	0	(5,457,488)	(5,037,682)
Hour 7-17 (Btu/hr)	0	(1,049,517)	0
Hour 18-24 (Btu/hr)	0	0	0

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	91,717,790	0	62,591,195	29,126,596	0	5,690,109	4,160,942
Stor. Tank Htg. Sup	11,544,687	10,495,170	1,049,517	0	1,749,195	95,411	0
Reheat	(4,542,096)	(0)	(4,894,912)	352,816	(0)	(444,992)	50,402
Clg.Twr. Disch.	0	0	0	0	0	0	0
Totals*	98,720,381	10,495,170	58,745,800	29,479,411	1,749,195	5,340,527	4,211,344

Clg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Clg. Supply	(68,953,267)	0	(46,598,555)	(22,354,712)	0	(4,236,232)	(3,193,530)
Stor. Tank Clg. Sup	0	0	0	0	0	0	0
Free cooling	0	0	0	0	0	0	0
Ventilation	(21,397,257)	0	(21,397,257)	0	0	(1,945,205)	0
Infiltration	(41,858,353)	(13,180,770)	(4,492,703)	(24,184,880)	(2,196,795)	(408,428)	(3,454,983)
Reheat	4,542,096	0	4,894,912	(352,816)	0	444,992	(50,402)
Totals	(127,666,781)	(13,180,770)	(67,593,603)	(46,892,408)	(2,196,795)	(6,144,873)	(6,698,915)
Daily Energy Balance (Btu/hr)	7,041,002	1,044,458	14,034,895	(8,038,352)	174,076	1,275,900	(1,148,336)

Electric Use Summary (kW)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
Heat Pumps	4,712	0	3,064	1,648	0	279	235
Pumps and Miscellaneous	3,965	956	1,876	1,134	159	171	162
Fans and Cooling Towers	2,225	522	1,155	549	87	105	78
Computer Rooms	2,102	375	1,239	488	63	113	70
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	21,413	4,892	10,594	5,928	815	963	847
Totals	40,135	6,973	23,148	10,014	309	667	546

Table C-43: Daily Energy System Summary Sheet - 2/5/86

Transportation Building Daily Energy System Summary Sheet							
Date:	2/5/86	Wednesday		Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)	34			Hour 1-6 (Btu/hr)	0	(6,297,102)	(2,308,937)
Ave. outdoor Dewpt. (degF)	34			Hour 7-17 (Btu/hr)	0	1,049,517	2,938,648
Ave. Outdoor Enthalpy (Btu/lb	12.72			Hour 18-24 (Btu/hr)	0	0	0
Ave. Indoor Enthalpy (Btu/lb)	25.90						
Htg. Use Summary (Btu/hr)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
HP Htg. Supply	104,731,801	0	69,408,058	35,323,744	0	6,309,823	5,046,249
Stor. Tank Htg. Sup	4,617,875	8,606,039	(3,988,165)	0	1,434,340	(362,560)	0
Reheat	(8,108,865)	(0)	(6,112,597)	(1,996,268)	(0)	(555,691)	(285,181)
Clg.Twr. Disch.	0	0	0	0	0	0	0
Totals*	101,240,811	8,606,039	59,307,296	33,327,475	1,434,340	5,391,572	4,761,068
Clg. Use Summary (Btu/hr)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
HP Clg. Supply	(71,831,942)	0	(47,857,975)	(23,973,967)	0	(4,350,725)	(3,424,852)
Stor. Tank Clg. Sup	0	0	0	0	0	0	0
Free cooling	0	0	0	0	0	0	0
Ventilation	(20,120,214)	0	(20,120,214)	0	0	(1,829,110)	0
Infiltration	(29,828,053)	(10,109,987)	(3,779,464)	(15,938,602)	(1,684,998)	(343,588)	(2,276,943)
Reheat	8,108,865	0	6,112,597	1,996,268	0	555,691	285,181
Totals	(113,671,343)	(10,109,987)	(65,645,055)	(37,916,301)	(1,684,998)	(5,967,732)	(5,416,614)
Daily Energy Balance (Btu/hr)	30,300,880	5,700,298	18,946,215	5,654,367	950,050	1,722,383	807,767
Electric Use Summary (kW)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
Heat Pumps	4,935	0	3,149	1,787	0	286	255
Pumps and Miscellaneous	3,928	919	1,876	1,134	153	171	162
Fans and Cooling Towers	1,920	387	1,072	460	65	97	66
Computer Rooms	2,102	375	1,239	488	63	113	70
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	21,413	4,892	10,594	5,928	815	963	847
Totals	40,016	6,802	23,150	10,064	280	667	553

Table C-44: Daily Energy System Summary Sheet - 2/6/86

Transportation Building Daily Energy System Summary Sheet

Date: 2/6/86	Thursday				Storage Capacity Change	Tank 1	Tank 2 / Tank 3
Ave. outdoor Temp (degF)	26				Hour 1-6 (Btu/hr)	0	(6,507,005) (2,518,841)
Ave. outdoor Dewpt. (degF)	19				Hour 7-17 (Btu/hr)	0	(2,938,648) 3,778,261
Ave. Outdoor Enthalpy (Btu/lb	8.63				Hour 18-24 (Btu/hr)	0	(4,198,068) 209,903
Ave. Indoor Enthalpy (Btu/lb)	24.88						
Htg. Use Summary (Btu/hr)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
HP Htg. Supply	112,168,379	0	78,084,065	34,084,314	0	7,098,551	4,869,188
Stor. Tank Htg. Sup	12,174,397	9,025,846	(839,614)	3,988,165	1,504,308	(76,329)	569,738
Reheat	(2,939,995)	(0)	(2,939,995)	(0)	(0)	(267,272)	(0)
Clg.Twr. Disch.	0	0	0	0	0	0	0
Totals*	121,402,781	9,025,846	74,304,456	38,072,479	1,504,308	6,754,951	5,438,926
Clg. Use Summary (Btu/hr)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
HP Clg. Supply	(69,852,853)	0	(46,778,472)	(23,074,381)	0	(4,252,588)	(3,296,340)
Stor. Tank Clg. Sup	0	0	0	0	0	0	0
Free cooling	0	0	0	0	0	0	0
Ventilation	(22,171,008)	0	(22,171,008)	0	0	(2,015,546)	0
Infiltration	(37,943,134)	(11,815,350)	(6,234,849)	(19,892,935)	(1,969,225)	(566,804)	(2,841,848)
Reheat	2,939,995	0	2,939,995	0	0	267,272	0
Totals	(127,027,000)	(11,815,350)	(72,244,334)	(42,967,316)	(1,969,225)	(6,567,667)	(6,138,188)
Daily Energy Balance (Btu/hr)	28,319,542	4,057,105	23,052,453	1,209,984	676,184	2,095,678	172,855
Electric Use Summary (kW)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
Heat Pumps	4,739	0	2,995	1,744	0	272	249
Pumps and Miscellaneous	3,928	919	1,876	1,134	153	171	162
Fans and Cooling Towers	1,273	410	722	142	68	66	20
Computer Rooms	2,102	375	1,239	488	63	113	70
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	21,413	4,892	10,594	5,928	815	963	847
Totals	39,173	6,824	22,646	9,703	284	621	501

Table C-45: Daily Energy System Summary Sheet - 2/7/86

Transportation Building Daily Energy System Summary Sheet

Date: 2/7/86	Friday	Storage Capacity Change	Tank 1	Tank 2	Tank 3
Ave. outdoor Temp (degF)	20	Hour 1-6 (Btu/hr)	0	(5,037,682)	(3,148,551)
Ave. outdoor Dewpt. (degF)	19	Hour 7-17 (Btu/hr)	(11,334,784)	0	0
Ave. Outdoor Enthalpy (Btu/lb	7.15	Hour 18-24 (Btu/hr)	0	0	(4,617,875)
Ave. Indoor Enthalpy (Btu/lb)	24.18				

Htg. Use Summary (Btu/hr)	Daily Total	Hours 1-6	Hours 7-17	Hours 18-24	Hourly average (1-6)	Hourly average (7-17)	Hourly average (18-24)
HP Htg. Supply	110,928,949	0	72,506,632	38,422,318	0	6,591,512	5,488,903
Stor. Tank Htg. Sup	8,186,233	8,186,233	0	0	1,364,372	0	0
Reheat	(10,651,451)	(0)	(9,586,714)	(1,064,737)	(0)	(871,519)	(152,105)
Clg.Twr. Disch.	0	0	0	0	0	0	0
Totals*	108,463,730	8,186,233	62,919,918	37,357,580	1,364,372	5,719,993	5,336,797
Clg. Use Summary (Btu/hr)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
HP Clg. Supply	(62,926,041)	0	(48,847,520)	(14,078,521)	0	(4,440,684)	(2,011,217)
Stor. Tank Clg. Sup	15,952,658	0	11,334,784	4,617,875	0	1,030,435	659,696
Free cooling	0	0	0	0	0	0	0
Ventilation	(27,618,960)	0	(27,618,960)	0	0	(2,510,815)	0
Infiltration	(40,435,532)	(11,901,127)	0	(28,534,405)	(1,983,521)	0	(4,076,344)
Reheat	10,651,451	0	9,586,714	1,064,737	0	871,519	152,105
Totals	(104,376,424)	(11,901,127)	(55,544,983)	(36,930,314)	(1,983,521)	(5,049,544)	(5,275,759)
Daily Energy Balance (Btu/hr)	31,133,783	(2,386,113)	26,425,808	7,094,088	(397,686)	2,402,346	1,013,441
Electric Use Summary (kW)	**Daily Total**	**Hours 1-6**	**Hours 7-17**	**Hours 18-24**	**Hourly average (1-6)**	**Hourly average (7-17)**	**Hourly average (18-24)**
Heat Pumps	4,168	0	3,313	855	0	301	122
Pumps and Miscellaneous	4,015	931	1,950	1,134	155	177	162
Fans and Cooling Towers	2,527	558	1,316	652	93	120	93
Computer Rooms	2,102	375	1,239	488	63	113	70
Appliances and Elevators	5,717	229	5,221	267	38	475	38
Lights	21,413	4,892	10,594	5,928	815	963	847
Totals	39,942	6,985	23,633	9,324	311	711	447

Table C-46: Summary of Computer Model Outputs From Monitored Days

Date Day	Daily Average Outdoor Temp	Calc. Daily Average Outdoor Temp	Calc. Daily Average Outdoor Enthalpy (Btu/lb)	Calc. Daily Average Indoor Enthalpy (Btu/lb)	Daily Average Conduction (Btu/hr)	Occupied Daily Average Conduction (Btu/hr)	Daily Total Electric Load (MWh)	Calculated Daily Variable Electric Load (MWh)	Calculated Daily Total Electric Load (MWh)	Actual Minus Calc. Total Electric Load (MWh)	Daily Heat Pump Hot Water Supply (Btu/hr)	Daily Tank Heating Supply (Btu/hr)	Daily Reheat (Btu/hr)	Daily Steam Reheat (Btu/hr)	Daily Cooling Tower Discharge (Btu/hr)	Daily Space Heating Load (Btu/hr)	Percent Daily Heating Load Due to Outdr.Air (%)
1 7/22 mon	76	76	28.15	24.24	357,637	1,686,003	38.71	10.54	35.76	2.95	0	0	0	0	(188,388,302)	0	0
2 7/23 tues	71	70	22.94	23.55	(5,058,009)	(766,365)	33.37	12.21	37.43	(4.06)	0	0	0	0	(252,706,701)	0	0
3 7/24 wed	72	72	24.01	23.74	(2,043,640)	919,638	38.39	9.54	34.76	3.63	0	0	0	0	(138,761,141)	0	0
4 7/25 thurs	74	76	27.53	25.39	1,277,275	3,167,642	37.79	11.08	36.30	1.49	0	0	0	0	(163,199,894)	0	0
5 7/26 fri	76	75	30.05	26.23	(102,182)	970,729	41.46	12.24	37.46	4.00	0	0	0	0	(278,271,936)	0	0
8 8/12 mon	70	72	25.23	25.91	(5,671,101)	(1,737,094)	39.26	11.39	36.61	2.65	0	0	0	0	(165,074,031)	0	0
9 8/13 tues	66	69	23.42	24.49	(6,386,375)	(1,941,458)	37.29	10.48	35.70	1.59	0	0	0	0	(125,117,420)	0	0
10 8/14 wed	80	80	29.76	25.69	6,846,194	4,955,827	43.15	16.19	41.41	1.74	0	0	0	0	(254,357,942)	0	0
11 8/15 thurs	84	84	32.68	26.49	9,247,471	6,948,376	42.85	15.22	40.44	2.41	0	0	0	0	(220,023,743)	0	0
12 8/16 fri	75	76	27.68	25.84	(868,547)	1,072,911	41.87	13.61	38.83	3.04	0	0	0	0	(223,397,190)	0	0
14 9/11 wed	59	60	19.63	23.00	(15,480,573)	(6,641,830)			30.65		14,253,440	0	7,409,969	0	(58,173,228)	6,843,471	217
15 9/12 thurs	57	60	18.79	22.35	(15,787,119)	(7,357,104)	31.32		28.49	2.83	30,366,025	(15,620,311)	4,757,872	0	0	9,987,842	317
16 9/13 fri	53	52	17.11	22.52	(23,910,588)	(13,283,660)	31.52		27.18	4.34	26,647,736	(17,282,047)	2,193,262	0	0	7,172,427	636
17 10/3 thurs	58	56	19.16	23.88	(20,845,128)	(10,473,655)	27.11	7.08	32.30	(5.19)	83,041,783	(13,223,914)	25,702,140	0	0	44,115,729	36
18 10/4 fri	55	54	18.72	24.10	(26,209,683)	(11,137,838)		7.19	32.41		76,844,635	1,661,735	28,506,636	0	(16,192,548)	49,999,734	21
21 10/7 mon	55	58	18.37	22.48	(19,567,853)	(8,225,651)	33.03	8.99	28.79	4.24	57,013,762	(12,296,841)	17,257,558	0	0	27,459,363	121
22 10/8 tues	53	58	18.28	22.51	(19,823,308)	(8,838,743)	32.03	3.57	28.79	3.24	62,591,195	(7,556,522)	6,193,195	0	(5,397,516)	48,841,478	166
23 10/9 wed	63	64	21.52	24.19	(12,619,477)	(4,904,736)	32.37	3.62	28.84	3.53	51,436,328	5,632,408	17,963,878	0	(34,184,268)	39,104,858	94
24 10/28mon	49	50	16.52	23.20	(30,092,599)	(15,122,936)	31.06		29.26	1.80	49,577,184	7,556,522	5,280,090	0	(13,793,652)	51,853,616	58
25 10/29tues	43	44	14.66	22.55	(38,164,977)	(17,422,031)	32.20		30.07	2.13	57,013,762	(5,247,585)	8,540,511	0	0	43,225,666	37
26 10/30wed	43	45	15.83	23.80	(37,092,066)	(17,422,031)	32.12		29.64	2.48	66,929,198	(5,667,392)	7,367,394	0	0	53,894,412	43
27 10/31thurs	46	48	17.74	26.19	(33,975,515)	(17,881,850)	28.28		26.41	1.87	0	16,232,530	0	0	0	16,232,530	333
33 12/2 mon	46	47	18.19	26.15	(33,566,787)	(13,385,842)	33.55	5.88	31.10	2.45	91,098,076	(1,559,282)	10,126,440	0	0	79,412,354	43
34 12/3 tues	28	32	10.43	24.10	(51,244,273)	(23,195,314)	36.23	7.49	32.71	3.52	97,914,938	6,971,792	7,803,770	0	0	97,082,960	67
35 12/4 wed	29	32	10.78	23.87	(49,456,088)	(21,713,675)	37.27	9.15	34.37	2.90	118,365,527	3,168,542	11,744,166	0	0	109,789,903	46
36 1/14 tues	13	13	4.85	24.40	(74,643,951)	(34,639,698)	44.57	10.08	41.03	3.54	101,633,227	9,445,653	4,045,509	43,200,000	0	150,233,371	51
37 1/15 wed	13	12	4.74	23.86	(73,877,586)	(33,617,878)	46.73	11.88	42.83	3.90	146,252,693	(3,358,454)	1,872,045	43,200,000	0	184,222,194	41
38 1/16 thurs	24	24	8.28	24.50	(59,469,924)	(26,516,229)	45.16	10.88	41.82	3.34	124,562,675	(5,667,392)	3,374,493	43,200,000	0	158,720,790	39
39 1/22 wed	40	43	16.04	24.97	(42,712,076)	(19,465,671)	39.79	6.11	37.06	2.73	87,379,787	(4,892,748)	18,277,558	43,200,000	0	107,409,481	30
40 1/23 thur	32	30	9.88	22.27	(59,521,015)	(26,311,865)	40.23	6.10	37.04	3.19	86,760,072	2,333,926	15,530,443	43,200,000	0	116,763,555	27
41 1/24 fri	22	21	6.73	23.42	(67,440,120)	(30,348,054)	41.52	7.30	38.25	3.27	68,168,628	1,909,121	16,958,326	43,200,000	0	96,319,423	46
42 2/4 tues	27	28	10.28	25.22	(56,711,010)	(26,005,319)	43.95	9.19	40.14	3.82	91,717,790	11,544,687	4,542,096	43,200,000	0	141,920,381	45
43 2/5 wed	35	34	12.72	25.90	(49,966,998)	(23,664,042)	42.78	9.07	40.02	2.76	104,731,801	4,617,875	8,109,865	43,200,000	0	144,440,811	35
44 2/6 thurs	26	26	8.63	24.88	(58,754,650)	(27,895,686)	40.64	8.15	39.10	1.54	112,168,379	12,174,397	2,939,995	43,200,000	0	164,602,781	37
45 2/7 fri	19	20	7.15	24.18	(65,651,935)	(29,837,144)	39.05	9.00	39.94	(0.89)	110,928,949	8,186,233	10,651,451	43,200,000	0	151,663,731	45
(Unoccupied Days)																	
6 7/27 sat	74	75	26.67		(1,226,184)	(562,001)	27.86	7.14	21.84	5.02	0	0	0	0	(149,856,035)	0	0
7 7/28 sun	68	71	24.89		(8,583,286)	(3,934,007)	22.80	6.26	20.96	1.84	0	0	0	0	(91,158,048)	0	0
13 8/17 sat	74	74	25.02		(1,226,184)	(562,001)		12.95	27.65		0	0	0	0	(170,021,754)	0	0
19 10/5 sat	63	61	21.99		(14,714,208)	(6,744,012)		0.05	14.74		0	0	0	0	0	0	0
20 10/6 sun	57	58	19.53		(22,071,312)	(10,116,018)	19.78	0.95	15.65	4.13	0	6,244,626	0	0	0	6,244,626	174
28 11/27wed	40	40	15.36	24.14	(42,916,440)	(19,670,035)			32.38		73,126,346	3,148,551	7,330,470	0	0	68,944,427	59
29 11/28thurs	35	36	13.37		(49,047,360)	(22,480,040)	23.98	4.80	19.50	4.48	50,196,899	12,174,397	1,696,714	0	0	60,674,582	61
30 11/29fri	32	33	11.91		(52,725,912)	(24,166,043)		5.48	20.18		63,830,624	9,650,559	5,135,257	0	0	68,345,926	65
31 11/30sat	37	37	13.93		(46,594,992)	(21,356,038)		9.84	24.54		105,351,516	(9,445,653)	2,741,059	0	0	93,164,804	51
32 12/1 sun	44	44	16.90		(38,0:1,704)	(17,422,031)	22.42	5.11	19.81	2.61	79,943,209	14,343,399	4,562,986	0	0	89,723,670	26

Table C-46, continued (p. 2 of 4)

Date	Daily Space Heating Load Including Reheat (Btu/hr)	Daily Heating Percent Reheat (%)	Daily Heat Pump Heat Discharge (Btu/hr)	Daily Heat Pump Cooling Supply (Btu/hr)	Daily Tank Cooling Supply (Btu/hr)	Daily Free Cooling Supply (Btu/hr)	Daily Ventilation (Btu/hr)	Daily Infiltration (Btu/hr)	Occupied Total Outdoor Air Load (Btu/hr)	Daily Space Cooling Load Including Sta.reht. (Btu/hr)	Daily Space Cooling Load Including Reheats (Btu/hr)	Daily Space Cooling Load (Btu/hr)	Daily Cooling Percent Reheat (not sta.) (%)	Daily Cooling Percent Reheat (due to sta.) (%)	Occupied Heat Pump Hot Water Supply (Btu/hr)	Occupied Tank Heating Supply (Btu/hr)
1 7/22	0	0	188,388,302	(133,532,297)	(8,973,370)	(243,831)	710,483	10,384,877	10,851,529	(142,505,667)	(142,505,667)	(142,505,667)	0	0	0	0
2 7/23	0	0	252,708,701	(149,931,000)	24,593,682	4,050,633	(553,969)	(1,101,819)	2,394,845	(125,337,318)	(125,337,318)	(125,337,318)	0	0	0	0
3 7/24	0	0	138,761,141	(95,581,013)	(10,967,453)	8,538,018	366,921	(1,010,059)	7,894,880	(106,548,466)	(106,548,466)	(106,548,466)	0	0	0	0
4 7/25	0	0	163,199,894	(136,287,279)	(28,581,846)	(352,836)	5,578,279	568,291	5,793,734	(164,869,125)	(164,869,125)	(164,869,125)	0	0	0	0
5 7/26	0	0	278,271,936	(131,189,625)	5,649,900	0	0	16,361,283	16,361,283	(125,539,725)	(125,539,725)	(125,539,725)	0	0	0	0
8 8/12	0	0	165,074,031	(116,496,387)	12,961,535	(139,299)	219,130	(913,226)	(833,395)	(104,368,247)	(104,368,247)	(104,368,247)	0	0	0	0
9 8/13	0	0	125,117,420	(112,898,043)	11,632,147	(9,398,568)	0	(1,626,266)	(11,024,834)	(112,290,730)	(112,290,730)	(112,290,730)	0	0	0	0
10 8/14	0	0	254,357,942	(171,820,926)	18,611,435	0	4,718,338	9,465,188	14,183,526	(153,209,491)	(153,209,491)	(153,209,491)	0	0	0	0
11 8/15	0	0	220,023,743	(165,074,031)	15,952,658	0	0	27,988,026	27,988,026	(149,121,373)	(149,121,373)	(149,121,373)	0	0	0	0
12 8/16	0	0	223,397,190	(146,182,725)	25,590,723	0	0	9,172,858	9,172,858	(120,592,002)	(120,592,002)	(120,592,002)	0	0	0	0
14 9/11	14,253,440	52	72,426,668	(50,826,609)	6,979,288	(9,598,391)	(4,055,248)	(1,187,214)	(14,840,853)	(51,278,205)	(58,688,174)	(51,278,205)	13	0	14,253,440	0
15 9/12	14,745,714	32	30,366,025	(21,590,064)	(1,329,388)	(26,655,065)	(3,398,446)	(1,574,512)	(31,628,023)	(49,789,603)	(54,547,475)	(49,789,603)	9	0	30,366,025	(15,620,311)
16 9/13	9,365,689	23	26,647,736	(13,943,583)	0	(37,512,255)	(2,708,853)	(5,371,254)	(45,592,362)	(57,342,683)	(59,535,945)	(57,342,683)	4	0	26,647,736	(17,282,047)
17 10/3	69,817,869	37	83,041,783	(71,067,294)	0	0	(14,571,671)	(1,248,611)	(15,820,282)	(61,185,436)	(86,887,576)	(61,185,436)	30	0	83,041,783	(13,223,914)
18 10/4	78,506,370	36	93,037,183	(73,559,897)	1,661,735	0	(10,479,797)	0	(10,479,797)	(53,871,323)	(82,377,959)	(53,871,323)	35	0	76,844,635	1,661,735
21 10/7	44,716,921	39	57,013,762	(28,112,063)	0	(21,519,925)	(1,905,674)	(9,756,099)	(33,181,698)	(44,036,203)	(61,293,761)	(44,036,203)	28	0	57,013,762	(12,961,535)
22 10/8	55,034,673	11	67,988,711	(25,188,408)	0	(77,612,885)	(1,722,177)	(1,818,555)	(81,153,617)	(100,148,830)	(106,342,025)	(100,148,830)	6	0	31,295,598	(7,556,522)
23 10/9	57,068,736	31	85,620,596	(24,286,822)	0	(33,681,070)	(168,208)	(2,729,938)	(36,579,216)	(42,904,160)	(60,868,038)	(42,904,160)	30	0	25,718,164	3,463,406
24 10/28	57,133,706	9	63,370,836	(30,136,131)	0	(18,253,193)	(7,038,335)	(4,992,923)	(30,284,451)	(55,140,492)	(60,420,582)	(55,140,492)	9	0	49,577,184	6,297,102
25 10/29	51,766,177	16	57,013,762	(40,931,163)	0	0	(13,308,159)	(2,547,416)	(15,855,575)	(48,246,227)	(56,786,738)	(48,246,227)	15	0	50,816,614	(5,667,392)
26 10/30	61,261,806	12	66,929,198	(34,184,268)	0	0	(12,311,693)	(11,092,324)	(23,404,017)	(50,220,891)	(57,588,285)	(50,220,891)	13	0	61,351,765	(6,507,005)
27 10/31	16,232,530	0	0	0	0	(45,334,969)	0	(8,790,387)	(54,125,356)	(54,125,356)	(54,125,356)	(54,125,356)	0	0	0	15,392,916
33 12/2	89,538,794	11	91,098,076	(58,238,823)	3,148,551	0	0	(34,245,448)	(34,245,448)	(79,209,280)	(89,335,720)	(79,209,280)	11	0	86,140,357	(6,232,132)
34 12/3	104,886,730	7	97,914,938	(67,468,950)	8,895,906	0	0	(65,122,638)	(65,122,638)	(115,891,912)	(123,695,682)	(115,891,912)	6	0	73,746,061	(214,901)
35 12/4	121,534,069	10	118,365,527	(103,639,804)	21,620,050	0	(15,599,987)	(34,479,745)	(50,079,732)	(120,355,320)	(132,099,486)	(120,355,320)	9	0	70,027,772	0
36 1/14	111,078,880	4	101,633,227	(74,575,679)	25,608,215	0	(26,348,655)	(49,956,275)	(76,304,930)	(121,226,885)	(125,272,394)	(78,026,885)	3	34	59,492,621	(629,710)
37 1/15	142,894,239	1	146,252,693	(93,646,903)	29,806,283	0	(27,301,371)	(48,855,024)	(76,156,395)	(138,124,970)	(139,997,015)	(94,924,970)	1	31	72,506,632	(1,259,420)
38 1/16	118,895,263	3	124,562,675	(91,532,876)	25,608,215	0	(29,584,948)	(31,769,014)	(61,353,962)	(123,904,130)	(127,278,623)	(80,704,130)	3	34	60,732,050	(5,247,585)
39 1/22	82,487,039	22	87,379,787	(41,793,266)	0	0	(16,894,808)	(15,248,968)	(32,143,776)	(55,659,484)	(73,937,042)	(12,459,484)	25	58	79,323,494	(11,104,889)
40 1/23	89,093,998	17	86,760,072	(56,270,978)	0	0	(23,724,291)	(8,084,148)	(31,808,439)	(72,548,974)	(88,079,417)	(29,348,974)	18	49	86,760,072	419,807
41 1/24	70,077,749	24	68,168,628	(54,959,082)	0	0	(28,070,089)	(15,756,709)	(43,826,798)	(81,827,554)	(98,785,880)	(38,627,554)	17	44	57,013,762	0
42 2/4	103,262,477	4	91,717,790	(68,953,267)	0	0	(21,397,257)	(41,858,353)	(63,255,610)	(127,666,781)	(132,208,877)	(84,466,781)	3	33	62,591,195	1,049,517
43 2/5	109,349,676	7	104,731,801	(71,831,942)	0	0	(20,120,214)	(29,828,053)	(49,948,267)	(113,671,344)	(121,780,209)	(70,471,344)	7	35	69,408,058	(3,988,165)
44 2/6	124,342,776	2	112,168,379	(69,852,853)	0	0	(22,171,008)	(37,943,134)	(60,114,142)	(127,027,000)	(129,966,995)	(83,827,000)	2	33	78,084,065	(839,614)
45 2/7	119,115,182	9	110,928,949	(62,926,041)	15,952,658	0	(27,618,960)	(40,435,532)	(68,054,492)	(104,376,424)	(115,027,875)	(61,176,424)	9	38	72,506,632	0
(Unoccupied Days)																
6 7/27	0	0	149,856,035	(72,622,828)	9,638,064	11,314,454	0	0	11,314,454	(62,984,764)	(62,984,764)	(62,984,764)	0	0	0	0
7 7/28	0	0	91,158,048	(72,154,294)	5,649,900	170,864	241,488	(316,713)	95,639	(66,504,394)	(66,504,394)	(66,504,394)	0	0	0	0
13 8/17	0	0	170,021,754	(72,622,828)	9,638,064	11,314,454	0	569,968	11,884,422	(62,984,764)	(62,984,764)	(62,984,764)	0	0	0	0
19 10/5	0	0	0	0	0	(780,236)	(1,750,531)	0	(2,530,767)	(2,530,767)	(2,530,767)	(2,530,767)	0	0	0	0
20 10/6	6,244,626	0	0	0	0	(8,301,793)	(1,822,266)	(765,995)	(10,890,054)	(10,890,054)	(10,890,054)	(10,890,054)	0	0	0	3,743,277
28 11/27	76,274,897	10	73,126,346	(7,219,177)	4,198,068	0	0	(40,493,552)	(40,493,552)	(36,184,191)	(43,514,661)	(36,184,191)	17	0	66,309,484	(2,938,648)
29 11/28	62,371,296	3	50,196,899	(51,321,381)	2,099,034	0	0	(36,864,608)	(36,864,608)	(84,390,241)	(86,086,955)	(84,390,241)	2	0	50,196,899	839,614
30 11/29	73,481,183	7	63,830,624	(51,726,195)	10,315,253	0	(9,948,499)	(34,442,039)	(44,390,538)	(80,666,223)	(85,801,480)	(80,666,223)	6	0	63,830,624	0
31 11/30	95,905,863	3	105,351,516	(143,753,843)	30,016,186	0	0	(47,300,067)	(47,300,067)	(158,296,665)	(161,037,724)	(159,296,665)	2	0	60,732,050	(7,976,329)
32 12/1	94,286,608	5	79,943,209	(43,667,404)	0	0	0	(23,424,135)	(23,424,135)	(62,528,551)	(67,091,539)	(62,528,551)	7	0	41,520,892	1,239,430

Table C-46, continued (p. 3 of 4)

Date	Occupied Reheat (Btu/hr)	Occupied Steam Supply (Btu/hr)	Occupied Cooling Tower Discharge (Btu/hr)	Occupied Space Heating Load (Btu/hr)	Occupied Percent Htg.Ld. Due to Outdoor Air (%)	Conduction Percent Total Occupied Heating Load (%)	Occupied Space Heating Load Including Reheat (Btu/hr)	Occupied Heating Load Percent Reheat (%)	Occupied Heat Pump Heat Discharge (Btu/hr)	Occupied Heat Pump Cooling Supply (Btu/hr)	Occupied Tank Cooling Supply (Btu/hr)	Occupied Free Cooling Supply (Btu/hr)	Occupied Ventilation (Btu/hr)	Occupied Infiltration (Btu/hr)	Occupied Total Outdoor Air Load (Btu/hr)	Occupied Percent Clg.Ld. Due to Outdoor Air (%)
1 7/22	0	0	(99,479,219)	0	0	0	0	0	99,479,219	(84,804,722)	(21,270,211)	0	710,483	9,111,113	9,821,596	(9)
2 7/23	0	0	(132,613,970)	0	0	0	0	0	132,613,970	(73,091,363)	10,967,453	4,050,633	(266,998)	0	3,783,635	(6)
3 7/24	0	0	(79,463,430)	0	0	0	0	0	79,463,430	(40,762,491)	(8,308,676)	8,538,018	310,399	(34,527)	8,813,890	(18)
4 7/25	0	0	(95,955,840)	0	0	0	0	0	95,955,840	(97,605,081)	(31,905,317)	4,526,895	5,373,522	0	9,900,417	(8)
5 7/26	0	0	(165,223,962)	0	0	0	0	0	165,223,962	(58,566,797)	(332,347)	0	0	12,430,111	12,430,111	(21)
8 8/12	0	0	(116,271,491)	0	0	0	0	0	116,271,491	(76,914,603)	(6,646,941)	0	219,130	(183,223)	35,907	(0)
9 8/13	0	0	(40,781,232)	0	0	0	0	0	40,781,232	(49,477,230)	(9,305,717)	(8,508,824)	0	(407,028)	(8,915,852)	13
10 8/14	0	0	(125,942,040)	0	0	0	0	0	125,942,040	(84,561,084)	(8,973,370)	0	4,817,481	7,859,758	12,677,239	(14)
11 8/15	0	0	(113,347,836)	0	0	0	0	0	113,347,836	(90,408,393)	(11,632,147)	0	0	20,538,285	20.538,285	(20)
12 8/16	0	0	(116,571,353)	0	0	0	0	0	116,571,353	(70,617,501)	(4,985,206)	0	0	7,100,343	7,100,343	(9)
14 9/11	7,409,969	0	(17,242,065)	6,843,471	188	97	14,253,440	52	31,495,505	(14,843,169)	1,329,388	(8,796,715)	(4,055,248)	0	(12,851,963)	68
15 9/12	4,757,872	0	0	9,987,842	244	74	14,745,714	32	30,366,025	(21,590,064)	0	(20,995,569)	(3,398,446)	0	(24,394,015)	59
16 9/13	2,193,262	0	0	7,172,427	604	185	9,365,689	23	26,647,736	(13,943,583)	0	(37,512,255)	(2,708,853)	(3,076,469)	(43,297,577)	79
17 10/3	25,702,140	0	0	44,115,729	19	24		0	83,041,783	(71,067,294)	0	0	(8,465,847)	0	(8,465,847)	16
18 10/4	28,506,636	0	(16,192,548)	49,999,734	17	22		0	93,037,183	(73,559,897)	1,661,735	0	(8,742,424)	0	(8,742,424)	17
21 10/7	17,257,558	0	0	26,794,669	94	31	44,052,227	39	57,013,762	(28,112,063)	0	(18,160,266)	(1,267,503)	(5,848,020)	(25,275,789)	70
22 10/8	6,193,195	0	(5,397,516)	17,545,881	303	50	23,739,076	26	36,693,114	(25,188,408)	0	(52,440,039)	(734,320)	0	(53,174,359)	74
23 10/9	17,963,878	0	(34,184,268)	11,217,692	252	44	29,181,570	62	59,902,432	(24,288,822)	0	(28,322,817)	0	0	(28,322,817)	82
24 10/28	5,280,090	0	(13,793,652)	50,594,196	50	30	55,874,286	9	63,370,836	(30,136,131)	0	(17,388,569)	(7,038,335)	(842,641)	(25,269,545)	50
25 10/29	7,781,503	0	0	37,367,719	37	47	45,149,222	17	50,816,614	(36,883,026)	0	0	(12,043,512)	(1,904,317)	(13,947,829)	32
26 10/30	6,604,819	0	0	48,239,941	36	36	54,844,760	12	61,351,765	(31,485,510)	0	0	(10,829,296)	(6,455,246)	(17,284,542)	41
27 10/31	0	0	0	15,392,916	344	116	15,392,916	0	0	0	0	(45,334,969)	0	(7,659,986)	(52,994,955)	100
33 12/2	9,458,246	0	0	70,449,979	29	19	79,908,225	12	86,140,357	(53,084,945)	2,938,648	0	0	(20,194,513)	(20,194,513)	33
34 12/3	4,786,803	0	0	68,744,357	56	34	73,531,160	7	73,746,061	(50,273,738)	8,686,003	0	0	(38,541,455)	(38,541,455)	51
35 12/4	6,319,037	0	0	63,708,735	47	34	70,027,772	9	70,027,772	(59,035,331)	14,063,528	0	(7,734,671)	(22,403,360)	(30,138,031)	44
36 1/14	4,045,509	19,800,000	0	65,283,538	56	53		0	59,492,621	(49,387,271)	8,606,039	0	(26,348,655)	(9,910,532)	(36,259,187)	68
37 1/15	1,872,045	19,800,000	0	79,841,303	40	42	91,047,212	2	72,506,632	(50,466,775)	10,075,363	0	(27,301,371)	(4,562,202)	(31,863,573)	63
38 1/16	2,774,657	19,800,000	0	63,175,944	41	42	75,284,465	4	60,732,050	(47,498,141)	7,136,716	0	(26,032,280)	0	(26,032,280)	59
39 1/22	16,797,206	19,800,000	0	61,887,535	31	31	88,018,605	19	79,323,494	(38,419,819)	0	0	(15,508,084)	(3,728,967)	(19,237,051)	91
40 1/23	15,530,443	19,800,000	0	82,115,572	33	32	106,979,879	15	86,760,072	(56,270,978)	0	0	(23,329,213)	(4,060,778)	(27,389,991)	57
41 1/24	15,402,224	19,800,000	0	52,077,674	54	58		0	57,013,762	(44,604,473)	0	0	(28,070,089)	0	(28,070,089)	75
42 2/4	4,894,912	19,800,000	0	69,211,936	37	38	83,440,712	6	62,591,195	(46,598,555)	0	0	(21,397,257)	(4,492,703)	(25,889,960)	54
43 2/5	6,112,597	19,800,000	0	69,773,432	34	34	85,219,893	7	69,408,058	(47,857,975)	0	0	(20,120,214)	(3,779,464)	(23,899,678)	52
44 2/6	2,939,995	19,800,000	0	84,770,592	34	33	97,044,451	3	78,084,065	(46,778,472)	0	0	(22,171,008)	(6,234,849)	(28,405,857)	54
45 2/7	9,586,714	19,800,000	0	73,386,054	38	41	92,306,632	10	72,506,632	(48,847,520)	11,334,784	0	(27,618,960)	0	(27,618,960)	77
(Unoccupied Days)																
6 7/27	0	0	(110,724,044)	0	0	0	0	0	110,724,044	(50,133,178)	4,652,859	11,314,454	0	1,893,140	13,207,594	(29)
7 7/28	0	0	(70,767,432)	0	0	0	0	0	70,767,432	(54,818,522)	2,991,123	134,163	241,488	186,534	562,185	(1)
13 8/17	0	0	(83,436,602)	0	0	0	0	0	83,436,602	(88,159,428)	24,926,029	0	0	831,484	831,484	(1)
19 10/5	0	0	0	0	0	0	0	0	0	0	0	(780,236)	(550,427)	0	(1,330,663)	100
20 10/6	0	0	0	3,743,277	190	270	3,743,277	0	0	0	0	(7,097,665)	0	0	(7,097,665)	100
28 11/27	6,662,627	0	0	56,708,209	56	35	63,370,836	11	66,309,484	(66,839,240)	1,679,227	0	0	(31,768,455)	(31,768,455)	35
29 11/28	1,696,714	0	0	49,339,799	55	46	51,036,513	3	50,196,899	(51,321,381)	2,099,034	0	0	(27,022,690)	(27,022,690)	36
30 11/29	5,135,257	0	0	58,695,367	49	41	63,830,624	8	63,830,624	(51,726,195)	10,315,253	0	(9,948,499)	(19,092,352)	(29,040,851)	44
31 11/30	2,046,325	0	0	50,709,396	53	42	52,755,721	4	60,732,050	(95,356,116)	12,174,397	0	0	(26,795,354)	(26,795,354)	25
32 12/1	1,983,223	0	0	40,777,099	27	43	42,760,322	5	41,520,892	(23,707,839)	0	0	0	(11,063,081)	(11,063,081)	34

Table C-46, continued (p. 4 of 4)

Date	Occupied Space Cooling Load (incld. sta.reht.) (Btu/hr)	Occupied Space Cooling Load Including Reheats (Btu/hr)	Occupied Space Cooling Load (Btu/hr)	Occupied Cooling Load Percent Reheat (not sta.) (%)	Occupied Cooling Load Percent Reheat (sta.) (%)	Occupied Space Cooling Load w/Enthalpy Control (Btu/hr)	Occupied Peak Hourly Cooling Load (Btu/hr)	Occupied Peak Hourly Heating Load (Btu/hr)	Occupied Average Hourly Cooling Load (w/reheat) (Btu/hr)	Occupied Average Hourly Heating Load (w/reheat) (Btu/hr)	Unoccupied Average Hourly Heating Load (w/reheat) (Btu/hr)	Unoccupied Daily Heating Load (Btu/hr)	Unoccupied Daily Cooling Load (Btu/hr)	Unoccupied Daily Ventil. Load (Btu/hr)	Unoccupied Daily Conduction Load (Btu/hr)
1 7/22	(106,074,933)	(106,074,933)	(106,074,933)	0	0	(106,074,933)	(12,301,839)	0	(9,643,176)	0	0	0	36,430,734	1,029,933	(1,328,366)
2 7/23	(62,123,910)	(62,123,910)	(62,123,910)	0	0	(58,073,277)	(7,496,550)	0	(5,647,628)	0	0	0	63,213,408	(1,388,790)	(4,291,644)
3 7/24	(49,071,167)	(49,071,167)	(49,071,167)	0	0	(40,533,149)	(6,891,828)	0	(4,461,015)	0	0	0	57,477,299	(919,010)	(2,963,278)
4 7/25	(129,510,398)	(129,510,398)	(129,510,398)	0	0	(124,983,503)	(13,004,015)	0	(11,773,673)	0	0	0	35,358,727	(4,106,683)	(1,890,367)
5 7/26	(58,899,144)	(58,899,144)	(58,899,144)	0	0	(58,899,144)	(6,287,107)	0	(5,354,468)	0	0	0	66,640,581	3,931,172	(1,072,911)
8 8/12	(83,561,544)	(83,561,544)	(83,561,544)	0	0	(83,561,544)	(11,193,132)	0	(7,596,504)	0	0	0	20,806,703	(869,302)	(3,934,007)
9 8/13	(67,698,799)	(67,698,799)	(67,698,799)	0	0	(67,698,799)	(8,256,325)	0	(6,154,436)	0	0	0	44,591,931	(2,108,982)	(4,444,917)
10 8/14	(93,534,454)	(93,534,454)	(93,534,454)	0	0	(93,534,454)	(10,657,595)	0	(8,503,132)	0	0	0	59,675,037	1,506,287	1,890,367
11 8/15	(102,040,540)	(102,040,540)	(102,040,540)	0	0	(102,040,540)	(10,325,248)	0	(9,276,413)	0	0	0	47,080,833	7,449,741	2,299,095
12 8/16	(75,602,707)	(75,602,707)	(75,602,707)	0	0	(75,602,707)	(9,328,207)	0	(2,396,886)	0	0	0	44,989,295	2,072,515	(1,941,458)
14 9/11	(18,955,775)	(26,365,744)	(18,955,775)	28	0	(18,955,775)	(5,731,895)	4,487,240	(4,180,371)	1,295,767	0	0	32,322,430	(1,988,890)	(8,838,743)
15 9/12	(41,226,207)	(45,984,079)	(41,226,207)	10	0	(41,226,207)	(3,768,895)	2,343,921	(5,203,742)	1,340,519	0	0	8,563,396	(7,234,008)	(8,430,015)
16 9/13	(55,047,898)	(57,241,160)	(55,047,898)	4	0	(55,047,898)	(6,868,387)	1,921,616	(7,230,286)	851,426	0	0	2,294,785	(2,294,785)	(10,626,928)
17 10/3	(53,831,001)	(79,533,141)	(53,831,001)	32	0	(53,831,001)	(6,814,761)	5,094,514	(7,230,286)	0	5,370,605	0	7,354,435	(7,354,435)	(10,371,473)
18 10/4	(52,133,950)	(80,640,586)	(52,133,950)	35	0	(52,133,950)	(12,689,597)	7,555,192	(7,330,962)	0	6,038,952	0	1,737,373	(1,737,373)	(15,071,845)
21 10/7	(36,130,294)	(53,387,852)	(36,130,294)	32	0	(36,130,294)	(9,446,589)	4,647,135	(4,853,441)	4,004,748	51,130	664,694	7,905,909	(7,905,909)	(11,342,202)
22 10/8	(72,169,572)	(78,362,767)	(72,169,572)	8	0	(72,169,572)	(10,030,953)	7,626,490	(7,123,888)	2,158,098	2,407,354	31,295,598	27,979,258	(27,979,258)	(10,984,565)
23 10/9	(34,647,761)	(52,611,639)	(34,647,761)	34	0	(34,647,761)	(6,866,539)	8,147,664	(4,782,876)	2,652,870	2,145,167	27,887,166	8,256,399	(8,256,399)	(7,714,741)
24 10/28	(50,125,586)	(55,405,676)	(50,125,586)	10	0	(50,125,586)	(8,015,689)	6,217,139	(5,036,880)	5,079,481	96,878	1,259,420	5,014,906	(5,014,906)	(14,969,663)
25 10/29	(43,049,352)	(50,830,855)	(43,049,352)	15	0	(43,049,352)	(4,590,646)	4,186,646	(4,620,987)	4,104,475	508,997	5,857,947	5,196,875	(1,907,746)	(20,742,946)
26 10/30	(42,165,233)	(48,770,052)	(42,165,233)	14	0	(42,165,233)	(5,370,499)	5,524,623	(4,433,641)	4,985,887	493,619	5,654,471	8,055,658	(6,119,475)	(19,670,035)
27 10/31	(52,994,955)	(52,994,955)	(52,994,955)	0	0	(52,994,955)	(5,851,004)	1,924,115	(4,817,723)	1,399,356	64,586	839,614	1,130,401	(1,130,401)	(16,093,665)
33 12/2	(60,882,564)	(70,340,810)	(60,882,564)	13	0	(60,882,564)	(6,940,184)	7,361,804	(6,394,619)	7,264,384	740,813	8,962,375	18,326,716	(14,050,935)	(20,180,945)
34 12/3	(75,342,387)	(80,129,190)	(75,342,387)	6	0	(75,342,387)	(7,943,719)	8,588,643	(7,284,472)	6,684,651	2,411,967	28,338,603	40,549,525	(26,581,183)	(28,048,959)
35 12/4	(68,790,797)	(75,109,834)	(68,790,797)	8	0	(68,790,797)	(8,496,896)	7,066,718	(6,828,167)	6,366,161	3,962,023	46,081,168	51,564,523	(19,941,701)	(27,742,413)
36 1/14	(72,994,910)	(77,040,419)	(53,194,910)	5	27	(72,994,910)	(9,588,084)	7,856,384	(7,003,674)	0	8,544,529	84,949,833	24,831,975	(40,045,743)	(40,004,253)
37 1/15	(70,382,940)	(72,254,985)	(50,582,940)	3	28	(70,382,940)	(9,330,007)	7,836,761	(6,568,635)	8,277,019	3,988,233	104,380,891	44,342,030	(44,292,822)	(40,259,708)
38 1/16	(63,619,048)	(66,393,705)	(43,819,048)	4	31	(63,619,048)	(738,904)	7,436,578	(6,035,791)	6,844,042	3,354,678	95,544,846	36,885,082	(35,321,682)	(32,953,695)
39 1/22	(40,859,664)	(57,656,870)	(21,059,664)	29	48	(40,859,664)	(5,907,771)	5,309,117	(5,241,534)	8,001,691	(425,505)	45,521,946	0	(12,906,725)	(23,246,405)
40 1/23	(68,130,526)	(83,660,969)	(48,330,526)	19	29	(68,130,526)	(6,848,092)	8,056,292	(7,605,543)	9,725,444	(1,375,837)	34,647,983	0	(4,418,448)	(33,209,150)
41 1/24	(57,272,338)	(72,674,562)	(37,472,338)	21	35	(57,272,338)	(5,772,918)	5,386,253	(6,606,778)	0	5,390,596	44,241,749	1,155,216	(15,756,709)	(37,092,066)
42 2/4	(67,593,603)	(72,486,515)	(47,793,603)	7	29	(67,593,603)	(6,593,249)	5,629,540	(6,589,865)	7,585,519	1,524,751	72,708,445	36,673,178	(37,365,650)	(30,705,691)
43 2/5	(65,645,056)	(71,757,653)	(45,845,056)	9	30	(65,645,056)	(6,754,998)	7,851,123	(6,523,423)	7,747,263	1,856,137	74,667,379	24,626,288	(26,048,589)	(26,362,956)
44 2/6	(72,244,334)	(75,184,329)	(52,444,334)	4	27	(72,244,334)	(8,280,659)	8,519,173	(6,834,939)	8,822,223	2,099,871	79,832,189	31,382,666	(31,708,285)	(30,858,964)
45 2/7	(55,544,982)	(65,131,696)	(35,744,982)	15	36	(55,544,982)	(6,935,005)	7,660,922	(5,921,063)	8,391,512	2,062,196	78,277,677	25,431,442	(40,435,532)	(35,814,791)
(Unoccupied Days)															
6 7/27	(45,480,319)	(45,480,319)	(45,480,319)	0	0	(34,165,865)			(4,134,574)	0	0	0	17,504,445	(1,893,140)	
7 7/28	(51,827,399)	(51,827,399)	(51,827,399)	0	0	(51,693,236)			(4,711,582)	0	0	0	14,676,995	(466,546)	
13 8/17	(63,233,399)	(63,233,399)	(63,233,399)	0	0	(63,233,399)			(4,180,371)	0	0	0	(248,635)	11,052,938	
19 10/5	(1,330,663)	(1,330,663)	(1,330,663)	0	0	(1,330,663)			(120,969)	0	0	0	1,200,104	(1,200,104)	
20 10/6	(7,097,665)	(7,097,665)	(7,097,665)	0	0	(7,097,665)			(645,242)	340,298	192,411	2,501,349	3,792,389	(3,792,389)	
28 11/27	(90,265,841)	(96,928,468)	(90,265,841)	7	0	(90,265,841)			(8,811,679)	5,760,985	992,620	12,236,218	(54,081,650)	(8,725,097)	
29 11/28	(74,548,323)	(76,245,037)	(74,548,323)	2	0	(74,548,323)			(6,931,367)	4,639,683	871,906	11,334,783	9,841,918	(9,841,918)	
30 11/29	(65,316,536)	(70,451,793)	(65,316,536)	7	0	(65,316,536)			(6,404,708)	5,802,784	742,351	9,650,559	15,349,687	(15,349,687)	
31 11/30	(107,930,748)	(109,977,073)	(107,930,748)	2	0	(107,930,748)			(9,997,916)	4,795,975	3,319,242	42,455,408	50,365,917	(20,504,713)	
32 12/1	(32,787,697)	(34,770,926)	(32,787,697)	6	0	(32,787,697)			(3,160,993)	3,887,302	3,963,560	48,946,521	29,740,854	(12,361,054)	

Table C-47: Free Cooling vs. Mechanical Cooling COP's For Present Building Cooling Requirements

Outside Temperature (degF)	Cooling Load (Btu/hr)	Free Cooling Flow rate (cfm)	Free Cooling Fan Power (kW)	Free Cooling COP Net	AC-1 Mechanical Cooling Flow rate (cfm)	AC-2 Mechanical Cooling Flow rate (cfm)	AC-3 Mechanical Cooling Flow rate (cfm)	Total Mechanical Cooling Flow rate (cfm)	Mechanical Cooling Fan Power (kW)	Mechanical Cooling COP Net
30	4,202,514	86,471	3	480.10	112,580	100,761	81,474	294,815	102	3.76
40	4,202,514	111,178	5	225.89	105,269	98,702	77,706	281,677	89	3.91
50	4,202,514	155,649	15	82.32	97,958	96,643	84,683	279,284	86	3.94
51	4,202,514	162,134	17	72.83	97,227	96,437	85,606	279,269	86	3.94
52	4,202,514	169,183	19	64.10	96,496	92,841	86,528	275,865	83	3.98
53	4,202,514	176,873	22	56.10	95,764	93,336	87,450	276,550	84	3.97
54	4,202,514	185,296	25	48.79	95,033	93,830	88,372	277,236	85	3.97
55	4,202,514	194,561	29	42.15	94,302	94,325	89,294	277,921	85	3.96
56	4,202,514	204,801	34	36.14	93,571	94,819	90,217	278,607	86	3.95
57	4,202,514	216,179	40	30.73	92,840	95,314	91,139	279,293	86	3.94
58	4,202,514	228,895	48	25.88	92,109	95,808	92,061	279,978	87	3.93
59	4,202,514	243,201	57	21.58	91,378	96,303	92,983	280,664	88	3.93
60	4,202,514	259,414	69	17.78	90,647	96,797	93,905	281,349	88	3.51
61	4,436,308	293,407	100	12.97	92,702	97,292	94,828	284,821	92	3.60
62	4,645,687	330,889	144	9.47	93,793	97,786	95,750	287,329	94	3.67
63	4,855,066	374,619	209	6.82	94,884	98,281	96,672	289,837	97	3.75
64	5,064,444	426,300	307	4.83	95,975	98,775	97,594	292,344	99	3.81
65	5,273,823	488,317	462	3.35	97,066	99,270	98,516	294,852	102	3.86
66	5,483,202	564,115	712	2.26	98,157	99,764	99,439	297,360	104	3.91
67	5,692,581	658,864	1,135	1.47	99,248	100,259	100,361	299,868	107	3.95
68	5,901,960	780,682	1,887	0.92	100,339	100,753	101,283	302,375	110	3.98

Notes:
1. Maximum possible Transportation Building fan flow rate is 600,000 cfm.
2. Cooling Loads from Figure 5-3a
3. Free Cooling Fan Flow Rate = Cooling Load/(1.08 x (75-Tout))
4. Free Cooling Fan Power calculated with equation 4-4
5. Free Cooling COP net = Cooling Load/Fan Power
6. Mechanical Fan Flow rate calculated using equations in Table 4-3.
7. Mechanical Cooling COP net = Cooling Load/(Fans + Heat Pumps + Pumps + Cooling Towers power use)

Table C-48: Monitored Heating Sources and Uses

Daily Average Outdoor Temp	Occupied Heat Pump Hot Water Supply (Btu/hr)	Occupied Tank Heating Source (Btu/hr)	Occupied Tank Heating Use (Btu/hr)	Occupied Reheat (Btu/hr)	Occupied Daily Average Conduction (Btu/lb)	Occupied Total Outdoor Air Load (Btu/hr)	Heat Due to 24 hrs. Lighting (Btu/hr)
13	59,492,621	0	629,710	4,045,509	34,639,698	36,259,187	10,466,136
13	72,506,632	0	1,259,420	1,872,045	33,617,878	31,863,573	10,466,136
19	72,506,632	0	0	9,586,714	29,837,144	27,618,960	10,466,136
22	57,013,762	0	0	15,402,224	30,348,054	28,070,089	10,466,136
24	60,732,050	0	5,247,585	2,774,657	26,516,229	26,032,280	10,466,136
26	78,084,065	0	839,614	2,939,995	27,895,686	28,405,857	10,466,136
27	62,591,195	1,049,517	0	4,894,912	26,005,319	25,889,960	10,466,136
28	73,746,061	0	214,901	4,786,803	23,195,314	38,541,455	0
29	70,027,772	0	0	6,319,037	21,713,675	30,138,031	0
32	86,760,072	419,807	0	15,530,443	26,311,865	27,389,991	10,466,136
35	69,408,058	0	3,988,165	6,112,597	23,604,042	23,899,678	10,466,136
40	79,323,494	0	11,104,889	16,797,206	19,465,671	19,237,051	10,466,136
43	61,351,765	0	6,507,005	6,604,819	17,422,031	17,284,542	0
43	50,816,614	0	5,667,392	7,781,503	17,422,031	13,947,829	0
46	86,140,357	0	6,232,132	9,458,246	13,385,842	20,194,513	0
49	49,577,184	6,297,102	0	5,280,090	15,122,936	25,269,545	0
53	31,295,598	0	7,556,522	6,193,195	8,838,743	5,181,859	0
55	57,013,762	0	12,961,535	17,257,558	8,225,651	15,554,649	0
55	76,844,635	1,661,735	0	28,506,636	11,137,838	8,742,424	0
57	30,366,025	0	15,620,311	4,757,872	7,357,104	0	0
58	83,041,783	0	13,223,914	25,702,140	10,473,655	8,465,847	0
59	14,253,440	0	0	7,409,969	6,641,830	0	0
63	25,718,164	3,463,406	0	17,963,878	4,904,736	4,473,680	0

Table C-49(a): Monitored Cooling Sources and Uses

Daily Average Outdoor Temp	Occupied Heat Pump Cooling Supply (Btu/hr)	Occupied Tank Cooling Source (Btu/hr)	Occupied Tank Cooling Use (Btu/hr)	Occupied Total Outdoor Air Clg.Source (Btu/hr)	Occupied Total Outdoor Air Clg.Use (Btu/hr)	Reheat (Btu/hr)	Occupied Daily Average Conduction (Btu/hr)	Internal Gains (Btu/hr)
13	50,466,775	0	8,606,039	31,863,573	0	21,672,045	0	48,900,000
13	49,387,271	0	10,075,363	36,259,187	0	23,845,509	0	48,900,000
19	48,847,520	0	11,334,784	27,618,960	0	29,386,714	0	48,900,000
22	44,604,473	0	(0)	28,070,089	0	35,202,224	0	48,900,000
24	47,498,141	0	7,136,716	26,032,280	0	22,574,657	0	48,900,000
26	46,778,472	0	(0)	28,405,857	0	22,739,995	0	48,900,000
27	46,598,555	0	(0)	25,889,960	0	24,694,912	0	48,900,000
28	50,273,738	0	8,686,003	38,541,455	0	4,786,803	0	38,500,000
29	59,035,331	0	14,063,528	30,138,031	0	6,319,037	0	38,500,000
32	56,270,978	0	(0)	27,389,991	0	35,330,443	0	48,900,000
35	47,857,975	0	(0)	23,899,678	0	25,912,597	0	48,900,000
40	38,419,819	(0)	(0)	19,237,051	0	36,597,206	0	48,900,000
43	36,883,026	(0)	(0)	13,947,829	0	7,781,503	0	38,500,000
43	31,485,510	(0)	(0)	17,284,542	0	6,604,819	0	38,500,000
46	(0)	(0)	(0)	52,994,955	0	0	0	38,500,000
46	53,084,945	0	0	20,194,513	0	9,458,246	0	38,500,000
49	30,136,131	(0)	(0)	25,269,545	0	5,280,090	0	38,500,000
53	13,943,583	(0)	(0)	43,297,577	0	2,193,262	0	38,500,000
53	25,188,408	(0)	(0)	53,174,359	0	6,193,195	0	38,500,000
55	73,559,897	0	1,661,735	8,742,424	0	28,506,636	0	38,500,000
55	28,112,063	(0)	(0)	25,275,789	0	17,257,558	0	38,500,000
57	21,590,064	(0)	(0)	24,394,015	0	4,757,872	0	38,500,000
58	71,067,294	(0)	(0)	8,465,847	0	25,702,140	0	38,500,000
59	14,843,169	0	1,329,388	12,851,963	0	7,409,969	0	38,500,000
63	24,288,822	(0)	(0)	28,322,817	0	17,963,878	0	38,500,000
66	49,477,230	9,305,717	0	8,915,852	0	0	0	38,500,000
70	76,914,603	6,646,941	0	0	35,907	0	0	38,500,000
71	73,091,363	0	10,967,453	0	3,783,635	0	0	38,500,000
72	40,762,491	8,308,676	0	0	8,813,890	0	919,638	38,500,000
74	97,605,081	0	0	0	9,900,417	0	3,167,642	38,500,000
75	70,617,501	4,985,206	0	0	7,100,343	0	1,072,911	38,500,000
76	58,566,797	332,347	0	0	12,430,111	0	970,729	38,500,000
76	84,804,722	21,270,211	0	0	9,821,596	0	1,686,003	38,500,000
80	84,561,084	8,973,370	0	0	12,677,239	0	4,955,827	38,500,000
84	90,408,393	11,632,147	0	0	20,538,285	0	6,948,376	38,500,000

Table C-49(b): Unoccupied Hours Conduction Loads and Internal Gains Balance

Average Daily Outdoor Temp. (degF)	Daily Unoccupied Hours Conduction (Btu/day)	Daily Total Conduction (Btu/day)	Weekday Unoccupied Hours Internal Gain (Btu/day)	Weekday Unoccupied Hours Net Heating Heating Load (Btu/day)	Weekend Unoccupied Hours Internal Gains (Btu/day)	Weekend Unoccupied Hours Net Heating Heating Load (Btu/day)	Weekday Unoccupied Hours Internal Gains w/24 hr lights (Btu/day)	Weekday Unoccupied Hours Net Heating Heating Load w/24 hr lights (Btu/day)	Weekend Unoccupied Hours Internal Gains w/24 hr lights (Btu/day)	Weekend Unoccupied Hours Net Heating Heating Load w/24 hr lights (Btu/day)
0	(47,588,931)	(87,059,064)	22,467,636	(25,121,295)	9,664,663	(77,394,401)	43,810,395	(3,778,536)	77,302,812	(9,756,252)
10	(41,315,271)	(74,797,224)	22,467,636	(18,847,635)	9,664,663	(65,132,561)	43,810,395	2,495,124	77,302,812	2,505,588
20	(35,041,611)	(62,535,384)	22,467,636	(12,573,975)	9,664,663	(52,870,721)	43,810,395	8,768,784	77,302,812	14,767,428
30	(28,767,951)	(50,273,544)	22,467,636	(6,300,315)	9,664,663	(40,608,881)	43,810,395	15,042,444	77,302,812	27,029,268
40	(22,494,291)	(38,011,704)	22,467,636	(26,655)	9,664,663	(28,347,041)	43,810,395	21,316,104	77,302,812	39,291,108
50	(16,220,631)	(25,749,864)	22,467,636	6,247,005	9,664,663	(16,085,201)	43,810,395	27,589,764	77,302,812	51,552,948
60	(9,946,971)	(13,488,024)	22,467,636	12,520,665	9,664,663	(3,823,361)	43,810,395	33,863,424	77,302,812	63,814,788
70	(3,673,311)	(1,226,184)	22,467,636	18,794,325	9,664,663	8,438,479	43,810,395	40,137,084	77,302,812	76,076,628

Equations:

1. Daily Unoccupied Conduction = (Tout * 627,366) - 47,588,931
2. Net Heating Load = Conduction Load + Internal Gains
3. Weekend values use total day internal gains and total day conduction
4. Daily Total Conduction = 51,091 * (Tout - 71) *24

Table C-49(c): Occupied and Unoccupied Heating and Cooling Loads

(a) OA temp	(b) Occupied Monitored Htgld	(c) Occupied Monitored Clgld	(d) Occupied Pred. Clgld(1.26)	(e) Occupied Present Heating Supplied	(f) Occupied Predicted Heating Supplied	(g) Occupied Present Net Auxiliary Heating	(h) Occupied Predicted Net Auxiliary Heating	(i) (cond+intgn) Unoccupied Present Heating Required	(j) (cond+intgn) Unoccupied Predicted Heating Required	(k) Daily Total Present Heating Load	(l) Daily Total Present Predicted Load	(m) Occupied Daily Present Net Auxiliary Heating Required	(n) Occupied Daily Predicted Net Auxiliary Heating Required	(o) Present Daily Occupied OA Load	(p) Future Daily Occupied OA Load	(q) Present Daily Unoccupied OA Load
10	(94,235,816)	46,227,650	61,939,650	55,700,586	76,281,076	(38,535,230)	(17,954,740)	(19,496,636)	(3,821,636)	(113,732,452)	(98,057,452)	(58,031,866)	(21,776,376)	(39,340,097)	(35,763,725)	(48,958,311)
20	(78,200,886)	46,227,650	61,939,650	55,700,586	76,281,076	(22,500,300)	(1,919,810)	(13,222,976)	2,452,024	(91,423,862)	(75,748,862)	(35,723,276)	532,214	(32,231,627)	(29,301,479)	(37,130,421)
30	(62,165,956)	46,227,650	61,939,650	55,700,586	76,281,076	(6,465,370)	14,115,120	(6,949,316)	8,725,684	(69,115,272)	(53,440,272)	(13,414,686)	22,840,804	(25,123,157)	(22,839,234)	(25,302,531)
40	(46,131,026)	46,227,650	61,939,650	55,700,586	76,281,076	9,569,560	30,150,050	(675,656)	14,999,344	(46,806,682)	(31,131,682)	8,893,904	45,149,394	(18,014,687)	(16,376,988)	(13,474,641)
50	(30,096,096)	46,227,650	61,939,650	55,700,586	76,281,076	25,604,490	46,184,980	5,598,004	21,273,004	(24,498,092)	(8,823,092)	31,202,494	67,457,984	(10,906,217)	(9,914,743)	(1,646,751)
60	(14,061,166)	46,227,650	61,939,650	55,700,586	76,281,076	41,639,420	62,219,910	11,871,664	27,546,664	(2,189,502)	13,485,498	53,511,084	89,766,574	(3,797,747)	(3,452,497)	0
70	1,973,764	69,527,890	87,605,141													
80	18,008,694	92,559,560	116,625,046													
90	34,043,624	115,591,230	145,644,950													

(r) Future Daily Unoccupied OA Load	(s) Total Present Occupied Day OA Load	(t) Total Future Occupied Day OA Load	(u) Btu/day Saved	(v) Present New Daily Heating Load (airhndl)	(w) Present New Auxiliary Heating Required	(x) Predicted New Daily Heating Load (airhndl)	(y) Predicted New Auxiliary Heating Required
(8,509,177)	(88,298,408)	(44,352,902)	43,945,506	(69,786,946)	(14,086,360)	(54,111,946)	22,169,130
(6,514,109)	(69,362,048)	(35,815,588)	33,546,460	(57,877,402)	(2,176,816)	(42,202,402)	34,078,674
(4,439,041)	(50,425,688)	(27,278,274)	23,147,414	(45,967,858)	9,732,728	(30,292,858)	45,988,218
(2,363,972)	(31,489,328)	(18,740,960)	12,748,368	(34,058,314)	21,642,272	(18,383,314)	57,897,762
(288,904)	(12,552,968)	(10,203,646)	2,349,322	(22,148,770)	33,551,816	(6,473,770)	69,807,306
0	(3,797,747)	(3,452,497)	345,250	(1,844,252)	53,856,334	13,830,748	90,111,824

Equations:

```
B10: (,0) -((-1603493*A10)+110270746)
C10: (,0) 46227650
D10: (,0) +C10+15712000
E10: (,0) +C10+9472936
F10: (,0) +D10+14341426
G10: (,0) +E10+B10
H10: (,0) +F10+B10
I10: (,0) (A10*627366)-47588931+21818635
J10: (,0) (A10*627366)-47588931+21818635+15675000
K10: (,0) +B10+I10
L10: (,0) +B10+J10
M10: (,0) +G10+I10
N10: (,0) +H10+J10
O10: (,0) (710847*A10)-46448567
P10: (,0) +O10*30/33
Q10: (,0) (A10*1182789)-60786201
R10: (,0) +Q10*10/57
S10: (,0) +O10+Q10
T10: (,0) +P10+R10
U10: (,0) -(S10-T10)
V10: (,0) +B10+I10+U10
W10: (,0) +V10+E10
X10: (,0) +B10+J10+U10
Y10: (,0) +F10+X10
```

Table C-50: Weekly Net Auxiliary Heating Requirements

M	D	Y	Wkly Ave. Temp. (degF)	Wkly Net Heat (base)	Wkly Net Heat (oa dampers)	Wkly Net Heat (retail)	Wkly Net Heat (OA&Ret)	
1	6	85	31	(76,557,506)	24,620,998	1,817,494	102,995,998	1
1	13	85	22	(219,262,326)	(53,609,774)	(140,887,326)	24,765,226	2
1	20	85	22	(209,362,763)	(48,909,731)	(130,987,763)	29,465,269	3
1	27	85	23	(187,681,539)	(37,627,547)	(109,306,539)	40,747,453	4
2	3	85	27	(137,418,065)	(8,162,153)	(59,043,065)	70,212,847	5
2	10	85	20	(240,316,184)	(64,264,592)	(161,941,184)	14,110,408	6
2	17	85	34	(46,371,763)	43,367,797	32,003,237	121,742,797	7
2	24	85	42	13,789,255	86,890,351	92,164,255	165,265,351	8
3	3	85	41	26,757,511	87,379,759	105,132,511	165,754,759	9
3	10	85	35	(62,198,244)	41,060,068	16,176,756	119,435,068	10
3	17	85	43	62,800,016	105,743,896	141,175,016	184,118,896	11
3	24	85	37	(33,824,443)	55,915,117	44,550,557	134,290,117	12
3	31	85	46	108,950,533	132,136,237	187,325,533	210,511,237	13
4	7	85	46	67,608,476	116,791,780	145,983,476	195,166,780	14
11	24	85	48	135,093,475	145,800,331	213,468,475	224,175,331	47
12	1	85	36	(43,026,484)	49,832,788	35,348,516	128,207,788	48
12	8	85	34	(58,223,580)	38,795,308	20,151,420	117,170,308	49
12	15	85	34	(34,519,946)	47,940,286	43,855,054	126,315,286	50
12	22	85	25	(164,466,978)	(23,772,122)	(86,091,978)	54,602,878	51
12	29	85	30	(99,214,857)	13,402,591	(20,839,857)	91,777,591	52
1	5	86	34	(39,079,115)	44,816,184	39,295,885	123,191,184	53
1	12	86	30	(129,921,405)	1,019,152	(51,546,405)	79,394,152	54
1	19	86	32	(137,457,832)	4,880,072	(59,082,832)	83,255,072	55
1	26	86	39	(8,460,237)	69,289,230	69,914,763	147,664,230	56

Equations:

Weekly Net Auxiliary Heating = Sum of Weekday Auxiliary Heating + Sum of Weekend Auxiliary Heating
Present Weekday Heating = (Tout*2,230,859)-80,340,456
w/Retail Weekday Heating = (Tout*2,230,859)-64,665,456
w/Air Handler Improvements Weekday Heating = -((Tout*1,039,904)-54,344,552)
+(-80,340,456)+(Tout*2,230,859)
w/Retail and Air Hndlr Imprvnts Weekday Heating = -((Tout*1,039,904)-54,344,552)
+(-80,340,456)+(Tout*2,230,859)+15,675,000
Tout = Average Daily Outdoor Air Temperature

Table C-51: Potential For Part-Load Storage Tank Cooling

Month	Day	Ave. Outdoor Temp (degF)	Day #	Present Daily Cooling Load (Btu/hr)	Daily Storage Tank Cooling Demand (Btu/hr)	Peak Cooling Load Above 600 tons (Btu/hr)	Montnly Peak and Monthly Total Storage Tank Cooling (Btu/hr)	w/Retail Daily Cooling Load (Btu/hr)	w/Retail Daily Storage Tank Cooling Demand (Btu/hr)	w/Retail Peak Cooling Load Above 600 tons (Btu/hr)	w/Retail Monthly Peak and Monthly Total Storage Tank Cooling (Btu/hr)
4	25	54	120	46,227,650				61,939,650			
4	26	69	121	67,224,723				84,703,151	5,503,151	1,270,315	
	27	56	122	46,227,650				61,939,650		0	
4	28	55	123	46,227,650				61,939,650		0	
4	29	55	124	46,227,650				61,939,650		0	
	30	66	125	60,315,222				75,997,180	0	399,718	
5	1	66	126	60,315,222				75,997,180	0	399,718	
5	2	52	127	46,227,650				61,939,650		0	
5	3	44	128	46,227,650				61,939,650		0	
5	4	53	129	46,227,650				61,939,650		0	
5	5	59	130	46,227,650				61,939,650		0	
5	6	47	131	46,227,650				61,939,650		0	
5	7	56	132	46,227,650				61,939,650		0	
5	8	51	133	46,227,650				61,939,650		0	
5	9	51	134	46,227,650				61,939,650		0	
5	10	68	135	64,921,556				81,801,161	2,601,161	980,116	
5	11	76	136	83,346,892	4,146,892	1,134,689		105,017,084	25,817,084	3,301,708	
5	12	55	137	46,227,650				61,939,650		0	
5	13	64	138	55,708,888			1,134,689	70,193,199		0	3,301,708
5	14	57	139	46,227,650			4,146,892	61,939,650		0	33,921,395
5	15	53	140	46,227,650				61,939,650		0	
5	16	61	141	48,799,387				61,487,228		0	
5	17	62	142	51,102,554				64,389,218		0	
5	18	57	143	46,227,650				61,939,650		0	
5	19	54	144	46,227,650				61,939,650		0	
5	20	69	145	67,224,723				84,703,151	5,503,151	1,270,315	
5	21	69	146	67,224,723				84,703,151	5,503,151	1,270,315	
5	22	67	147	62,618,389				78,899,170	0	689,917	
5	23	58	148	46,227,650				61,939,650	0	0	
5	24	61	149	48,799,387				61,487,228	0	0	
5	25	62	150	51,102,554				64,389,218	0	0	
5	26	59	151	46,227,650				61,939,650	0	0	
5	27	70	152	69,527,890				87,605,141	8,405,141	1,560,514	
5	28	59	153	46,227,650				61,939,650	0	0	
5	29	55	154	46,227,650				61,939,650	0	0	
5	30	61	155	48,799,387				61,487,228	0	0	
5	31	65	156	58,012,055				73,095,189	0	109,519	
6	1	70	157	69,527,890				87,605,141	8,405,141	1,560,514	
6	2	70	158	69,527,890				87,605,141	8,405,141	1,560,514	
6	3	73	159	76,437,391	0	443,739		96,311,113	17,111,113	2,431,111	
6	4	63	160	53,405,721				67,291,208	0	0	
6	5	56	161	46,227,650				61,939,650	0	0	
6	6	60	162	46,227,650				61,939,650	0	0	
6	7	64	163	55,708,888				70,193,199	0	0	
6	8	64	164	55,708,888				70,193,199	0	0	
6	9	66	165	60,315,222				75,997,180	0	399,718	
6	10	74	166	78,740,558	0	674,056		99,213,103	20,013,103	2,721,310	

Table C-51, continued (p. 2 of 4)

Month	Day	Ave. Outdoor Temp (degF)	Day #	Present Daily Cooling Load (Btu/hr)	Daily Storage Tank Cooling Demand (Btu/hr)	Peak Cooling Load Above 600 tons (Btu/hr)	Monthly Peak and Monthly Total Storage Tank Cooling (Btu/hr)	w/Retail Daily Cooling Load (Btu/hr)	w/Retail Daily Storage Tank Cooling Demand (Btu/hr)	w/Retail Peak Cooling Load Above 600 tons (Btu/hr)	w/Retail Monthly Peak and Monthly Total Storage Tank Cooling (Btu/hr)
6	11	71	167	71,831,057				90,507,132	11,307,132	1,850,713	
6	12	61	168	48,799,387			674,056	61,487,228	0	0	2,721,310
6	13	60	169	46,227,650			0	61,939,650	0	0	84,653,074
6	14	61	170	48,799,387				61,487,228	0	0	
6	15	65	171	58,012,055				73,095,189	0	109,519	
6	16	62	172	51,102,554				64,389,218	0	0	
6	17	66	173	60,315,222				75,997,180	0	399,718	
6	18	70	174	69,527,890				87,605,141	8,405,141	1,560,514	
6	19	71	175	71,831,057				90,507,132	11,307,132	1,850,713	
6	20	71	176	71,831,057				90,507,132	11,307,132	1,850,713	
6	21	68	177	64,921,556				81,801,161	2,601,161	980,116	
6	22	71	178	71,831,057				90,507,132	11,307,132	1,850,713	
6	23	71	179	71,831,057				90,507,132	11,307,132	1,850,713	
6	24	70	180	69,527,890				87,605,141	8,405,141	1,560,514	
6	25	62	181	51,102,554				64,389,218	0	0	
6	26	58	182	46,227,650				61,939,650	0	0	
6	27	55	183	46,227,650				61,939,650	0	0	
6	28	59	184	46,227,650				61,939,650	0	0	
6	29	57	185	46,227,650				61,939,650	0	0	
6	30	62	186	51,102,554				64,389,218	0	0	
7	1	62	187	51,102,554				64,389,218	0	0	
7	2	68	188	64,921,556				81,801,161	2,601,161	980,116	
7	3	72	189	74,134,224	0	213,422		93,409,122	14,209,122	2,140,912	
7	4	76	190	83,346,892	4,146,892	1,134,689		105,017,084	25,817,084	3,301,708	
7	5	74	191	78,740,558	0	674,056		99,213,103	20,013,103	2,721,310	
7	6	77	192	85,650,059	6,450,059	1,365,006		107,919,074	28,719,074	3,591,907	
7	7	78	193	87,953,226	8,753,226	1,595,323		110,821,065	31,621,065	3,882,106	
7	8	72	194	74,134,224	0	213,422		93,409,122	14,209,122	2,140,912	
7	9	71	195	71,831,057	0	0		90,507,132	11,307,132	1,850,713	
7	10	77	196	85,650,059	6,450,059	1,365,006		107,919,074	28,719,074	3,591,907	
7	11	77	197	85,650,059	6,450,059	1,365,006		107,919,074	28,719,074	3,591,907	
7	12	72	198	74,134,224	0	213,422		93,409,122	14,209,122	2,140,912	
7	13	72	199	74,134,224	0	213,422		93,409,122	14,209,122	2,140,912	
7	14	76	200	83,346,892	4,146,892	1,134,689		105,017,084	25,817,084	3,301,708	
7	15	78	201	87,953,226	8,753,226	1,595,323	1,595,323	110,821,065	31,621,065	3,882,106	3,882,106
7	16	77	202	85,650,059	6,450,059	1,365,006	45,150,413	107,919,074	28,719,074	3,591,907	356,431,375
7	17	71	203	71,831,057	0	0		90,507,132	11,307,132	1,850,713	
7	18	70	204	69,527,890	0	0		87,605,141	8,405,141	1,560,514	
7	19	76	205	83,346,892	4,146,892	1,134,689		105,017,084	25,817,084	3,301,708	
7	20	82	206	97,165,894	17,965,894	2,516,589		122,429,026	43,229,026	5,042,903	
7	21	77	207	85,650,059	6,450,059	1,365,006		107,919,074	28,719,074	3,591,907	
7	22	76	208	83,346,892	4,146,892	1,134,689		105,017,084	25,817,084	3,301,708	
7	23	71	209	71,831,057	0	0		90,507,132	11,307,132	1,850,713	
7	24	72	210	74,134,224	0	213,422		93,409,122	14,209,122	2,140,912	
7	25	74	211	78,740,558	0	674,056		99,213,103	20,013,103	2,721,310	
7	26	76	212	83,346,892	4,146,892	1,134,689		105,017,084	25,817,084	3,301,708	
7	27	74	213	78,740,558	0	674,056		99,213,103	20,013,103	2,721,310	

Table C-51, continued (p. 3 of 4)

Month	Day	Ave. Outdoor Temp (degF)	Day #	Present Daily Cooling Load (Btu/hr)	Daily Storage Tank Cooling Demand (Btu/hr)	Peak Cooling Load Above 600 tons (Btu/hr)	Monthly Peak and Monthly Total Storage Tank Cooling (Btu/hr)	w/Retail Daily Cooling Load (Btu/hr)	w/Retail Daily Storage Tank Cooling Demand (Btu/hr)	w/Retail Peak Cooling Load Above 600 tons (Btu/hr)	w/Retail Monthly Peak and Monthly Total Storage Tank Cooling (Btu/hr)
7	28	68	214	64,921,556	0	0		81,801,161	2,601,161	980,116	
7	29	73	215	76,437,391	0	443,739		96,311,113	17,111,113	2,431,111	
7	30	78	216	87,953,226	8,753,226	1,595,323		110,821,065	31,621,065	3,882,106	
7	31	66	217	60,315,222	0	0		75,997,180	0	399,718	
8	1	67	218	62,618,389		0		78,899,170	0	689,917	
8	2	64	219	55,708,888		0		70,193,199	0	0	
8	3	68	220	64,921,556		0		81,801,161	2,601,161	980,116	
8	4	71	221	71,831,057		0		90,507,132	11,307,132	1,850,713	
8	5	73	222	76,437,391	0	443,739		96,311,113	17,111,113	2,431,111	
8	6	74	223	78,740,558	0	674,056		99,213,103	20,013,103	2,721,310	
8	7	71	224	71,831,057	0	0		90,507,132	11,307,132	1,850,713	
8	8	72	225	74,134,224	0	213,422		93,409,122	14,209,122	2,140,912	
8	9	74	226	78,740,558	0	674,056		99,213,103	20,013,103	2,721,310	
8	10	74	227	78,740,558	0	674,056		99,213,103	20,013,103	2,721,310	
8	11	78	228	87,953,226	8,753,226	1,595,323		110,821,065	31,621,065	3,882,106	
8	12	70	229	69,527,890	0	0		87,605,141	8,405,141	1,560,514	
8	13	66	230	60,315,222	0	0		75,997,180	0	399,718	
8	14	80	231	92,559,560	13,359,560	2,055,956	2,516,589	116,625,046	37,425,046	4,462,505	5,042,903
8	15	84	232	101,772,228	22,572,228	2,977,223	74,172,700	128,233,007	49,033,007	5,623,301	508,732,718
8	16	75	233	81,043,725	1,843,725	904,373		102,115,094	22,915,094	3,011,509	
8	17	74	234	78,740,558	0	674,056		99,213,103	20,013,103	2,721,310	
8	18	70	235	69,527,890	0	0		87,605,141	8,405,141	1,560,514	
8	19	65	236	58,012,055	0	0		73,095,189	0	109,519	
8	20	71	237	71,831,057	0	0		90,507,132	11,307,132	1,850,713	
8	21	71	238	71,831,057	0	0		90,507,132	11,307,132	1,850,713	
8	22	68	239	64,921,556	0	0		81,801,161	2,601,161	980,116	
8	23	68	240	64,921,556	0	0		81,801,161	2,601,161	980,116	
8	24	70	241	69,527,890	0	0		87,605,141	8,405,141	1,560,514	
8	25	67	242	62,618,389	0	0		78,899,170	0	689,917	
8	26	67	243	62,618,389	0	0		78,899,170	0	689,917	
8	27	73	244	76,437,391	0	443,739		96,311,113	17,111,113	2,431,111	
8	28	75	245	81,043,725	1,843,725	904,373		102,115,094	22,915,094	3,011,509	
8	29	67	246	62,618,389	0	0		78,899,170	0	689,917	
8	30	62	247	51,102,554	0	0		64,389,218	0	0	
8	31	58	248	46,227,650	0	0		61,939,650	0	0	
9	1	61	249	48,799,387	0	0		61,487,228	0	0	
9	2	65	250	58,012,055	0	0		73,095,189	0	109,519	
9	3	70	251	69,527,890	0	0		87,605,141	8,405,141	1,560,514	
9	4	80	252	92,559,560	13,359,560	2,055,956		116,625,046	37,425,046	4,462,505	
9	5	74	253	78,740,558	0	674,056		99,213,103	20,013,103	2,721,310	
9	6	65	254	58,012,055	0	0		73,095,189	0	109,519	
9	7	66	255	60,315,222	0	0		75,997,180	0	399,718	
9	8	78	256	87,953,226	8,753,226	1,595,323		110,821,065	31,621,065	3,882,106	
9	9	67	257	62,618,389	0	0		78,899,170	0	689,917	
9	10	61	258	48,799,387	0	0		61,487,228	0	0	
9	11	59	259	46,227,650	0	0		61,939,650	0	0	
9	12	57	260	46,227,650	0	0		61,939,650	0	0	

Table C-51, continued (p. 4 of 4)

Month	Day	Ave. Outdoor Temp (degF)	Day #	Present Daily Cooling Load (Btu/hr)	Daily Storage Tank Cooling Demand (Btu/hr)	Peak Cooling Load Above 600 tons (Btu/hr)	Monthly Peak and Monthly Total Storage Tank Cooling (Btu/hr)	w/Retail Daily Cooling Load (Btu/hr)	w/Retail Daily Storage Tank Cooling Demand (Btu/hr)	w/Retail Peak Cooling Load Above 600 tons (Btu/hr)	w/Retail Monthly Peak and Monthly Total Storage Tank Cooling (Btu/hr)
9	13	53	261	46,227,650	0	0	2,977,223	61,939,650	0	0	5,623,301
9	14	59	262	46,227,650	0	0	48,372,464	61,939,650	0	0	274,078,632
9	15	61	263	48,799,387	0	0		61,487,228	0	0	
9	16	60	264	46,227,650	0	0		61,939,650	0	0	
9	17	62	265	51,102,554	0	0		64,389,218	0	0	
9	18	66	266	60,315,222	0	0		75,997,180	0	399,718	
9	19	72	267	74,134,224	0	213,422		93,409,122	14,209,122	2,140,912	
9	20	77	268	85,650,059	6,450,059	1,365,006		107,919,074	28,719,074	3,591,907	
9	21	76	269	83,346,892	4,146,892	1,134,689		105,017,084	25,817,084	3,301,708	
9	22	65	270	58,012,055		0		73,095,189	0	109,519	
9	23	62	271	51,102,554		0		64,389,218	0	0	
9	24	67	272	62,618,389		0		78,899,170	0	689,917	
9	25	66	273	60,315,222		0		75,997,180	0	399,718	
9	26	59	274	46,227,650		0		61,939,650	0	0	
9	27	68	275	64,921,556		0		81,801,161	2,601,161	980,116	
9	28	66	276	60,315,222		0		75,997,180	0	399,718	
9	29	61	277	48,799,387		0		61,487,228	0	0	
9	30	55	278	46,227,650		0		61,939,650	0	0	
10	1	66	279	60,315,222		0		75,997,180	0	399,718	
10	2	69	280	67,224,723		0		84,703,151	5,503,151	1,270,315	
10	3	58	281	46,227,650		0		61,939,650	0	0	
10	4	55	282	46,227,650		0		61,939,650	0	0	
10	5	63	283	53,405,721		0		67,291,208	0	0	
10	6	57	284	46,227,650		0		61,939,650	0	0	
10	7	55	285	46,227,650		0		61,939,650	0	0	
10	8	53	286	46,227,650		0		61,939,650	0	0	
10	9	63	287	53,405,721		0		67,291,208	0	0	
10	10	67	288	62,618,389		0		78,899,170	0	689,917	
10	11	55	289	46,227,650		0	1,365,006	61,939,650	0	0	3,591,907
10	12	46	290	46,227,650		0	10,596,951	61,939,650	0	0	76,849,592
10	13	53	291	46,227,650		0		61,939,650	0	0	
10	14	56	292	46,227,650		0		61,939,650	0	0	
10	15	66	293	60,315,222		0		75,997,180	0	399,718	
10	16	60	294	46,227,650		0		61,939,650		0	

Equations:

1. Present Daily Cooling Load: if Tout<= 60 then PDCL = 46,227,650 else PDCL = (2,303,167 * Tout) - 91,693,800
2. Retail Daily Cooling Load: if Tout<= 60 then RDCL = PDCL + 15,712,000 else RDCL = PDCL * 1.26
3. Peak Load = Daily Load * 1.1/11
4. If Peak Load > 7,200,000 then Daily Storage Tank Cooling Load = Daily Load - 11*7,200,000

Table C-52: 1985 Building Cooling Requirements

Month	Day	Ave. Outdoor Temp (degF)	Day #	Present Daily Cooling Requrmts (Btu/hr)	w/Retail Daily Cooling Requrmts (Btu/hr)	Amount Free Clg Available (Btu/hr)	Present Clg rqrd Minus Possible Free Clg (Btu/hr)	w/Retail Clg rqrd Minus Possible Free Clg (Btu/hr)
12	27	17	1	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
12	28	37	2	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
12	31	34	5	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	1	38	6	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	2	36	7	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	3	29	8	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	4	27	9	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	7	29	12	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	8	22	13	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	9	15	14	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	10	17	15	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	11	19	16	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	14	29	19	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	15	26	20	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	16	13	21	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	17	18	22	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	18	21	23	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	21	9	26	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	22	19	27	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	23	30	28	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	24	30	29	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	25	29	30	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	28	29	33	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	29	27	34	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	30	25	35	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	31	25	36	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
2	1	31	37	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
2	4	21	40	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
2	5	20	41	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
	6	20	42	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
	7	20	43	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
2	8	11	44	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
2	11	30	47	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
2	12	37	48	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
2	13	39	49	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
2	14	35	50	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
2	15	34	51	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
2	18	36	54	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
2	19	40	55	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
	20	36	56	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
2	21	33	57	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
2	22	46	58	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
2	25	49	61	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
2	26	41	62	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
2	27	40	63	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
	28	29	64	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
3	1	44	65	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
3	4	25	68	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
3	5	36	69	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)

3	6	28	70	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
3	7	29	71	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
3	8	44	72	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
3	11	45	75	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
3	12	48	76	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
3	13	46	77	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
3	14	45	78	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
3	15	36	79	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
	18	32	82	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
3	19	30	83	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
3	20	47	84	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
3	21	34	85	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
3	22	32	86	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
3	25	37	89	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
3	26	39	90	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
3	27	47	91	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
3	28	61	92	48,799,387	61,487,228	99,792,000	(50,992,613)	(38,304,772)
3	29	55	93	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
4	1	37	96	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
4	2	42	97	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
4	3	39	98	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
4	4	46	99	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
4	5	50	100	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
4	8	42	103	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
4	9	39	104	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
4	10	36	105	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
4	11	48	106	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
4	12	46	107	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
4	15	59	110	46,227,650	61,939,650	114,048,000	(67,820,350)	(52,108,350)
4	16	60	111	46,227,650	61,939,650	106,920,000	(60,692,350)	(44,980,350)
4	17	45	112	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
4	18	43	113	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
4	19	53	114	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
4	22	54	117	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
4	23	44	118	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
4	24	47	119	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
4	25	54	120	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
4	26	69	121	67,224,723	84,703,151	42,768,000	24,456,723	41,935,151
4	29	55	124	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
	30	66	125	60,315,222	75,997,180	64,152,000	(3,836,778)	11,845,180
5	1	66	126	60,315,222	75,997,180	64,152,000	(3,836,778)	11,845,180
5	2	52	127	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
5	3	44	128	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
5	6	47	131	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
5	7	56	132	46,227,650	61,939,650	135,432,000	(89,204,350)	(73,492,350)
5	8	51	133	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
5	9	51	134	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
5	10	68	135	64,921,556	81,801,161	49,896,000	15,025,556	31,905,161
5	13	64	138	55,708,888	70,193,199	78,408,000	(22,699,112)	(8,214,801)
5	14	57	139	46,227,650	61,939,650	128,304,000	(82,076,350)	(66,364,350)
5	15	53	140	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
5	16	61	141	48,799,387	61,487,228	99,792,000	(50,992,613)	(38,304,772)
5	17	62	142	51,102,554	64,389,218	92,664,000	(41,561,446)	(28,274,782)
5	20	69	145	67,224,723	84,703,151	42,768,000	24,456,723	41,935,151
5	21	69	146	67,224,723	84,703,151	42,768,000	24,456,723	41,935,151
5	22	67	147	62,618,389	78,899,170	57,024,000	5,594,389	21,875,170

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5	23	58	148	46,227,650	61,939,650	121,176,000	(74,948,350)	(59,236,350)
5	24	61	149	48,799,387	61,487,228	99,792,000	(50,992,613)	(38,304,772)
5	27	70	152	69,527,890	87,605,141	35,640,000	33,887,890	51,965,141
5	28	59	153	46,227,650	61,939,650	114,048,000	(67,820,350)	(52,108,350)
5	29	55	154	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
5	30	61	155	48,799,387	61,487,228	99,792,000	(50,992,613)	(38,304,772)
5	31	65	156	58,012,055	73,095,189	71,280,000	(13,267,945)	1,815,189
6	3	73	159	76,437,391	96,311,113	14,256,000	62,181,391	82,055,113
6	4	63	160	53,405,721	67,291,208	85,536,000	(32,130,279)	(18,244,792)
6	5	56	161	46,227,650	61,939,650	135,432,000	(89,204,350)	(73,492,350)
6	6	60	162	46,227,650	61,939,650	106,920,000	(60,692,350)	(44,980,350)
6	7	64	163	55,708,888	70,193,199	78,408,000	(22,699,112)	(8,214,801)
6	10	74	166	78,740,558	99,213,103	7,128,000	71,612,558	92,085,103
6	11	71	167	71,831,057	90,507,132	28,512,000	43,319,057	61,995,132
6	12	61	168	48,799,387	61,487,228	99,792,000	(50,992,613)	(38,304,772)
6	13	60	169	46,227,650	61,939,650	106,920,000	(60,692,350)	(44,980,350)
6	14	61	170	48,799,387	61,487,228	99,792,000	(50,992,613)	(38,304,772)
6	17	66	173	60,315,222	75,997,180	64,152,000	(3,836,778)	11,845,180
6	18	70	174	69,527,890	87,605,141	35,640,000	33,887,890	51,965,141
6	19	71	175	71,831,057	90,507,132	28,512,000	43,319,057	61,995,132
6	20	71	176	71,831,057	90,507,132	28,512,000	43,319,057	61,995,132
6	21	68	177	64,921,556	81,801,161	49,896,000	15,025,556	31,905,161
6	24	70	180	69,527,890	87,605,141	35,640,000	33,887,890	51,965,141
6	25	62	181	51,102,554	64,389,218	92,664,000	(41,561,446)	(28,274,782)
6	26	58	182	46,227,650	61,939,650	121,176,000	(74,948,350)	(59,236,350)
6	27	55	183	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
6	28	59	184	46,227,650	61,939,650	114,048,000	(67,820,350)	(52,108,350)
7	1	62	187	51,102,554	64,389,218	92,664,000	(41,561,446)	(28,274,782)
7	2	68	188	64,921,556	81,801,161	49,896,000	15,025,556	31,905,161
7	3	72	189	74,134,224	93,409,122	21,384,000	52,750,224	72,025,122
7	5	74	191	78,740,558	99,213,103	7,128,000	71,612,558	92,085,103
7	8	72	194	74,134,224	93,409,122	21,384,000	52,750,224	72,025,122
7	9	71	195	71,831,057	90,507,132	28,512,000	43,319,057	61,995,132
7	10	77	196	85,650,059	107,919,074	(14,256,000)	99,906,059	122,175,074
7	11	77	197	85,650,059	107,919,074	(14,256,000)	99,906,059	122,175,074
7	12	72	198	74,134,224	93,409,122	21,384,000	52,750,224	72,025,122
7	15	78	201	87,953,226	110,821,065	(21,384,000)	109,337,226	132,205,065
7	16	77	202	85,650,059	107,919,074	(14,256,000)	99,906,059	122,175,074
7	17	71	203	71,831,057	90,507,132	28,512,000	43,319,057	61,995,132
7	18	70	204	69,527,890	87,605,141	35,640,000	33,887,890	51,965,141
7	19	76	205	83,346,892	105,017,084	(7,128,000)	90,474,892	112,145,084
7	22	76	208	83,346,892	105,017,084	(7,128,000)	90,474,892	112,145,084
7	23	71	209	71,831,057	90,507,132	28,512,000	43,319,057	61,995,132
7	24	72	210	74,134,224	93,409,122	21,384,000	52,750,224	72,025,122
7	25	74	211	78,740,558	99,213,103	7,128,000	71,612,558	92,085,103
7	26	76	212	83,346,892	105,017,084	(7,128,000)	90,474,892	112,145,084
7	29	73	215	76,437,391	96,311,113	14,256,000	62,181,391	82,055,113
7	30	78	216	87,953,226	110,821,065	(21,384,000)	109,337,226	132,205,065
7	31	66	217	60,315,222	75,997,180	64,152,000	(3,836,778)	11,845,180
8	1	67	218	62,618,389	78,899,170	57,024,000	5,594,389	21,875,170
8	2	64	219	55,708,888	70,193,199	78,408,000	(22,699,112)	(8,214,801)
8	5	73	222	76,437,391	96,311,113	14,256,000	62,181,391	82,055,113
8	6	74	223	78,740,558	99,213,103	7,128,000	71,612,558	92,085,103
8	7	71	224	71,831,057	90,507,132	28,512,000	43,319,057	61,995,132
8	8	72	225	74,134,224	93,409,122	21,384,000	52,750,224	72,025,122
8	9	74	226	78,740,558	99,213,103	7,128,000	71,612,558	92,085,103

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8	12	70	229	69,527,890	87,605,141	35,640,000	33,887,890	51,965,141
8	13	66	230	60,315,222	75,997,180	64,152,000	(3,836,778)	11,845,180
8	14	80	231	92,559,560	116,625,046	(35,640,000)	128,199,560	152,265,046
8	15	84	232	101,772,228	128,233,007	(64,152,000)	165,924,228	192,385,007
8	16	75	233	81,043,725	102,115,094	0	81,043,725	102,115,094
8	19	65	236	58,012,055	73,095,189	71,280,000	(13,267,945)	1,815,189
8	20	71	237	71,831,057	90,507,132	28,512,000	43,319,057	61,995,132
8	21	71	238	71,831,057	90,507,132	28,512,000	43,319,057	61,995,132
8	22	68	239	64,921,556	81,801,161	49,896,000	15,025,556	31,905,161
8	23	68	240	64,921,556	81,801,161	49,896,000	15,025,556	31,905,161
8	26	67	243	62,618,389	78,899,170	57,024,000	5,594,389	21,875,170
8	27	73	244	76,437,391	96,311,113	14,256,000	62,181,391	82,055,113
8	28	75	245	81,043,725	102,115,094	0	81,043,725	102,115,094
8	29	67	246	62,618,389	78,899,170	57,024,000	5,594,389	21,875,170
9	3	70	251	69,527,890	87,605,141	35,640,000	33,887,890	51,965,141
9	4	80	252	92,559,560	116,625,046	(35,640,000)	128,199,560	152,265,046
9	5	74	253	78,740,558	99,213,103	7,128,000	71,612,558	92,085,103
9	6	65	254	58,012,055	73,095,189	71,280,000	(13,267,945)	1,815,189
9	9	67	257	62,618,389	78,899,170	57,024,000	5,594,389	21,875,170
9	10	61	258	48,799,387	61,487,228	99,792,000	(50,992,613)	(38,304,772)
9	11	59	259	46,227,650	61,939,650	114,048,000	(67,820,350)	(52,108,350)
9	12	57	260	46,227,650	61,939,650	128,304,000	(82,076,350)	(66,364,350)
9	13	53	261	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
9	16	60	264	46,227,650	61,939,650	106,920,000	(60,692,350)	(44,980,350)
9	17	62	265	51,102,554	64,389,218	92,664,000	(41,561,446)	(28,274,782)
9	18	66	266	60,315,222	75,997,180	64,152,000	(3,836,778)	11,845,180
9	19	72	267	74,134,224	93,409,122	21,384,000	52,750,224	72,025,122
9	20	77	268	85,650,059	107,919,074	(14,256,000)	99,906,059	122,175,074
9	23	62	271	51,102,554	64,389,218	92,664,000	(41,561,446)	(28,274,782)
9	24	67	272	62,618,389	78,899,170	57,024,000	5,594,389	21,875,170
9	25	66	273	60,315,222	75,997,180	64,152,000	(3,836,778)	11,845,180
9	26	59	274	46,227,650	61,939,650	114,048,000	(67,820,350)	(52,108,350)
9	27	68	275	64,921,556	81,801,161	49,896,000	15,025,556	31,905,161
9	30	55	278	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
10	1	66	279	60,315,222	75,997,180	64,152,000	(3,836,778)	11,845,180
10	2	69	280	67,224,723	84,703,151	42,768,000	24,456,723	41,935,151
10	3	58	281	46,227,650	61,939,650	121,176,000	(74,948,350)	(59,236,350)
10	4	55	282	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
10	7	55	285	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
10	8	53	286	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
10	9	63	287	53,405,721	67,291,208	85,536,000	(32,130,279)	(18,244,792)
10	10	67	288	62,618,389	78,899,170	57,024,000	5,594,389	21,875,170
10	11	55	289	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
10	14	56	292	46,227,650	61,939,650	135,432,000	(89,204,350)	(73,492,350)
10	15	66	293	60,315,222	75,997,180	64,152,000	(3,836,778)	11,845,180
10	16	60	294	46,227,650	61,939,650	106,920,000	(60,692,350)	(44,980,350)
10	17	52	295	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
10	18	55	296	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
10	21	47	299	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
10	22	53	300	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
10	23	51	301	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
10	24	55	302	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
10	25	61	303	48,799,387	61,487,228	99,792,000	(50,992,613)	(38,304,772)
10	28	49	306	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
10	29	43	307	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
10	30	43	308	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)

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10	31	46	309	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
11	1	47	310	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
11	4	48	313	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
11	5	52	314	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
11	6	54	315	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
11	7	53	316	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
11	8	50	317	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
11	12	38	321	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
11	13	53	322	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
11	14	50	323	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
11	15	43	324	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
11	18	49	327	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
11	19	52	328	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
11	20	63	329	53,405,721	67,291,208	85,536,000	(32,130,279)	(18,244,792)
11	21	47	330	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
11	22	40	331	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
11	25	37	334	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
11	26	31	335	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
11	27	37	336	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
11	28	35	337	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
11	29	32	338	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
12	2	46	341	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
12	3	28	342	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
12	4	29	343	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
12	5	31	344	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
12	6	34	345	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
12	9	38	348	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
12	10	34	349	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
12	11	37	350	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
12	12	37	351	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
12	13	36	352	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
12	16	32	355	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
12	17	31	356	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
12	18	22	357	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
12	19	17	358	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
12	20	24	359	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
12	23	34	362	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
12	24	42	363	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
12	26	19	365	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
12	27	28	366	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
12	30	30	369	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
12	31	37	370	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	1	36	371	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	2	38	372	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	3	40	373	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	6	29	376	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	7	21	377	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	8	18	378	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	9	29	379	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	10	38	380	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	13	37	383	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	14	13	384	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	15	13	385	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	16	24	386	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	17	38	387	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	21	39	391	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)

Table C-52, continued (p. 6 of 6)

1	22	43	392	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	23	33	393	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	24	22	394	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	27	45	397	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	28	23	398	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	29	21	399	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	30	25	400	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)
1	31	32	401	46,227,650	61,939,650	142,560,000	(96,332,350)	(80,620,350)

Equations:

1. Occupied Cooling Required from Figure 5-3a
2. w/Retail Occupied Cooling Required from Figure 5-8b
3. Free Cooling Available: if Tout>=55,
   12 x 55,000 cfm x1.08 x (75 - Tout)

Table C-53: 1985 Annual Heating Calculations

Month	Day	Ave. Outdoor Temp (degF)	Day #	Present Daily Occupied Heating Requrmts (Btu/hr)	w/AH Daily Occupied Heating Requrmts (Btu/hr)	Present Daily Unocc. Heating Requrmts (Btu/hr)	w/AH Daily Unocc. Heating Requrmts (Btu/hr)
12	27	17	1	83,011,365	75,540,342	14,456,073	7,809,805
12	28	37	2	50,941,505	46,356,770	1,908,753	(2,478,997)
12	31	34	5	55,751,984	50,734,305	3,790,851	(935,677)
1	1	38	6	49,338,012	44,897,591	1,281,387	(2,993,437)
1	2	36	7	52,544,998	47,815,948	2,536,119	(1,964,557)
1	3	29	8	63,769,449	58,030,199	6,927,681	1,636,524
1	4	27	9	66,976,435	60,948,556	8,182,413	2,665,404
1	7	29	12	63,769,449	58,030,199	6,927,681	1,636,524
1	8	22	13	74,993,900	68,244,449	11,319,243	5,237,605
1	9	15	14	86,218,351	78,458,699	15,710,805	8,838,686
1	10	17	15	83,011,365	75,540,342	14,456,073	7,809,805
1	11	19	16	79,804,379	72,621,985	13,201,341	6,780,925
1	14	29	19	63,769,449	58,030,199	6,927,681	1,636,524
1	15	26	20	68,579,928	62,407,734	8,809,779	3,179,844
1	16	13	21	89,425,337	81,377,057	16,965,537	9,867,566
1	17	18	22	81,407,872	74,081,164	13,828,707	7,295,365
1	18	21	23	76,597,393	69,703,628	11,946,609	5,752,045
1	21	9	26	95,839,309	87,213,771	19,475,001	11,925,326
1	22	19	27	79,804,379	72,621,985	13,201,341	6,780,925
1	23	30	28	62,165,956	56,571,020	6,300,315	1,122,084
1	24	30	29	62,165,956	56,571,020	6,300,315	1,122,084
1	25	29	30	63,769,449	58,030,199	6,927,681	1,636,524
1	28	29	33	63,769,449	58,030,199	6,927,681	1,636,524
1	29	27	34	66,976,435	60,948,556	8,182,413	2,665,404
1	30	25	35	70,183,421	63,866,913	9,437,145	3,694,284
1	31	25	36	70,183,421	63,866,913	9,437,145	3,694,284
2	1	31	37	60,562,463	55,111,841	5,672,949	607,644
2	4	21	40	76,597,393	69,703,628	11,946,609	5,752,045
2	5	20	41	78,200,886	71,162,806	12,573,975	6,266,485
	6	20	42	78,200,886	71,162,806	12,573,975	6,266,485
	7	20	43	78,200,886	71,162,806	12,573,975	6,266,485
2	8	11	44	92,632,323	84,295,414	18,220,269	10,896,446
2	11	30	47	62,165,956	56,571,020	6,300,315	1,122,084
2	12	37	48	50,941,505	46,356,770	1,908,753	(2,478,997)
2	13	39	49	47,734,519	43,438,412	654,021	(3,507,877)
2	14	35	50	54,148,491	49,275,127	3,163,485	(1,450,117)
2	15	34	51	55,751,984	50,734,305	3,790,851	(935,677)
2	18	36	54	52,544,998	47,815,948	2,536,119	(1,964,557)
2	19	40	55	46,131,026	41,979,234	26,655	(4,022,317)
	20	36	56	52,544,998	47,815,948	2,536,119	(1,964,557)
2	21	33	57	57,355,477	52,193,484	4,418,217	(421,237)
2	22	46	58	36,510,068	33,224,162	(3,737,541)	(7,108,958)
2	25	49	61	31,699,589	28,846,626	(5,619,639)	(8,652,278)
2	26	41	62	44,527,533	40,520,055	(600,711)	(4,536,758)
2	27	40	63	46,131,026	41,979,234	26,655	(4,022,317)
	28	29	64	63,769,449	58,030,199	6,927,681	1,636,524
3	1	44	65	39,717,054	36,142,519	(2,482,809)	(6,080,078)

3	4	25	68	70,183,421	63,866,913	9,437,145	3,694,284
3	5	36	69	52,544,998	47,815,948	2,536,119	(1,964,557)
3	6	28	70	65,372,942	59,489,377	7,555,047	2,150,964
3	7	29	71	63,769,449	58,030,199	6,927,681	1,636,524
3	8	44	72	39,717,054	36,142,519	(2,482,809)	(6,080,078)
3	11	45	75	38,113,561	34,683,341	(3,110,175)	(6,594,518)
3	12	48	76	33,303,082	30,305,805	(4,992,273)	(8,137,838)
3	13	46	77	36,510,068	33,224,162	(3,737,541)	(7,108,958)
3	14	45	78	38,113,561	34,683,341	(3,110,175)	(6,594,518)
3	15	36	79	52,544,998	47,815,948	2,536,119	(1,964,557)
	18	32	82	58,958,970	53,652,663	5,045,583	93,204
3	19	30	83	62,165,956	56,571,020	6,300,315	1,122,084
3	20	47	84	34,906,575	31,764,983	(4,364,907)	(7,623,398)
3	21	34	85	55,751,984	50,734,305	3,790,851	(935,677)
3	22	32	86	58,958,970	53,652,663	5,045,583	93,204
3	25	37	89	50,941,505	46,356,770	1,908,753	(2,478,997)
3	26	39	90	47,734,519	43,438,412	654,021	(3,507,877)
3	27	47	91	34,906,575	31,764,983	(4,364,907)	(7,623,398)
3	28	61	92	12,457,673	11,336,482	(13,148,031)	(14,825,560)
3	29	55	93	22,078,631	20,091,554	(9,383,835)	(11,738,919)
4	1	37	96	50,941,505	46,356,770	1,908,753	(2,478,997)
4	2	42	97	42,924,040	39,060,876	(1,228,077)	(5,051,198)
4	3	39	98	47,734,519	43,438,412	654,021	(3,507,877)
4	4	46	99	36,510,068	33,224,162	(3,737,541)	(7,108,958)
4	5	50	100	30,096,096	27,387,447	(6,247,005)	(9,166,719)
4	8	42	103	42,924,040	39,060,876	(1,228,077)	(5,051,198)
4	9	39	104	47,734,519	43,438,412	654,021	(3,507,877)
4	10	36	105	52,544,998	47,815,948	2,536,119	(1,964,557)
4	11	48	106	33,303,082	30,305,805	(4,992,273)	(8,137,838)
4	12	46	107	36,510,068	33,224,162	(3,737,541)	(7,108,958)
4	15	59	110	15,664,659	14,254,840	(11,893,299)	(13,796,680)
4	16	60	111	14,061,166	12,795,661	(12,520,665)	(14,311,120)
4	17	45	112	38,113,561	34,683,341	(3,110,175)	(6,594,518)
4	18	43	113	41,320,547	37,601,698	(1,855,443)	(5,565,638)
4	19	53	114	25,285,617	23,009,911	(8,129,103)	(10,710,039)
4	22	54	117	23,682,124	21,550,733	(8,756,469)	(11,224,479)
4	23	44	118	39,717,054	36,142,519	(2,482,809)	(6,080,078)
4	24	47	119	34,906,575	31,764,983	(4,364,907)	(7,623,398)
4	25	54	120	23,682,124	21,550,733	(8,756,469)	(11,224,479)
4	26	69	121	(370,271)	(336,947)	(18,166,959)	(18,941,081)
4	29	55	124	22,078,631	20,091,554	(9,383,835)	(11,738,919)
	30	66	125	4,440,208	4,040,589	(16,284,861)	(17,397,761)
5	1	66	126	4,440,208	4,040,589	(16,284,861)	(17,397,761)
5	2	52	127	26,889,110	24,469,090	(7,501,737)	(10,195,599)
5	3	44	128	39,717,054	36,142,519	(2,482,809)	(6,080,078)
5	6	47	131	34,906,575	31,764,983	(4,364,907)	(7,623,398)
5	7	56	132	20,475,138	18,632,376	(10,011,201)	(12,253,359)
5	8	51	133	28,492,603	25,928,269	(6,874,371)	(9,681,159)
5	9	51	134	28,492,603	25,928,269	(6,874,371)	(9,681,159)
5	10	68	135	1,233,222	1,122,232	(17,539,593)	(18,426,641)
5	13	64	138	7,647,194	6,958,947	(15,030,129)	(16,368,880)
5	14	57	139	18,871,645	17,173,197	(10,638,567)	(12,767,799)
5	15	53	140	25,285,617	23,009,911	(8,129,103)	(10,710,039)
5	16	61	141	12,457,673	11,336,482	(13,148,031)	(14,825,560)
5	17	62	142	10,854,180	9,877,304	(13,775,397)	(15,340,000)
5	20	69	145	(370,271)	(336,947)	(18,166,959)	(18,941,081)

Table C-53, continued (p. 3 of 6)

5	21	69	146	(370,271)	(336,947)	(18,166,959)	(18,941,081)
5	22	67	147	2,836,715	2,581,411	(16,912,227)	(17,912,201)
5	23	58	148	17,268,152	15,714,018	(11,265,933)	(13,282,240)
5	24	61	149	12,457,673	11,336,482	(13,148,031)	(14,825,560)
5	27	70	152	(1,973,764)	(1,796,125)	(18,794,325)	(19,455,521)
5	28	59	153	15,664,659	14,254,840	(11,893,299)	(13,796,680)
5	29	55	154	22,078,631	20,091,554	(9,383,835)	(11,738,919)
5	30	61	155	12,457,673	11,336,482	(13,148,031)	(14,825,560)
5	31	65	156	6,043,701	5,499,768	(15,657,495)	(16,883,320)
6	3	73	159	(6,784,243)	(6,173,661)	(20,676,423)	(20,998,841)
6	4	63	160	9,250,687	8,418,125	(14,402,763)	(15,854,440)
6	5	56	161	20,475,138	18,632,376	(10,011,201)	(12,253,359)
6	6	60	162	14,061,166	12,795,661	(12,520,665)	(14,311,120)
6	7	64	163	7,647,194	6,958,947	(15,030,129)	(16,368,880)
6	10	74	166	(8,387,736)	(7,632,840)	(21,303,789)	(21,513,281)
6	11	71	167	(3,577,257)	(3,255,304)	(19,421,691)	(19,969,961)
6	12	61	168	12,457,673	11,336,482	(13,148,031)	(14,825,560)
6	13	60	169	14,061,166	12,795,661	(12,520,665)	(14,311,120)
6	14	61	170	12,457,673	11,336,482	(13,148,031)	(14,825,560)
6	17	66	173	4,440,208	4,040,589	(16,284,861)	(17,397,761)
6	18	70	174	(1,973,764)	(1,796,125)	(18,794,325)	(19,455,521)
6	19	71	175	(3,577,257)	(3,255,304)	(19,421,691)	(19,969,961)
6	20	71	176	(3,577,257)	(3,255,304)	(19,421,691)	(19,969,961)
6	21	68	177	1,233,222	1,122,232	(17,539,593)	(18,426,641)
6	24	70	180	(1,973,764)	(1,796,125)	(18,794,325)	(19,455,521)
6	25	62	181	10,854,180	9,877,304	(13,775,397)	(15,340,000)
6	26	58	182	17,268,152	15,714,018	(11,265,933)	(13,282,240)
6	27	55	183	22,078,631	20,091,554	(9,383,835)	(11,738,919)
6	28	59	184	15,664,659	14,254,840	(11,893,299)	(13,796,680)
7	1	62	187	10,854,180	9,877,304	(13,775,397)	(15,340,000)
7	2	68	188	1,233,222	1,122,232	(17,539,593)	(18,426,641)
7	3	72	189	(5,180,750)	(4,714,483)	(20,049,057)	(20,484,401)
7	5	74	191	(8,387,736)	(7,632,840)	(21,303,789)	(21,513,281)
7	8	72	194	(5,180,750)	(4,714,483)	(20,049,057)	(20,484,401)
7	9	71	195	(3,577,257)	(3,255,304)	(19,421,691)	(19,969,961)
7	10	77	196	(13,198,215)	(12,010,376)	(23,185,887)	(23,056,602)
7	11	77	197	(13,198,215)	(12,010,376)	(23,185,887)	(23,056,602)
7	12	72	198	(5,180,750)	(4,714,483)	(20,049,057)	(20,484,401)
7	15	78	201	(14,801,708)	(13,469,554)	(23,813,253)	(23,571,042)
7	16	77	202	(13,198,215)	(12,010,376)	(23,185,887)	(23,056,602)
7	17	71	203	(3,577,257)	(3,255,304)	(19,421,691)	(19,969,961)
7	18	70	204	(1,973,764)	(1,796,125)	(18,794,325)	(19,455,521)
7	19	76	205	(11,594,722)	(10,551,197)	(22,558,521)	(22,542,162)
7	22	76	208	(11,594,722)	(10,551,197)	(22,558,521)	(22,542,162)
7	23	71	209	(3,577,257)	(3,255,304)	(19,421,691)	(19,969,961)
7	24	72	210	(5,180,750)	(4,714,483)	(20,049,057)	(20,484,401)
7	25	74	211	(8,387,736)	(7,632,840)	(21,303,789)	(21,513,281)
7	26	76	212	(11,594,722)	(10,551,197)	(22,558,521)	(22,542,162)
7	29	73	215	(6,784,243)	(6,173,661)	(20,676,423)	(20,998,841)
7	30	78	216	(14,801,708)	(13,469,554)	(23,813,253)	(23,571,042)
7	31	66	217	4,440,208	4,040,589	(16,284,861)	(17,397,761)
8	1	67	218	2,836,715	2,581,411	(16,912,227)	(17,912,201)
8	2	64	219	7,647,194	6,958,947	(15,030,129)	(16,368,880)
8	5	73	222	(6,784,243)	(6,173,661)	(20,676,423)	(20,998,841)
8	6	74	223	(8,387,736)	(7,632,840)	(21,303,789)	(21,513,281)
8	7	71	224	(3,577,257)	(3,255,304)	(19,421,691)	(19,969,961)

Table C-53, continued (p. 4 of 6)

8	8	72	225	(5,180,750)	(4,714,483)	(20,049,057)	(20,484,401)
8	9	74	226	(8,387,736)	(7,632,840)	(21,303,789)	(21,513,281)
8	12	70	229	(1,973,764)	(1,796,125)	(18,794,325)	(19,455,521)
8	13	66	230	4,440,208	4,040,589	(16,284,861)	(17,397,761)
8	14	80	231	(18,008,694)	(16,387,912)	(25,067,985)	(24,599,922)
8	15	84	232	(24,422,666)	(22,224,626)	(27,577,449)	(26,657,683)
8	16	75	233	(9,991,229)	(9,092,018)	(21,931,155)	(22,027,722)
8	19	65	236	6,043,701	5,499,768	(15,657,495)	(16,883,320)
8	20	71	237	(3,577,257)	(3,255,304)	(19,421,691)	(19,969,961)
8	21	71	238	(3,577,257)	(3,255,304)	(19,421,691)	(19,969,961)
8	22	68	239	1,233,222	1,122,232	(17,539,593)	(18,426,641)
8	23	68	240	1,233,222	1,122,232	(17,539,593)	(18,426,641)
8	26	67	243	2,836,715	2,581,411	(16,912,227)	(17,912,201)
8	27	73	244	(6,784,243)	(6,173,661)	(20,676,423)	(20,998,841)
8	28	75	245	(9,991,229)	(9,092,018)	(21,931,155)	(22,027,722)
8	29	67	246	2,836,715	2,581,411	(16,912,227)	(17,912,201)
9	3	70	251	(1,973,764)	(1,796,125)	(18,794,325)	(19,455,521)
9	4	80	252	(18,008,694)	(16,387,912)	(25,067,985)	(24,599,922)
9	5	74	253	(8,387,736)	(7,632,840)	(21,303,789)	(21,513,281)
9	6	65	254	6,043,701	5,499,768	(15,657,495)	(16,883,320)
9	9	67	257	2,836,715	2,581,411	(16,912,227)	(17,912,201)
9	10	61	258	12,457,673	11,336,482	(13,148,031)	(14,825,560)
9	11	59	259	15,664,659	14,254,840	(11,893,299)	(13,796,680)
9	12	57	260	18,871,645	17,173,197	(10,638,567)	(12,767,799)
9	13	53	261	25,285,617	23,009,911	(8,129,103)	(10,710,039)
9	16	60	264	14,061,166	12,795,661	(12,520,665)	(14,311,120)
9	17	62	265	10,854,180	9,877,304	(13,775,397)	(15,340,000)
9	18	66	266	4,440,208	4,040,589	(16,284,861)	(17,397,761)
9	19	72	267	(5,180,750)	(4,714,483)	(20,049,057)	(20,484,401)
9	20	77	268	(13,198,215)	(12,010,376)	(23,185,887)	(23,056,602)
9	23	62	271	10,854,180	9,877,304	(13,775,397)	(15,340,000)
9	24	67	272	2,836,715	2,581,411	(16,912,227)	(17,912,201)
9	25	66	273	4,440,208	4,040,589	(16,284,861)	(17,397,761)
9	26	59	274	15,664,659	14,254,840	(11,893,299)	(13,796,680)
9	27	68	275	1,233,222	1,122,232	(17,539,593)	(18,426,641)
9	30	55	278	22,078,631	20,091,554	(9,383,835)	(11,738,919)
10	1	66	279	4,440,208	4,040,589	(16,284,861)	(17,397,761)
10	2	69	280	(370,271)	(336,947)	(18,166,959)	(18,941,081)
10	3	58	281	17,268,152	15,714,018	(11,265,933)	(13,282,240)
10	4	55	282	22,078,631	20,091,554	(9,383,835)	(11,738,919)
10	7	55	285	22,078,631	20,091,554	(9,383,835)	(11,738,919)
10	8	53	286	25,285,617	23,009,911	(8,129,103)	(10,710,039)
10	9	63	287	9,250,687	8,418,125	(14,402,763)	(15,854,440)
10	10	67	288	2,836,715	2,581,411	(16,912,227)	(17,912,201)
10	11	55	289	22,078,631	20,091,554	(9,383,835)	(11,738,919)
10	14	56	292	20,475,138	18,632,376	(10,011,201)	(12,253,359)
10	15	66	293	4,440,208	4,040,589	(16,284,861)	(17,397,761)
10	16	60	294	14,061,166	12,795,661	(12,520,665)	(14,311,120)
10	17	52	295	26,889,110	24,469,090	(7,501,737)	(10,195,599)
10	18	55	296	22,078,631	20,091,554	(9,383,835)	(11,738,919)
10	21	47	299	34,906,575	31,764,983	(4,364,907)	(7,623,398)
10	22	53	300	25,285,617	23,009,911	(8,129,103)	(10,710,039)
10	23	51	301	28,492,603	25,928,269	(6,874,371)	(9,681,159)
10	24	55	302	22,078,631	20,091,554	(9,383,835)	(11,738,919)
10	25	61	303	12,457,673	11,336,482	(13,148,031)	(14,825,560)
10	28	49	306	31,699,589	28,846,626	(5,619,639)	(8,652,278)

Table C-53, continued (p. 5 of 6)

10	29	43	307	41,320,547	37,601,698	(1,855,443)	(5,565,638)
10	30	43	308	41,320,547	37,601,698	(1,855,443)	(5,565,638)
10	31	46	309	36,510,068	33,224,162	(3,737,541)	(7,108,958)
11	1	47	310	34,906,575	31,764,983	(4,364,907)	(7,623,398)
11	4	48	313	33,303,082	30,305,805	(4,992,273)	(8,137,838)
11	5	52	314	26,889,110	24,469,090	(7,501,737)	(10,195,599)
11	6	54	315	23,682,124	21,550,733	(8,756,469)	(11,224,479)
11	7	53	316	25,285,617	23,009,911	(8,129,103)	(10,710,039)
11	8	50	317	30,096,096	27,387,447	(6,247,005)	(9,166,719)
11	12	38	321	49,338,012	44,897,591	1,281,387	(2,993,437)
11	13	53	322	25,285,617	23,009,911	(8,129,103)	(10,710,039)
11	14	50	323	30,096,096	27,387,447	(6,247,005)	(9,166,719)
11	15	43	324	41,320,547	37,601,698	(1,855,443)	(5,565,638)
11	18	49	327	31,699,589	28,846,626	(5,619,639)	(8,652,278)
11	19	52	328	26,889,110	24,469,090	(7,501,737)	(10,195,599)
11	20	63	329	9,250,687	8,418,125	(14,402,763)	(15,854,440)
11	21	47	330	34,906,575	31,764,983	(4,364,907)	(7,623,398)
11	22	40	331	46,131,026	41,979,234	26,655	(4,022,317)
11	25	37	334	50,941,505	46,356,770	1,908,753	(2,478,997)
11	26	31	335	60,562,463	55,111,841	5,672,949	607,644
11	27	37	336	50,941,505	46,356,770	1,908,753	(2,478,997)
11	28	35	337	54,148,491	49,275,127	3,163,485	(1,450,117)
11	29	32	338	58,958,970	53,652,663	5,045,583	93,204
12	2	46	341	36,510,068	33,224,162	(3,737,541)	(7,108,958)
12	3	28	342	65,372,942	59,489,377	7,555,047	2,150,964
12	4	29	343	63,769,449	58,030,199	6,927,681	1,636,524
12	5	31	344	60,562,463	55,111,841	5,672,949	607,644
12	6	34	345	55,751,984	50,734,305	3,790,851	(935,677)
12	9	38	348	49,338,012	44,897,591	1,281,387	(2,993,437)
12	10	34	349	55,751,984	50,734,305	3,790,851	(935,677)
12	11	37	350	50,941,505	46,356,770	1,908,753	(2,478,997)
12	12	37	351	50,941,505	46,356,770	1,908,753	(2,478,997)
12	13	36	352	52,544,998	47,815,948	2,536,119	(1,964,557)
12	16	32	355	58,958,970	53,652,663	5,045,583	93,204
12	17	31	356	60,562,463	55,111,841	5,672,949	607,644
12	18	22	357	74,993,900	68,244,449	11,319,243	5,237,605
12	19	17	358	83,011,365	75,540,342	14,456,073	7,809,805
12	20	24	359	71,786,914	65,326,092	10,064,511	4,208,725
12	23	34	362	55,751,984	50,734,305	3,790,851	(935,677)
12	24	42	363	42,924,040	39,060,876	(1,228,077)	(5,051,198)
12	26	19	365	79,804,379	72,621,985	13,201,341	6,780,925
12	27	28	366	65,372,942	59,489,377	7,555,047	2,150,964
12	30	30	369	62,165,956	56,571,020	6,300,315	1,122,084
12	31	37	370	50,941,505	46,356,770	1,908,753	(2,478,997)
1	1	36	371	53,074,151	48,297,477	2,743,150	(1,794,792)
1	2	38	372	49,001,278	44,591,163	1,149,640	(3,101,470)
1	3	40	373	46,547,934	42,358,620	189,770	(3,888,563)
1	6	29	376	63,705,309	57,971,831	6,902,586	1,615,946
1	7	21	377	76,661,533	69,761,995	11,971,704	5,772,623
1	8	18	378	81,135,278	73,833,103	13,722,055	7,207,910
1	9	29	379	63,833,589	58,088,566	6,952,776	1,657,102
1	10	38	380	48,937,139	44,532,796	1,124,546	(3,122,047)
1	13	37	383	51,679,112	47,027,992	2,197,341	(2,242,355)
1	14	13	384	89,152,743	81,128,996	16,858,885	9,780,111
1	15	13	385	90,018,629	81,916,953	17,197,662	10,057,909
1	16	24	386	71,514,320	65,078,031	9,957,859	4,121,270

1	17	38	387	49,482,326	45,028,917	1,337,850	(2,947,138)
1	21	39	391	48,007,113	43,686,473	760,673	(3,420,422)
1	22	43	392	40,967,779	37,280,678	(1,993,464)	(5,678,815)
1	23	33	393	58,061,014	52,835,523	4,694,258	(194,883)
1	24	22	394	75,795,647	68,974,038	11,632,926	5,494,825
1	27	45	397	37,424,059	34,055,894	(3,379,942)	(6,815,727)
1	28	23	398	74,192,154	67,514,860	11,005,560	4,980,385
1	29	21	399	76,533,253	69,645,260	11,921,514	5,731,467
1	30	25	400	70,456,015	64,114,973	9,543,797	3,781,739
1	31	32	401	58,237,398	52,996,032	4,763,268	(138,294)

Equations:

1. Present Occupied Heating = (Tout x 1,603,493) + 110,270,746
2. Present Occupied Heating w/AH = ((Tout x 1,603,493) + 110,270,746) x 0.91
3. Present Unoccupied Heating = -(Tout x 627,366) + 47,588,931 - 22,467,636
4. Present Unoccupied Heating w/AH = (-(Tout x 627,366) + 47,588,931) x 0.82 - 22,467,636

Table C-54: 1985 Unoccupied Daily Heating Requirements

Month	Day	Ave. Outdoor Temp (degF)	Day #	weekend Daily Heating Requirements (Btu/hr)
12	29	63	3	300,329
12	30	50	4	16,493,441
1	5	28	10	43,897,169
1	6	28	11	43,897,169
1	12	21	17	52,616,537
1	13	28	18	43,897,169
1	19	29	24	42,651,545
1	20	18	25	56,353,409
1	26	23	31	50,125,289
1	27	23	32	50,125,289
2	2	32	38	38,914,673
2	3	23	39	50,125,289
2	9	19	45	55,107,785
2	10	32	46	38,914,673
2	16	29	52	42,651,545
2	17	36	53	33,932,177
	23	48	59	18,984,689
2	24	56	60	9,019,697
3	2	49	66	17,739,065
3	3	33	67	37,669,049
	9	46	73	21,475,937
3	10	40	74	28,949,681
3	16	35	80	35,177,801
3	17	44	81	23,967,185
3	23	44	87	23,967,185
3	24	41	88	27,704,057
3	30	48	94	18,984,689
	31	37	95	32,686,553
4	6	55	101	10,265,321
4	7	53	102	12,756,569
4	13	45	108	22,721,561
4	14	43	109	25,212,809
4	20	49	115	17,739,065
4	21	54	116	11,510,945
	27	56	122	9,019,697
4	28	55	123	10,265,321
5	4	53	129	12,756,569
5	5	59	130	5,282,825
5	11	76	136	(15,892,783)
5	12	55	137	10,265,321
5	18	57	143	7,774,073
5	19	54	144	11,510,945
5	25	62	150	1,545,953
5	26	59	151	5,282,825
6	1	70	157	(8,419,039)
6	2	70	158	(8,419,039)
6	8	64	164	(945,295)
6	9	66	165	(3,436,543)
6	15	65	171	(2,190,919)
6	16	62	172	1,545,953
6	22	71	178	(9,664,663)
6	23	71	179	(9,664,663)
6	29	57	185	7,774,073
6	30	62	186	1,545,953
7	4	76	190	(15,892,783)
7	6	77	192	(17,138,407)
7	7	78	193	(18,384,031)
7	13	72	199	(10,910,287)
7	14	76	200	(15,892,783)
7	20	82	206	(23,366,527)
7	21	77	207	(17,138,407)
7	27	74	213	(13,401,535)
7	28	68	214	(5,927,791)
8	3	68	220	(5,927,791)
8	4	71	221	(9,664,663)
8	10	74	227	(13,401,535)
8	11	78	228	(18,384,031)
8	17	74	234	(13,401,535)
8	18	70	235	(8,419,039)
8	24	70	241	(8,419,039)
8	25	67	242	(4,682,167)
8	30	62	247	1,545,953
8	31	58	248	6,528,449
9	1	61	249	2,791,577
9	2	65	250	(2,190,919)
9	7	66	255	(3,436,543)
9	8	78	256	(18,384,031)
9	14	59	262	5,282,825
9	15	61	263	2,791,577
9	21	76	269	(15,892,783)
9	22	65	270	(2,190,919)
9	28	66	276	(3,436,543)
9	29	61	277	2,791,577
10	5	63	283	300,329
10	6	57	284	7,774,073
10	12	46	290	21,475,937
10	13	53	291	12,756,569
10	19	59	297	5,282,825
10	20	51	298	15,247,817
10	26	56	304	9,019,697
10	27	62	305	1,545,953
11	2	50	311	16,493,441
11	3	48	312	18,984,689
11	9	50	318	16,493,441
11	10	63	319	300,329
11	11	47	320	20,230,313
11	16	34	325	36,423,425
11	17	46	326	21,475,937
11	23	41	332	27,704,057
11	24	43	333	25,212,809
11	30	37	339	32,686,553
12	1	44	340	23,967,185
12	7	32	346	38,914,673
12	8	39	347	30,195,305
12	14	33	353	37,669,049

Table C-54, continued (p. 2 of 2)

12	15	26	354	46,388,417
12	21	26	360	46,388,417
12	22	25	361	47,634,041
12	25	30	364	41,405,921
12	28	31	367	40,160,297
12	29	28	368	43,897,169
1	4	26	374	46,214,030
1	5	31	375	40,783,109
1	11	30	381	41,978,908
1	12	43	382	25,001,053
1	18	50	388	16,804,847
1	19	50	389	16,593,091
1	20	50	390	15,970,279
1	25	28	395	43,573,307
1	26	56	396	8,807,941

Equations:

Daily Weekend Heating Requirement =
-(51,901 x (Tout - 71)) x 24 + 9,664,663

Table C-55: Occupied and Unoccupied Weekly Heating Requirements

Month	Day	Ave. Outdoor Temp (degF)	Day #	Present Weekly Unoccupied Heating Requrmts (Btu/hr)	w/AH Weekly Unoccupied Heating Requrmts (Btu/hr)		Present Monthly Unoccupied Heating Requrmts (Btu/hr)	w/AH Monthly Unoccupied Heating Requrmts (Btu/hr)	
1	6	28	11	110,512,789	92,096,266	1			
1	13	28	18	158,128,849	126,817,251	2			
1	20	18	25	157,483,267	126,736,298	3			
1	27	23	32	152,455,231	122,837,521	4	578,580,136	468,487,336	1
2	3	23	39	128,697,295	101,338,103	5			
2	10	32	46	161,911,261	129,470,404	6			
2	17	36	53	92,401,147	77,705,806	7			
2	24	56	60	37,521,496	28,004,386	8	420,531,199	336,518,699	2
3	3	33	67	62,362,450	57,044,638	9			
3	10	40	74	76,881,610	57,907,390	10			
3	17	44	81	61,681,105	59,144,986	11			
3	24	41	88	71,853,574	52,979,733	12			
	31	37	95	54,234,016	51,671,242	13	327,012,755	278,747,989	3
4	7	53	102	25,584,664	23,021,890	14			
4	14	43	109	51,124,510	47,934,370	15			
4	21	54	116	29,250,010	29,250,010	16			
4	28	55	123	19,285,018	19,285,018	17	125,244,202	119,491,288	4
5	5	59	130	18,039,394	18,039,394	18			
5	12	55	137	10,265,321	10,265,321	19			
5	19	54	144	19,285,018	19,285,018	20			
5	26	59	151	6,828,778	6,828,778	21	54,418,511	54,418,511	5
6	2	70	158	0	0	22			
6	9	66	165	0	0	23			
6	16	62	172	1,545,953	1,545,953	24			
6	23	71	179	0	0	25			
6	30	62	186	9,320,026	9,320,026	26	10,865,979	10,865,979	6
7	7	78	193	0	0	27			
7	14	76	200	0	0	28			
7	21	77	207	0	0	29			
7	28	68	214	0	0	30	0	0	7
8	4	71	221	0	0	31			
8	11	78	228	0	0	32			
8	18	70	235	0	0	33			
8	25	67	242	0	0	34	0	0	8
9	1	61	249	10,865,979	10,865,979	35			
9	8	78	256	0	0	36			
9	15	61	263	8,074,402	8,074,402	37			
9	22	65	270	0	0	38			
9	29	61	277	2,791,577	2,791,577	39	21,731,958	21,731,958	9
10	6	57	284	8,074,402	8,074,402	40			
10	13	53	291	34,232,506	34,232,506	41			
10	20	51	298	20,530,642	20,530,642	42			
10	27	62	305	10,565,650	10,565,650	43	73,403,200	73,403,200	10
11	3	48	312	35,478,130	35,478,130	44			
11	10	63	319	16,793,770	16,793,770	45			
11	17	46	326	79,411,062	78,129,675	46			
11	24	43	333	52,943,521	52,916,866	47	184,626,483	183,318,441	11

Table C-55, continued (p. 2 of 2)

12	1	44	340	74,353,261	57,354,585	48			
12	8	39	347	93,056,506	73,505,110	49			
12	15	26	354	95,483,329	84,057,466	50			
12	22	25	361	140,580,817	111,979,440	51			
12	29	28	368	150,010,626	134,395,276	52	553,484,539	461,291,877	12
1	5	31	375	99,288,767	88,119,222	53			
1	12	43	382	107,653,627	83,233,542	54			
1	19	50	389	80,947,535	57,357,227	55			
1	26	56	396	85,439,384	73,846,351	56	373,329,313	302,556,343	13

Appendix D

Appendix D

Corridor Lights Off during Unoccupied Hours
Corridor Lights:-(368 1st floor) + 2231 fluorescent = 1,863 lamps

Assume 34 W lamps   1,863 x 46.63 = 86.872 kW

Weekdays: Assume off 8 hrs/day:
86.872 kW x 8 hrs/day x 5 days/wk x 52 wks/yr x $0.08/kW
= $14,455/yr

Weekends: Assume off 20 hrs/day:
86.872 kW x 20 hrs/day x 2 days/wk x 52 x 0.08 = $14,455/yr.

Total Savings: $28,890/yr

Atrium Corridor Lights off during Daylight Hours
330 lamps x 46.63 = 15.39 kW
off 8 hrs/day x 5 days/wk x 52 x 0.08 = $2,560/yr

demand savings
15.39kW x 116.27/yr = $1,789
Total Savings = $4,349

Perimeter Lighting Savings
13,545 floor fixtures (offices)

Assume 36 percent (perimeter floor area)   4,876 lamps
Assume 34 W lamps   4,876 x 46.63 = 227.370 kW
Weekdays: Assume 8 hrs/day x 0.9 corr. factor: 1,637 kWh
1,637 kWh x $0.08/kHw = $130.96/day
$34,050/yr

Demand: 227.4 kW x [(8 months x $9.276) + (4 mths x $10.5152)]
= $26,436/yr

Fluorescent   ((40, 34w) Demand Savings:
18,057 lamps x (6 w/lamp) x 1 kW/1000 w x $116.27/yr = $12,597/yr.

Incandescent (100, 75w) Demand Savings:
1,952 lamps x (25 w/lamp) x 1 kW/1000 w x $116.27/yr = $5,674/yr

Table D-1: Simulated Unoccupied Operation, Mixed Tanks, 8/1/85

E = 0.84

Initial Tank Temp = 51 degF

Hour	T tank o (degF)	T tank i (degF)	delT (degF)	Tchwsup (before tank) (degF)	Tchwr (after tank) (degF)	m cp(delT) (per tank) (Btu/hr)	m cp(delT) (per tank) (tons)
0	51	43	(8)	42	50	(2,422,442)	(202)
1	50	43	(7)	42	48	(2,211,741)	(184)
2	49	43	(5)	43	48	(1,627,333)	(136)
3	48	45	(3)	44	47	(991,642)	(83)
4	47	45	(3)	44	47	(850,299)	(71)
5	47	44	(3)	43	46	(998,263)	(83)
6	46	44	(3)	43	46	(855,976)	(71)
7	46	43	(2)	43	45	(733,971)	(61)
8	45	43	(2)	43	45	(629,355)	(52)
9	45	43	(2)	43	45	(539,650)	(45)
10	45	43	(1)	43	44	(462,732)	(39)
11	44	44	(0)	44	44	(127,617)	(11)
12	44	44	(0)	44	44	(109,427)	(9)
13	44	44	(0)	44	44	(93,830)	(8)
14	44	44	(0)	44	44	(80,456)	(7)
15	44	42	(2)	42	44	(607,309)	(51)
16	44	44	0	44	44	17,574	1
17	44	44	0	44	44	15,069	1
18	44	44	0	44	44	12,921	1
19	44	43	(1)	43	44	(258,081)	(22)
20	44	43	(1)	43	44	(221,295)	(18)
21	44	43	(1)	43	44	(189,753)	(16)
22	44	43	(1)	43	44	(162,707)	(14)
23	44	43	(0)	43	43	(139,516)	(12)
24	43						
					Total	(14,267,828)	(1,189)

Initial Tank Temp = 50 degF

Hour	T tank o (degF)	T tank i (degF)	delT (degF)	Tchwsup (before tank) (degF)	Tchwr (after tank) (degF)	m cp(delT) (per tank) (Btu/hr)	m cp(delT) (per tank) (tons)	m cp(delT) (total) (tons)
0	50	43	(7)	42	49	(2,153,282)	(179)	(583)
1	49	43	(6)	42	48	(1,980,946)	(165)	(534)
2	48	43	(4)	43	47	(1,429,433)	(119)	(390)
3	47	44	(3)	44	47	(821,950)	(68)	(234)
4	47	44	(2)	44	46	(704,794)	(59)	(200)
5	46	44	(3)	43	46	(873,497)	(73)	(239)
6	46	43	(2)	43	45	(748,994)	(62)	(205)
7	45	43	(2)	43	45	(642,237)	(54)	(176)
8	45	43	(2)	43	45	(550,696)	(46)	(151)
9	45	43	(1)	43	44	(472,203)	(39)	(129)
10	45	43	(1)	43	44	(404,898)	(34)	(111)
11	44	44	(0)	44	44	(78,026)	(7)	(28)
12	44	44	(0)	44	44	(66,905)	(6)	(24)
13	44	44	(0)	44	44	(57,369)	(5)	(20)
14	44	44	(0)	44	44	(49,192)	(4)	(18)
15	44	42	(2)	42	44	(580,501)	(48)	(150)
16	44	44	0	44	44	40,561	3	6
17	44	44	0	44	44	34,780	3	5
18	44	44	0	44	44	29,822	2	5
19	44	43	(1)	43	44	(243,589)	(20)	(63)
20	44	43	(1)	43	44	(208,869)	(17)	(54)
21	44	43	(1)	43	44	(179,098)	(15)	(47)
22	44	43	(0)	43	43	(153,570)	(13)	(40)
23	43	43	(0)	43	43	(131,681)	(11)	(34)
24	43							
					Total	(12,426,566)	(1,036)	(3,414)

Equations:

Given T tank o, T chwsup, and E:

T tank i = T tank o + E(T chwsup - T tank o)

del T = T tank i - T tank o = T chwsup - T chwret

T chwret = T chwsup + E(T tank o - T chwsup)

m cp (del T) = 320,428.8 * (del T)

for mixed calculations: T tank o (t+1) = T tank o (t) + (m cp (delT))/1,888,392

Assumes equal flow rates through heat exchangers.

Table D-2: Simulated Unoccupied Operation, Unmixed Tanks, 8/1/85

E = 0.84

Initial Tank Temperature = 51 degF

Hour	T tank o (degF)	T tank i (degF)	delT (degF)	Tchwsup (before tank) (degF)	Tchwr (after tank) (degF)	m cp(delT) (per tank) (Btu/hr)	m cp(delT) (per tank) (tons)
0	51	42	(9)	42	50	(2,883,859)	(240)
1	51	42	(9)	42	49	(2,883,859)	(240)
2	51	42	(9)	43	50	(2,883,859)	(240)
3	51	42	(9)	44	50	(2,883,859)	(240)
4	51	42	(9)	44	50	(2,883,859)	(240)
5	51	42	(9)	43	50	(2,883,859)	(240)
6	42						
					Total	(17,303,155)	(1,442)

Initial Tank Temperature = 50 degF

Hour	T tank o (degF)	T tank i (degF)	delT (degF)	Tchwsup (before tank) (degF)	Tchwr (after tank) (degF)	m cp(delT) (per tank) (Btu/hr)	m cp(delT) (per tank) (tons)	m cp(delT) (total) (tons)
0	50	42	(8)	42	49	(2,563,430)	(214)	(694)
1	50	42	(8)	42	49	(2,563,430)	(214)	(694)
2	50	42	(8)	43	49	(2,563,430)	(214)	(694)
3	50	42	(8)	44	49	(2,563,430)	(214)	(694)
4	50	42	(8)	44	49	(2,563,430)	(214)	(694)
5	50	42	(8)	43	49	(2,563,430)	(214)	(694)
6	42							
					Total	(15,380,582)	(1,282)	(4,166)

Equations:

Given T tank o, T chwsup, and E:

T tank i = T tank o + E(T chwsup - T tank o)

del T = T tank i - T tank o = T chwsup - T chwret

T chwret = T chwsup + E(T tank o - T chwsup)

m cp (del T) = 320,428.8 * (del T)

Assumes equal flow rates through heat exchangers.

Table D-3: Simulated Occupied Operation, Unmixed Tanks - 8/1/85

E = 0.84

Mixed Return

Hour	T tank o (degF)	T tank i (degF)	delT (degF)	T chwr (before tank) (degF)	Tchwsup (after tank) (degF)	m cp(delT) (per tank) (Btu/hr)	m cp(delT) (per tank) (tons)
0	43	59	16	62	46	5,114,044	426
1	46	59	14	62	48	4,385,118	365
2	48	60	12	62	50	3,760,089	313
3	50	60	10	62	52	3,224,149	269
4	52	60	9	62	53	2,764,598	230
5	53	61	7	62	55	2,370,548	198
6	54	61	6	62	56	2,032,664	169
7	56	61	5	62	57	1,742,940	145
8	56	61	5	62	57	1,494,512	125
9	57	61	4	62	58	1,281,493	107
10	58	61	3	62	59	1,098,837	92

Equations:

Given T tank o, T chwret, and E:

T tank i = T tank o x E(T chwret - T tank o)

del T = T tank i - T tank o = T chwret - T chwsup

T chwsup = T chwret x E(T tank o - T chwret)

m cp (del T) = 320,428.8 * (del T)

Table D-4: Calculations of Fluorescent and Incandescent Lamp Replacement Cost Savings

Weekday 40 W	Weekday ~~32W~~ 34	Savings	Weekend 40 W	Weekend ~~32W~~ 34	Savings	Weekday 100 W	Weekday ~~80W~~ 75	Savings	Weekend 100 W	Weekend ~~80W~~ 75	Savings
10,265,376	8,704,992		1,140,597	967,221		427,680	256,608		47,520	28,512	
2,818,021	2,389,669		2,818,021	2,389,669		2,104,800	1,262,880		2,104,800	1,262,880	
784,398	665,166		435,776	369,536		32,400	19,440		18,000	10,800	
7,579	6,427		7,579	6,427		55,200	33,120		55,200	33,120	
0	0		0	0		61,200	36,720		61,200	36,720	
1,169,649	991,857		1,169,649	991,857		453,600	272,160		453,600	272,160	
275,865	233,933		172,416	146,208		441,600	264,960		276,000	165,600	
12,000	10,176		12,000	10,176		112,800	67,680		112,800	67,680	
107,523	91,179		0	0		11,700	7,020		0	0	
1,347	1,143		337	286		176,640	105,984		44,160	26,496	
140,964	119,537		78,313	66,409		0	0		0	0	
0	0		0	0		4,200	2,520		4,200	2,520	
3,368	2,856		3,368	2,856		0	0		0	0	
15,586,090	~~13,216,933~~ 14,042,991	~~2,369,157~~ 1,543,099 Wh	5,838,056	~~4,950,645~~ 5,260,060	~~887,411~~ 577,996 Wh	3,881,820	~~2,329,092~~ 2,911,365	~~1,552,728~~ 970,455 W	3,177,480	~~1,906,488~~ 2,383,110	~~1,270,992~~ 794,370 W

Total Savings:
$ ~~56,662~~ /yr. 36,705 assumes $ 0.08/kW

Total Savings:
$ ~~42,871~~ /yr. 26,795 assumes $ 0.08/kW

Table D-5: Calculations of Fluorescent and Incandescent Lamp Replacement Lamp Costs

Flouresce	Incandescents	Wkday Hrs	Wkend hrs	Wkday CF	Wkend CF	Annual Total Hours	Flour Annual Cost	Inc Total Cost
13545	297	16	16	0.9	0.1	3910.4	$2,648	$823
2231	877	24	24	1	1	8736	$975	$5,427
690	15	24	24	0.9	0.5	6864	$237	$73
12	46	12	12	1	1	4368	$3	$142
	51	12	12	1	1	4368	$0	$158
926	189	24	24	1	1	8736	$404	$1,170
273	230	24	24	0.8	0.5	6240	$85	$1,017
19	94	24	24	0.5	0.5	4368	$4	$291
227	13	10	0	0.9	0	2340	$27	$22
2	138	16	16	0.8	0.2	3660.8	$0	$358
124	0	24	24	0.9	0.5	6864	$43	$0
	2	21	21	1	1	7644	$0	$11
8		8	8	1	1	2912	$1	$0
18057	1952					71011.2	$4,427	$9,490

Foures. Annual Costs=#lamps*(hours/yr)/20000*($2.75-$1.75)
Inc. Annual Costs=#lamps*(hrs/yr)*($0.5/750-$2.75/2000)