A FIELD COMPARISON OF RADIANT AND CONVECTIVE HEATING SYSTEMS IN ARMY MAINTENANCE FACILITIES

by

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CHAPTER 1

INTRODUCTION

Project Background

With increased awareness of the need for energy conservation in recent years has come an increasing usage of radiant heating systems. The advantages of radiant heating - specifically, the ability of such systems to maintain a comfortable operative temperature at a lower air temperature than convection heating systems - are particularly attractive for commercial and industrial applications where large, open spaces must be heated.

Radiant heating systems gain this advantage by increasing the mean radiant temperature of the environment. The mean radiant temperature is the uniform blackbody temperature of an imaginary enclosure with which the same amount of radiant heat would be exchanged as is in the actual environment. The operative temperature - a single "sensed" temperature which combines the effects of convective and radiative heat transfer - is related to the mean radiant temperature by the equation:

$$t_o = (h_r \times t_r + h_c \times t_a)/(h_r + h_c) \qquad \text{(eq.1.1)}$$

where

t_o = operative temperature

h_r = linear radiative heat transfer coefficient

h_c = linear convective heat transfer coefficient

t_a = ambient air temperature

t_r = mean radiant temperature

It can be seen from this equation that an increase in MRT will allow a decreased ambient air temperature without a change in the operative temperature.

If t_r is greater than the temperature of the body's surface, the radiant heat flux adds heat to the body system. Conversely, if t_r is less than the body's surface temperature, heat is lost by radiant cooling. The design goal for radiant heat is to maintain an appropriate total heat flux (radiant + convective) at a minimum t_a.

Several studies have been made of the performance of radiant heating systems. Janssen (1976), in a thermal comfort study of a warehouse with vented gas heaters, found that radiant heating producing t_o 5.2F (2.9^{o}C) greater than t_a resulted in a comfortable environment. Bryan (1981) performed a computer simulated comparison between radiant and convective heating in a rectangular space. The same t_o was specified for both applications. In this simulation, it was determined that 100% radiant heating produced a mean radiant temperature 8^{o}C higher than 100% convective heating, thereby allowing a lower air temperature. Bailey (1980) compared radiant and convective heating systems in several applications. The convective systems used 13% to 16% more energy to achieve the same environmental conditions.

The U.S. Army has been pursuing the use of radiant heating in its Tactical Equipment Maintenance Facilities. Existing facilities are being retrofitted and radiant heating is being specified for new construction. Maintenance facilities are in many respects an ideal application for radiant heating. They are characterized by large open areas with high ceilings. Only the lower levels are occupied. The facilities have large garage doors which when open allow the entire space to be flushed with outside air, and high ventilation rates are necessary to remove vehicle exhaust fumes. Under these conditions, a conventional forced-air convection system is generally unable to maintain a comfortable air temperature at the occupied level, or uses excessive amounts of energy to maintain comfortable conditions.

Radiant heating, by operating directly on the surfaces in the space rather than on the air, should not have such problems. The air is not heated by radiant heaters, since the infrared energy is not absorbed by the air in any appreciable amount. The walls, floor, ceiling, and other surfaces absorb the energy, and the air is heated by natural convection from these surfaces. The occupants also benefit from the radiant exchange, since it raises the mean radiant temperature, and therefore allows comfort at a lower air temperature. The lower air temperature also reduces heat losses through infiltration.

The U.S. Army Construction Engineering Research Laboratory (CERL) has been assigned the task of monitoring the performance of heating and cooling systems in Army facilities. Through the Facilities Technical Applications Test (FTAT) program, CERL collects data concerning the performance of generally accepted heating and cooling systems as they are used in specifically military applications. One such FTAT project, entitled "Radiant Heat Effectiveness", is being conducted at two Tactical Equipment Maintenance Facilities at Fort Riley, Kansas.

Project Goals

The two buildings selected by CERL for this study are of almost identical construction. They differ most significantly in their heating systems. One building is heated by gas-fired, tube type radiant heaters while the other is heated by unducted forced convection heaters. The project was initiated in order to evaluate the performance of radiant heaters in maintenance facilities, in comparison with that of conventional heating systems.

The buildings are to be compared on the basis of energy consumption and the thermal environment provided by the different heating systems. The data provided by this comparison can then be used to modify the design of the heating systems in future construction. In addition, this project will provide data which can be used in computer simulations. CERL does extensive work with the simulation program BLAST (Building Loads Analysis and System Thermodynamics). In order to run a simulation, BLAST requires information on a building's structure and geometry, hourly environmental information, and hourly internal loading information. The Radiant Heat Effectiveness project will provide such data.

It was initially intended that all necessary instrumentation would be in place and operational by October 1987, so as to allow data collection throughout the entire heating season. However, useful data collection did not begin until mid-January 1988. At the end of the heating season in May 1988, data collection ceased. All instrumentation was left in place to be used during the 1988-89 heating season.

Scope of Study

This study does not attempt to analyze all of the data collected from the two buildings during the period

February- April 1988. While many data points were sampled every three minutes, the focus here is on hourly and daily averages of measured values. This study will be primarily concerned with a comparison of the energy use and thermal characteristics of the two heating systems. The effects of door openings, as well as ceiling fan and exhaust fan use, on energy usage will be addressed. Thermal characteristics such as air stratification, ambient air temperature, and operative temperature of the two buildings will also be compared.

CHAPTER 2

DESCRIPTION OF BUILDINGS AND HEATING SYSTEMS

General Discussion

The two buildings studied for this project are both located in the Custer Hill area of Fort Riley (map, Appendix A).This area of the post features rolling hills and little substantial vegetation. Both buildings are situated in the middle of large concrete vehicle parking areas, and while there are several outlying buildings, these are not large enough to cause shielding of the main buildings. The buildings are identified by number- Building 8370 and Building 8390. The buildings were constructed in accordance with standardized specifications, and therefore are identical in many of their construction details. Each was built with a slab on grade foundation. The end walls are of concrete block construction, with one end wall separating the maintenance bays from conditioned office space. There are no side walls to speak of, the sides consisting mostly of large insulated metal garage doors separated by vertical steel columns. Translucent panels are set above the doors to provide lighting. The roofs are insulated double metal. The relevant specified U-values are 0.05 $BTU/hr*ft^2*F$ for the walls, 0.07 $BTU/hr*ft^2*F$ for the roofs, and 0.10 $BTU/hr*ft^2*F$ for the bay doors.

Plans and elevations for Building 8370 and Building 8390 are shown in Figure 2.1 and Figure 2.2 respectively.The major difference between the two buildings, besides the heating systems, is size. Building 8370 consists of eight maintenance bays, totaling approximately 8,500 square feet of floor space, while the portion of Building 8390 studied in this project consists of six bays totaling approximately 6,400 square feet. Building 8370 was completed in the fall of 1987, and Building 8390 was completed about one year earlier. Building 8370 is occupied by a Military Intelligence Battalion, and the bays are used for maintenance of a wide variety of wheeled vehicles and armored tracked vehicles. Building 8390 is occupied by an Armor Battalion. The north bay of Building 8390, which is studied here, is used almost exclusively for the maintenance of wheeled vehicles.

DESCRIPTION OF HEATING SYSTEMS

Building 8370

The heating system in Building 8370 is shown in Figure 3.1. The system consists of five separate Perfection-Schwank Model JP125 DSAN indirect, gas-fired, tube type radiant heaters. The heaters consist of 4 in. diameter tubing with individual burners and blowers. Exhaust gases are vented through the ceiling. Each heater

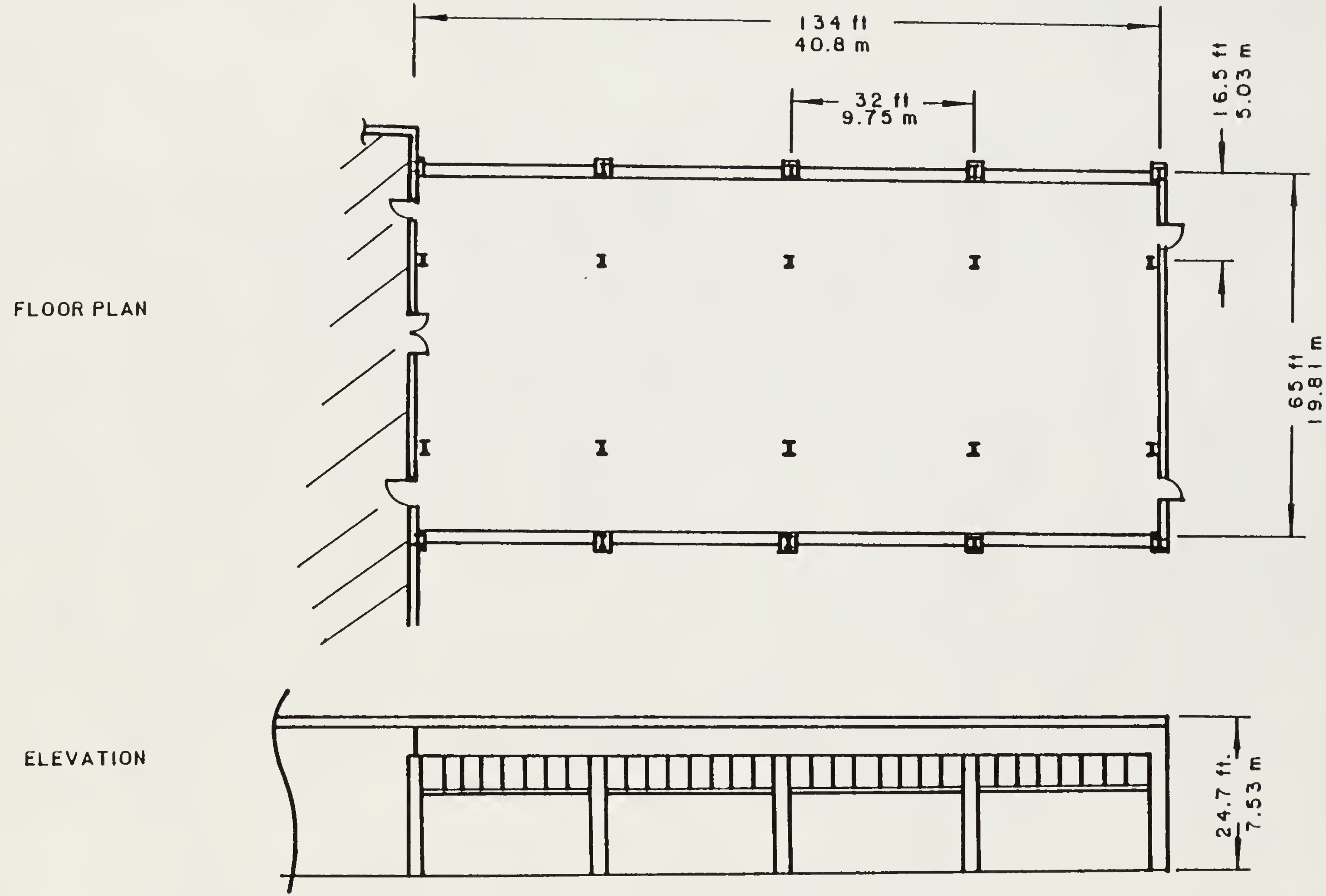


Figure 2.1 - Plan and Elevation, Building 8370

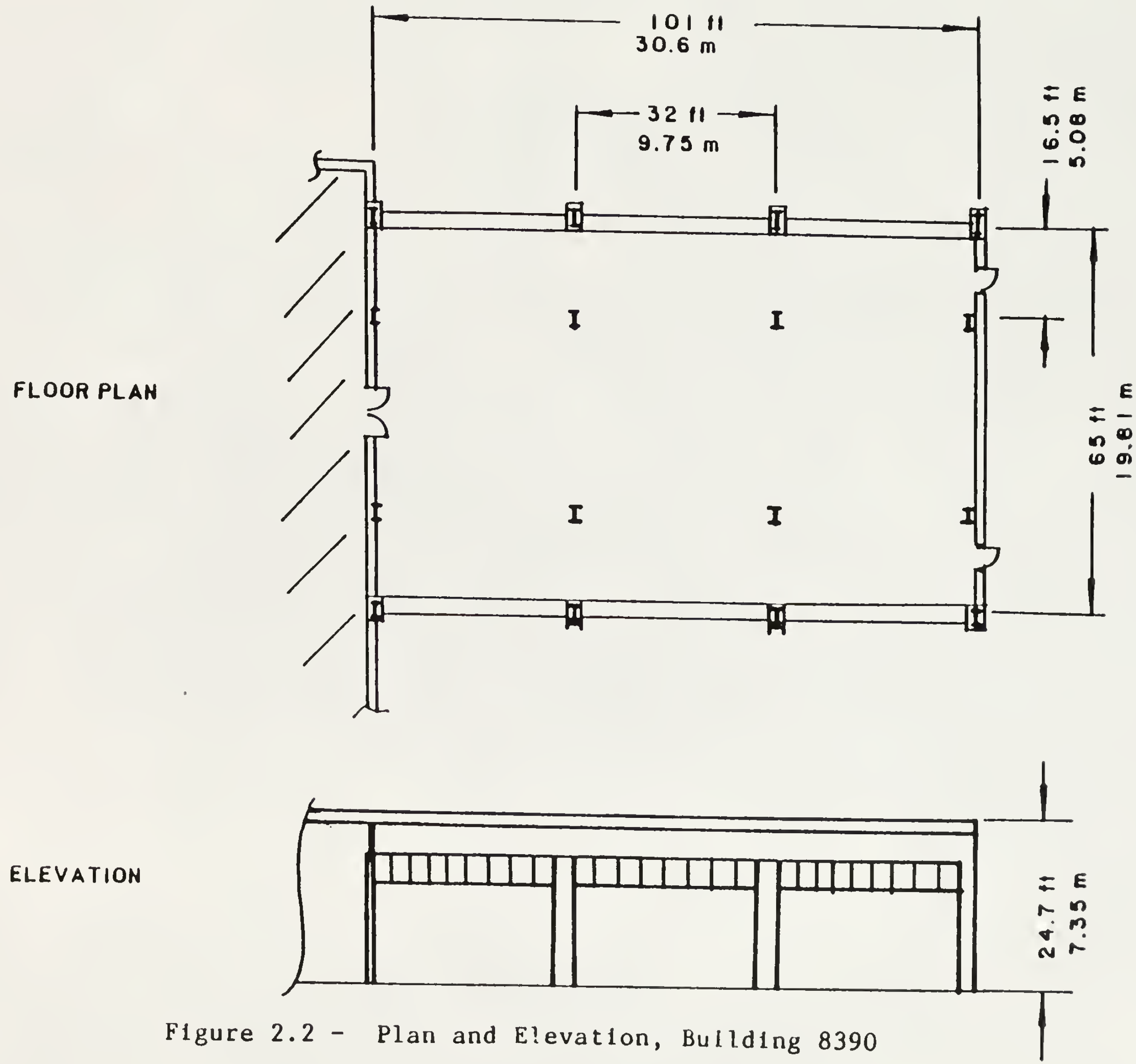


Figure 2.2 - Plan and Elevation, Building 8390

has a rated capacity of 125,000 BTU/hr, for a total capacity of 625,000 BTU/hr. Typical operating temperatures are 800F or greater at the burner end of the tube and 250F or less at the exhaust end. All heaters are mounted at a height of 20 ft above the floor. Reflectors are mounted over the tubes. The heaters are controlled by four thermostats mounted five feet above the floor on vertical structural members. Heaters 2 and 3 are operated by the same thermostat. Each of the other three heaters has its own thermostat. The thermostats operate on line voltage and turn on the blowers and open the gas valves when activated. The burners do not modulate; each heater operates at full capacity whenever it is on.

In addition to the radiant heaters, the building is equipped with a makeup air unit (MAU) which uses a gas burner to heat fresh air brought into the building. The rated capacity of the MAU is 550,000 BTU/hr at 5000 cfm. The MAU has a modulated burner and a specified supply air temperature of 55F. In practice it was found that the air temperature was usually 70-75 F. The controls for the MAU are mounted on the end wall of the bay. The MAU was not operated for much of the heating season, and was operated manually by the building occupants when used.

Building 8370 has two other features, besides the eight garage doors, that affect its thermal characteristics. Four three-bladed ceiling fans are located at a height of 22 feet above the floor. A separate wall switch is provided for each fan. There are also two banks of vehicle exhaust fans, one bank on each side of the bay. Each bank has a separate wall switch.

Building 8390

The heating system for building 8390 is shown in Figure 3.2. All heat to the building is provided by circulating a hot 50/50 water/glycol mixture. There are two unit heaters in each bay, for a total of six heaters. These heaters, rated at 88,000 BTU/hr each, are mounted at a height of 18 feet above the floor. Each heater consists of a finned-tube heat exchanger and a propeller fan which draws air downward through the heat exchanger. When the system is on, the hot water mixture flows through the heat exchanger continuously, and the heater is turned on by activating the fan. The hot water circulation to the entire building is controlled by an outside thermostat, which activates the pump when the outside temperature falls below 65F. Operation of the fans is controlled by thermostats located inside metal electrical boxes which are in turn mounted on structural posts inside the bays. Each box contains both a day and a night thermostat. There are two pairs of thermostats, each of which controls one side of the space, or three heaters.

Like Building 8370, Building 8390 has a make up air unit which heats fresh air brought into the building. The MAU operates on the same hot water loop as the unit heaters. The MAU has a rated capacity of 288,000 BTU/hr, and while the operating schedule is not clear the MAU appeared to operate most of the time during the heating season.

Building 8390 has vehicle exhaust fans similar to those in Building 8370. The building is also equipped with air recirculation devices to reduce thermal stratification. Each device consists of a centrifugal fan mounted near the ceiling connected to a flexible 8-inch duct that hangs down to about two feet above the floor. There are four of these devices, each controlled by a separate wall switch.

CHAPTER 3

DESCRIPTION OF INSTRUMENTATION

General Discussion

The instrumentation used in both buildings was designed with several considerations in mind. First, instrumentation was required not only to measure energy consumption, but also for measurement of all aspects of the thermal environment within the buildings. These included the air temperature at several different elevations, the operative and mean radiant temperatures, the air velocity, and the moisture content of the air. Also, the operation of ceiling fans, exhaust fans, and bay doors had to be monitored. Secondly, all instrumentation had to be unobtrusive, so as not to interfere with the occupants' work. The third consideration was that the instrumentation had to be sufficiently rugged to withstand a certain amount of abuse, since it could not be expected that every occupant would look out for sensitive equipment.

The instrumentation layout in Building 8370 is shown in Figure 3.1, and that of Building 8390 in Figure 3.2.

Modular Measurement System

It was determined that certain similar conditions would be measured at several different locations in the buildings. To do this, a "Modular Measurement System" (MMS)

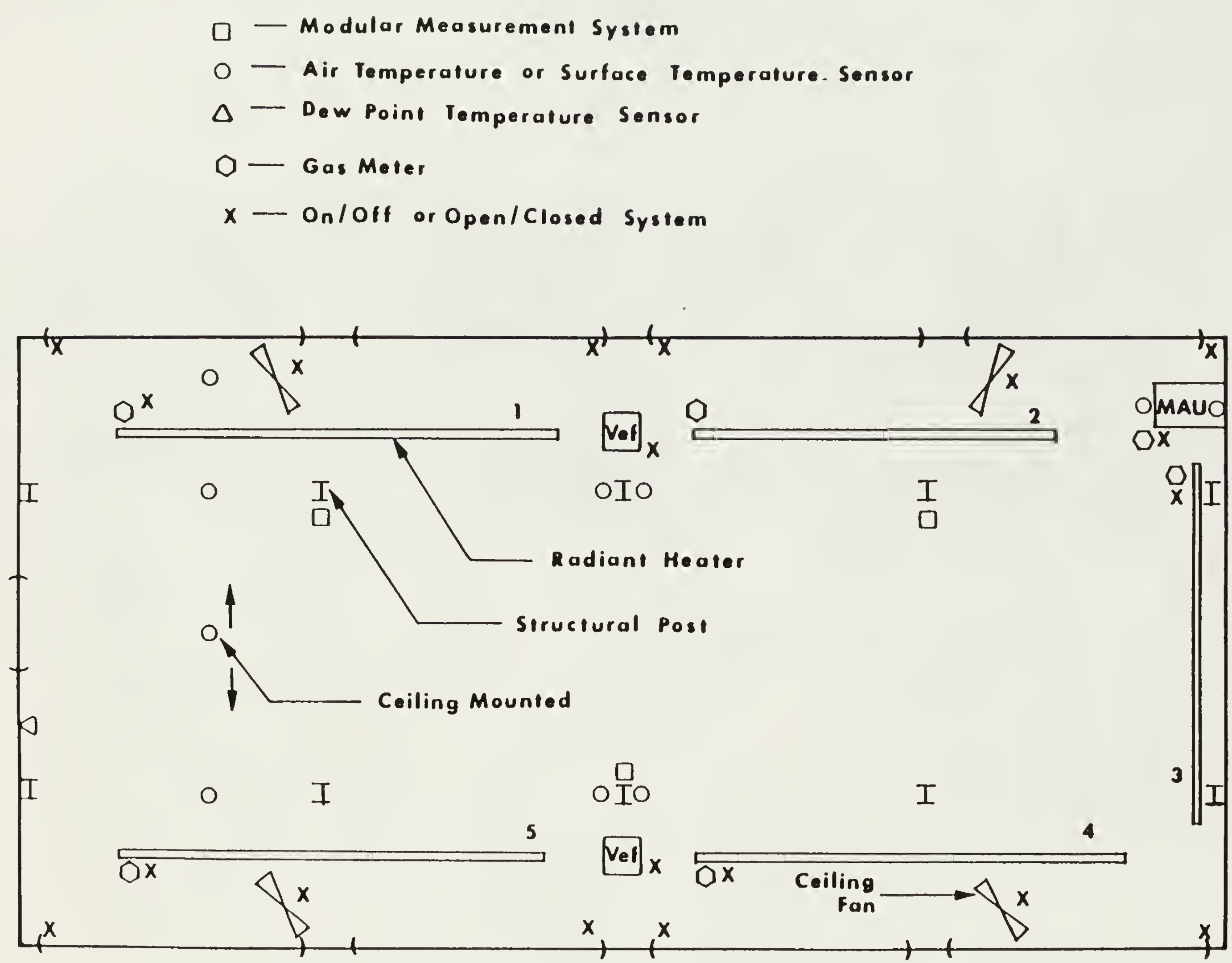


Fig 3.1 - Instrumentation Layout Building 8370

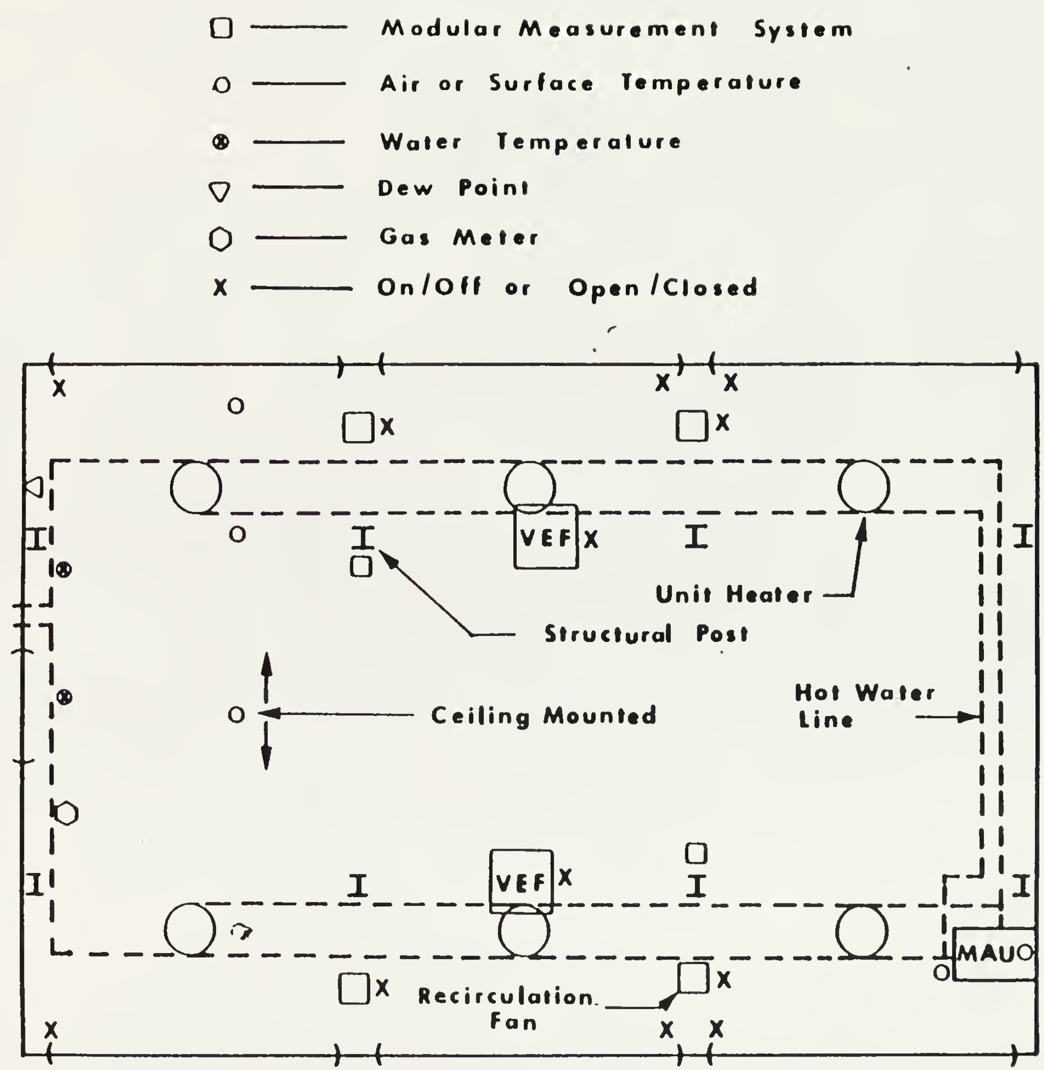


Fig 3.2 - Instrumentation Layout Building 8390

was designed. Three MMS were placed in Building 8370, while two were placed in Building 8390. Each MMS (Fig 3.3) consists of a vertical string of eight thermocouples, an omnidirectional anemometer, and a segmented black globe thermometer. The thermocouples are protected by 1/2 inch metal conduit, with the junctions exposed to the air. The anemometer and globe thermometer are mounted inside a cage made from 1/2 inch mesh hail screen.

The thermocouples used throughout this project are type "T" copper-constantan small gage thermocouples. Table 3.1 lists the elevations of the thermocouples used in the MMS.

Table 3-1: Thermocouple elevations for Modular Measurement System.

T/C Number	Elevation(in.)
1	2 below ceiling
2	264
3	192
4	120
5	72
6	48
7	6
8	-1 (in floor)

Each globe thermometer consists of a 6 inch diameter copper sphere, painted matte black.The classic unsegmented globe thermometer with a thermocouple at the center can be used, along with air temperature and air velocity data, to determine the operative and mean radiant

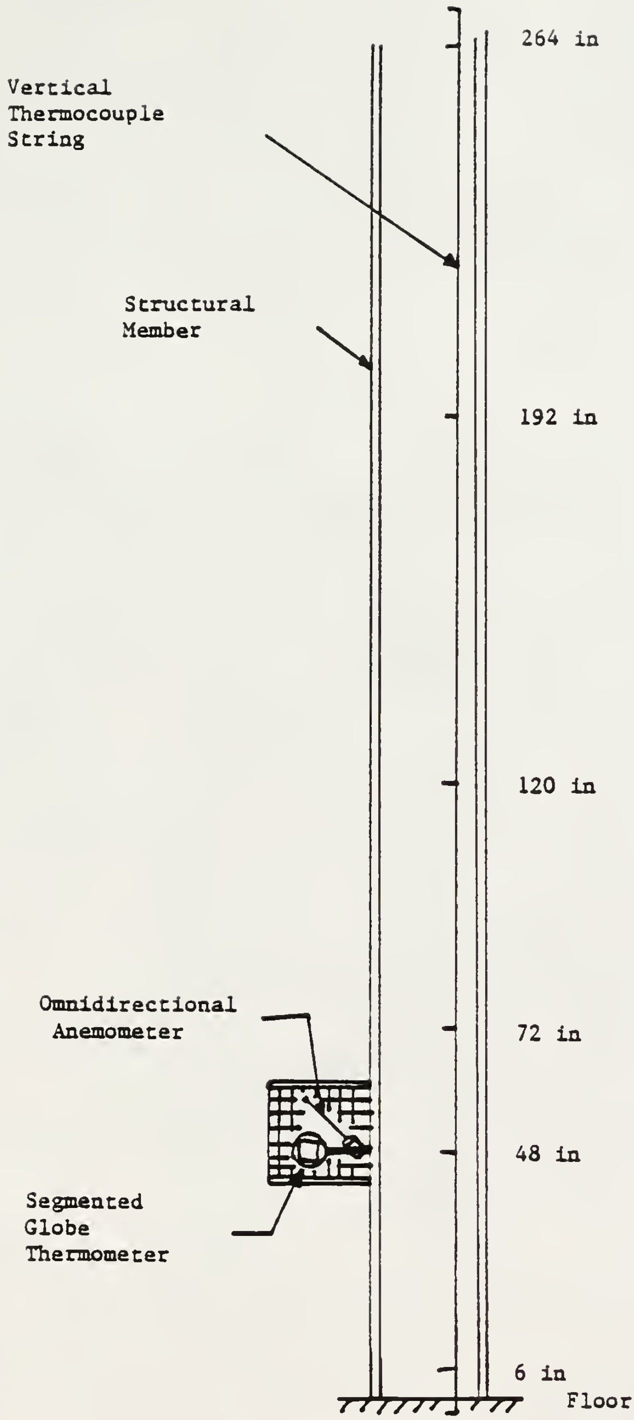


Fig 3.3 - Modular Measurement System

temperatures (ASHRAE 1987). The globes used in this project were segmented according to the six cartesian directions. A copper-constantan thermocouple was attached to the inside of each segment, and the globes were filled with fiberglass insulation to prevent internal radiant exchange between the segments.. Unpublished research by Jones and Tao has shown that the average of the six measurements from a segmented globe thermometer is essentially equal to the measurement from an unsegmented device. The segmented globe also allows for measurement of radiant asymmetry. The globe thermometers are mounted 48 inches above the floor.

The final component of the MMS is the omnidirectional anemometer. TSI Model 1620 OmniSensor anemometers were selected for this project. The tip of the sensor is positioned approximately six inches directly above the globe thermometer. The sensor produces a 0-10 volt signal which is translated to air velocity by use of calibration curves provided by the manufacturer.

Other Temperature Measurements

In addition to the thermocouples installed to measure thermal stratification, temperature sensors were placed in several other locations in each building. Since the MMS thermocouples were installed essentially underneath the heaters, there was concern that the data from these sensors might not be indicative of the typical conditions in the space. To measure temperatures away from the heaters, strings of thermocouples were installed transversely across the ceilings. Four ceiling thermocouples were placed in Building 8370, while three such sensors were placed in Building 8390.

Both buildings had thermocouples placed in the inlet and outlet ducts of the makeup air units. Four additional thermocouples were installed in Building 8370, one at each of the four thermostats. Late in the heating season, two thermocouples were attached to the fins of two of the unit heaters in building 8390. While the data from these sensors was not used in this study, it will be used during the 1988- 89 heating season to directly indicate when the heaters are operating.

Measurement of Ceiling Fan, Exhaust Fan, and Bay Door Operation

Monitoring of the ceiling fans and exhaust fans in both buildings was accomplished by a straightforward procedure. While the equipment in the two buildings differed in line voltages and switch types used, all of the data were collected by connecting a relay to the fan circuits which would close when the fans were in use.

To monitor the use of the bay doors, Sears Model

139.53710 Infrared Reversing Sensors were used. These devices are designed to reverse the operation of automatic garage door openers when the infrared beam is broken. The square-wave signal produced by these devices cannot be used directly by the Acurex dataloggers, so a circuit was designed which would translate the changing signal from the sensor to a relay closure. The circuit is shown in Figure 3.4. The door sensors were placed so that the beam is broken whenever the door is raised more than 12 inches.

Energy Use Measurement

Building 8370

Energy usage in Building 8370 is monitored by measurement of the natural gas flow into each radiant heater and the makeup air unit. An American Meter gas meter was installed by a commercial contractor on each heater, for a total of six. Model AC-250 meters were installed on the radiant heaters, and a Model AC-425 meter was installed on the MAU. The gas meters record the amount of gas used by volume. With each cubic foot of gas, a pulse is sent to the datalogger, which records the cumulative total each hour.

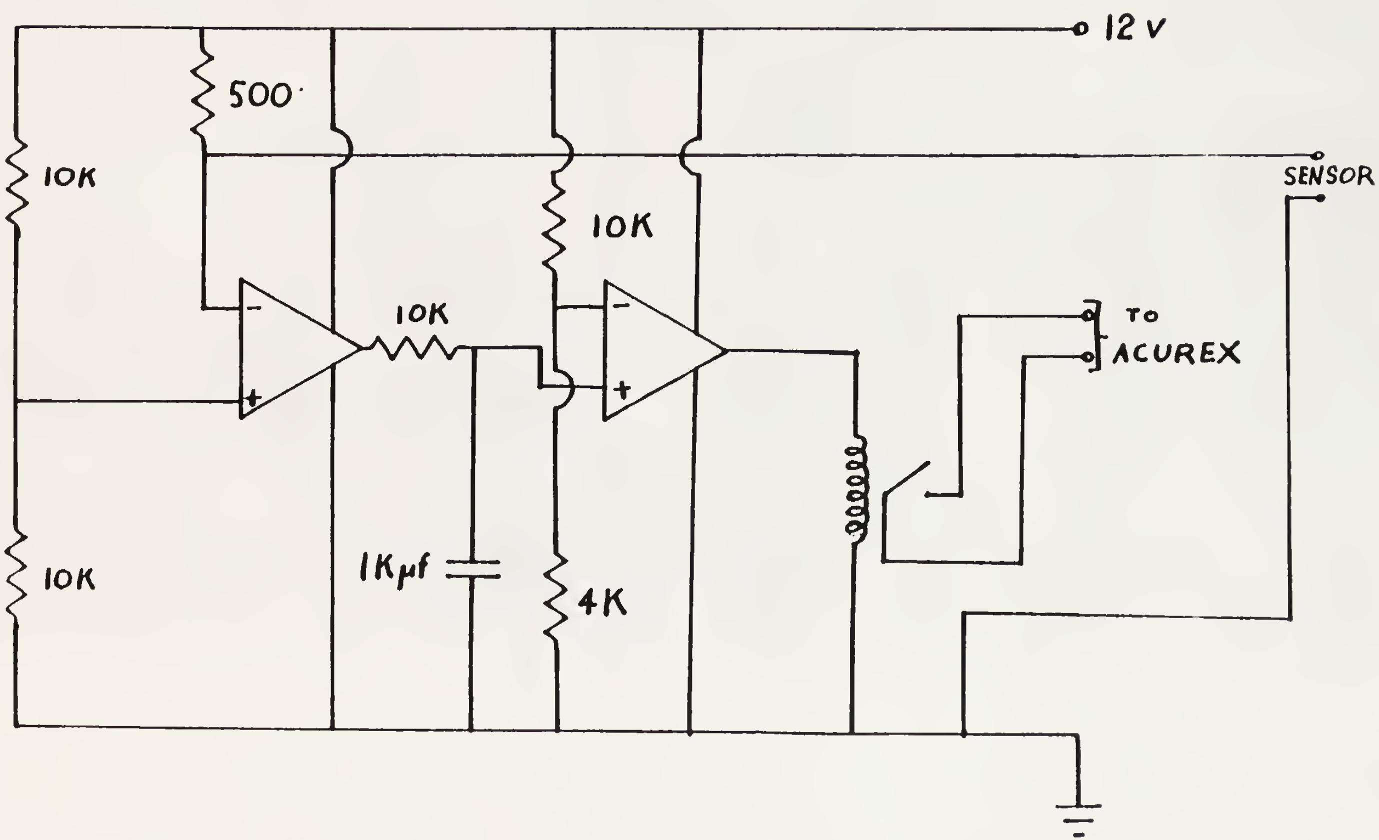


Fig 3.4 - Bay Door Sensor Circuit Diagram

The total volume used can then be converted to energy usage with the equation

$$1 \ ft^3 = 980 \ BTU \qquad \text{(Eqn 3.1)}$$

Each radiant heater, as well as the makeup air unit, is also monitored for on-time. Relays were installed which close when the heater is turned on, and the contact closure is recorded by the datalogger. The record of on-time became useful when it was discovered that the gas meter on the makeup air unit was not working.

Building 8390

The energy usage in Building 8390 could not be measured directly as could that of Building 8370. The building's boiler provides circulating hot water for the entire building, so it was necessary to use instrumentation that would measure only the energy use in the north maintenance bays. To do this, the water flow rate and the difference in temperature between the supply flow and the return flow are measured.

The temperatures are measured by 100-ohm platinum resistance temperature detectors (RTDs) inserted into brass thermowells in the water pipes. The signals from the RTD are converted to 4-20 mA current by HyCal CT-810-B Current transmitters. The 4-20 mA range corresponds to a temperature range of 0-200 F. The transmitters were calibrated once per month. The datalogger initially records the signal as a percentage of the 4-20 mA range, which is then translated to temperature using

Temp (F) = 2 x (percent of range) (Eqn 3.2)

Water flow rates are measured by Data Industrial Model 220B paddlewheel flowmeters. Data Industrial Model 500 Analog Transmitters convert the signal to a 4-20 mA output signal, which corresponds to a flow rate range of 0-250 GPM.

Measurement of Weather Conditions

Weather data is provided by a Climatronics Meteorological Monitoring System. The CMMS continuously monitors wind speed and direction, dry bulb temperature, dew point temperature, barometric pressure, and solar radiation. The weather station is located on a thirty foot tall tower behind Building 8025 on Custer Hill. Building 8025 is approximately one mile from Building 8370 and two miles from Building 8390. The station was installed one year prior to the beginning of this project and was calibrated and verified at that time (Erickson, 1987).

During the month of April, a malfunction of the datalogger in Building 8025 resulted in the loss of several days' weather data. For this time period, outside temperature data was provided by a sensor at Building 7108, also on Custer Hill.

Data Acquisition and Storage

All data from each building is collected by an Acurex AutoCalc Data Acquisition System. The AutoCalcs, Assembly # 42565-040, were configured with three analog input boards and two digital input boards. The Acurexes are mounted in cabinets located in offices adjacent to the maintenance bays. The circuits for the bay door sensors are located in the cabinets. Micronta Model 22-121 Dual-Tracking Power Supplies are used to provide power to the anemometers, dew point temperature sensors, door sensors, RTDs, and flow meters. The power supplies are also located in the cabinets, as are the RTD and Flow Meter Transmitters for Building 8390.

The AutoCalcs each have 360K bytes of internal RAM storage memory, which can be divided into as many as five history files. All data points are scanned once per minute. However, since the AutoCalc's memory is limited, it was apparent that storing all of the data require almost daily trips to Fort Riley to download the data onto floppy disks, as well as resulting in an unmanageably large data base. This being the case, the AutoCalcs were programmed to store certain data at three-minute intervals while most data were stored as hourly averages. With this programming, the AutoCalcs were able to store approximately four days' data before filling the available memory. Downloading of data was done with a Zenith portable computer, using the CROSSTALK XVI communications program.

The three-minute scans provide a "snapshot" of conditions in the space at a particular time. Tables 3.2 and 3.3 list the three-minute data for both buildings.

Table 3.2: Three-Minute Scan Data- Building 8370

DATE DESCRIPTION	NUMBER OF DATA POINTS
Average Globe Temperature	3
Thermostat Temperature	4
Air Velocity	3
MAU Inlet Temperature	1
MAU Outlet Temperature	1
Fans On/Off	6
Heaters On/Off	5
Doors Open/Closed	8
Ambient Air Temperature	3
Dew Point Temperature	1

Table 3.3: Three-Minute Scan Data- Building 8390

DATA DESCRIPTION	NUMBER OF DATA POINTS
Average Globe Temperature	2
Air Velocity	2
MAU Inlet Temperature	1
MAU Outlet Temperature	1
Fans On/Off	6
Doors Open/Closed	6
Ambient Air Temperature	2
Dew Point Temperature	1

The globe thermometer temperature recorded is the mean of the six segment temperatures. Air velocity data is recorded as volts. Ambient Temperature is the mean of the 48 inch and 72 inch temperatures from the MMS vertical thermocouple string.

The ceiling fan, exhaust fan, heater, and bay door operation data is processed to minimize memory requirements. The data from each sensor is initially collected as a single data bit, 1 or 0, 1 signifying "on" or "open" and 0 signifying "off" or "closed". Each data bit is then multiplied by a specified 2*n. For example, the data bit from Ceiling Fan 1 would be multiplied by 1, that of Ceiling Fan 2 would be multiplied by 2, that of Ceiling Fan 3 would be multiplied by 4, and so on through 8, 16, etc. A summation of the products results in a single integer number. In Building 8370 the ceiling fan, exhaust fan, and heater data are stored as one decimal number and the bay door data as a second number. In Building 8390 all fan and bay door data are stored as a single number.

The hourly data scans record time-averaged values for all temperature data, and also store hourly totals of energy use and bay door open time. Tables 3.4 and 3.5 summarize the hourly data.

Table 3.4: Hourly Scan Data - Building 8370

DATA DESCRIPTION	NUMBER OF DATA POINTS
Vertical Air Temperature	24 (8 per MMS)
Globe Segment Temperature	18 (6 per Globe)
Ceiling Temperature	4
Dew Point Temperature	1
Heater Gas Usage	6
Bay Door Open Time	8

Table 3.5: Hourly Scan Data - Building 8390

DATA DESCRIPTION	NUMBER OF DATA POINTS
Vertical Air Temperature	16
Globe Segment Temperature	12
Dew Point Temperature	1
Ceiling Temperature	4
North Bay Energy Use	1
South Bay Energy Use	1
Door Open Time	6
North Water Supply Temp	1
North Water Return Temp	1
South Water Supply Temp	1
South Water Return Temp	1
North Water Flow Rate	1
South Water Flow Rate	1

Energy use data for Building 8390 is calculated each minute by

$$\dot{Q} = 0.436 \times \dot{V} \times \Delta T \qquad \text{(Eqn 3.3)}$$

where

$\dot{Q}$ = Heat flow rate KBTU/hr

$\dot{V}$ = Flow Rate (GPM)

ΔT = Temperature difference between supply and return water

The factor 0.436 combines the necessary unit conversions and a specific heat = 0.85 (ASHRAE 1985). The average of the heat flow rates over one hour provides the hourly energy use in KBTUs.

It may be noted that the operation of the bay doors is recorded in two separate ways. The output signal from the door sensor circuit is read by both an analog board and a digital board in the AutoCalc. The analog board measures the voltage, compares it to a programmed threshold value, and stores a "1" if the voltage is above the threshold. These are the data stored every three minutes. The digital board scans the circuit every second, and counts the number of seconds the door circuit relay is closed. This equals the number of seconds the door is open. These data are stored in the hourly scans, at which time the digital "counter" is reset to zero.

Error Analysis for Energy Measurements

Building 8370

The relative error of the energy measurements in Building 8370 is

$$e_Q = \sqrt{(e_V)^2 + (e_C)^2} \qquad (3.4)$$

where

e_V = relative error of volume measurement

e_C = relative error of conversion factor

The total error of the volume measurement is

$$E_V = \sqrt{(E_{meter})^2 + (E_{least\ count})^2} \qquad (3.5)$$

The accuracy of the gas meters is $\pm$ 0.01 , which leads to

$$E_{meter} = \pm\ 0.01 \times (\text{volume measured})\ ft^3$$

$$E_{least\ count} = \pm 1.0\ ft^3$$

(3.5) thus becomes

$$E_V = \sqrt{(0.01 \times \text{volume})^2 + 1.0}$$

For the highest volume measured (125 ft^3), this results in

$$E_V = 1.6\ ft^3$$

The relative error then is

$$e_V = 1.6/V \qquad (3.6)$$

Depending on conditions, the heat from 1 ft^3 of gas varies between 972 BTU and 988 BTU. A value of 980 BTU/ft^3 was used in this study. Therefore,

$$E_C = \pm\ 8\ BTU/ft^3$$

$$e_C = \pm\ 0.01 \qquad (3.7)$$

Combining (3.6) and (3.7) with (3.4) results in

$$e_Q = \sqrt{(1.6/V)^2 + (0.01)^2}$$

For V = 125 ft^3 this becomes

$$e_Q = 0.016$$

Building 8390

The relative error for energy measurements in Building 8390, based on (3.3), is

$$e_Q = \sqrt{(e_\rho)^2 + (e_Cp)^2 + (e_V)^2 + (e_{\Delta T})^2} \qquad (3.8)$$

For the small temperature range involved in this study, the density and specific heat are assumed to be constant.

$$E_V = \sqrt{(E_{meter})^2 + (E_{Acurex})^2 + (E_{cal})^2}$$

$$E_{meter} = \pm\ 0.005 \times (\text{current range})$$

$$= \pm\ 0.08\ mA$$

$= \pm 1.0$ gpm

$E_{Acurex} = 0.0008 \times (\text{input current})$

For the highest input current (20 mA) this becomes

$E_{Acurex} = \pm 0.016$ mA

$= 0.2$ gpm

$E_{calibration} = \pm 0.1$ gpm

Therefore

$E_V = 1.025$ gpm

$e_V = 1.025/V$

The absolute error for each RTD is given by

$$E_T = \sqrt{(E_{trans})^2 + (E_{Acurex})^2 + (E_{cal})^2 + (E_{lc})^2}$$

$E_{transmitter} = \pm 0.2$ F

$E_{Acurex} = \pm 0.0008 \times (\text{input current})$

$= \pm 0.2$ F

$E_{calibration} = \pm 0.1$ F

$E_{least\ count} = \pm 0.05$ F

Combining these terms,

$E_T = 0.3$ F

The error of the temperature difference is

$$E_{\Delta T} = \sqrt{2 \times (E_T)^2}$$

$= 0.42$ F

$e_{\Delta T} = 0.42$ F/ T

Thus,

$$e_Q = \sqrt{(1.025/V)^2 + (0.42/\Delta T)^2}$$

When the system is operating, the flow rate $\dot{V}$ is generally constant at 95 gpm. Therefore, the relative error can be considered a function of T, or, using equation 3.3, a function of Q. Figure 3.5 shows this functional relationship. As can be seen, the relative error becomes extremely large for low values of Q, making these values suspect.

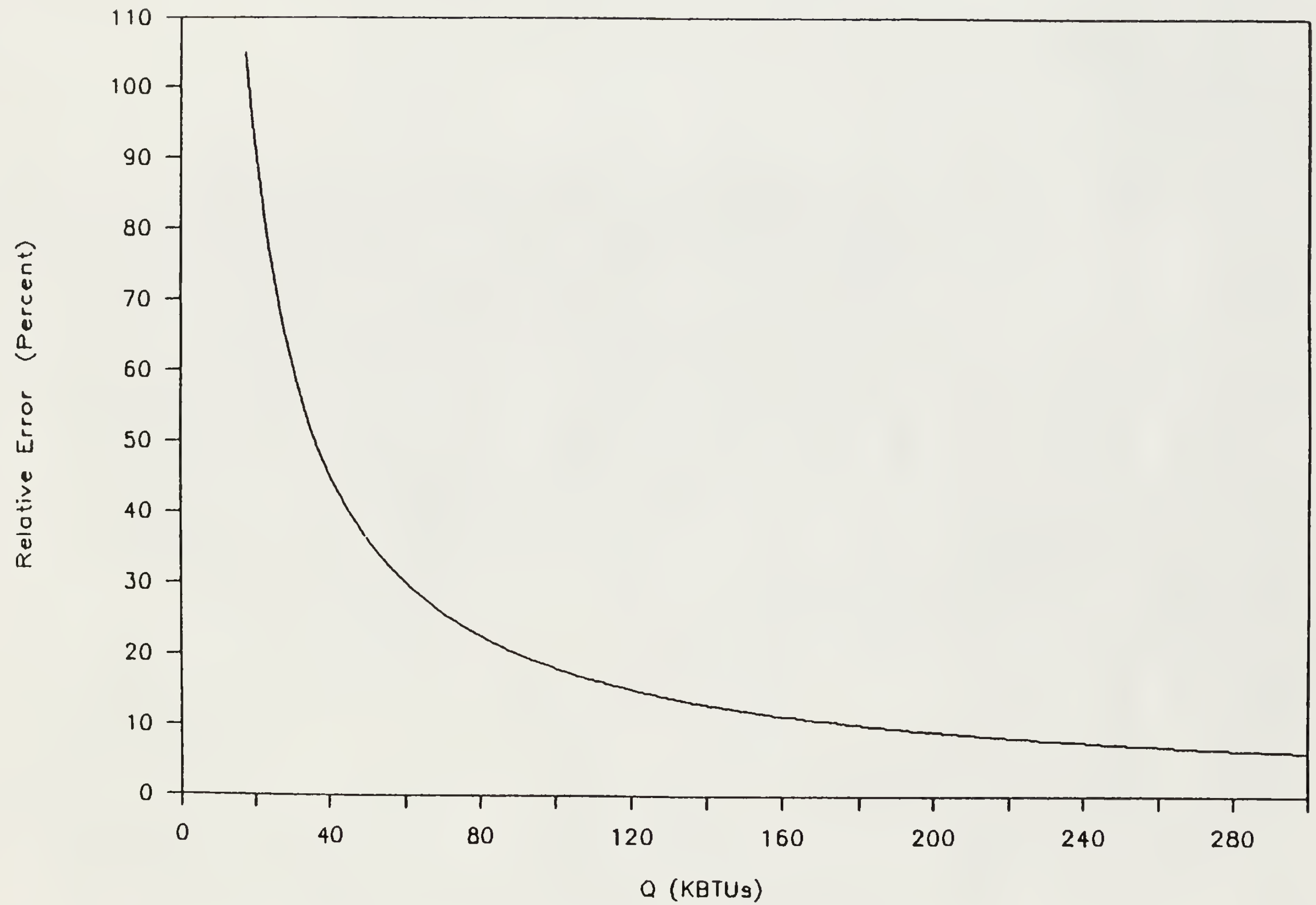


Fig 3.5 Relative Error In Energy Use Measurement - Building 8390

CHAPTER 4

COMPARISON OF BUILDING HEATING SYSTEM PERFORMANCE

Introduction

The scope of this study made it necessary to process the data from the AutoCalcs into daily averages which were then analyzed to compare the systems' performance. Initial processing was accomplished using FORTRAN programs developed by CERL investigators. These programs reformatted the data so that each recorded scan was now stored as a single line in a data file. This allowed the data to be read into the Lotus 1-2-3 spreadsheet program for analysis. The Lotus program was used along with some BASIC programs to convert the hourly and three minute data into daily averages.

The daily average values used for these comparisons are listed in Appendix C.

Energy Use Comparison

General Discussion

In order to make a meaningful comparison between the energy usage of the two buildings, it is important to take into consideration differences in the both the physical dimensions of the buildings and the character of the raw data collected. As was described in Chapter 2, Building 8370 is 33% larger in floor area than Building 8390, and would therefore be expected to use more energy. In order to simulate a comparison between two buildings of equal size, the energy data from Building 8390 was increased by a scale factor of 1.33.

The second consideration involves the meaning of the energy data collected from each building. the fuel energy input to Building 8370 was measured, as opposed to the thermal energy input measured for Building 8390. Since the boiler in Building 8390 provides heat for the entire building, it is not possible to directly measure the fuel energy used to heat the north bay. It is necessary, then, to adjust the energy data for Building 8390 to account for the efficiency of the boiler.

Boiler efficiency is described in two ways: combustion efficiency and overall efficiency. Combustion efficiency is defined as (input-stack loss)/input. ASHRAE (1988) shows that a non-condensing boiler with an input water temperature of 160F can be expected to have a combustion efficiency of approximately 85%. Overall efficiency takes into account the loss of energy through the walls of the boiler. For this study it was assumed that heat losses through the boiler and pipes equaled 10% of the input energy. The resulting overall efficiency for Building 8390 was therefore taken to be 75%, and the energy data for the building was adjusted for this efficiency.

Monthly Energy Consumption

The overall energy usage of Buildings 8370 and 8390 during the month of February is shown in Figure 4.1. Average daily outside temperatures for February are shown in Figure 4.2.

As would be expected, energy usage in both buildings generally varied inversely with outside temperature. Noticeable peaks in energy use show for February 11, which was the only day during the three month study period for which the average outside temperature was less than 0 F. It can be seen that Building 8370 used substantially more energy than Building 8390 during the period 1 - 24 February, after which the difference between the two buildings became less pronounced.

The energy usage and daily outside temperatures for March are shown in Figures 4.3 and 4.4. For the first six days of March, Building 8370 again used much more energy than did Building 8390. For the remainder of the month, there was no clear difference between the two buildings. It should be noted that the heaters in Building 8370 were turned off during the period 23 - 27 March.

Figures 4.5 and 4.6 show the energy use and daily outside temperatures for the period 1 April - 1 May.

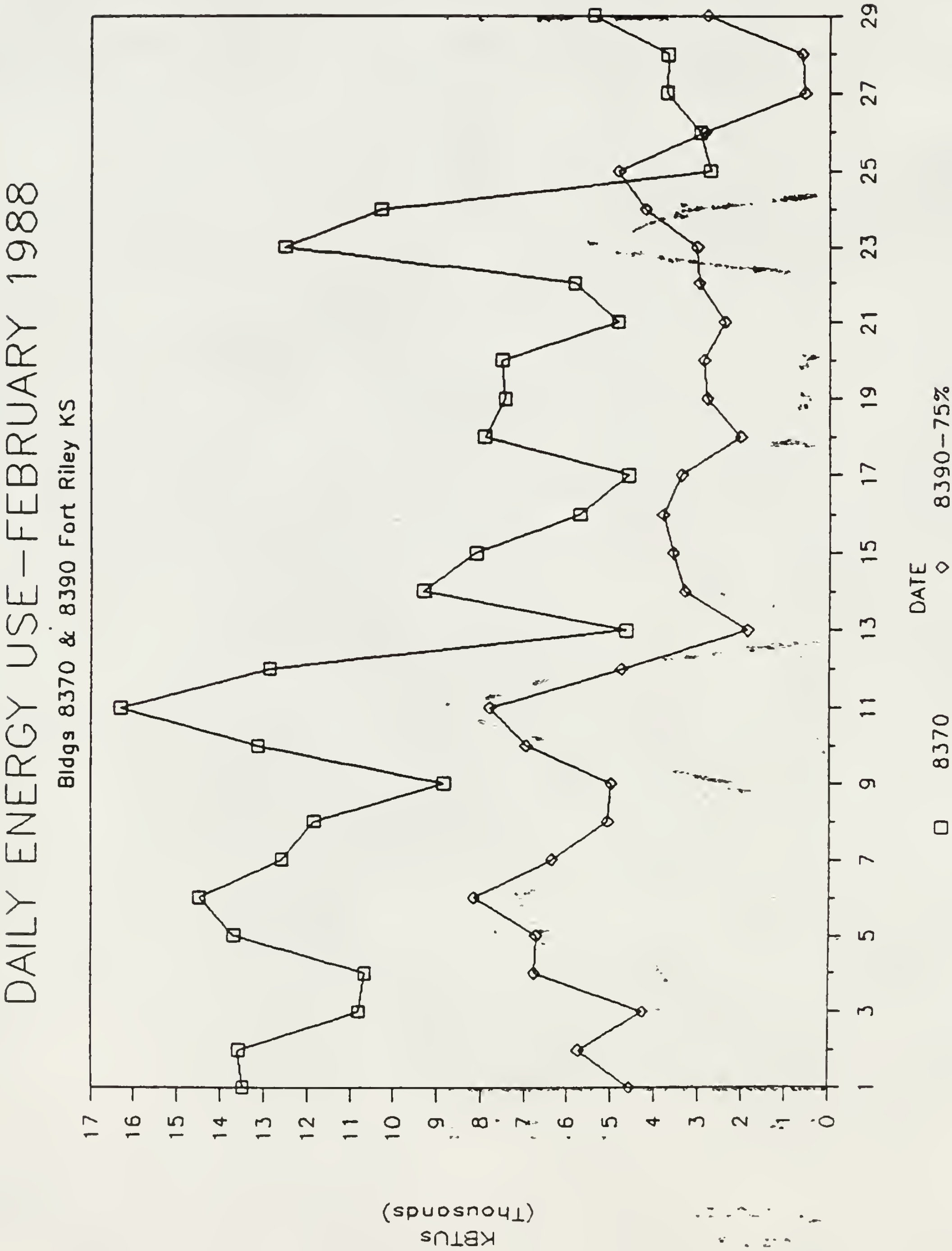

DAILY ENERGY USE—FEBRUARY 1988
Bldgs 8370 & 8390 Fort Riley KS
KBTUs
(Thousands)
DATE
8370
8390–75%
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29

Fig. 4.1

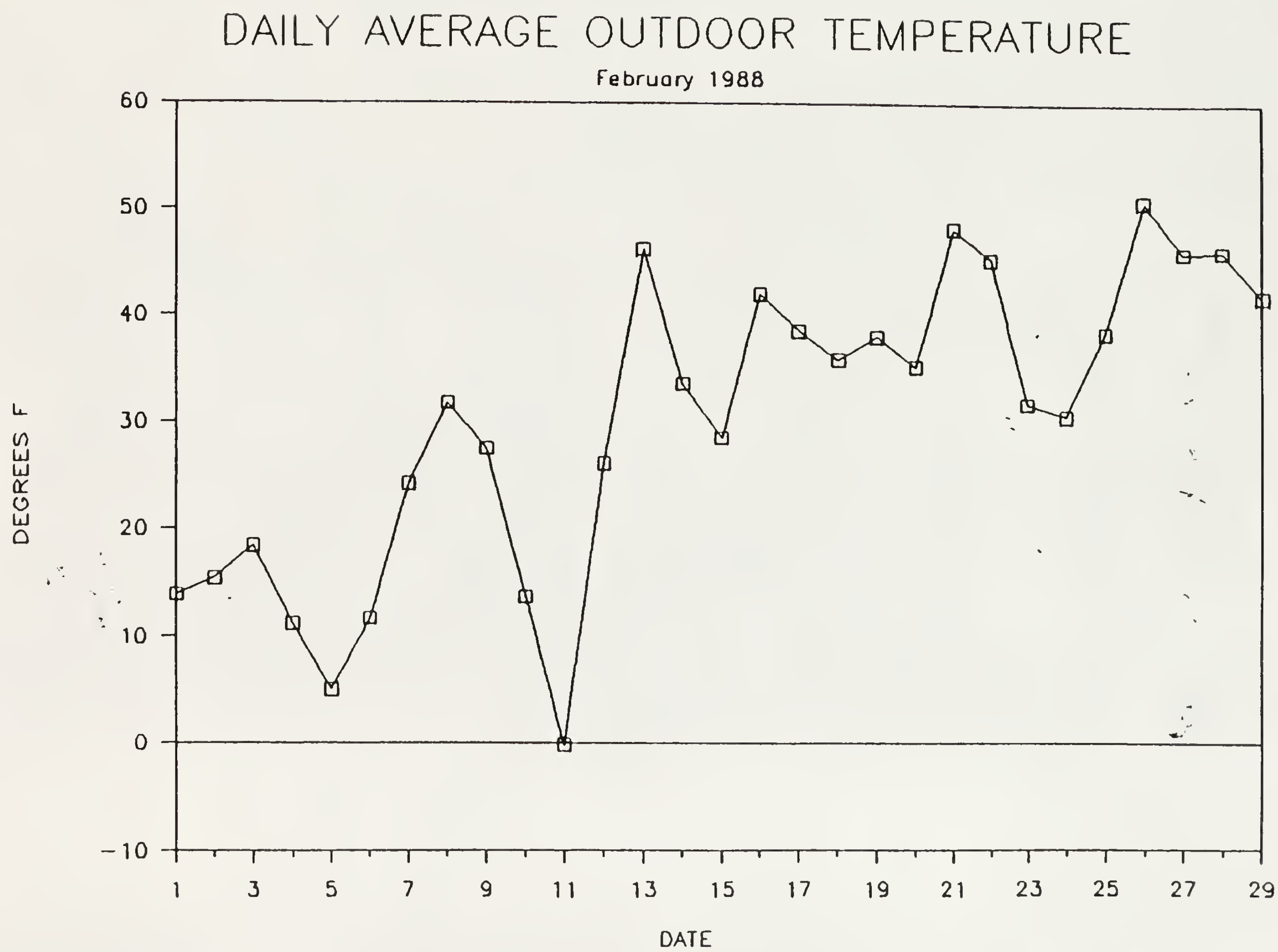

DAILY AVERAGE OUTDOOR TEMPERATURE
February 1988
DEGREES F
60
50
40
30
20
10
0
−10
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
DATE

Fig 4.2

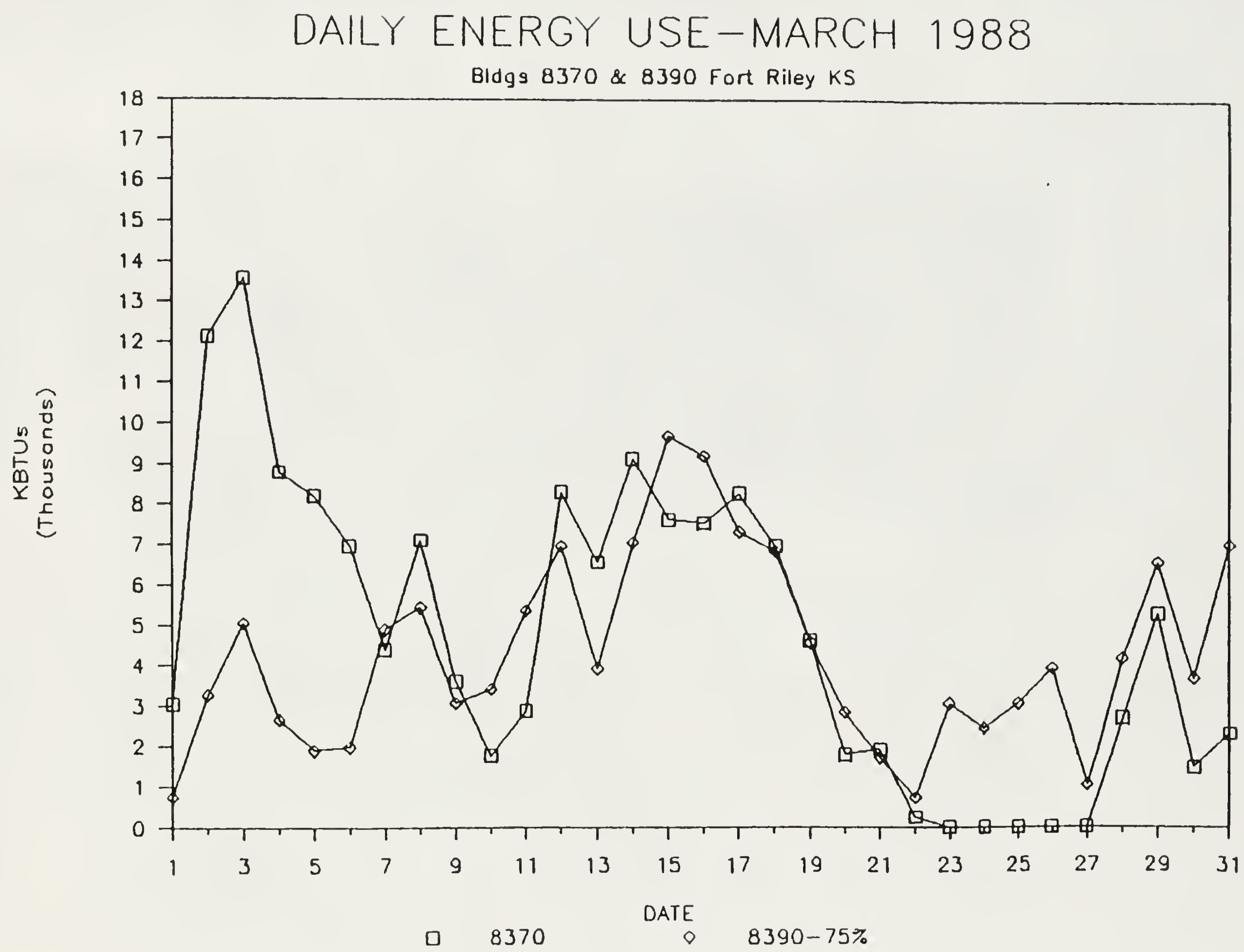

DAILY ENERGY USE—MARCH 1988
Bldgs 8370 & 8390 Fort Riley KS
KBTUs
(Thousands)
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
DATE
8370
8390—75%

Fig 4.3

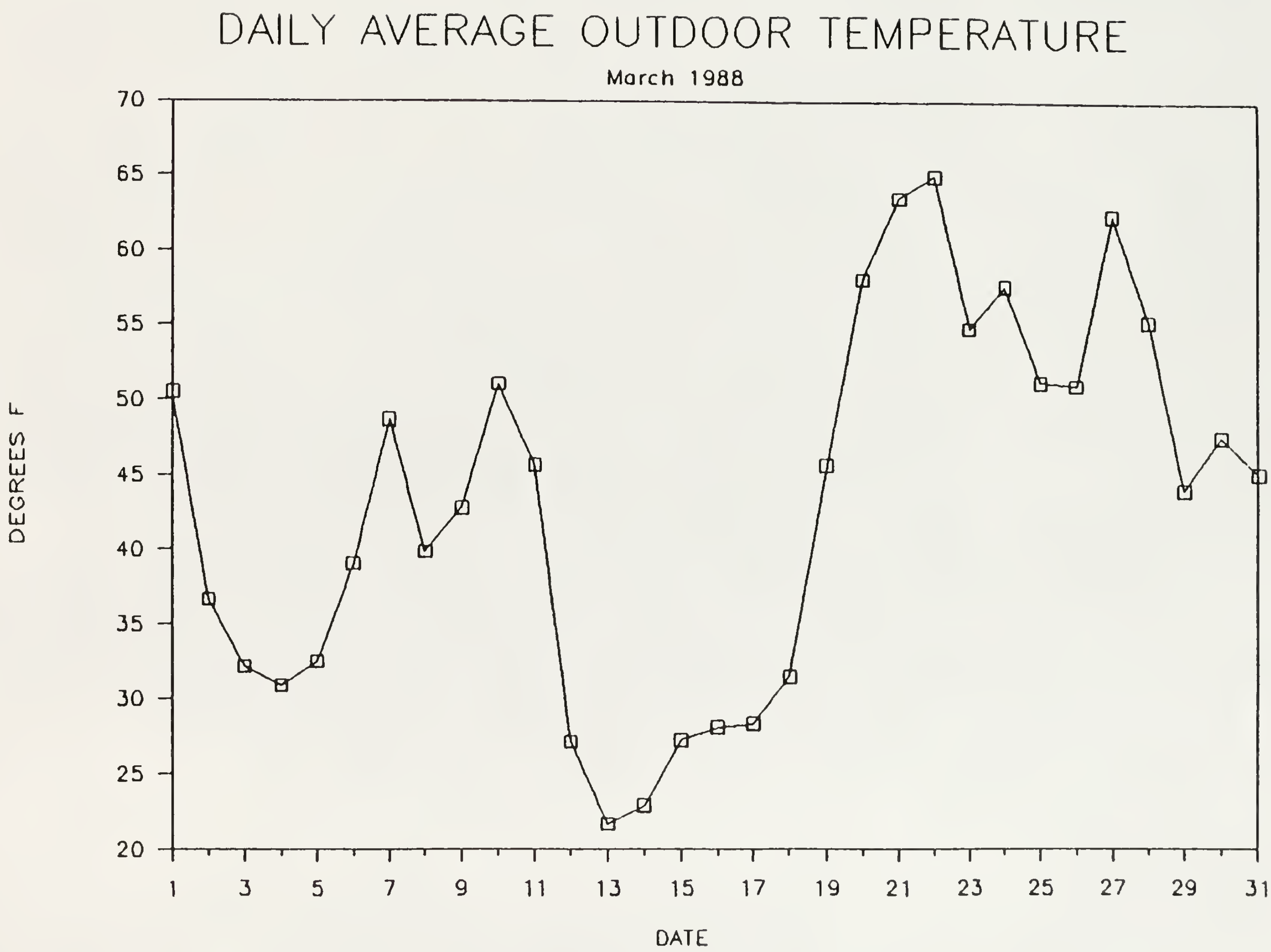

DAILY AVERAGE OUTDOOR TEMPERATURE
March 1988
DEGREES F
70
65
60
55
50
45
40
35
30
25
20
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
DATE

Fig 4.4

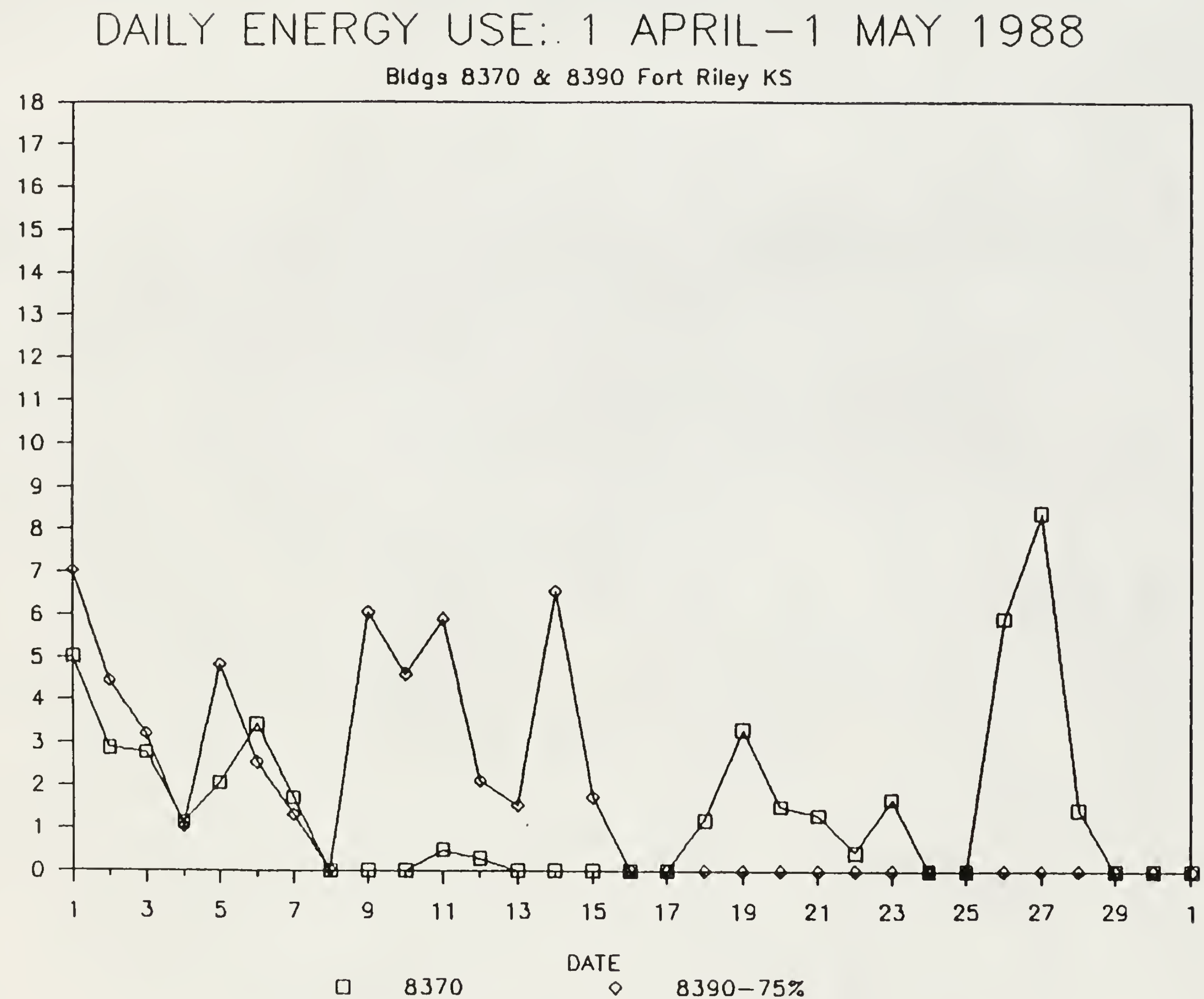

DAILY ENERGY USE: 1 APRIL-1 MAY 1988
Bldgs 8370 & 8390 Fort Riley KS
KBTUs
(Thousands)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
1
DATE
8370
8390-75%

Fig 4.5

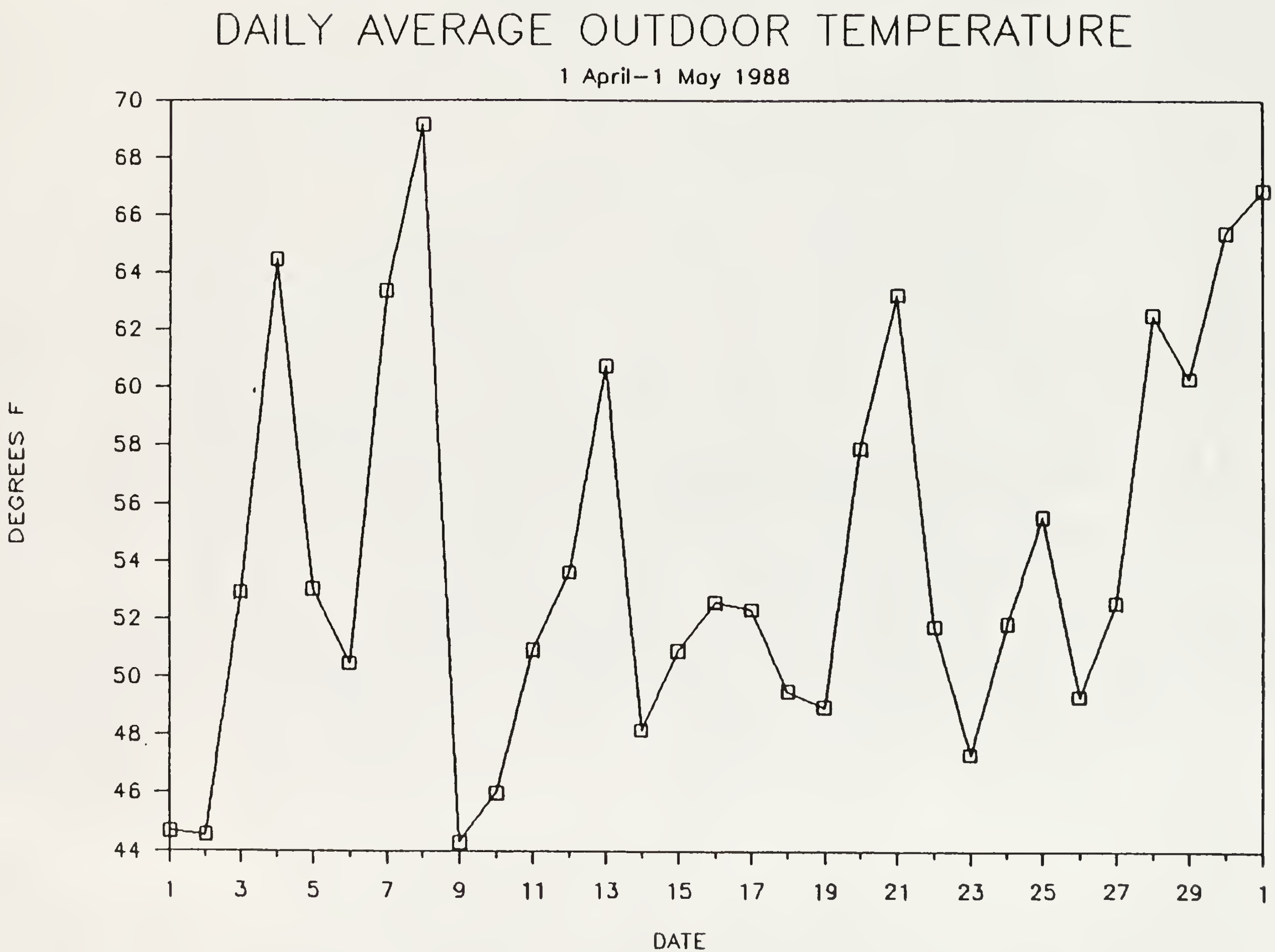

DAILY AVERAGE OUTDOOR TEMPERATURE
1 April–1 May 1988
DEGREES F
70
68
66
64
62
60
58
56
54
52
50
48
46
44
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
1
DATE

Fig 4.6

Outside temperatures varied widely, with the highest daily average temperature occuring on 8 April and the lowest occuring the next day. Energy usage also varied considerably. The pump in Building 8390 shut down on 16 April, while the heaters in Building 8370 continued in use throughout the month.

The monthly totals for energy usage are summarized in Table 4.1.

Table 4.1: Total Heating Energy Use (KBTUs)

	8370	8390
February	260000	123000
March	147000	137000
April	45000	54000
Total	452000	315000

Overall, Building 8370 used 43% more energy for heating than Building 8390. This was an unexpected result since the characteristics of the buildings would appear to favor radiant heating systems. While it was not possible to monitor all of the factors affecting energy use, severa[l] which may have caused the observed results were examined.

Daytime/Nighttime Energy Use

As was described in Chapter 2, the controls for th[e] radiant heaters in Building 8370 consist of single easily accessible thermostats. No night-time setback was provided Building 8390 has separate day and night thermostats i enclosed cabinets.

In order to examine the effects of this difference, the energy usage of each building was divided into daytime use, defined as energy use between 6 AM and 6 PM, and nighttime use, which was energy used between 6 PM and 6 AM. The results are shown in Figures 4.7 through 4.12 and are summarized in Table 4.2.

Table 4.2: Daytime and Nightime Energy Use (KBTUs)

	Day		Night	
	8370	8390	8370	8390
February	123000	90000	137000	34000
March	70000	88000	77000	49000
April	15000	32000	30000	22000
Total	208000	210000	244000	105000

It can be seen that Building 8390 consistently used less energy at night than did Building 8370. This difference is particularly notable in the February and early March data. The difference in nighttime energy use between the buildings was not as drastic during March and April, but Building 8370 still used more energy. Over the entire three month period, the total nighttime energy consumption of Building 8370 exceeded that of Building 8390 by 132%.

In terms of daytime energy usage, Building 8370 fared better. During March and April, Building 8370 used less energy than Building 8390. While the relative differences between the two buildings were large during

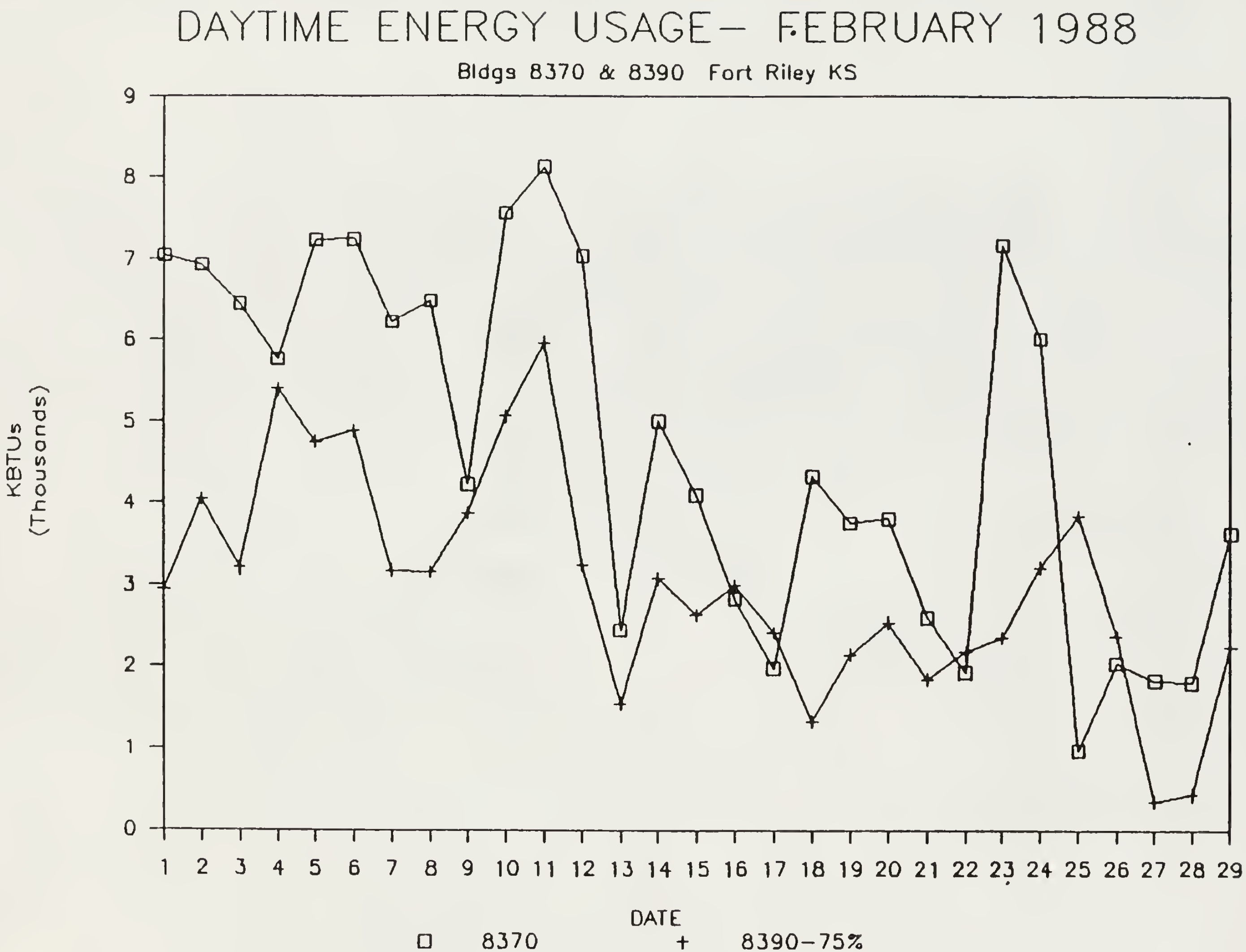

DAYTIME ENERGY USAGE– FEBRUARY 1988
Bldgs 8370 & 8390 Fort Riley KS
KBTUs
(Thousands)
0
1
2
3
4
5
6
7
8
9
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
DATE
□ 8370
+ 8390–75%

Fig 4.7

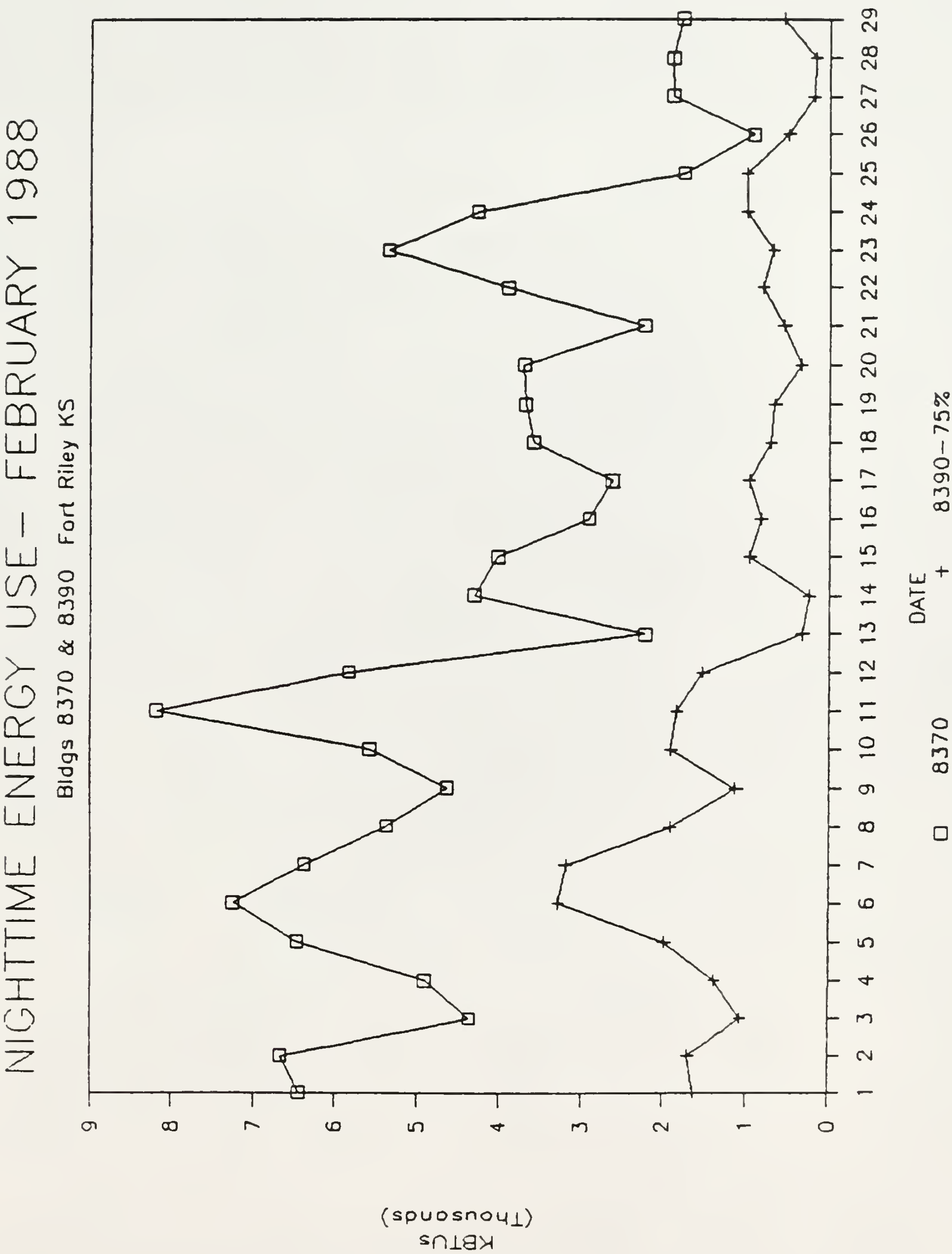
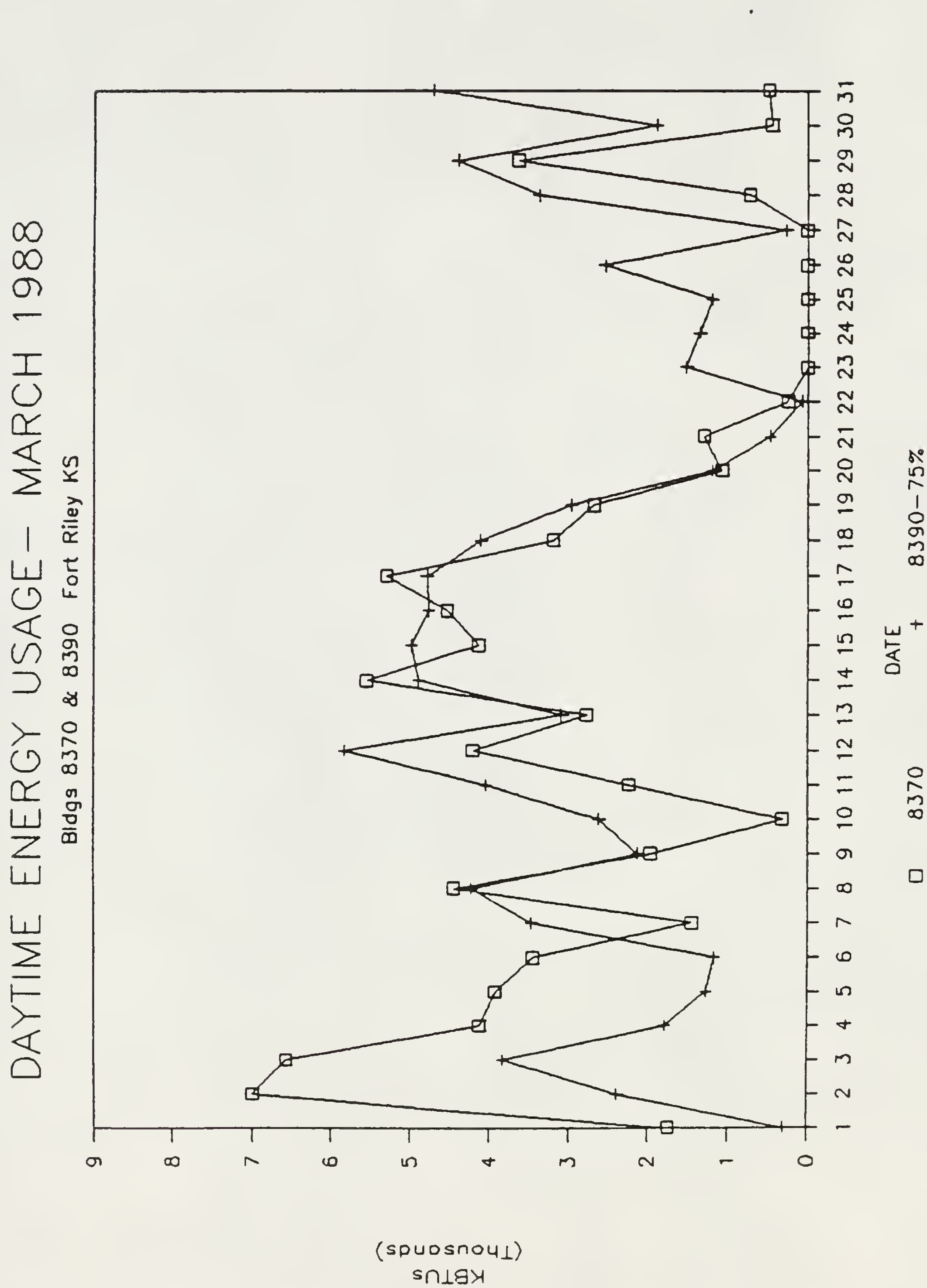

NIGHTTIME ENERGY USE – FEBRUARY 1988
Bldgs 8370 & 8390 Fort Riley KS
KBTUs
(Thousands)
0
1
2
3
4
5
6
7
8
9
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
DATE
□ 8370 + 8390–75%

Fig 4.8



DAYTIME ENERGY USAGE – MARCH 1988
Bldgs 8370 & 8390 Fort Riley KS
KBTUs
(Thousands)
0
1
2
3
4
5
6
7
8
9
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
DATE
□ 8370
+ 8390–75%

Fig 4.9

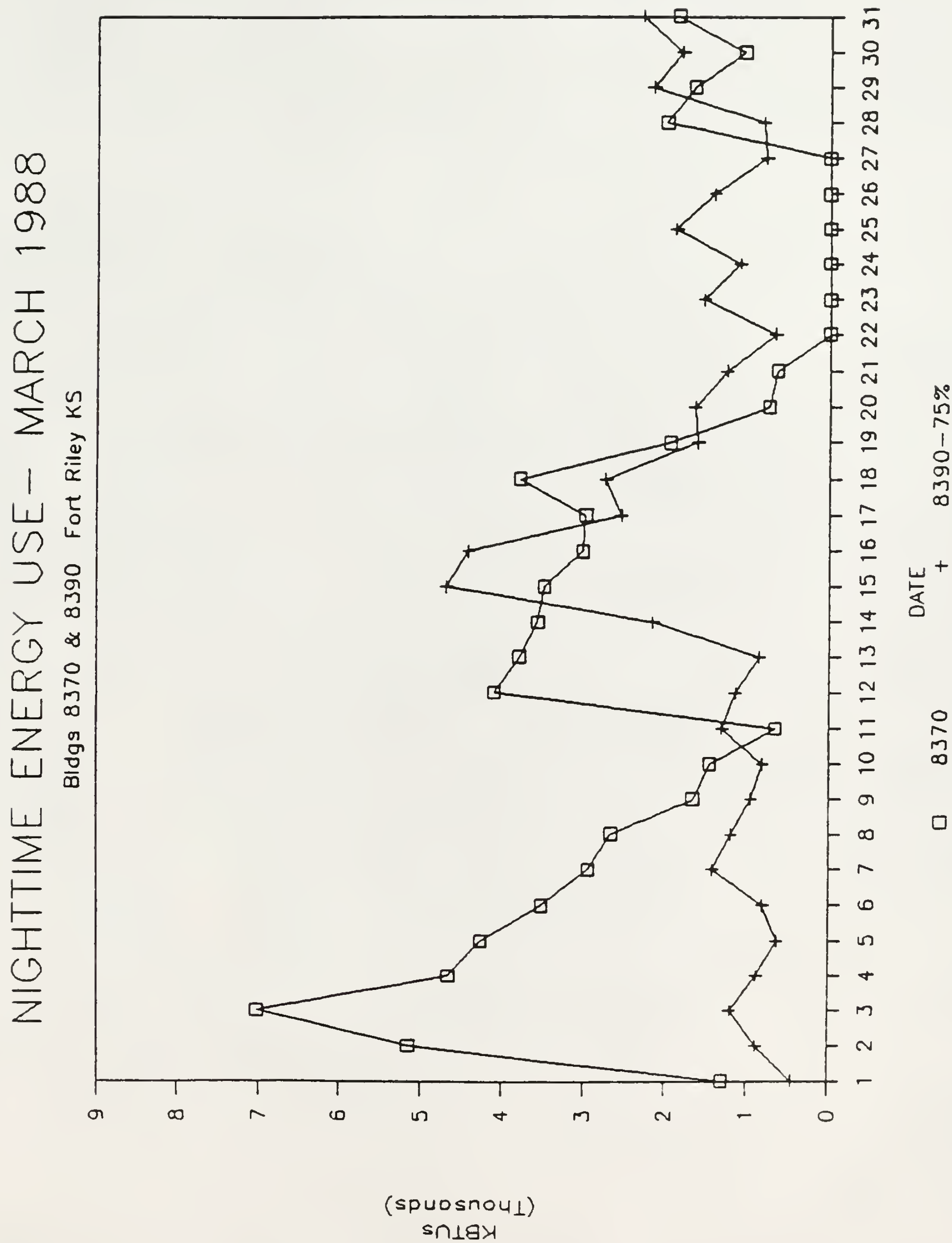
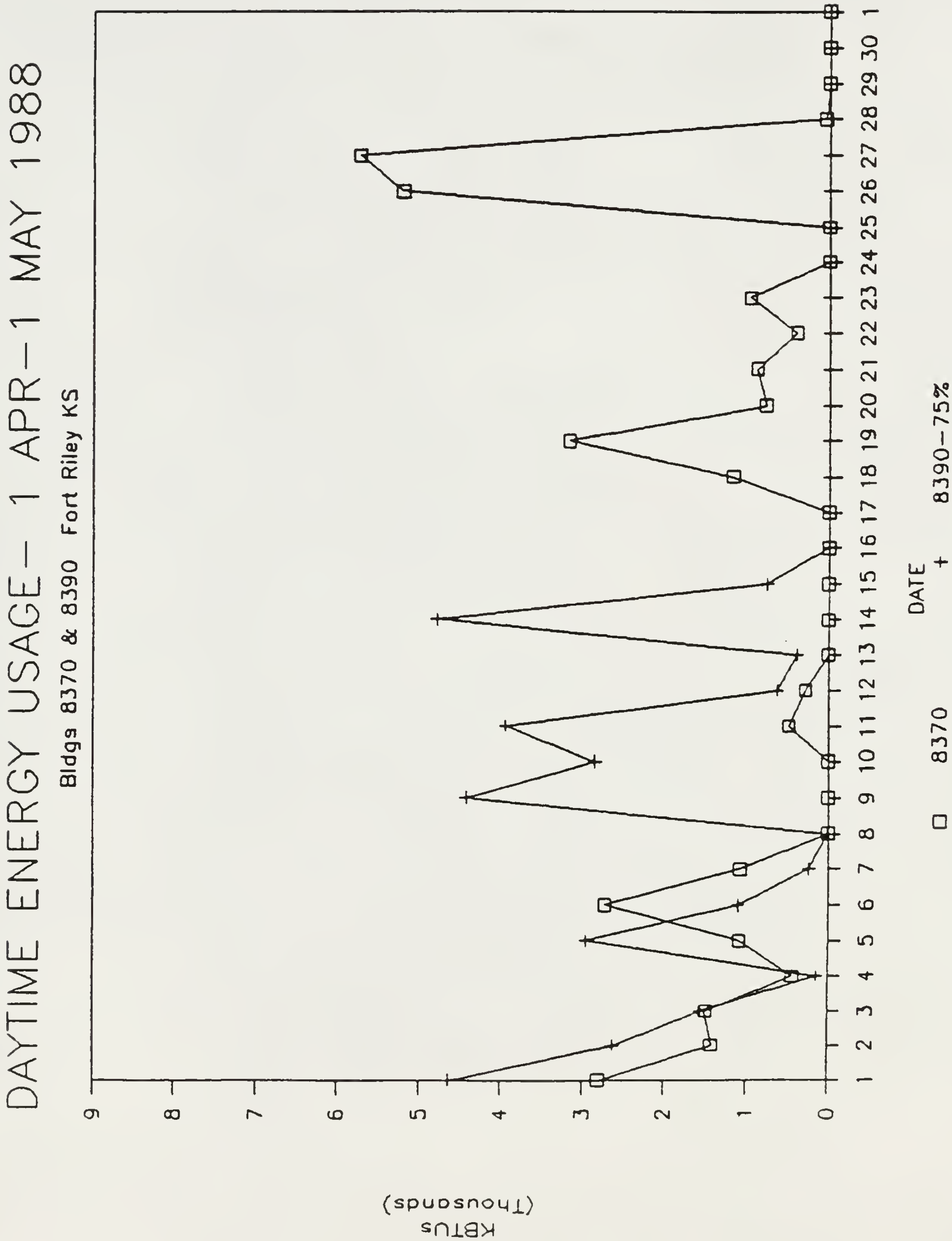
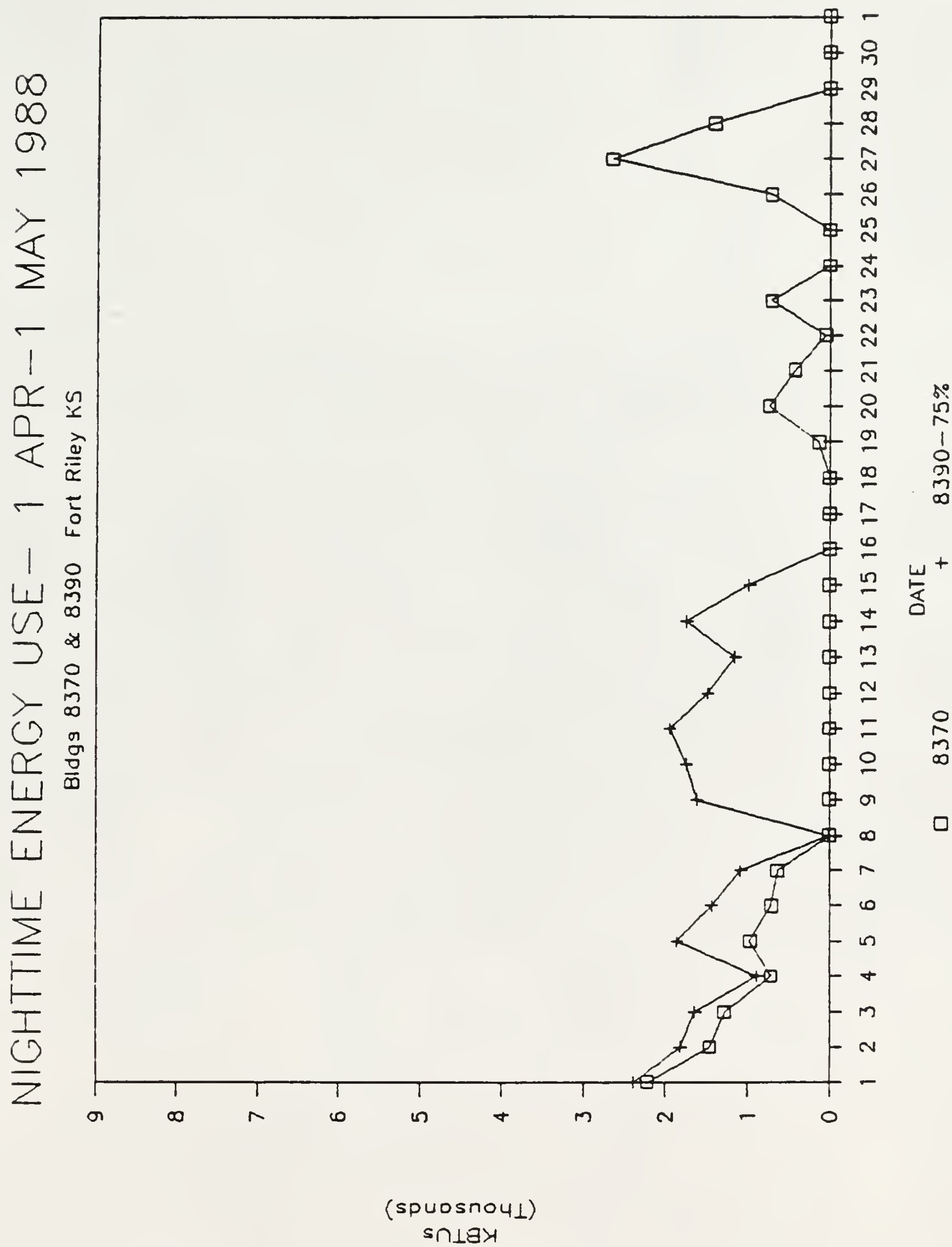

NIGHTTIME ENERGY USE— MARCH 1988
Bldgs 8370 & 8390 Fort Riley KS
KBTUs
(Thousands)
DATE
8370
8390–75%

Fig 4.10



DAYTIME ENERGY USAGE– 1 APR–1 MAY 1988
Bldgs 8370 & 8390 Fort Riley KS
KBTUs
(Thousands)
0
1
2
3
4
5
6
7
8
9
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 1
DATE
8370
8390–75%

Fig 4.11



NIGHTTIME ENERGY USE– 1 APR–1 MAY 1988
Bldgs 8370 & 8390 Fort Riley KS
KBTUs
(Thousands)
0
1
2
3
4
5
6
7
8
9
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 1
DATE
8370
8390–75%

Fig 4.12

those two months, the absolute differences were only sufficient to bring the two buildings to near equality in daytime energy consumption. Daytime energy consumption in Building 8370 for the entire period was 2% less than that of Building 8390.

There are several possible causes of the disparity in energy usage. It appears that the manner in which the occupants used the controls was the primary factor. The occupants in Building 8370 seemed to use the thermostats as on/off switches, setting them at a high temperature. The thermostats apparently were not reset at night. An examination of hourly average air temperatures, shown in Figures 4.13 through 4.18, demonstrates that while the air temperature in Building 8390 dropped sharply during the unoccupied hours, the air temperature in Building 8370 often remained constant or even increased. It was not until the fourth week of February that the overheating of Building 8370 at night was reduced. The air temperatures for Building 8390 have been intentionally reduced by 20F for clarity of the graph. As a result of this high setting, the heaters did not cycle on and off as would have been expected.

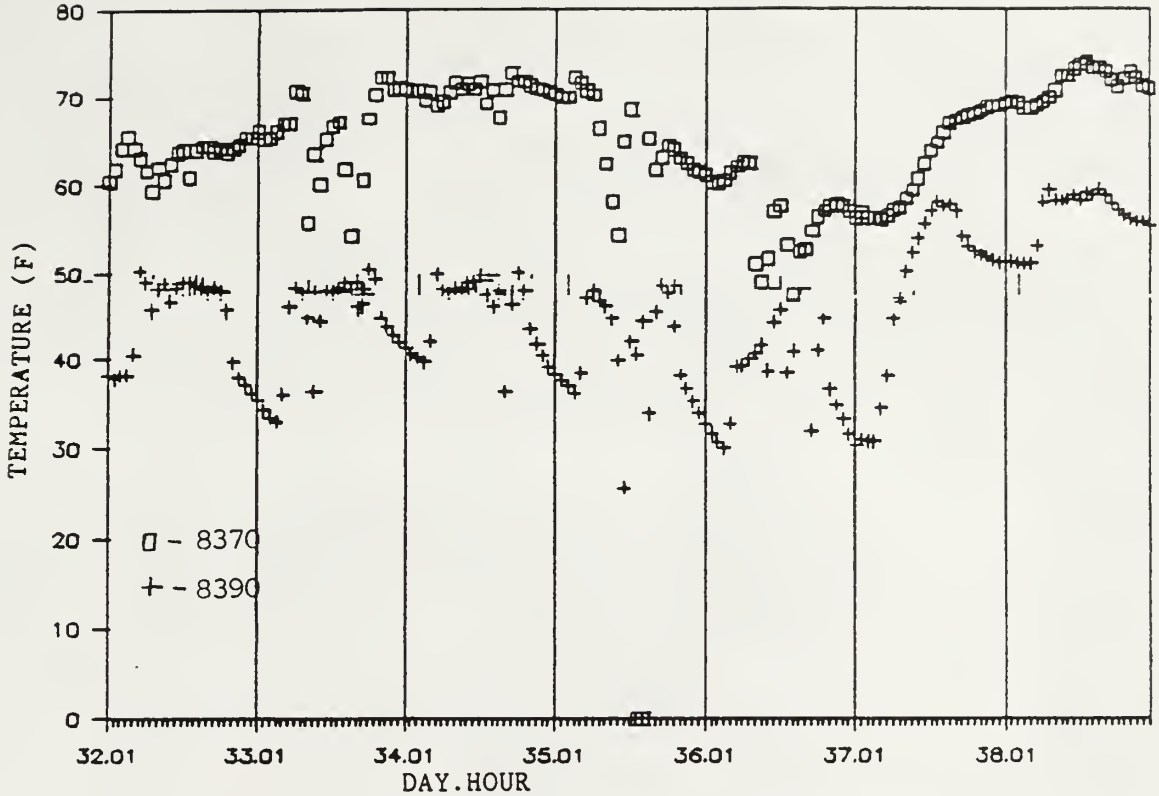


Fig 4.13 - Hourly Average Space Temperature: Week 1

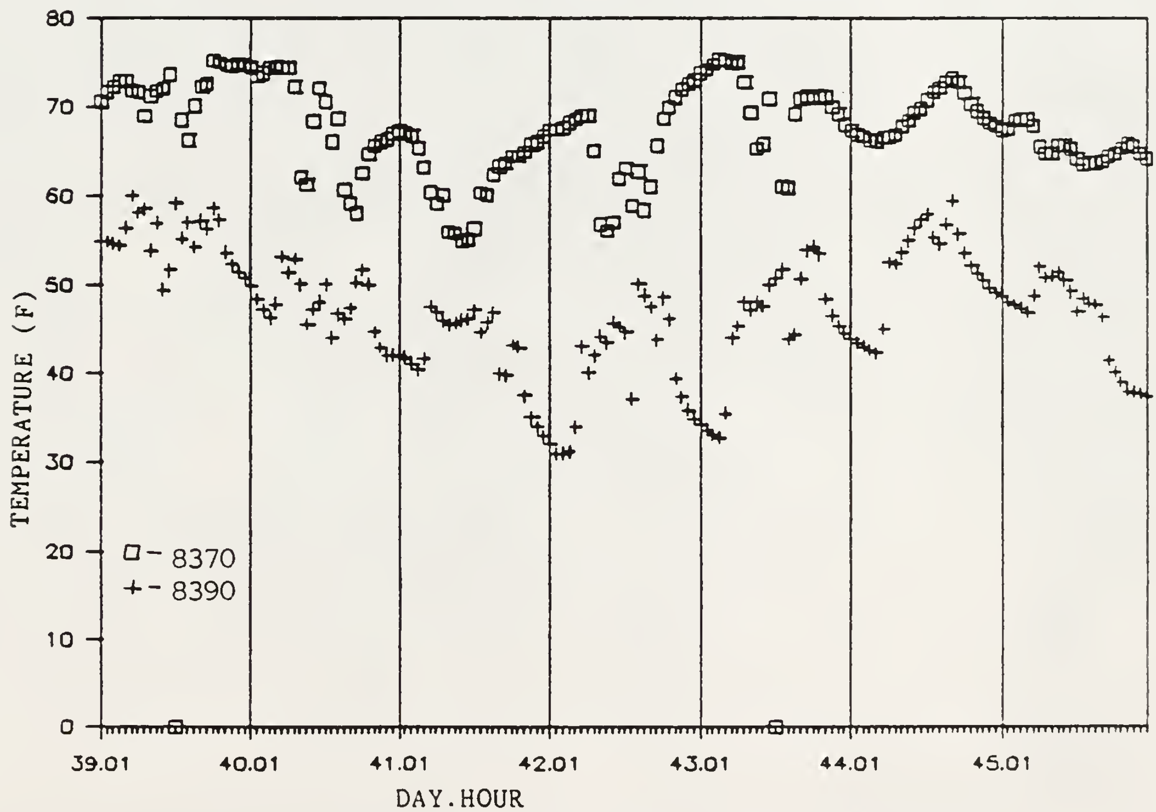


Fig 4.14 - Hourly Average Space Temperature: Week 2

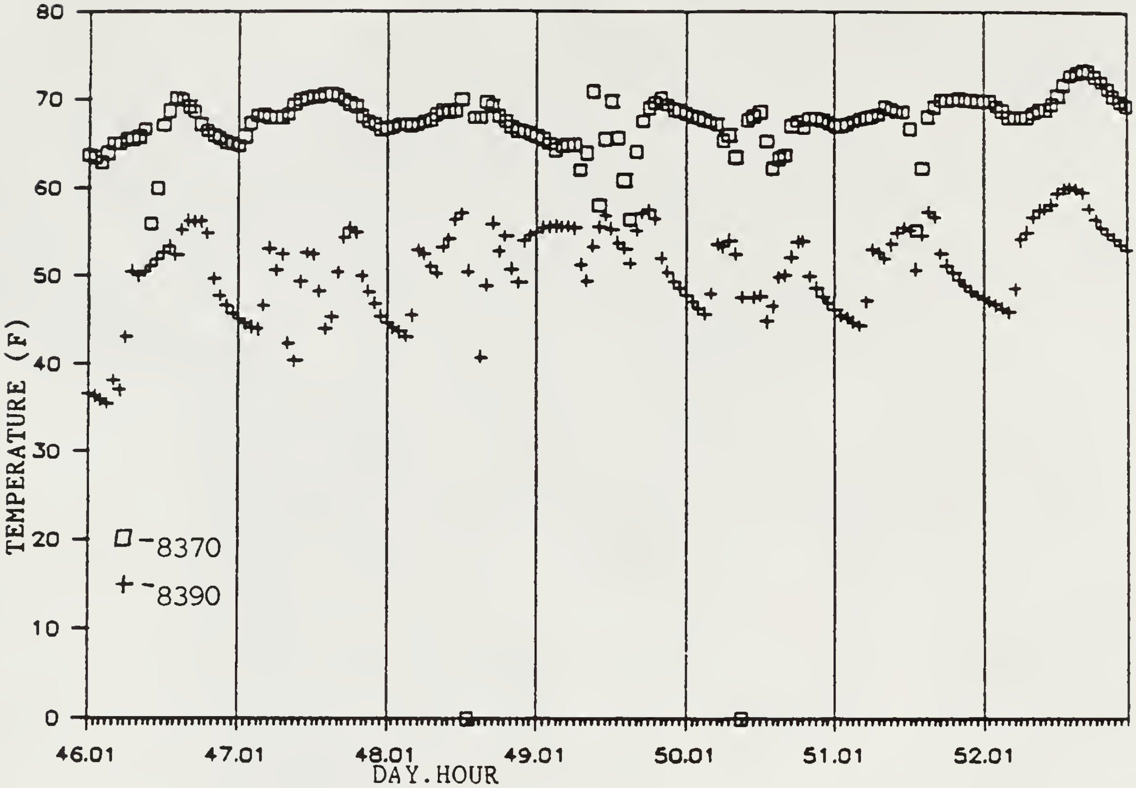


Fig 4.15 - Hourly Average Space Temperature: Week 3

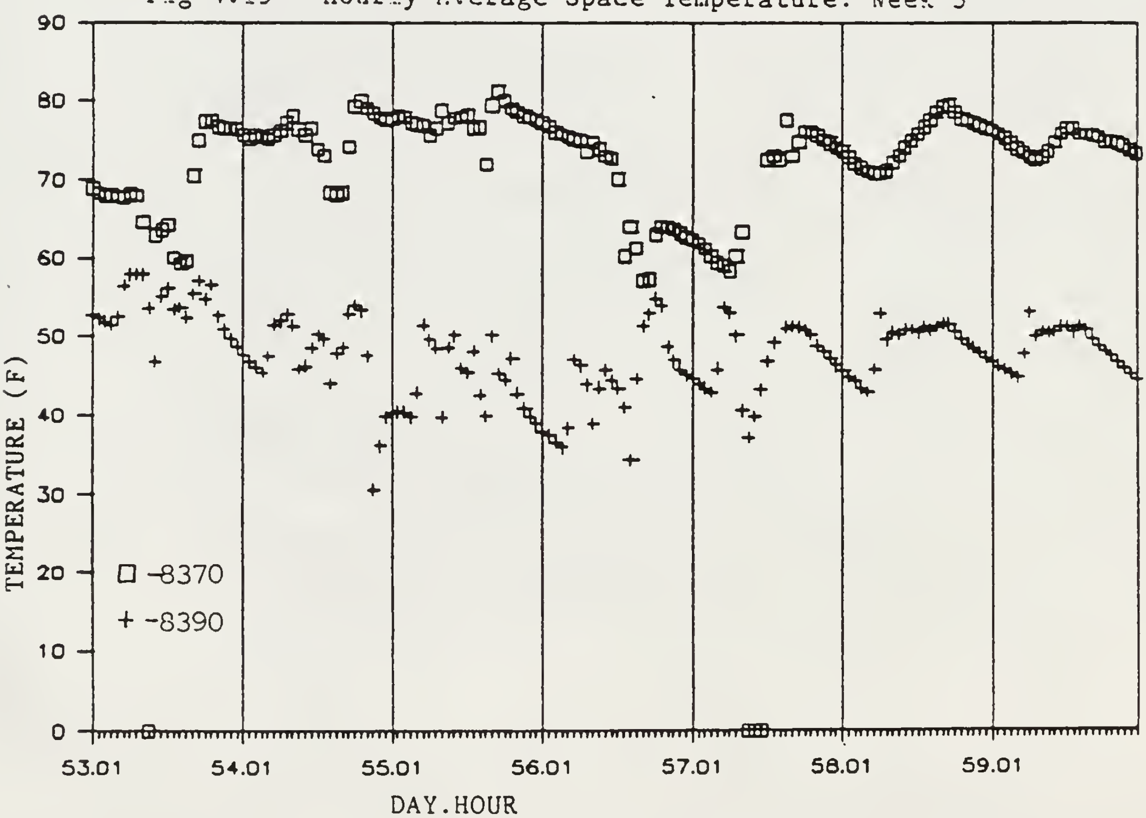


Fig 4.16 - Hourly Average Space Temperature: Week 4

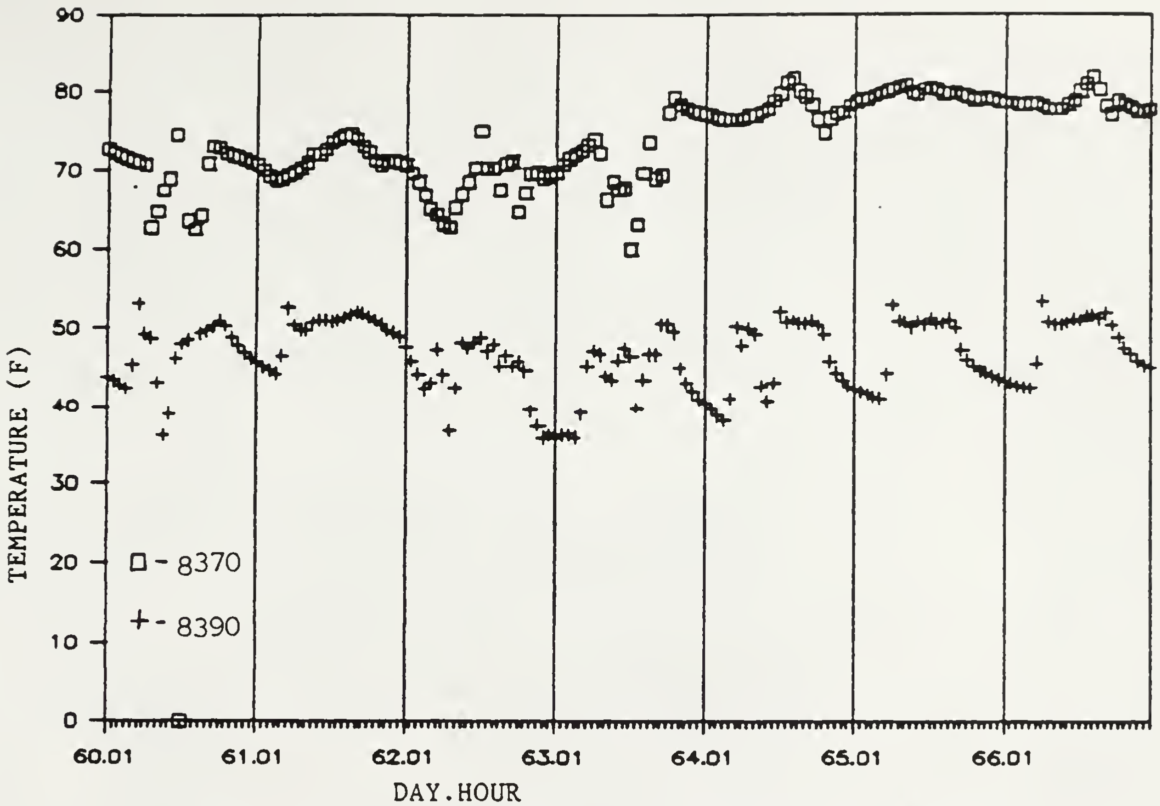


Fig 4.17 - Hourly Average Space Temperature: Week 5

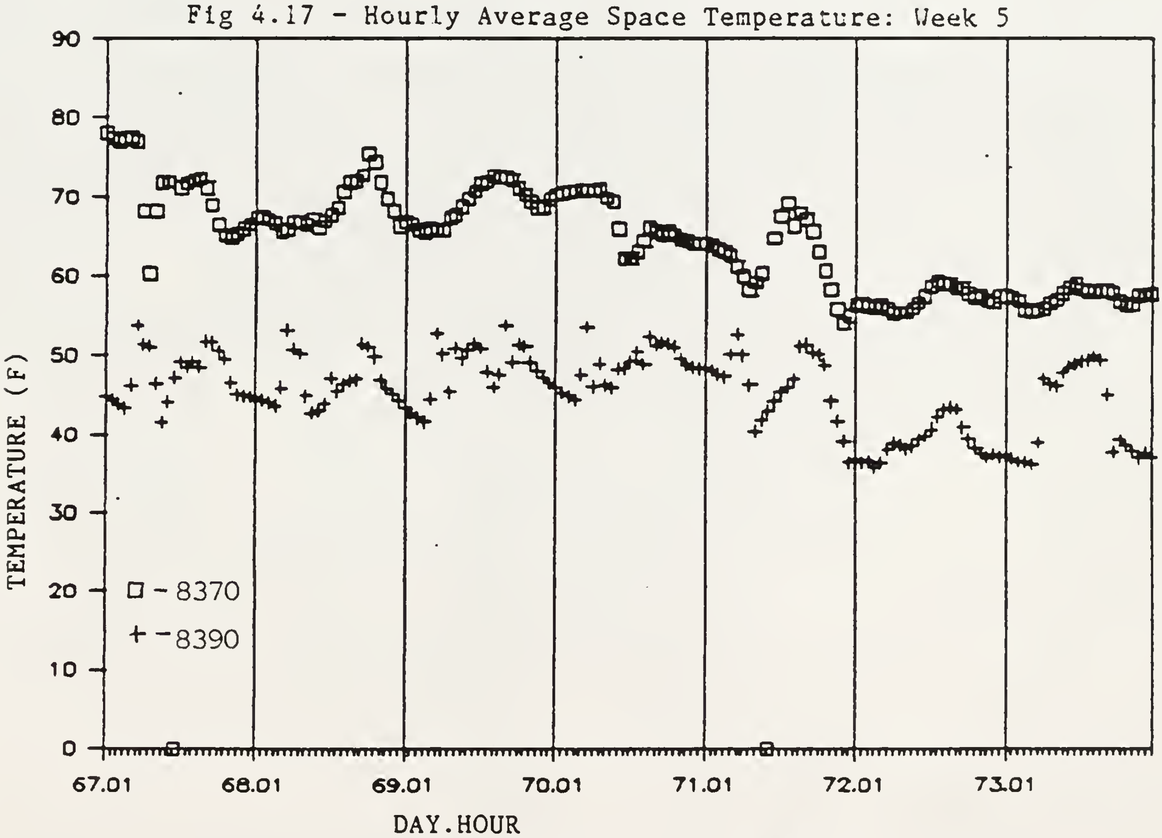


Fig 4.18 - Hourly Average Space Temperature: Week 6

Table 4.3: Radiant Heater Operation- Building 8370

Thermostat	1	2	3	4
February				
Total "On" Time (hrs)	526	527	219	482
Average Time per Cycle (hrs)	35.8	29.3	7.1	26.8
March				
Total "On" Time (hrs)	242	348	138	297
Average Time per Cycle (hrs)	13.5	16.6	4.9	12.4
April				
Total "On" Time (hrs)	48	85	36	168
Average Time per Cycle (hrs)	4.8	5.3	3.6	12.9

Table 4.3 shows that the heaters in Building 8370 did not cycle frequently in February, although this improved in March and April. The thermostat which appears to have operated most normally is Thermostat 3, and this was probably a result of the location of the thermostat. Thermostat 3 controls two of the radiant heaters, including the heater next to the building's end wall. This thermostat is also located 45 feet directly downstream from the outlet duct of the makeup air unit. The effects of two radiant heaters, as well as proximity to the MAU, may account for the more frequent cycling of this thermostat.

In the later part of February, the supervisory personnel in Building 8370 became more familiar with the building and its heating system. They began to turn the thermostats down at night, and this learning process appears to have been the reason for the improved performance of Building 8370 in March and April.

Operation of Doors, Ceiling Fans, and Exhaust Fans

Other factors likely to have an impact on the energy consumption in both buildings include the amount of bay door openings and use of the ceiling fans and exhaust fans. Figures 4.19 through 4.21 show the amount of door open time. These values were calculated as a ratio of the total actual time open for all doors and possible time open. In Building 8370, for example, one door open for 36 minutes in an hour would result in a percent time open of (36/8 x 60) x 100 or 7.5%. The hourly percentages were combined to provide a daily average of percent time open. It should be noted that there is some uncertainty in these figures. The data used to calculate these values came from the three-minute scans, which indicate whether a door was open or closed at a particular instant. The data do not give any information concerning how long the door was open. For this study the doors were considered to have been open for three minutes if they were open when the scan occurred. This study also makes no attempt to analyze the effects of the configuration of the open doors. Two open doors located directly across the bay from each other might well have different effects than two open doors on the same side of

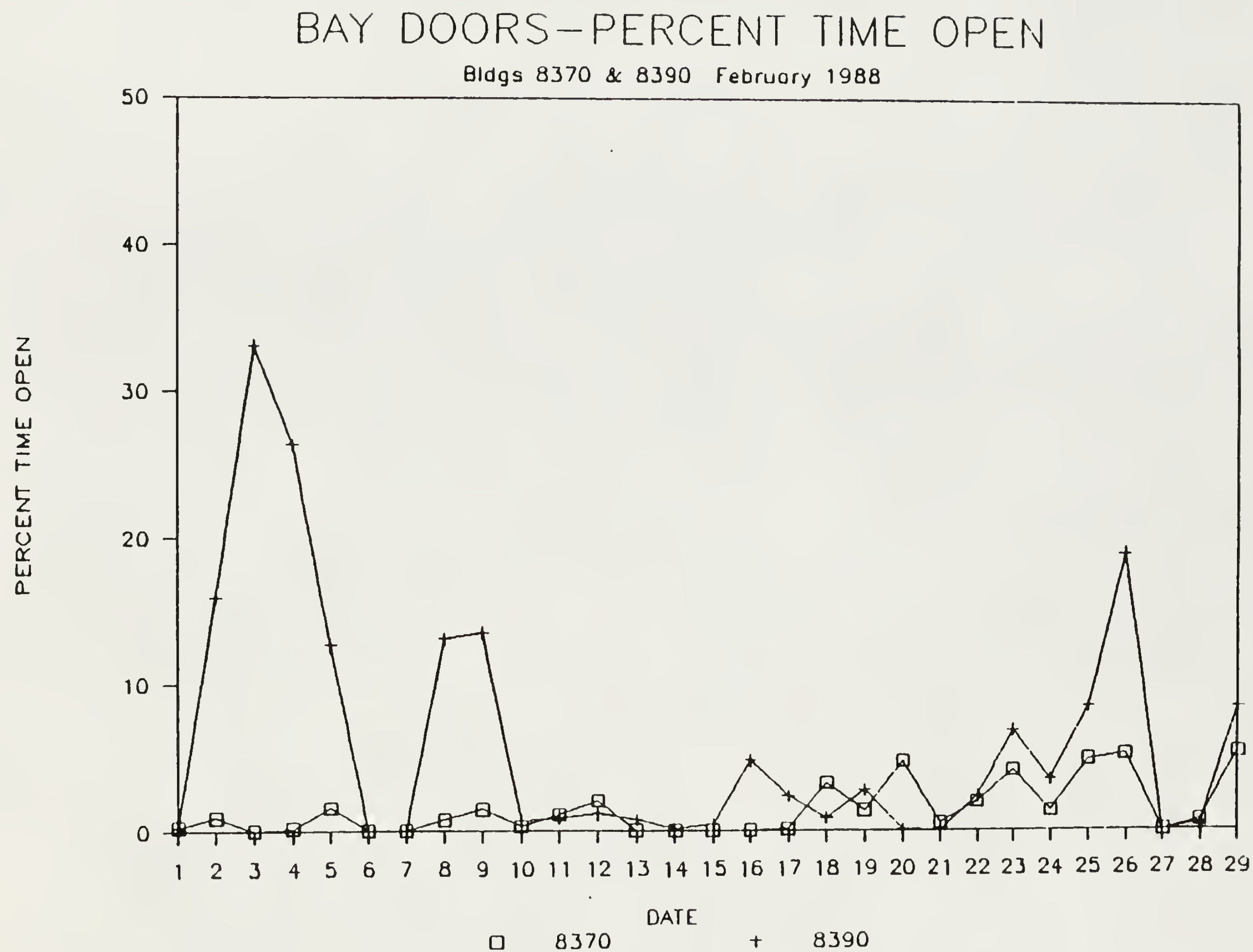

BAY DOORS—PERCENT TIME OPEN
Bldgs 8370 & 8390 February 1988
PERCENT TIME OPEN
0
10
20
30
40
50
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
DATE
□ 8370
+ 8390

Fig 4.19

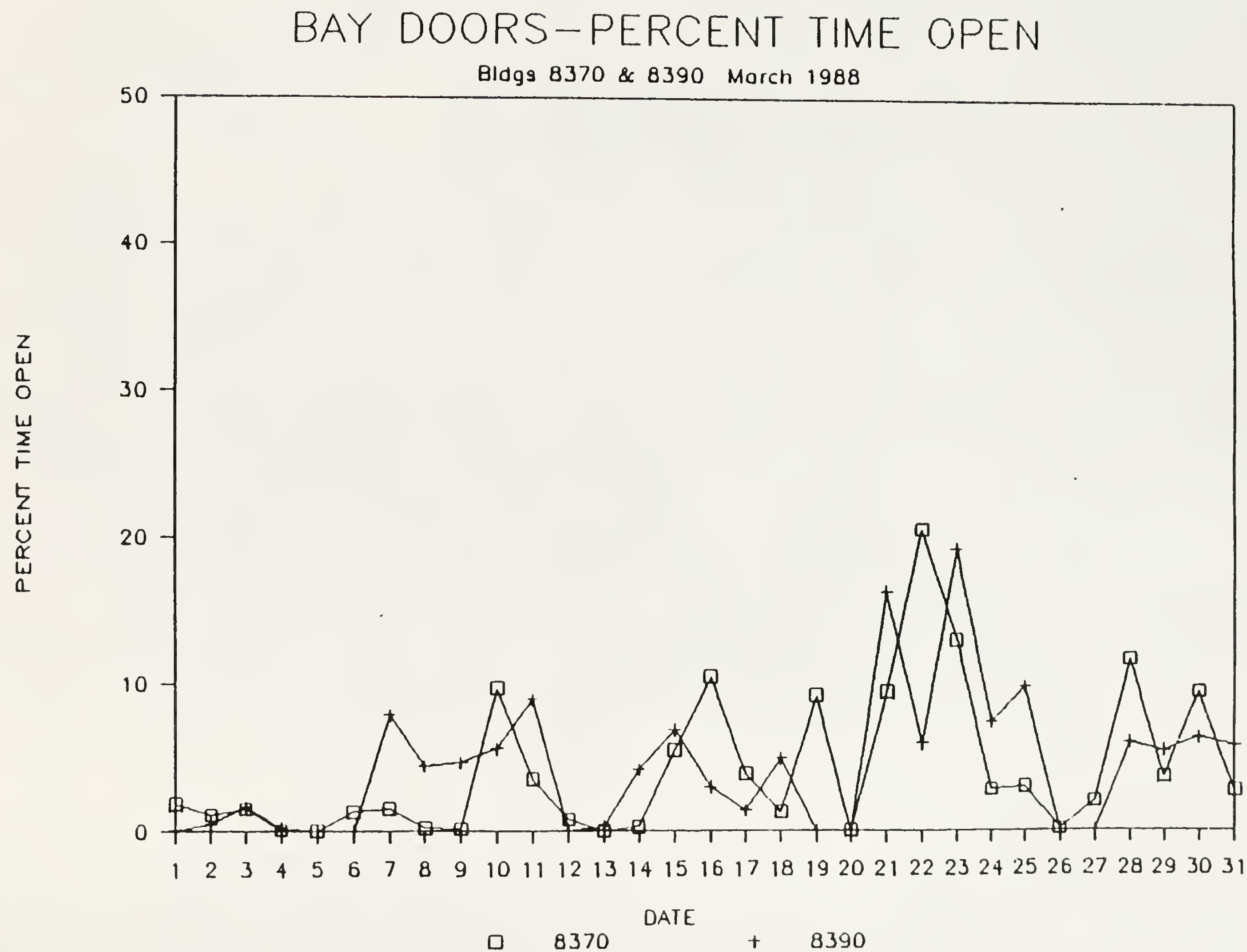

BAY DOORS—PERCENT TIME OPEN
Bldgs 8370 & 8390 March 1988
PERCENT TIME OPEN
0
10
20
30
40
50
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
DATE
8370
8390

Fig 4.20

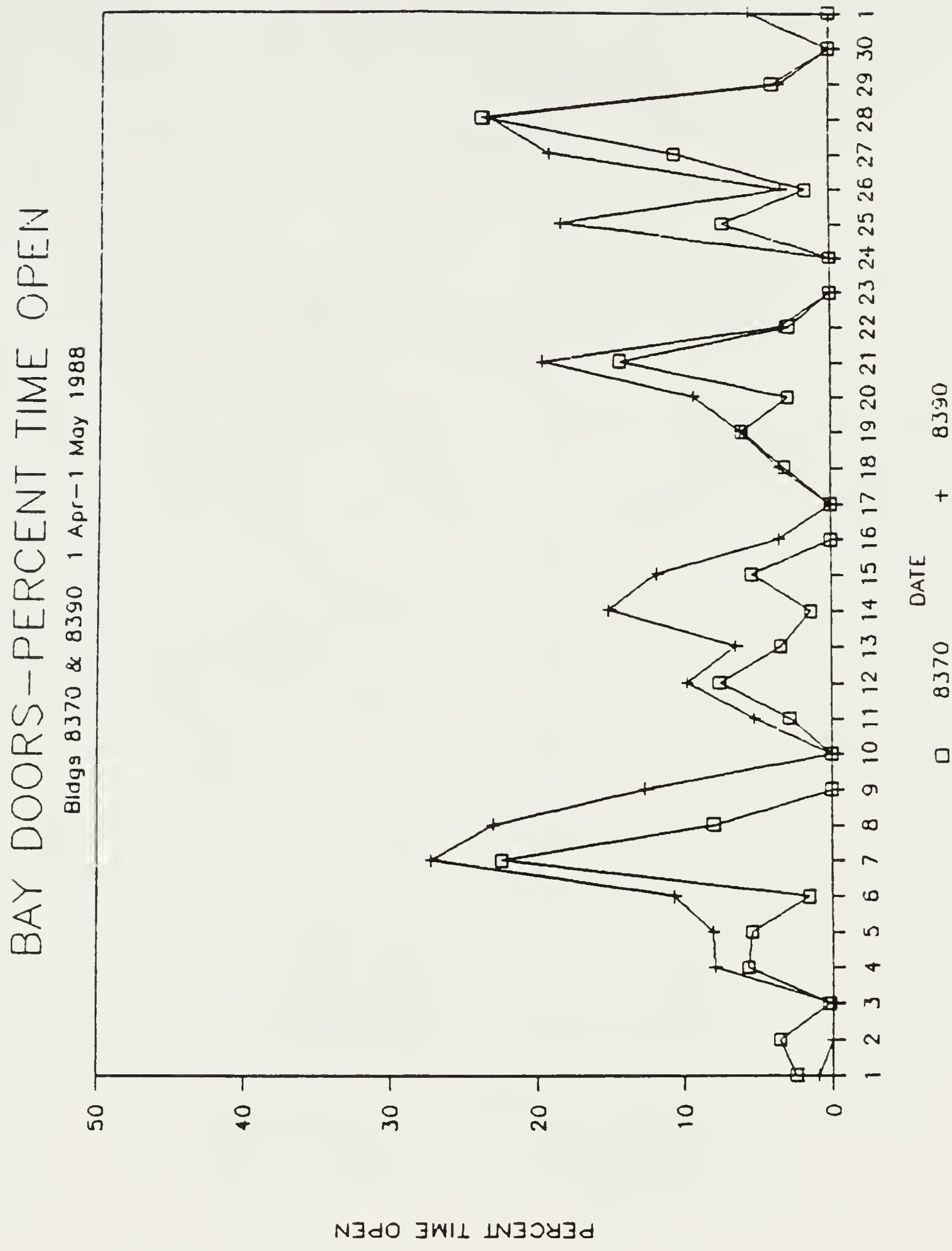

BAY DOORS-PERCENT TIME OPEN
Bldgs 8370 & 8390 1 Apr-1 May 1988
PERCENT TIME OPEN
0
10
20
30
40
50
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 1
DATE
□ 8370 + 8390

Fig 4.21

the building.

The high percentages shown for Building 8390 in early February (Fig 4.19) are the result of a faulty sensor and should be disregarded. Not surprisingly, door open time increased as the outside temperature increased. It can be seen that Building 8390 generally had more door open time than Building 8370. Researchers visiting the buildings observed that Building 8390 was the busier of the two. it appears, then, that door openings were not a primary factor in the higher energy use in Building 8370.

Figures 4.22 through 4.24 show the average daily ceiling fan on-time percentage for both buildings. These values were calculated in the same manner as those for the bay doors. A correlation between ceiling fan use and energy consumption is difficult to ascertain. High percentages for ceiling fan use occur at times of both high and low energy consumption. In February, Building 8390 used less energy regardless of which building had ceiling fans operating. The effects of the ceiling fans on the space thermal environment will be examined in a later section; it appears that ceiling fan operation had little if any impact on energy consumption.

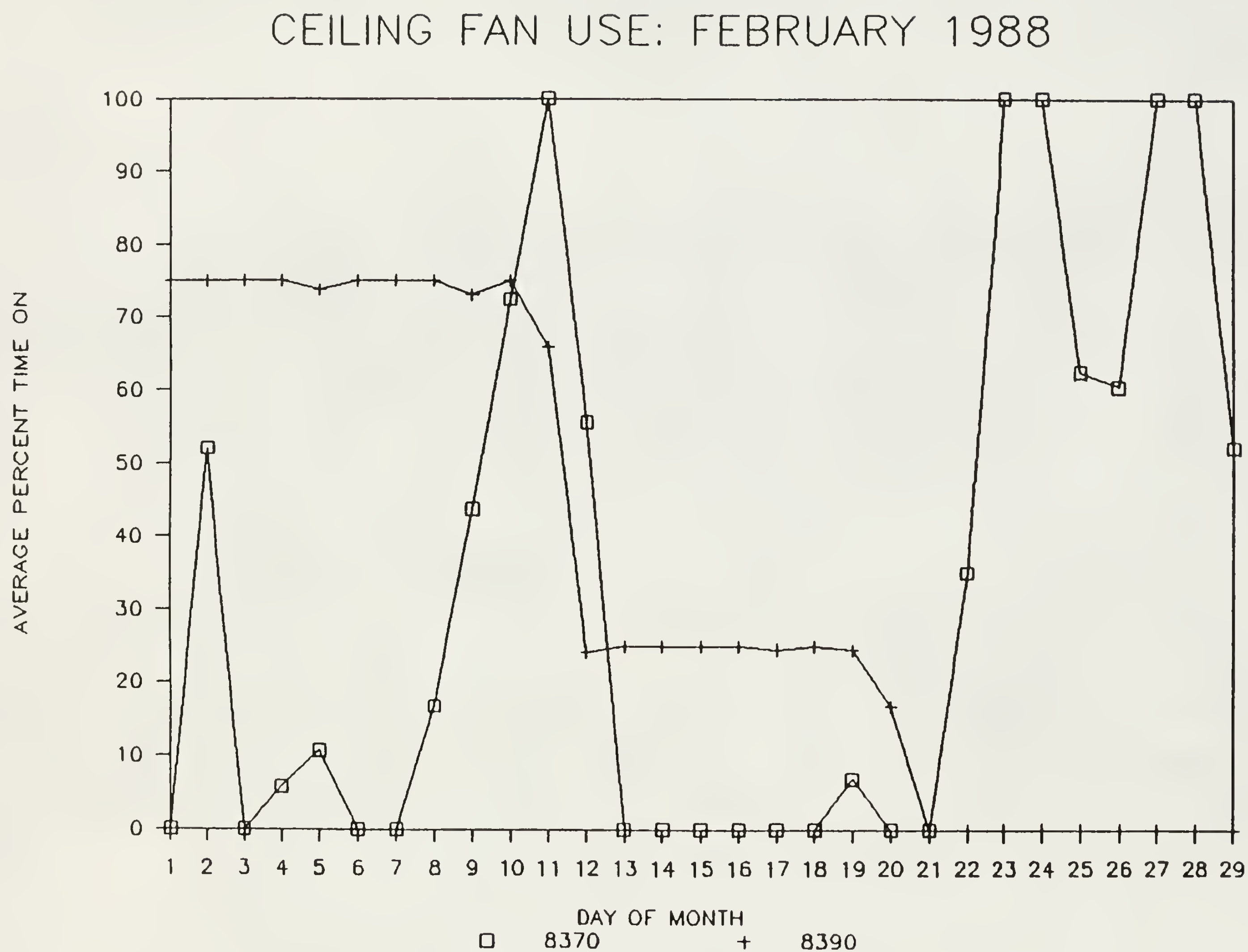

CEILING FAN USE: FEBRUARY 1988
AVERAGE PERCENT TIME ON
100
90
80
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
DAY OF MONTH
□ 8370
+ 8390

Fig 4.22

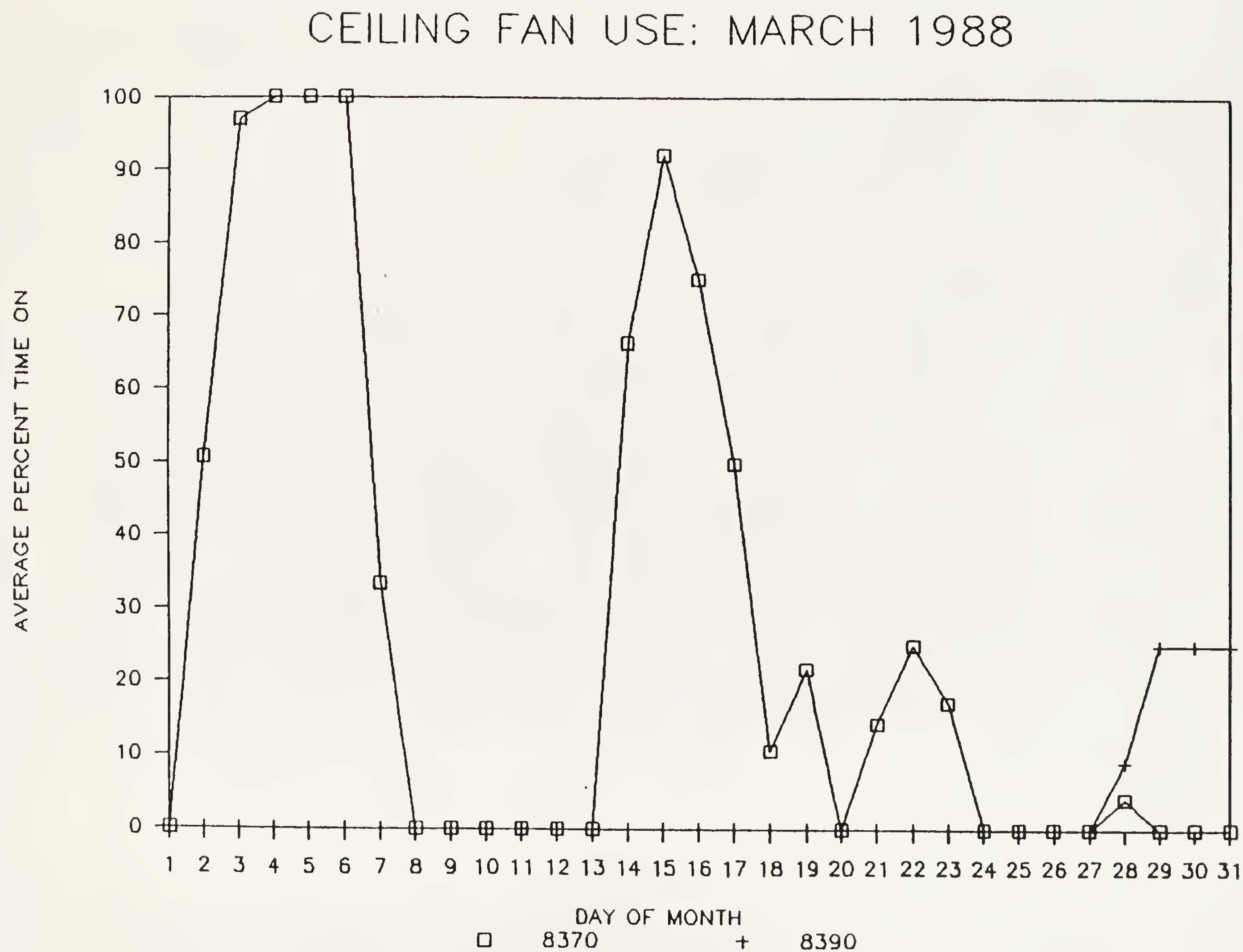

CEILING FAN USE: MARCH 1988
AVERAGE PERCENT TIME ON
100
90
80
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
DAY OF MONTH
□ 8370 + 8390

Fig 4.23

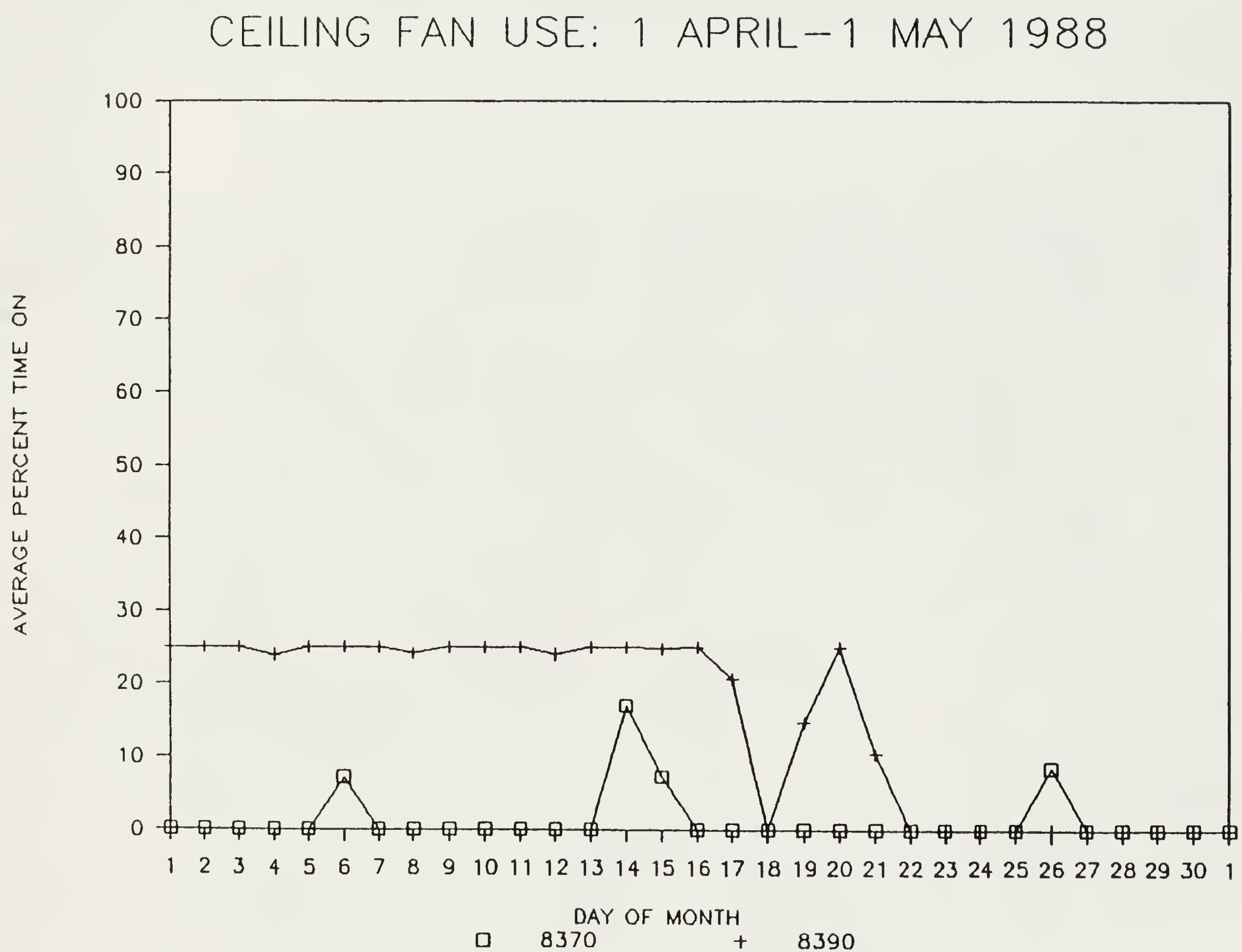

CEILING FAN USE: 1 APRIL–1 MAY 1988
AVERAGE PERCENT TIME ON
100
90
80
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 1
DAY OF MONTH
□ 8370
+ 8390

Fig 4.24

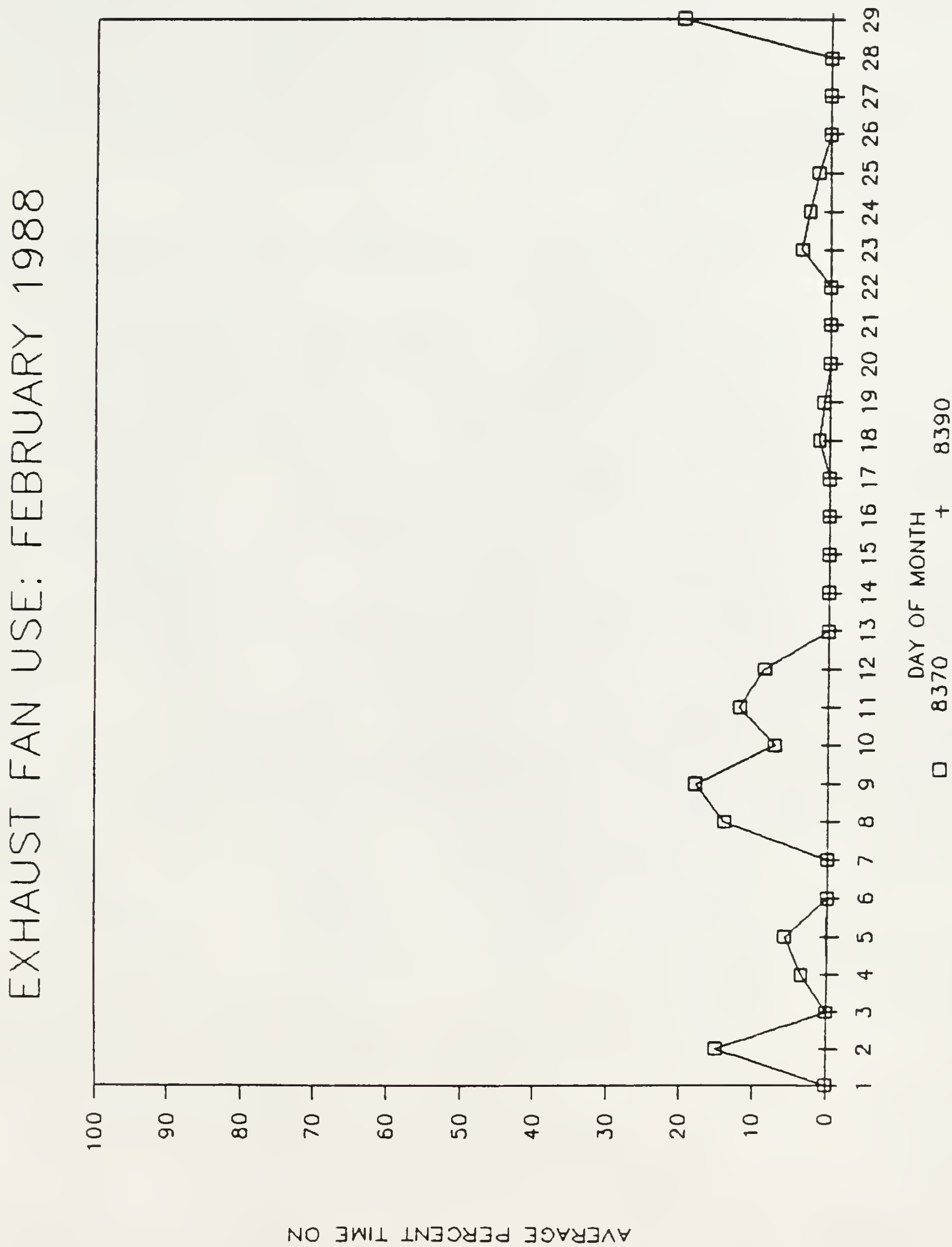

EXHAUST FAN USE: FEBRUARY 1988
AVERAGE PERCENT TIME ON
0
10
20
30
40
50
60
70
80
90
100
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
DAY OF MONTH
□ 8370
+ 8390

Fig 4.25

EXHAUST FAN USE: MARCH 1988

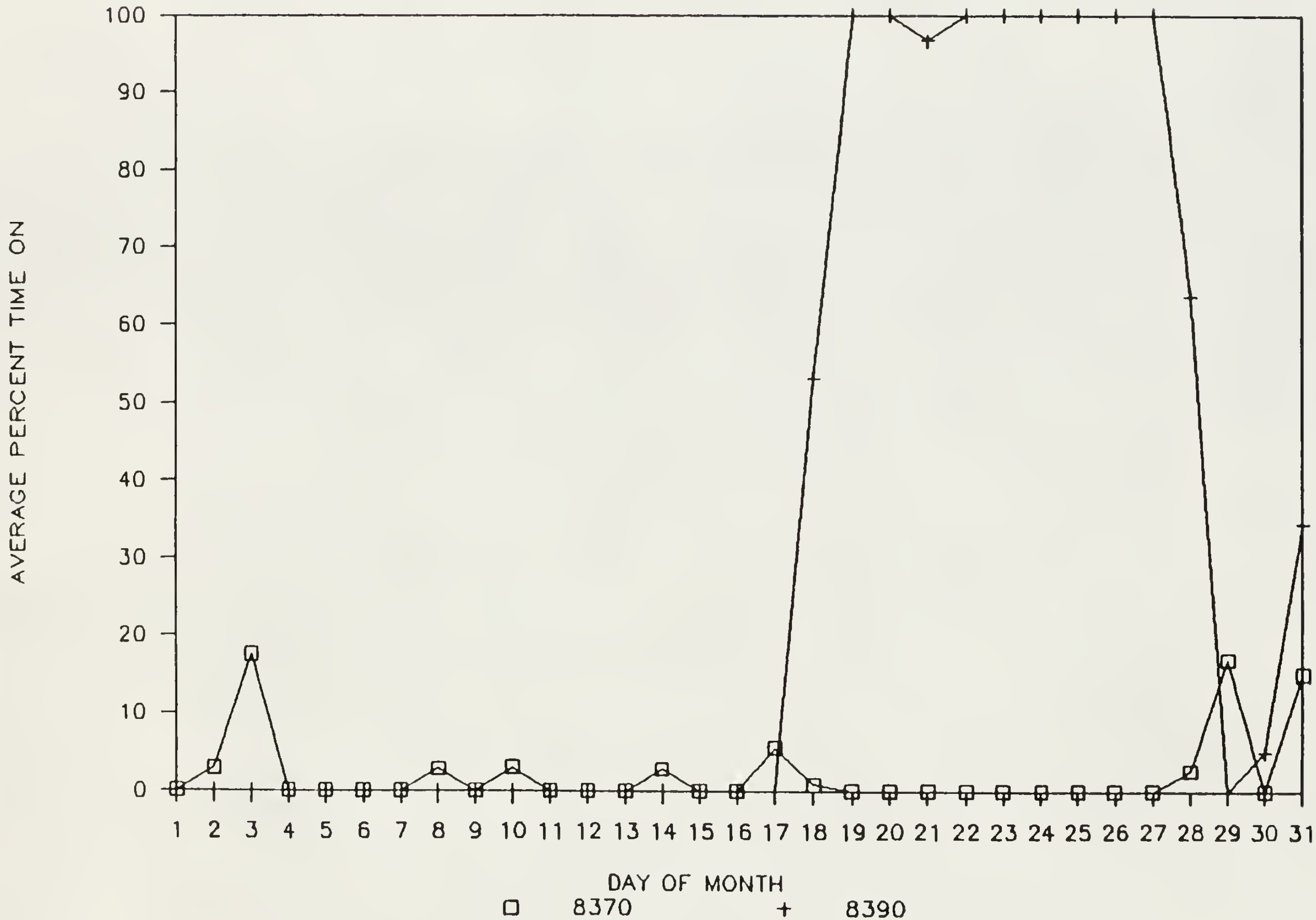


Fig 4.26

EXHAUST FAN USE: APRIL 1988

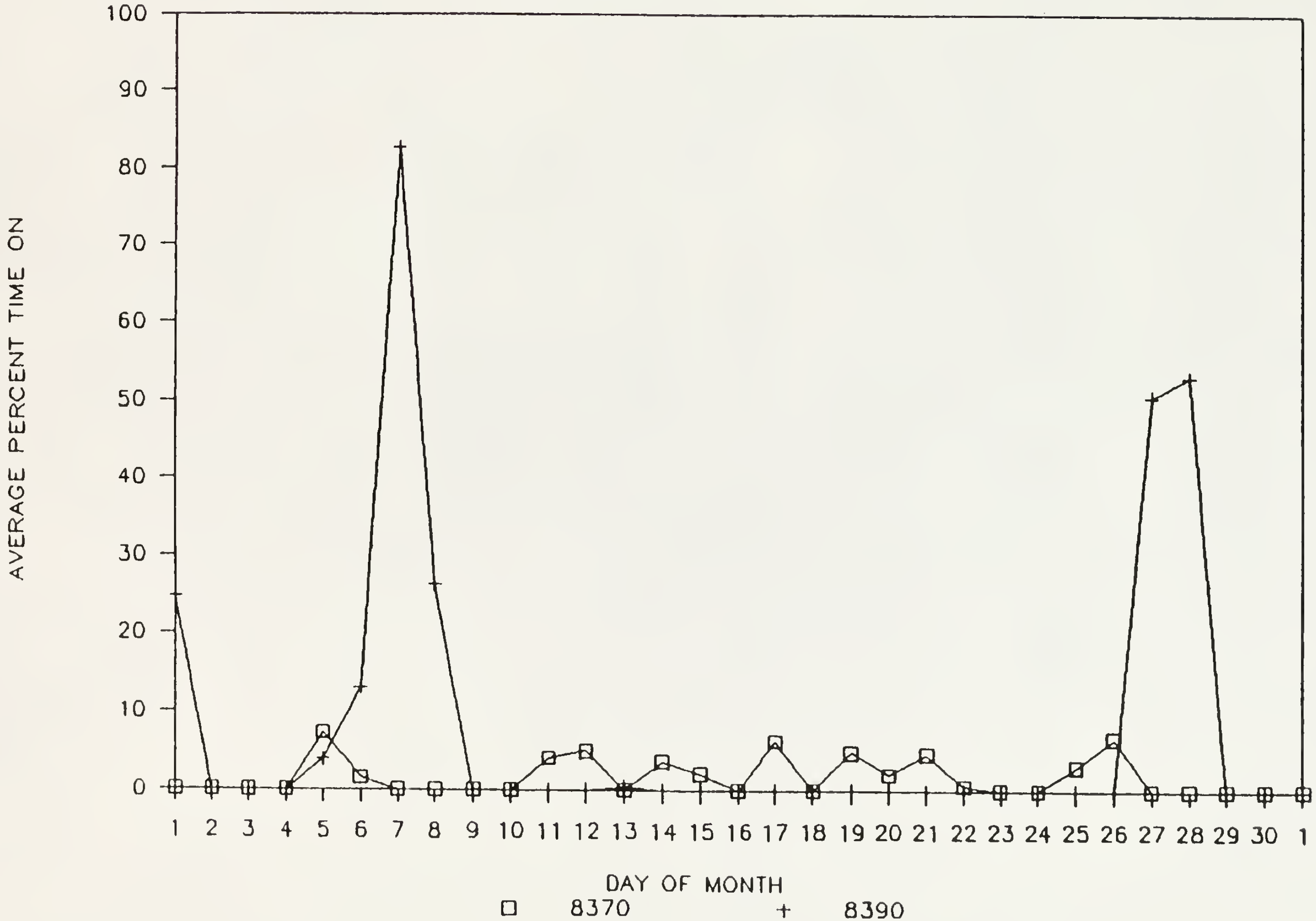


Fig 4.27

Table 4.4: Daily Average Ceiling Fan and Exhaust Fan Percent Time On

	8370		8390	
	C. Fan	E. Fan	C. Fan	E. Fan
Feb	33.6	4.0	35.0	---
Mar	27.6	2.3	2.7	34.0
Apr	1.3	1.7	15.1	8.2

The exhaust fans were used only sporadically in either bulding, with the exception of Building 8390 in March and early April. Exhaust fan use is shown in Figures 4.25 through 4.27. There is insufficient data to allow any conclusions concerning the effects of exhaust fan use on energy consumption.

Outside Temperature and Energy Consumption

It was noted earlier that energy consumption in both buildings varied inversely with outside temperature. This is not a surprising result; however, the rate at which energy use changes with outside temperature provides another way to compare the buildings' performance.

In Figures 4.28 and 4.29 the daily energy usages are shown, along with regression lines and confidence bands for Buildings 8370 and 8390 respectively. While all daily energy data are shown, the regression lines were calculated by Lotus 1-2-3 using only non-zero data. The data from both buildings resulted in large standard errors. When the two regression bands are superimposed, as in Figure 4.30, they

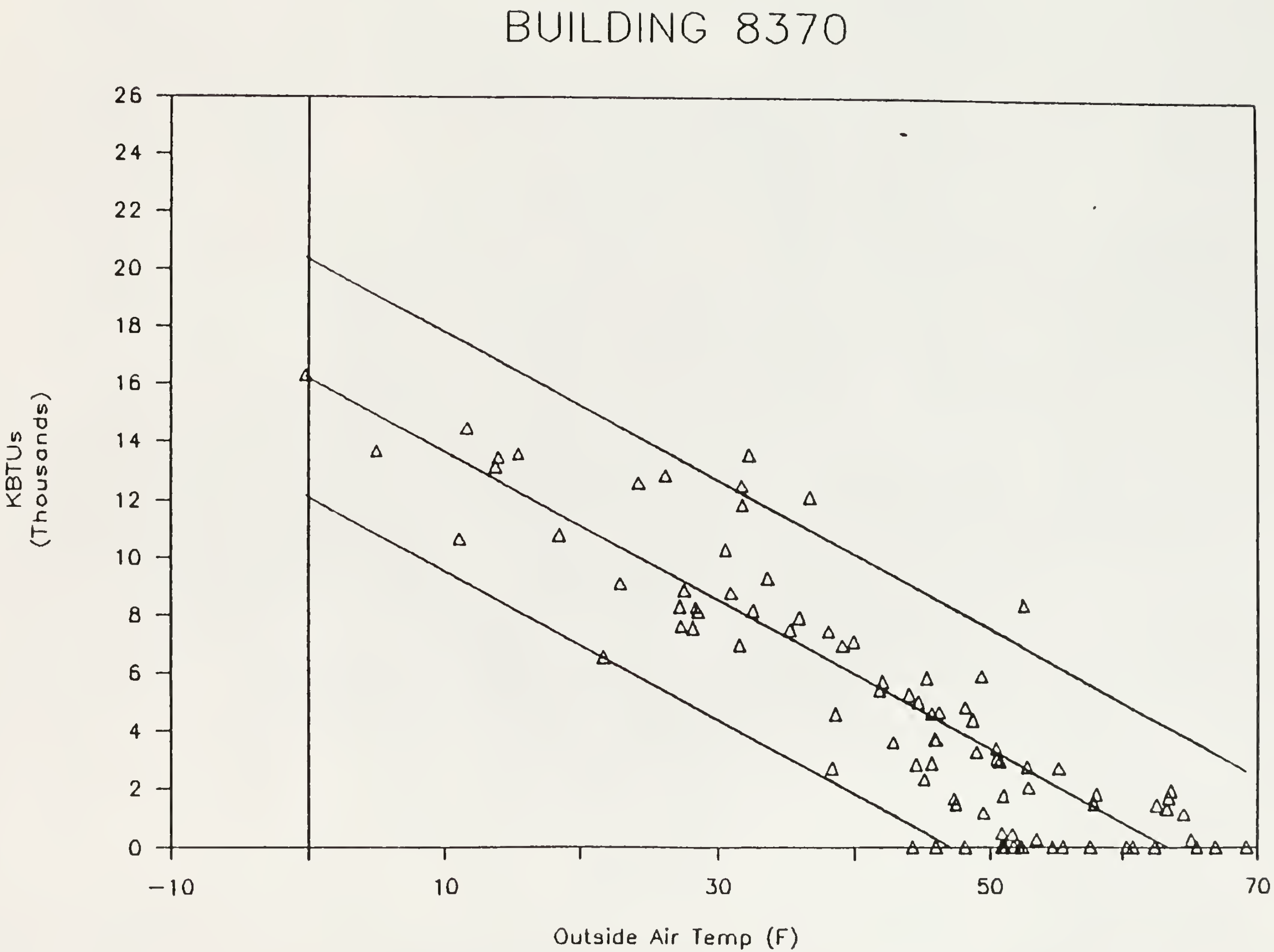


Fig 4.28 Relationship Between Outside Temperature and Energy Use - Building 8370

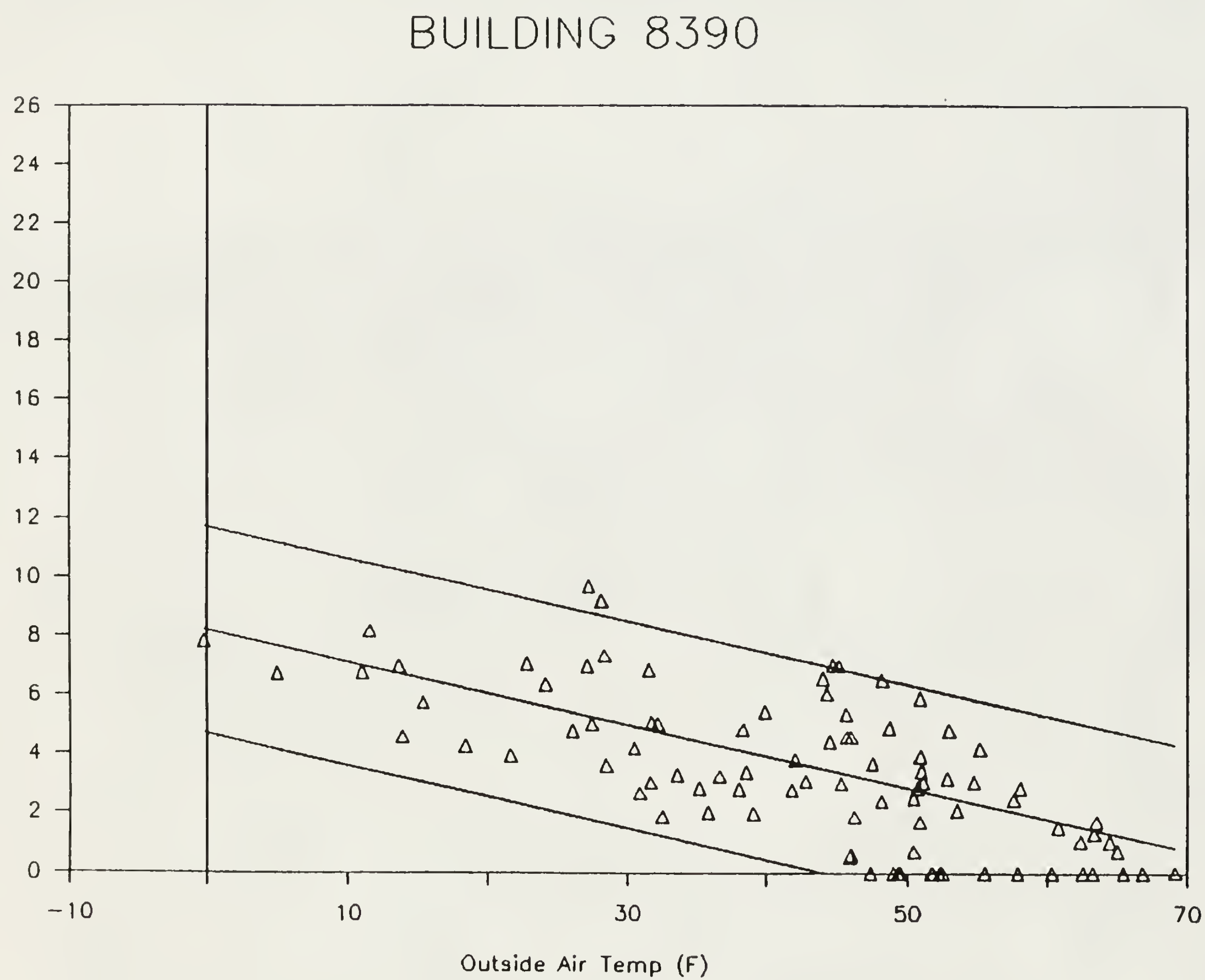


Fig 4.29 Relationship Between Outside Temperature and Energy Use - Building 8390

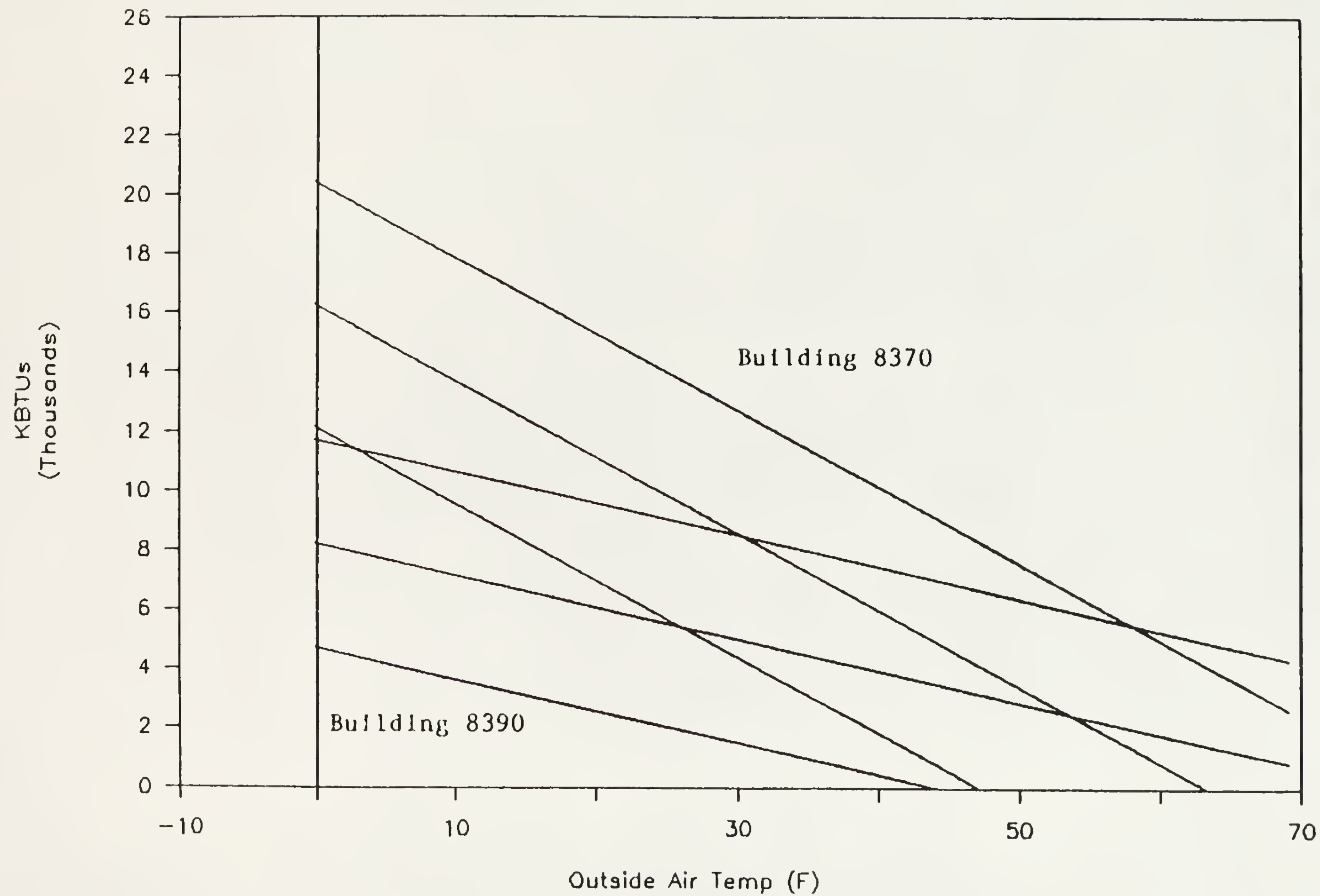


Fig 4.30 Comparison of Energy-Use Responses to Outside Temperature

overlap for all but the lowest temperatures. This figure indicates that Building 8390 is more energy eficient at lower temperatures. The surprisingly high energy consumption for Building 8370 in February is the main reason for the steeper slope of the regression line.

Comparison of Thermal Environments

General Discussion

Comparison of the thermal environments of the two buildings involves two primary areas of interest. The first is a comparison of the differences between operative temperatures, as measured by globe thermometers, and air temperatures. The radiant heaters in Building 8370 would be expected to provide a greater difference between these temperatures than the convection heaters in Building 8390. The comparison was made for both the occupied zone temperature and the overall average space temperature.

The second area of interest was the evaluation of thermal stratification. Building 8370 was expected to maintain a more uniform temperature throughout the space than Building 8390, since the radiant heaters are designed to transfer heat to the surfaces at the lower levels of the building. For each building, the temperatures at the 6 inch level, the 4 to 6 foot level, and upper levels were compared.

Analysis Method

The method used to compare the thermal characteristics of the buildings was the two-sided t-test. The null hypothesis tested was $\bar{x}_1 = \bar{x}_2$, i.e., the mean of the value analyzed for Building 8370 equals that of Building 8390. The critical t value t_{crit} is 2.00, which corresponds to degrees of freedom approximately equal to 60, which approximates the total number of data points from both buildings during a month. The t value for the analysis was calculated using

$$t = \frac{\bar{x}_1 - \bar{x}_2}{S_p \sqrt{2/n}} \qquad (4.1)$$

where t = comparison t value

$\bar{x}_1$ = mean value for 8370

$\bar{x}_2$ = mean value for 8390

n = number of measurements (days/month)

$$S_p = \sqrt{\frac{(S_1)^2 + (S_2)^2}{2}} \qquad (4.2)$$

where S_1 = standard deviation for 8370

S_2 = standard deviation for 8390

If the absolute value of the comparison t value $t < t_{crit}$, then the null hypothesis is accepted and it can be concluded that there is no statistically significant difference between the two buildings.

Occupied Zone Air Temperature

Figures 4.31 through 4.33 compare the average temperatures of the occupied zone, here defined as the volume between floor level and 6 feet. It can be seen that the occupied zone temperatures in both buildings generally followed the same trends. For February and March, analysis shows that there was no significant difference in occupied zone temperature between the two buildings, while in April Building 8390 had a higher average temperature. Table 4.5 summarizes this analysis, as well as that of the other thermal environment comparisons.

Difference Between Globe Temperature and Occupied Zone Temperature

Figures 4.34 through 4.36 compare the buildings with regard to the difference between the operative temperature and the average occupied zone temperature. For all three months there was a significant difference between he two buildings. Building 8370, as expected, provided a greater difference between operative and air temperatures than did Building 8390. However, as described in the previous section, the occupied zone temperatures were essentially the same in both buildings. Hence, while the

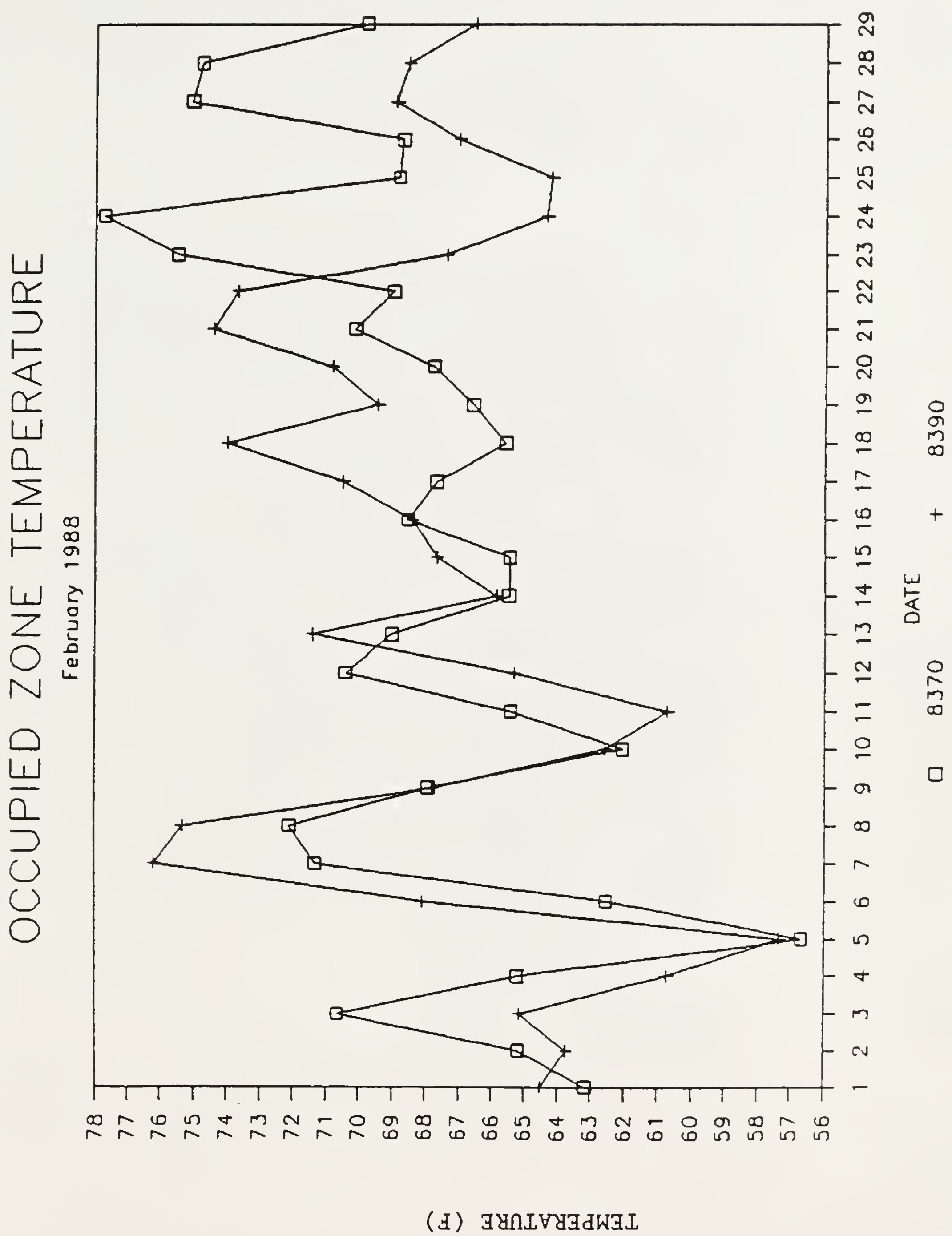

OCCUPIED ZONE TEMPERATURE
February 1988
TEMPERATURE (F)
DATE
8370
8390

Fig 4.31

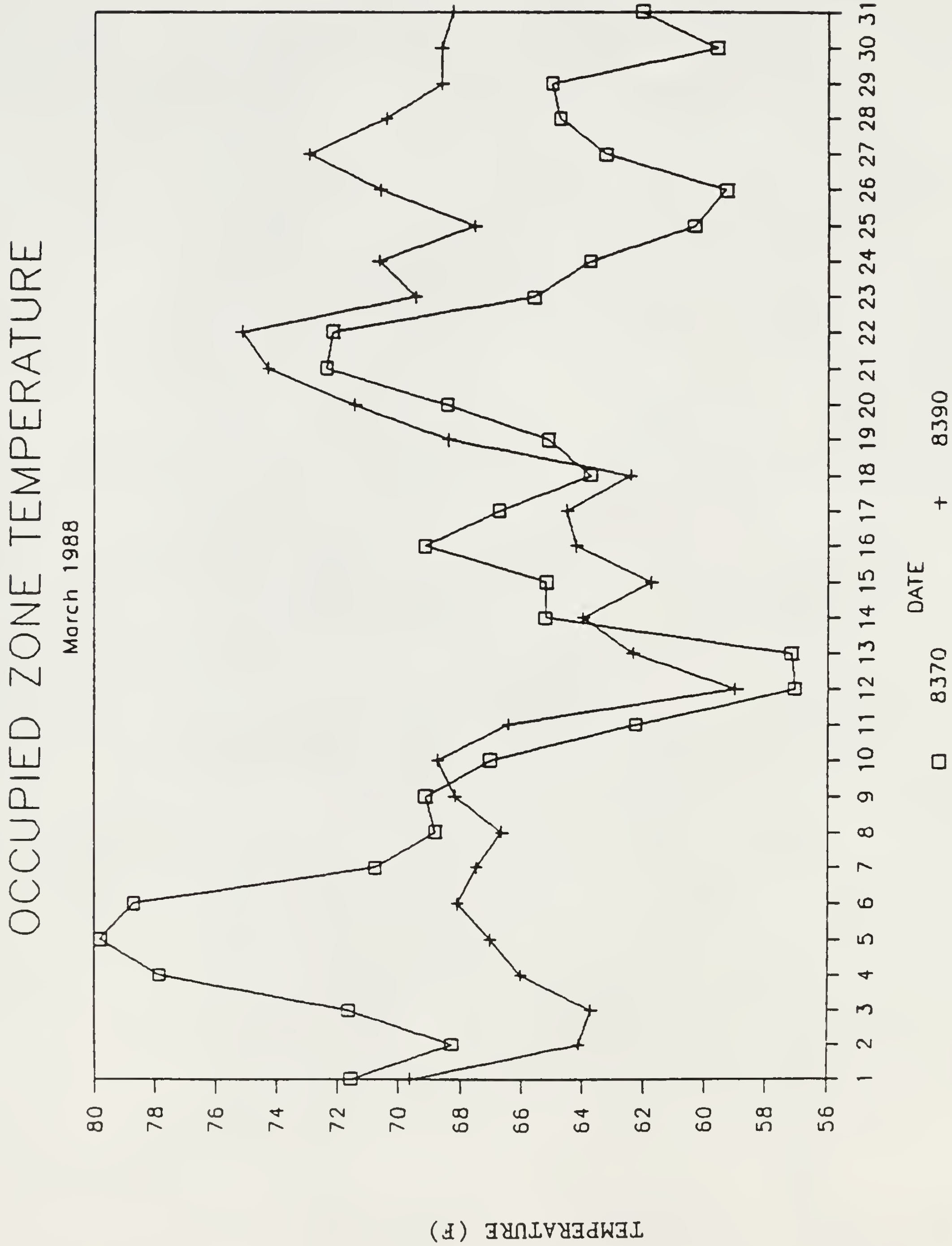

OCCUPIED ZONE TEMPERATURE
March 1988
TEMPERATURE (F)
80
78
76
74
72
70
68
66
64
62
60
58
56
DATE
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
□ 8370
+ 8390

Fig 4.32

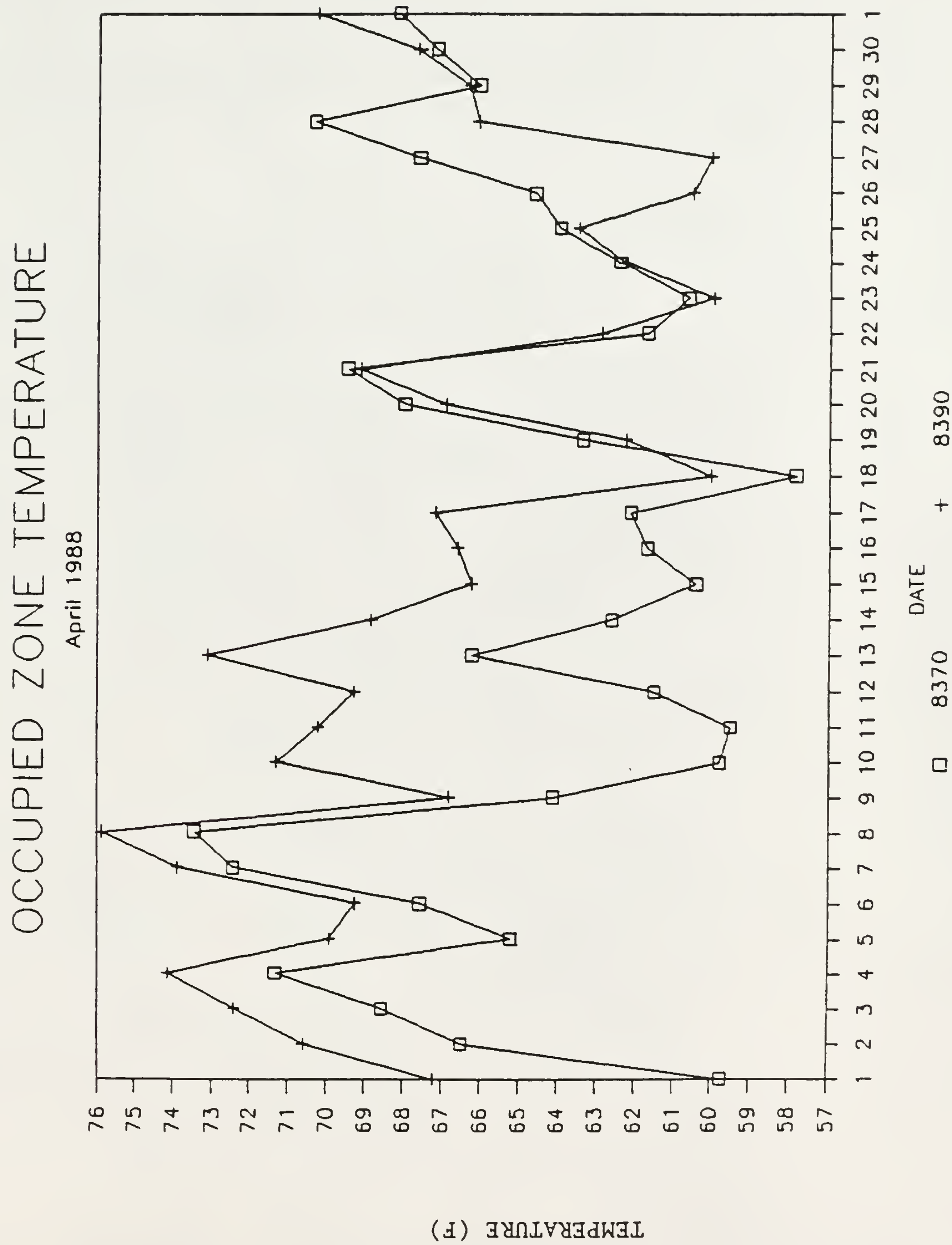

OCCUPIED ZONE TEMPERATURE
April 1988
TEMPERATURE (F)
76 75 74 73 72 71 70 69 68 67 66 65 64 63 62 61 60 59 58 57
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 1
DATE
□ 8370 + 8390

Fig 4.33

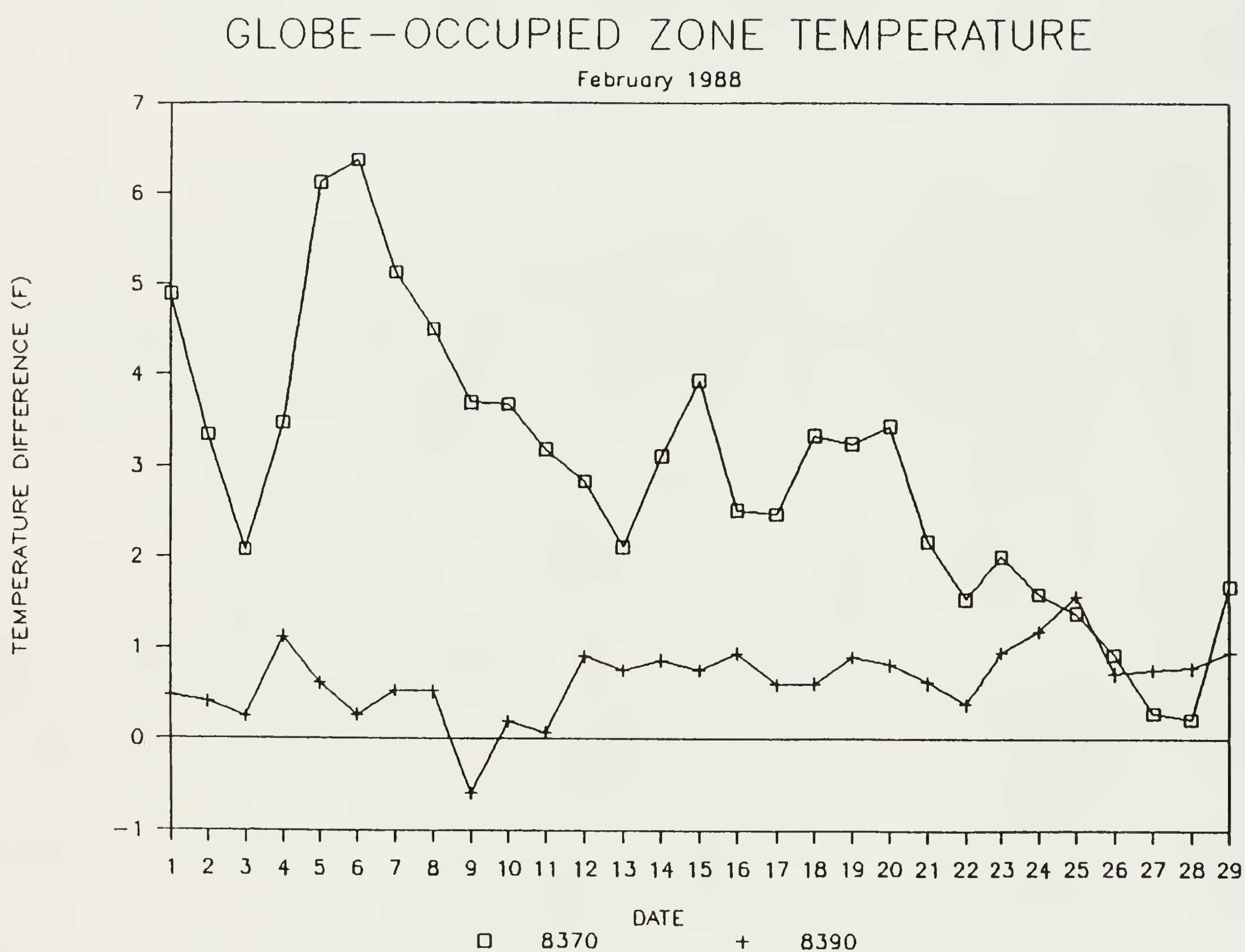

GLOBE-OCCUPIED ZONE TEMPERATURE
February 1988
TEMPERATURE DIFFERENCE (F)
7
6
5
4
3
2
1
0
-1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
DATE
□ 8370
+ 8390

Fig 4.34

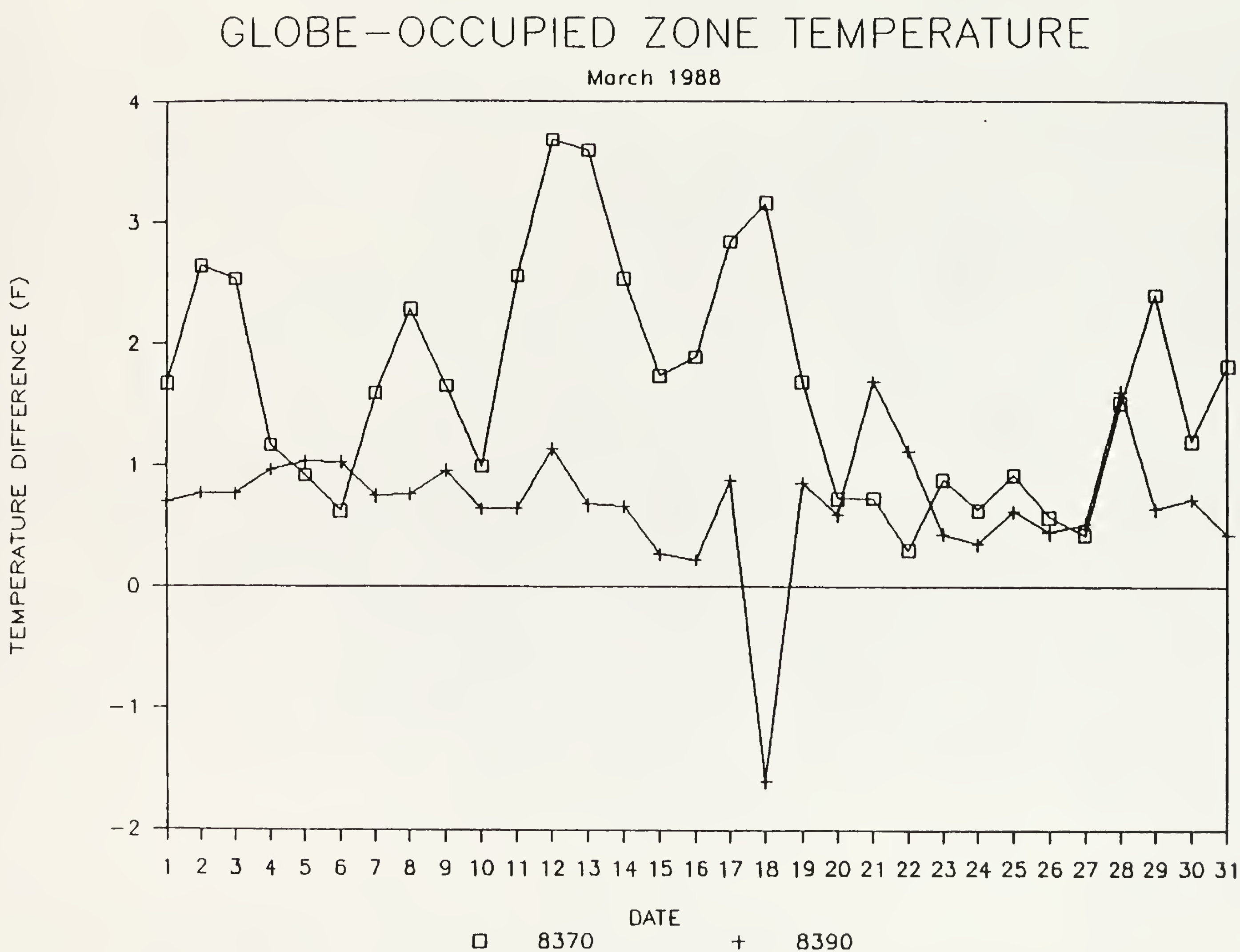

GLOBE-OCCUPIED ZONE TEMPERATURE
March 1988
TEMPERATURE DIFFERENCE (F)
4
3
2
1
0
-1
-2
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
DATE
□ 8370
+ 8390

Fig 4.35

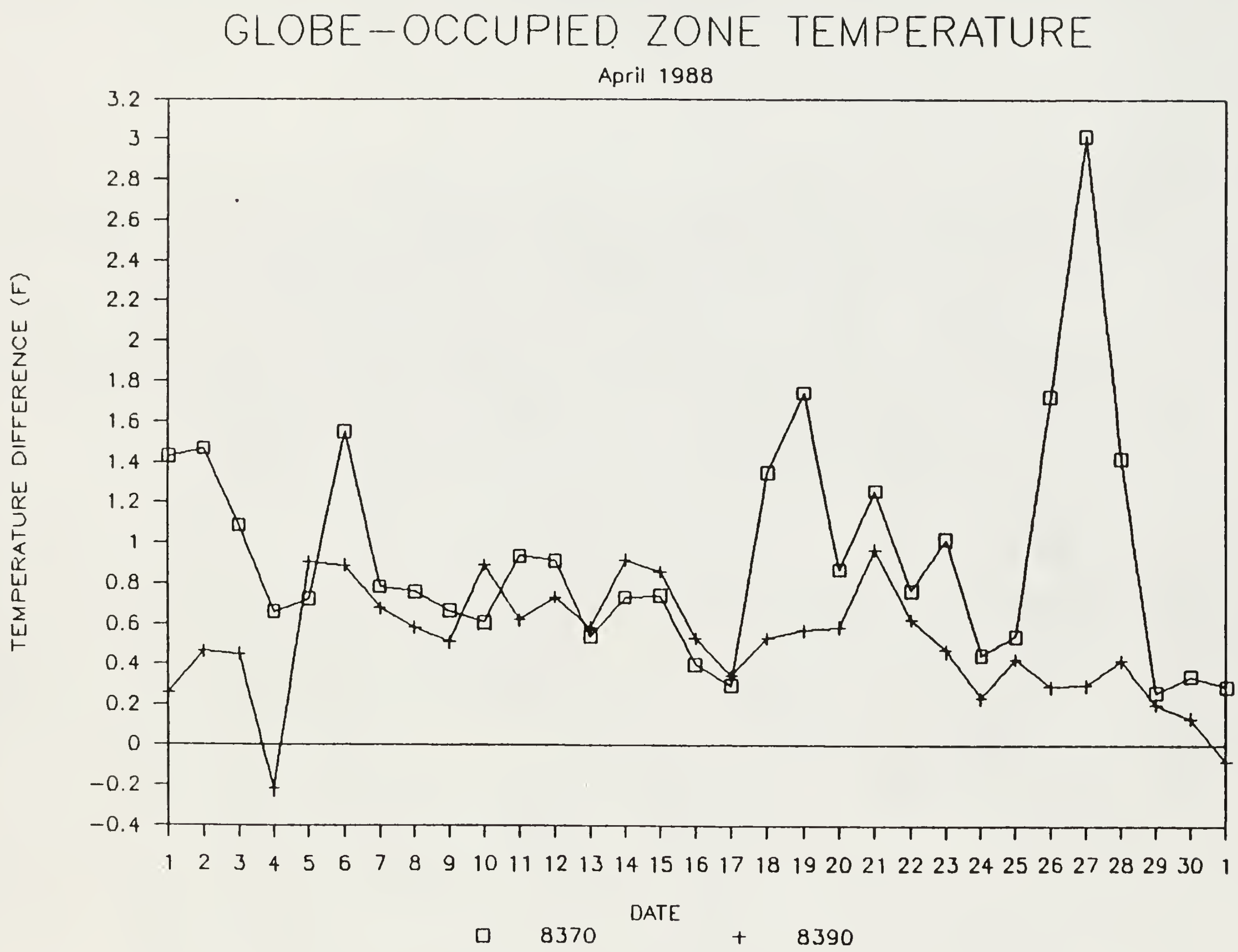

GLOBE-OCCUPIED ZONE TEMPERATURE
April 1988
TEMPERATURE DIFFERENCE (F)
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 1
DATE
□ 8370
+ 8390

Fig 4.36

radiant heaters in Building 8370 provided a higher mean radiant temperature than the heaters in Building 8390, the air temperature was not reduced to take advantage of this.

It is interesting to note that on four days, most noticeably 18 March, the globe temperature in Building 8390 was less than the occupied zone temperature. Examination of the hourly data from 18 March revealed a sharp drop in globe temperatures in the late afternoon. This may have been caused by cold vehicles being brought into the bays, thereby causing radiant cooling of the globe thermometers.

Difference Between Globe Temperature and Average Space Temperature

Examination of the differences between the globe temperatures and the average space temperatures, as shown in Figures 4.37 through 4.39, indicates a problem in both buildings. Throughout the study period, the globe temperature in both buildings was less than the space temperatures. During February and March, this difference was greater in Building 8390. In April both buildings were essentially the same.

Thermal Stratification

The findings described in the previous section indicate that both buildings had a problem with thermal stratification. Figures 4.40 through 4.45 show the

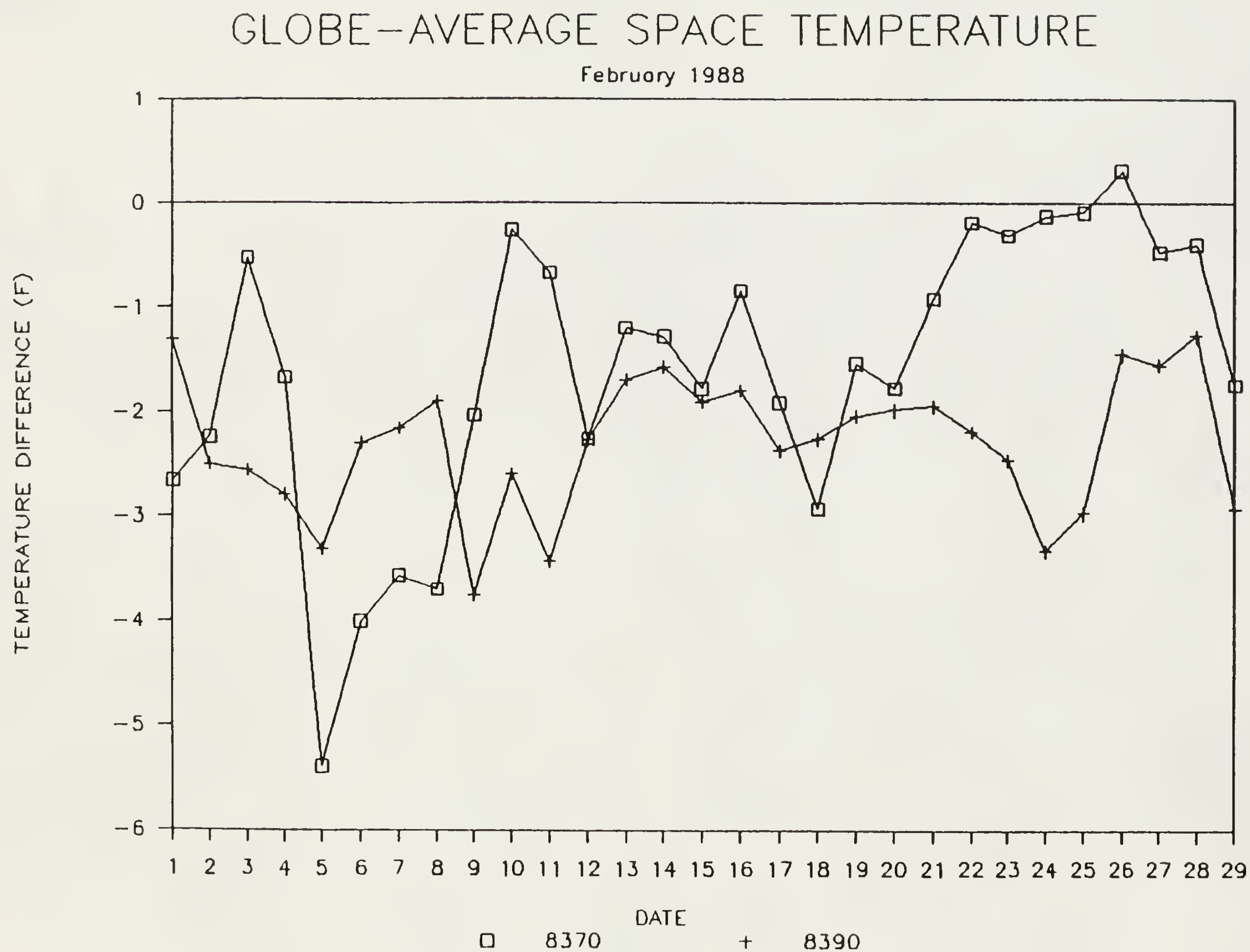

GLOBE-AVERAGE SPACE TEMPERATURE
February 1988
TEMPERATURE DIFFERENCE (F)
1
0
-1
-2
-3
-4
-5
-6
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
DATE
□ 8370
+ 8390

Fig 4.37

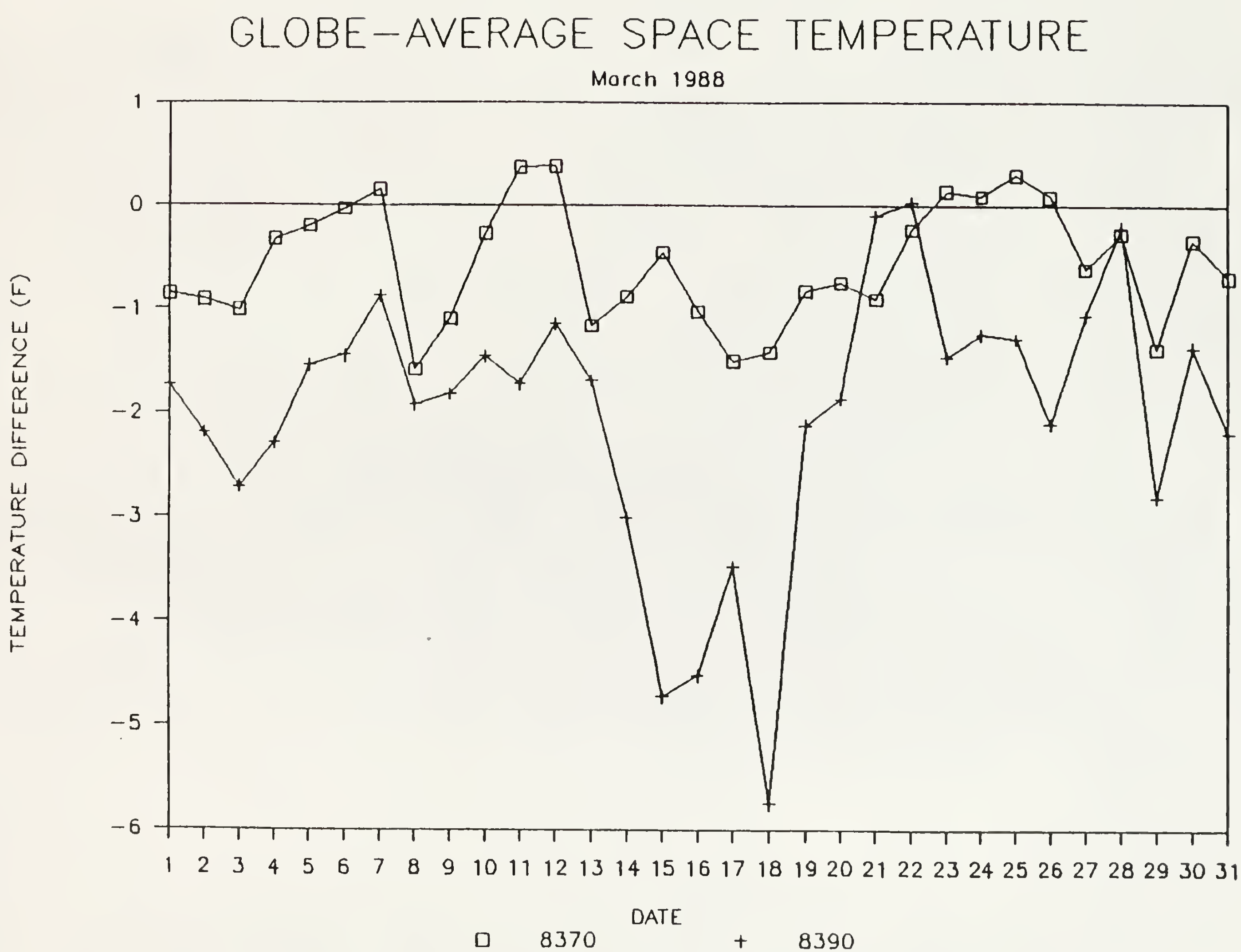

GLOBE-AVERAGE SPACE TEMPERATURE
March 1988
TEMPERATURE DIFFERENCE (F)
1
0
-1
-2
-3
-4
-5
-6
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
DATE
8370
8390

Fig 4.38

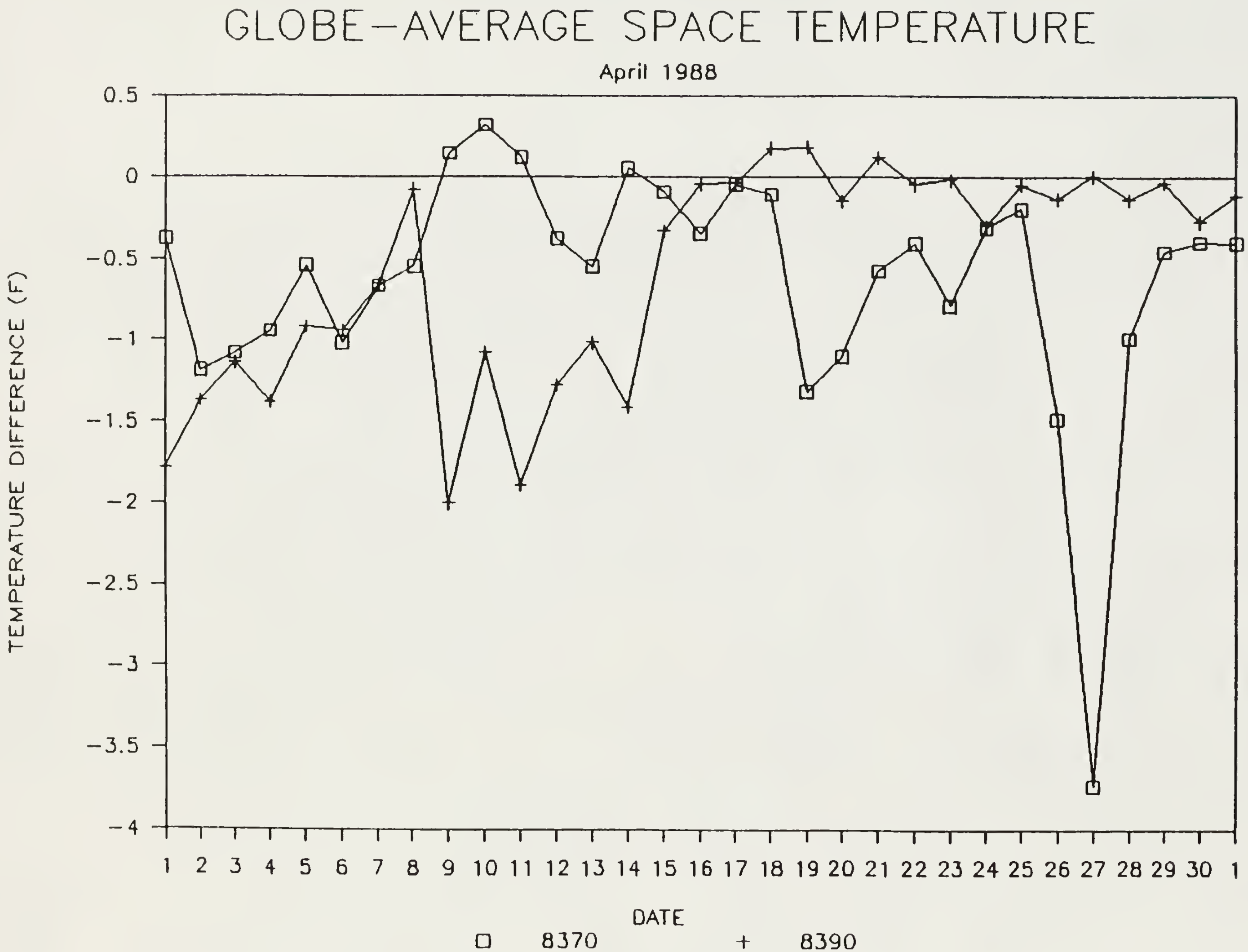

GLOBE-AVERAGE SPACE TEMPERATURE
April 1988
TEMPERATURE DIFFERENCE (F)
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 1
DATE
□ 8370
+ 8390

Fig 4.39

temperatures at three different levels in each building. During February and the first half of March, the temperatures in the upper levels of the space were much higher than the occupied zone temperaures. The most extreme stratification was observed in Building 8370 on 5 February, when the average upper-level temperature was 35 F higher than the temperature at the 6 inch level. The periods of greatest stratification in Building 8370 coincide with with high energy use and continuous operation of the radiant heaters.

Statistical analysis of thermal stratification was conducted using the difference between upper-level temperature and average 6 inch level temperature. During all three months, particularly February, Building 8370 showed greater stratification than Building 8390.

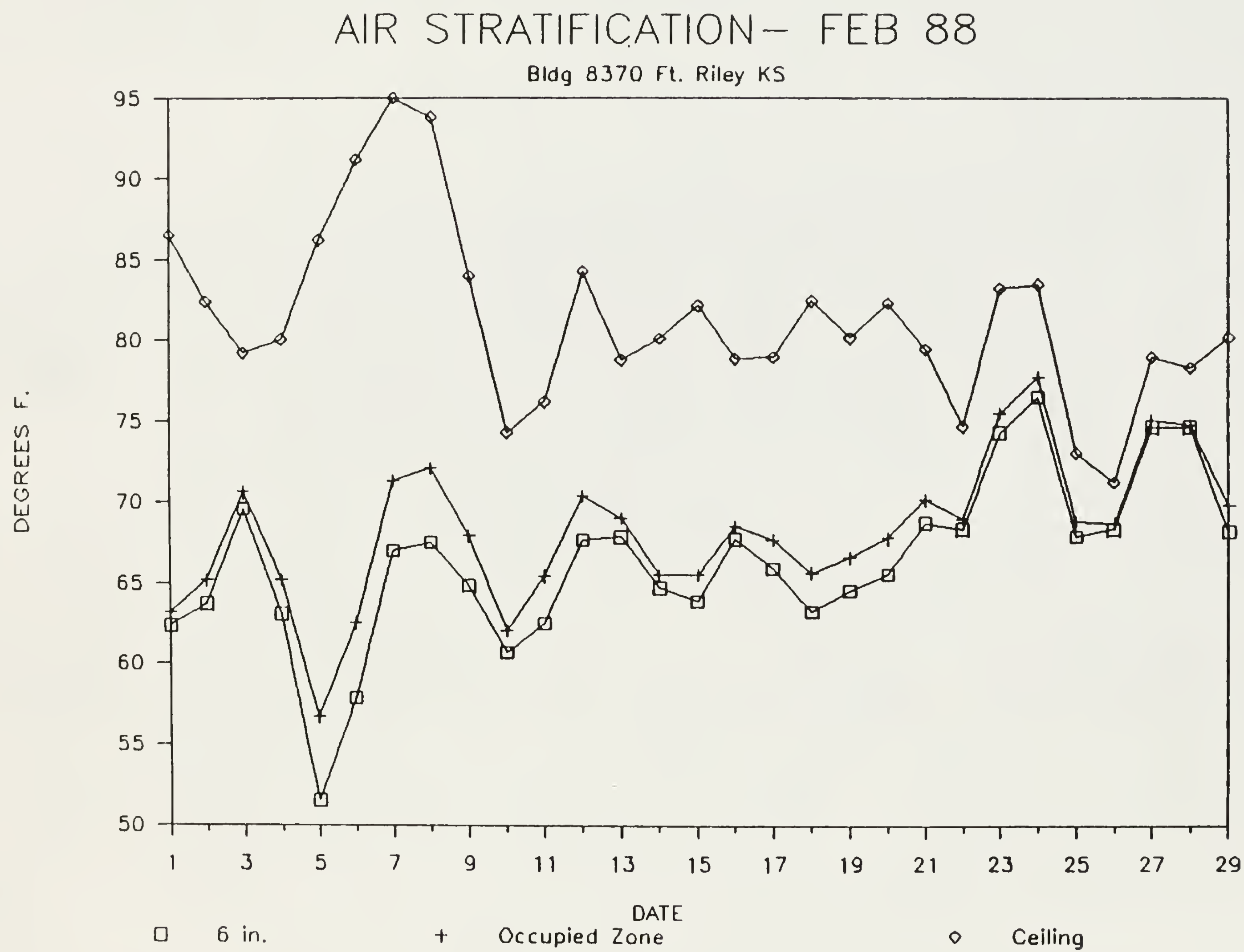

AIR STRATIFICATION— FEB 88
Bldg 8370 Ft. Riley KS
DEGREES F.
95
90
85
80
75
70
65
60
55
50
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
DATE
6 in.
Occupied Zone
Ceiling

Fig 4.40

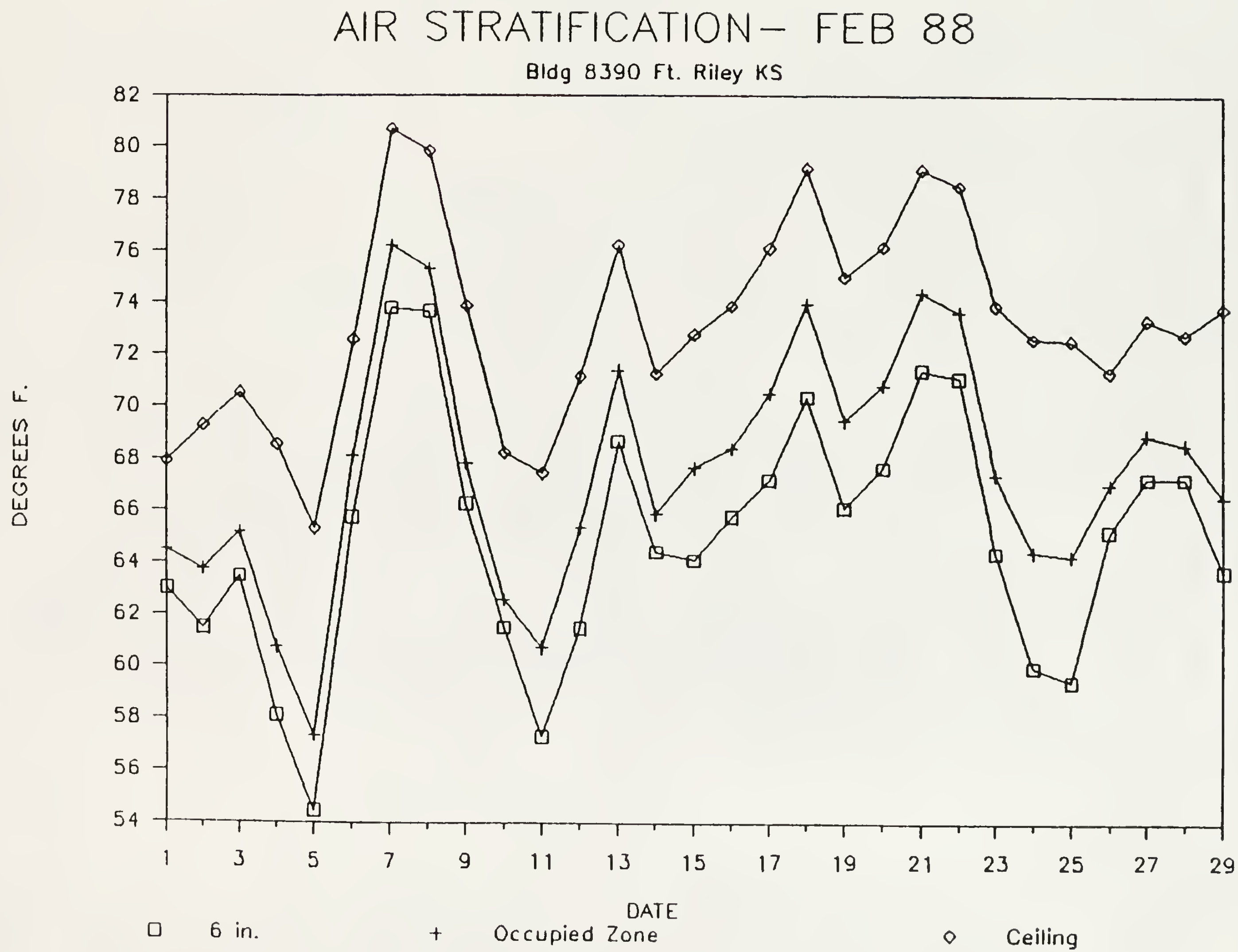

AIR STRATIFICATION– FEB 88
Bldg 8390 Ft. Riley KS
DEGREES F.
82
80
78
76
74
72
70
68
66
64
62
60
58
56
54
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
DATE
□ 6 in.
+ Occupied Zone
◇ Ceiling

Fig 4.41

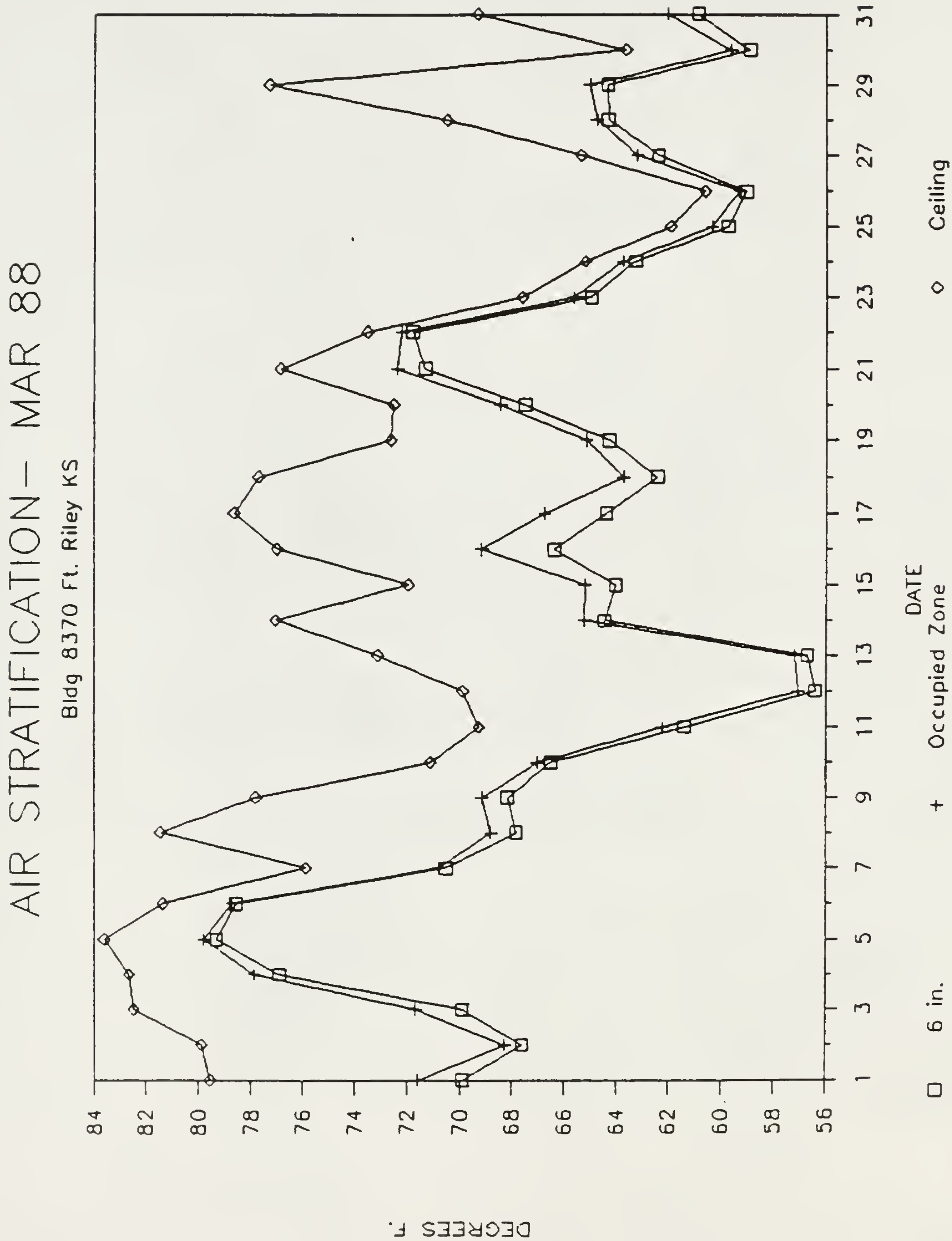

AIR STRATIFICATION— MAR 88
Bldg 8370 Ft. Riley KS
DEGREES F.
84
82
80
78
76
74
72
70
68
66
64
62
60
58
56
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
DATE
6 in.
Occupied Zone
Ceiling

Fig. 4.42

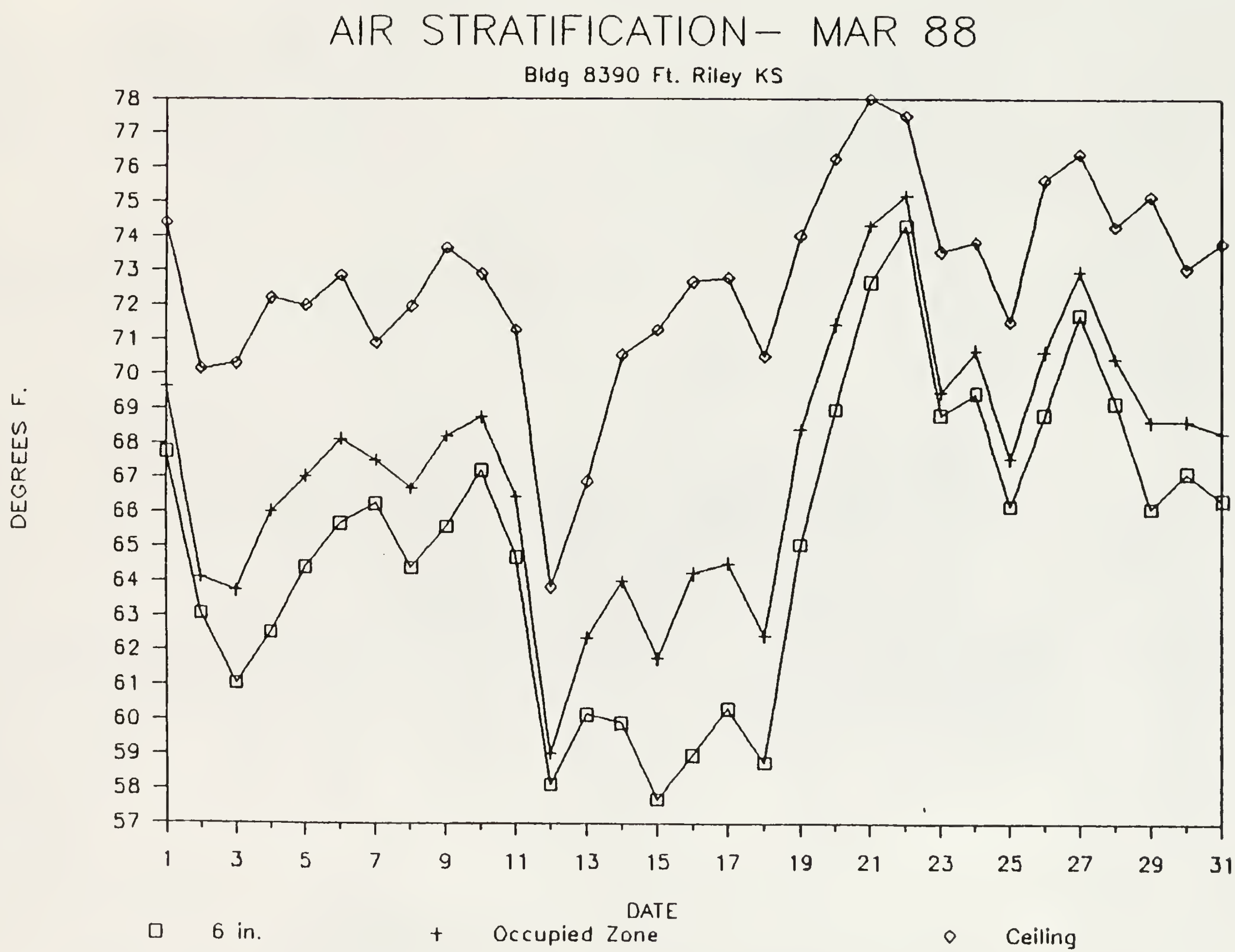
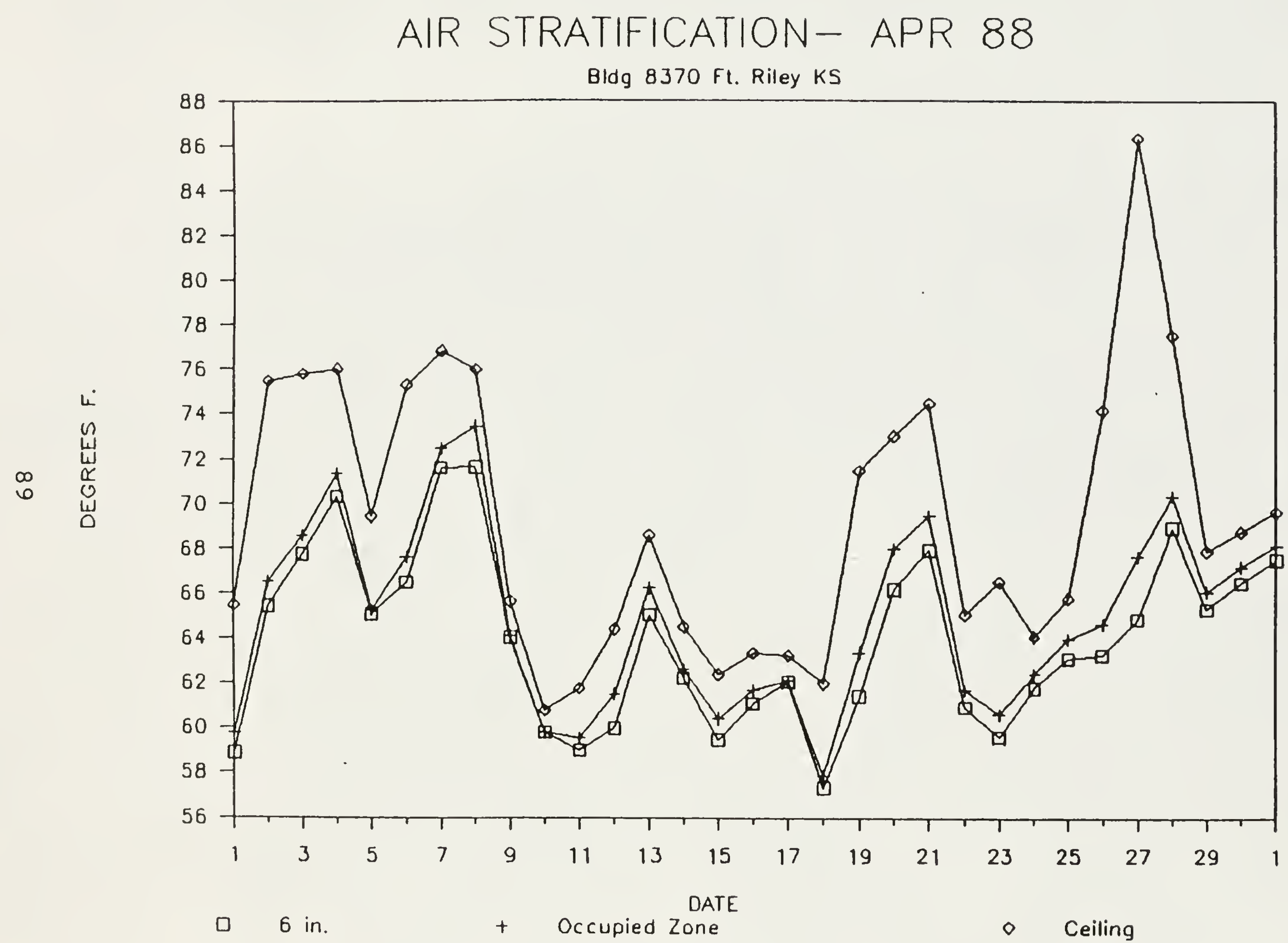

AIR STRATIFICATION– MAR 88
Bldg 8390 Ft. Riley KS
DEGREES F.
78
77
76
75
74
73
72
71
70
69
68
67
66
65
64
63
62
61
60
59
58
57
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
DATE
□ 6 in.
+ Occupied Zone
◇ Ceiling

Fig 4.43



AIR STRATIFICATION– APR 88
Bldg 8370 Ft. Riley KS
DEGREES F.
88
86
84
82
80
78
76
74
72
70
68
66
64
62
60
58
56
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
1
DATE
□ 6 in.
+ Occupied Zone
◇ Ceiling

Fig 4.44

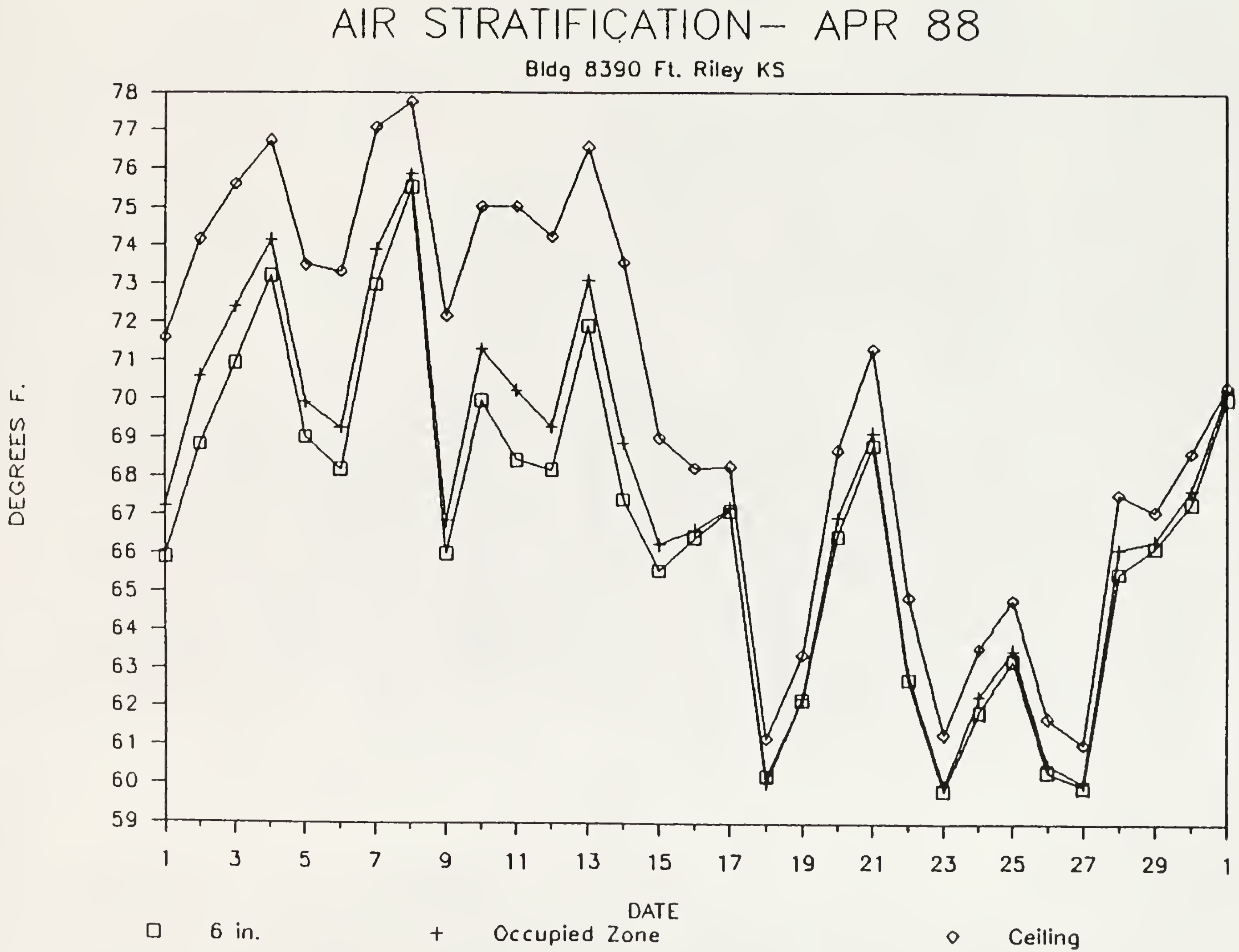

AIR STRATIFICATION– APR 88
Bldg 8390 Ft. Riley KS
DEGREES F.
78
77
76
75
74
73
72
71
70
69
68
67
66
65
64
63
62
61
60
59
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
1
DATE
□ 6 in.
+ Occupied Zone
◇ Ceiling

Fig 4.45

Table 4.5: Thermal Environmental Conditions

Parameter	Month	8370 Mean	8370 S. Dev	8390 Mean	8390 S. Dev	t
Occ. Zone (F)	Feb	68.2	4.45	67.6	4.56	0.52
	Mar	66.8	5.78	67.5	3.71	-0.49
	Apr	65.0	4.10	67.4	4.40	2.29
Globe-Occ. Zone (F)	Feb	2.94	1.53	0.65	0.40	7.77
	Mar	1.67	0.95	0.68	0.54	5.05
	Apr	0.95	0.58	0.50	0.29	3.81
Globe-Space (F)	Feb	-1.59	1.37	-2.30	0.65	2.51
	Mar	-0.56	0.58	-2.00	1.28	5.66
	Apr	-0.63	0.73	-0.58	0.68	-0.24
Thermal Strat. (F)	Feb	13.13	7.15	5.63	1.28	5.57
	Mar	6.94	4.30	5.25	1.67	2.04
	Apr	4.42	3.65	2.46	1.47	2.78

Underlined t values indicate a statistically significant difference

Figures 4.46 and 4.47 show the effects of the ceiling fans in Building 8370 and the recirculating fans in Building 8390 on thermal stratification. While the data is widely scattered, it can be seen that stratification in Building 8370 was reduced by increased use of the ceiling fans. The recirculating fans in Building 8390 do not appear to have had an obvious effect. At times of high use of the fans, the stratification is actually greater than at times of intermittent use. It should be noted that the cluster of points at the right of Figure 4.47 represent the first eleven days of February, and the stratification may be a result of cold outside air infiltrating into the building.

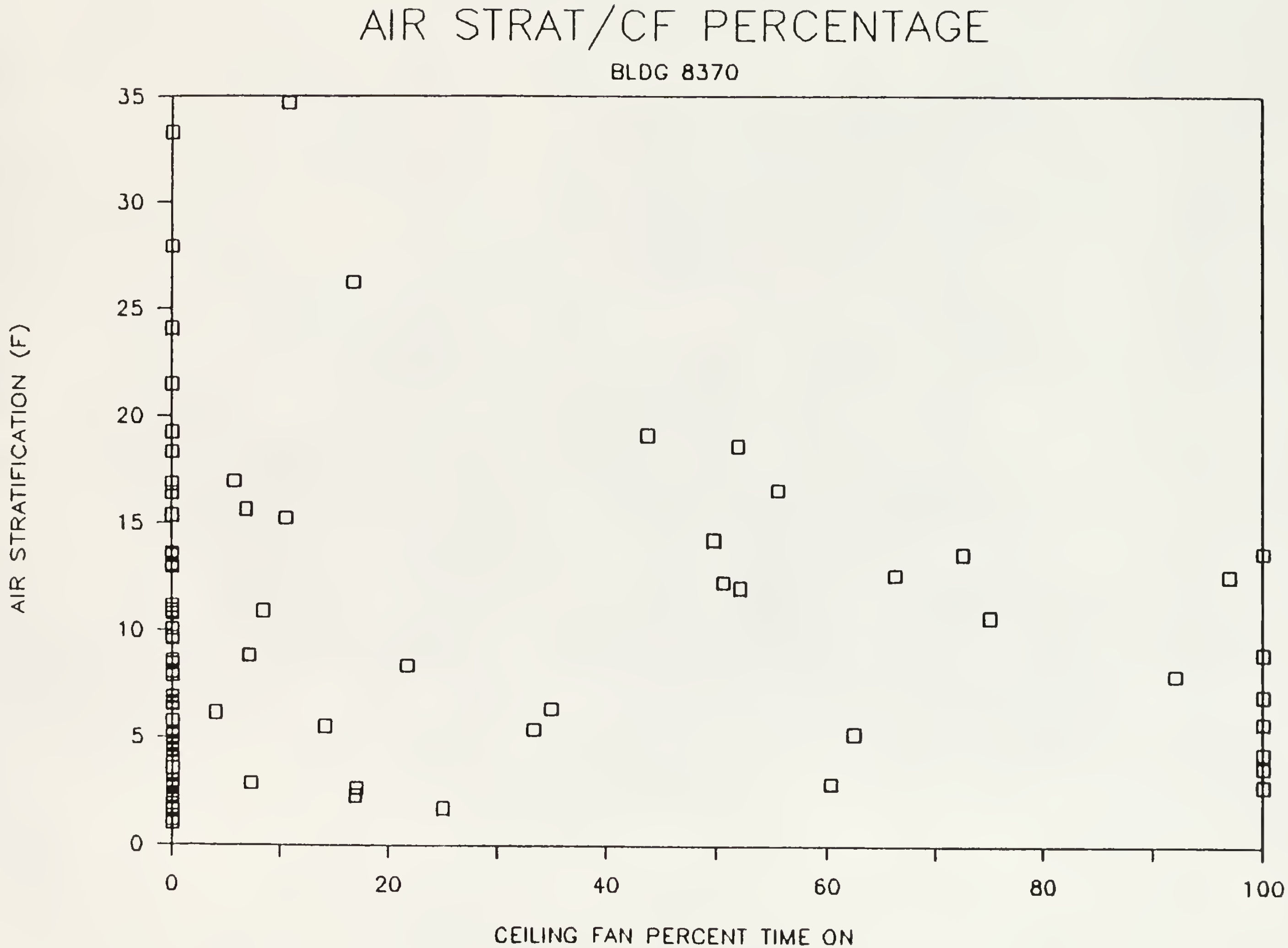


Fig 4.46 Effect of Ceiling Fan Use on Stratification - Building 8370

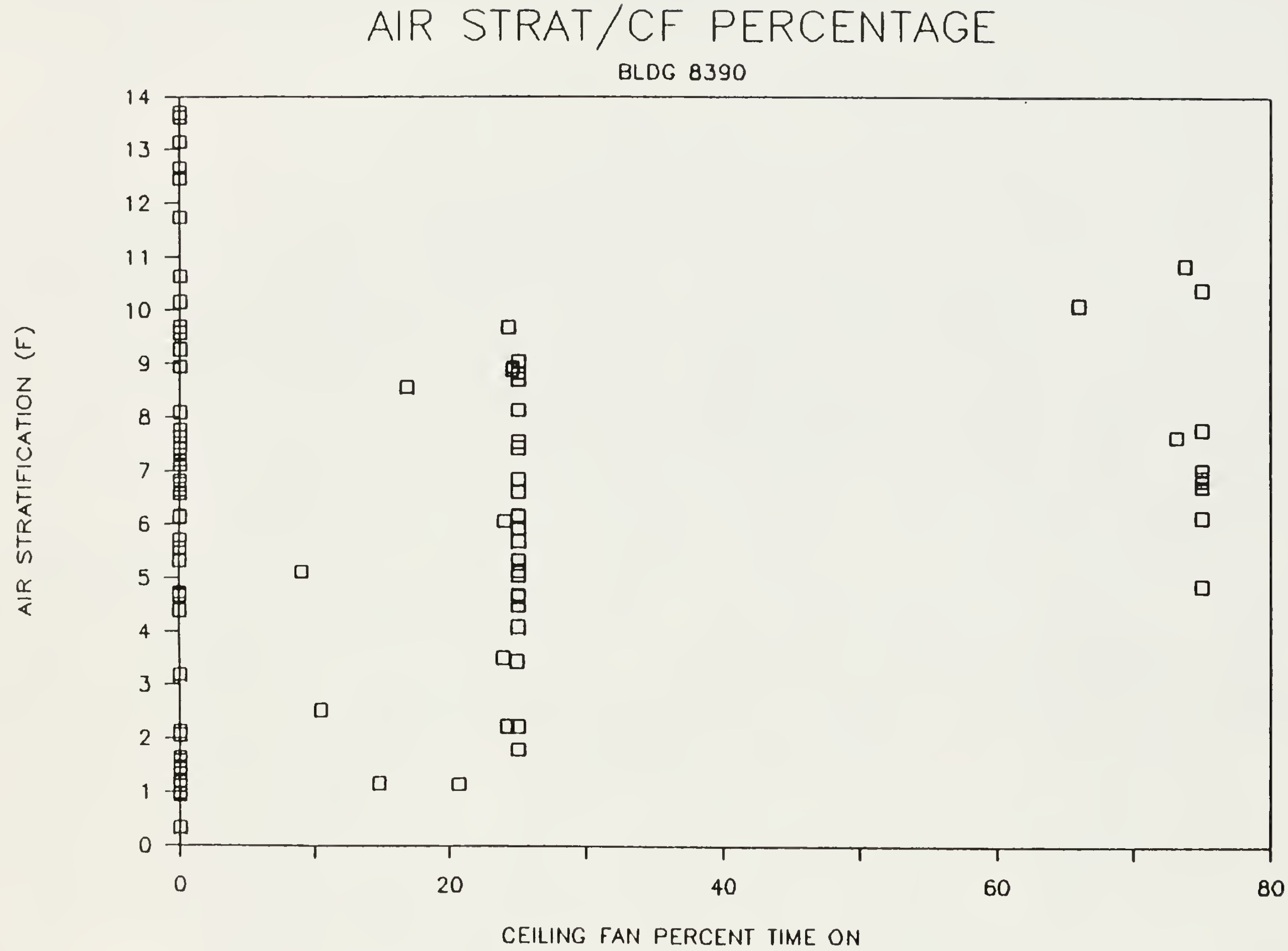


Fig 4.47 Effect of Ceiling Fan Use on Startification - Building 8390

Since the convective heaters in Building 8390 blow warm air downward to begin with, it may be that the recirculating fans are somewhat redundant and not as effective as the ceiling fans in Building 8370.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The purpose of this study was to compare the performance of radiant and convective heating systems in similar applications in terms of energy consumption and interior thermal characteristics. The nature of a field study such as this makes "noisy" data unavoidable. Taking data every three minutes meant that transient effects were not measured. Also, it is certain that events which could have had a great influence on thermal conditions, such as a bay door being opened for two minutes, were often missed. Finally, many aspects of the buildings' operation, such as the type of work being done in the bays at a given time, could not be monitored at all. Despite this, it is still possible to draw conclusions from long-term trends.

During the study period, Building 8370 used more energy than Building 8390. Given that maintenance buildings would seem to be an ideal location for radiant heating, this result was unexpected. The primary cause for this high energy use was the lack of an automatic nighttime setback at Building 8370. As the heating season progressed, Building 8370 became more energy efficient than Building 8390 during normal operating hours; however, Building 8390 saved energy at night because of an effective nighttime setback. The unfamiliarity of Building 8370's occupants with the heating system was also a factor, as can be seen from the continuous use of the heaters in early February.

Both buildings were plagued by a problem of thermal stratification. In February, when the highest energy consumption in Building 8370 occurred, stratification was particularly noticeable. It appears that much of the energy from the radiant heaters entered the space near the ceiling via natural convection from the heater tubes. The layer of warm air thus formed at the ceiling did not reach the occupied zone of the building except when ceiling fans were used.

In terms of the thermal environment, the radiant heaters peformed as expected.The opeative temperature in Building 8370 was substantially higher than the occupied zone air temperature, indicating a high mean radiant temperature. The difference between operative temperature and air temperature was not as great in Building 8390. The advantages thus gained in Building 8370, however,were offset by thermal stratification and a certain amount of overheating.

It can be concluded, then, that radiant heating is effective in large spaces such as the maintenance shops studied here. However, the advantages of radiant heating can be negated by improper control. It cannot be assumed that radiant heating will always be more efficient than convective heating.

Recommendations

This project will be continued through the 1988-89 heating season. Several modifications are planned which will help eliminate some of the uncontrolled factors noted in this study. The primary change involves a modiication of the controls in Building 8370. The thermostats will be replaced with preset thermostats with a nighttime setback. This modification will allow a more accurate comparison between the two systems, since the controls will be similar.

Further study of the effects of door openings and ceiling and exhaust fan opeation would be useful. Of particular interest is the effects of different configurations of open doors. A study of transient responses of the two systems would also be informative.

There are several other variations of radiant heating available. A study is being initiated at two of the aircraft hangers at Fort Riley's Marshall Army Airfield. These hangers are heated by heating the floor slab. A comparison of this type of heating system with the overhead heaters at Building 8370 would provide a means of concluding which variety of radiant heating is most effective in maintenance facilities.

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Appendix A.

Map of Fort Riley's Custer Hill

APPENDIX B

ACUREX AUTOCALC PROGRAMING

Table B.1 Engineering Units Conversion

EU	Quantity Measured
09	Type "T" Thermocouple
06	0-10 volts
21	4-20 milliamps
24	Contact Closure
25	Pseudochannel - arithmetic operations performed on collected data
47	Digital Input

Table B.2 Sensor Channel Locations - Building 8370

Sensor	Channel(s)
Vertical String 1	6-7, 28-33
Vertical String 2	8-15
Vertical String 3	20-27
Globe Thermometer 1	0-5
Globe Thermometer 2	48-53
Globe Thermometer 3	40-45
Ceiling Thermocouples	54-57
Dew Point Sensor	19
Radiant Heater 1	18
Radiant Heater 2/3	17
Radiant Heater 4	46
Radiant Heater 5	16
Make-up Air Unit	47
Exhaust Fans	34-35
Ceiling Fans	36-39
Bay Doors	58-65
Thermostat Temperatures	203-206
Air Velocites	207-209
MAU Inlet Temperature	210
MAU Outlet Temperature	211
Heater/Fan Conversion to Integer Number	66-67
Bay Door Conversion to Integer Number	128-135
Digital: Count Seconds of On-Time	
Heaters	230-235
Bay Doors	237-244

```
Channel programming:
000 EU=09   NETPAC:1/00/00   RES:D   SKIP:NO
001 EU=09   NETPAC:1/00/01   RES:D   SKIP:NO
002 EU=09   NETPAC:1/00/02   RES:D   SKIP:NO
003 EU=09   NETPAC:1/00/03   RES:D   SKIP:NO
004 EU=09   NETPAC:1/00/04   RES:D   SKIP:NO
005 EU=09   NETPAC:1/00/05   RES:D   SKIP:NO
006 EU=09   NETPAC:1/00/06   RES:D   SKIP:NO
007 EU=09   NETPAC:1/00/07   RES:D   SKIP:NO
008 EU=09   NETPAC:1/00/08   RES:D   SKIP:NO
009 EU=09   NETPAC:1/00/09   RES:D   SKIP:NO
010 EU=09   NETPAC:1/00/10   RES:D   SKIP:NO
011 EU=09   NETPAC:1/00/11   RES:D   SKIP:NO
012 EU=09   NETPAC:1/00/12   RES:D   SKIP:NO
013 EU=09   NETPAC:1/00/13   RES:D   SKIP:NO
014 EU=09   NETPAC:1/00/14   RES:D   SKIP:NO
015 EU=09   NETPAC:1/00/15   RES:D   SKIP:NO
016 EU=24   NETPAC:2/00/08   RES:D   SKIP:NO     LIMITS 07/00/00/00
017 EU=24   NETPAC:2/00/09   RES:D   SKIP:NO     LIMITS 07/00/00/00
018 EU=24   NETPAC:2/00/10   RES:D   SKIP:NO     LIMITS 07/00/00/00
019 EU=21   NETPAC:1/00/19   RES:D   SKIP:NO
020 EU=09   NETPAC:1/00/20   RES:D   SKIP:NO
021 EU=09   NETPAC:1/00/21   RES:D   SKIP:NO
022 EU=09   NETPAC:1/00/22   RES:D   SKIP:NO
023 EU=09   NETPAC:1/00/23   RES:D   SKIP:NO
024 EU=09   NETPAC:1/00/24   RES:D   SKIP:NO
025 EU=09   NETPAC:1/00/25   RES:D   SKIP:NO
026 EU=09   NETPAC:1/00/26   RES:D   SKIP:NO
027 EU=09   NETPAC:1/00/27   RES:D   SKIP:NO
028 EU=09   NETPAC:1/00/28   RES:D   SKIP:NO
029 EU=09   NETPAC:1/00/29   RES:D   SKIP:NO
030 EU=09   NETPAC:1/00/30   RES:D   SKIP:NO
031 EU=09   NETPAC:1/00/31   RES:D   SKIP:NO
032 EU=09   NETPAC:1/00/32   RES:D   SKIP:NO
033 EU=09   NETPAC:1/00/33   RES:D   SKIP:NO
034 EU=24   NETPAC:2/00/13   RES:D   SKIP:NO     LIMITS 08/00/00/00
035 EU=24   NETPAC:2/00/14   RES:D   SKIP:NO     LIMITS 08/00/00/00
036 EU=24   NETPAC:1/00/36   RES:D   SKIP:NO     LIMITS 08/00/00/00
037 EU=24   NETPAC:1/00/37   RES:D   SKIP:NO     LIMITS 08/00/00/00
038 EU=24   NETPAC:1/00/38   RES:D   SKIP:NO     LIMITS 08/00/00/00
039 EU=24   NETPAC:1/00/39   RES:D   SKIP:NO     LIMITS 08/00/00/00
040 EU=09   NETPAC:1/00/40   RES:D   SKIP:NO
041 EU=09   NETPAC:1/00/41   RES:D   SKIP:NO
042 EU=09   NETPAC:1/00/42   RES:D   SKIP:NO
043 EU=09   NETPAC:1/00/43   RES:D   SKIP:NO
044 EU=09   NETPAC:1/00/44   RES:D   SKIP:NO
045 EU=09   NETPAC:1/00/45   RES:D   SKIP:NO
046 EU=24   NETPAC:2/00/11   RES:D   SKIP:NO     LIMITS 07/00/00/00
```

```
047 EU=24  NETPAC:2/00/12  RES:D  SKIP:NO    LIMITS 07/00/00/00
048 EU=09  NETPAC:1/00/48  RES:D  SKIP:NO
049 EU=09  NETPAC:1/00/49  RES:D  SKIP:NO
050 EU=09  NETPAC:1/00/50  RES:D  SKIP:NO
051 EU=09  NETPAC:1/00/51  RES:D  SKIP:NO
052 EU=09  NETPAC:1/00/52  RES:D  SKIP:NO
053 EU=09  NETPAC:1/00/53  RES:D  SKIP:NO
054 EU=09  NETPAC:1/00/54  RES:D  SKIP:NO
055 EU=09  NETPAC:1/00/55  RES:D  SKIP:NO
056 EU=09  NETPAC:1/00/56  RES:D  SKIP:NO
057 EU=09  NETPAC:1/00/57  RES:D  SKIP:NO
058 EU=06  NETPAC:2/00/00  RES:D  SKIP:NO    LIMITS 05/00/00/00
059 EU=06  NETPAC:2/00/01  RES:D  SKIP:NO    LIMITS 05/00/00/00
060 EU=06  NETPAC:2/00/02  RES:D  SKIP:NO    LIMITS 05/00/00/00
061 EU=06  NETPAC:2/00/03  RES:D  SKIP:NO    LIMITS 06/00/00/00
062 EU=06  NETPAC:2/00/04  RES:D  SKIP:NO    LIMITS 06/00/00/00
063 EU=06  NETPAC:2/00/05  RES:D  SKIP:NO    LIMITS 06/00/00/00
064 EU=06  NETPAC:2/00/06  RES:D  SKIP:NO    LIMITS 06/00/00/00
065 EU=06  NETPAC:2/00/07  RES:D  SKIP:NO    LIMITS 06/00/00/00
066 EU=25  E=C16L1*1  SKIP:NO
067 EU=25  E=C17L1*2  SKIP:NO
068 EU=25  E=C18L1*4  SKIP:NO
069 EU=25  E=C46L1*8  SKIP:NO
070 EU=25  E=C47L1*16  SKIP:NO
071 EU=25  E=C36L1*32  SKIP:NO
072 EU=25  E=C37L1*64  SKIP:NO
073 EU=25  E=C38L1*128  SKIP:NO
074 EU=25  E=C39L1*256  SKIP:NO
075 EU=25  E=C34L1*512  SKIP:NO
076 EU=25  E=C35L1*1024  SKIP:NO
079 EU=25  E=TOD"**/30/**,**/31/**"  SKIP:NO
080 EU=25  E=AVT(C0,C79)  SKIP:NO
081 EU=25  E=AVT(C1,C79)  SKIP:NO
082 EU=25  E=AVT(C2,C79)  SKIP:NO
083 EU=25  E=AVT(C3,C79)  SKIP:NO
084 EU=25  E=AVT(C4,C79)  SKIP:NO
085 EU=25  E=AVT(C5,C79)  SKIP:NO
086 EU=25  E=AVT(C6,C79)  SKIP:NO
087 EU=25  E=AVT(C7,C79)  SKIP:NO
088 EU=25  E=AVT(C8,C79)  SKIP:NO
089 EU=25  E=AVT(C9,C79)  SKIP:NO
090 EU=25  E=AVT(C10,C79)  SKIP:NO
091 EU=25  E=AVT(C11,C79)  SKIP:NO
092 EU=25  E=AVT(C12,C79)  SKIP:NO
093 EU=25  E=AVT(C13,C79)  SKIP:NO
094 EU=25  E=AVT(C14,C79)  SKIP:NO
095 EU=25  E=AVT(C15,C79)  SKIP:NO
096 EU=25  E=AVT(C20,C79)  SKIP:NO
```

```
097 EU=25  E=AVT(C21,C79)  SKIP:NO
098 EU=25  E=AVT(C22,C79)  SKIP:NO
099 EU=25  E=AVT(C23,C79)  SKIP:NO
100 EU=25  E=AVT(C24,C79)  SKIP:NO
101 EU=25  E=AVT(C25,C79)  SKIP:NO
102 EU=25  E=AVT(C26,C79)  SKIP:NO
103 EU=25  E=AVT(C27,C79)  SKIP:NO
104 EU=25  E=AVT(C28,C79)  SKIP:NO
105 EU=25  E=AVT(C29,C79)  SKIP:NO
106 EU=25  E=AVT(C30,C79)  SKIP:NO
107 EU=25  E=AVT(C31,C79)  SKIP:NO
108 EU=25  E=AVT(C32,C79)  SKIP:NO
109 EU=25  E=AVT(C33,C79)  SKIP:NO
110 EU=25  E=AVT(C40,C79)  SKIP:NO
111 EU=25  E=AVT(C41,C79)  SKIP:NO
112 EU=25  E=AVT(C42,C79)  SKIP:NO
113 EU=25  E=AVT(C43,C79)  SKIP:NO
114 EU=25  E=AVT(C44,C79)  SKIP:NO
115 EU=25  E=AVT(C45,C79)  SKIP:NO
116 EU=25  E=AVT(C48,C79)  SKIP:NO
117 EU=25  E=AVT(C49,C79)  SKIP:NO
118 EU=25  E=AVT(C50,C79)  SKIP:NO
119 EU=25  E=AVT(C51,C79)  SKIP:NO
120 EU=25  E=AVT(C52,C79)  SKIP:NO
121 EU=25  E=AVT(C53,C79)  SKIP:NO
122 EU=25  E=AVT(C54,C79)  SKIP:NO
123 EU=25  E=AVT(C55,C79)  SKIP:NO
124 EU=25  E=AVT(C56,C79)  SKIP:NO
125 EU=25  E=AVT(C57,C79)  SKIP:NO
126 EU=25  E=AVT(C19,C79)  SKIP:NO
128 EU=25  E=C58L1*1  SKIP:NO
129 EU=25  E=C59L1*2  SKIP:NO
130 EU=25  E=C60L1*4  SKIP:NO
131 EU=25  E=C61L1*8  SKIP:NO
132 EU=25  E=C62L1*16  SKIP:NO
133 EU=25  E=C63L1*32  SKIP:NO
134 EU=25  E=C64L1*64  SKIP:NO
135 EU=25  E=C65L1*128  SKIP:NO
137 EU=25  E=AVG(C66,C76)  SKIP:NO
138 EU=25  E=AVG(C128,C135)  SKIP:NO
140 EU=25  E=C80  SKIP:NO
141 EU=25  E=C81  SKIP:NO
142 EU=25  E=C82  SKIP:NO
143 EU=25  E=C83  SKIP:NO
144 EU=25  E=C84  SKIP:NO
145 EU=25  E=C85  SKIP:NO
146 EU=25  E=C86  SKIP:NO
147 EU=25  E=C87  SKIP:NO
```

```
148 EU=25  E=C88  SKIP:NO
149 EU=25  E=C89  SKIP:NO
150 EU=25  E=C90  SKIP:NO
151 EU=25  E=C91  SKIP:NO
152 EU=25  E=C92  SKIP:NO
153 EU=25  E=C93  SKIP:NO
154 EU=25  E=C94  SKIP:NO
155 EU=25  E=C95  SKIP:NO
156 EU=25  E=C96  SKIP:NO
157 EU=25  E=C97  SKIP:NO
158 EU=25  E=C98  SKIP:NO
159 EU=25  E=C99  SKIP:NO
160 EU=25  E=C100  SKIP:NO
161 EU=25  E=C101  SKIP:NO
162 EU=25  E=C102  SKIP:NO
163 EU=25  E=C103  SKIP:NO
164 EU=25  E=C104  SKIP:NO
165 EU=25  E=C105  SKIP:NO
166 EU=25  E=C106  SKIP:NO
167 EU=25  E=C107  SKIP:NO
168 EU=25  E=C108  SKIP:NO
169 EU=25  E=C109  SKIP:NO
170 EU=25  E=C110  SKIP:NO
171 EU=25  E=C111  SKIP:NO
172 EU=25  E=C112  SKIP:NO
173 EU=25  E=C113  SKIP:NO
174 EU=25  E=C114  SKIP:NO
175 EU=25  E=C115  SKIP:NO
176 EU=25  E=C116  SKIP:NO
177 EU=25  E=C117  SKIP:NO
178 EU=25  E=C118  SKIP:NO
179 EU=25  E=C119  SKIP:NO
180 EU=25  E=C120  SKIP:NO
181 EU=25  E=C121  SKIP:NO
182 EU=25  E=C122  SKIP:NO
183 EU=25  E=C123  SKIP:NO
184 EU=25  E=C124  SKIP:NO
185 EU=25  E=C125  SKIP:NO
186 EU=25  E=C126  SKIP:NO
200 EU=25  UNITS=GT1   E=AVG(C0,C5)  SKIP:NO
201 EU=25  UNITS=GT2   E=AVG(C48,C53)  SKIP:NO
202 EU=25  UNITS=GT3   E=AVG(C40,C45)  SKIP:NO
203 EU=09  NETPAC:1/00/34  RES:D  SKIP:NO
204 EU=09  NETPAC:1/00/35  RES:D  SKIP:NO
205 EU=09  NETPAC:1/00/46  RES:D  SKIP:NO
206 EU=09  NETPAC:1/00/47  RES:D  SKIP:NO
207 EU=06  NETPAC:1/00/16  RES:D  SKIP:NO
208 EU=06  NETPAC:1/00/17  RES:D  SKIP:NO
```

```
209 EU=06  NETPAC:1/00/18  RES:D  SKIP:NO
210 EU=09  NETPAC:1/00/58  RES:D  SKIP:NO
211 EU=09  NETPAC:1/00/59  RES:D  SKIP:NO
212 EU=25  E=C137*11  SKIP:NO
213 EU=25  E=C138*8  SKIP:NO
214 EU=25  E=AVG(C32,C33)  SKIP:NO
215 EU=25  E=AVG(C12,C13)  SKIP:NO
216 EU=25  E=AVG(C24,C25)  SKIP:NO
217 EU=25  E=C19  SKIP:NO
230 EU=47  E=DIG(0,0,5)  SKIP:NO
231 EU=47  E=DIG(0,1,5)  SKIP:NO
232 EU=47  E=DIG(0,2,5)  SKIP:NO
233 EU=47  E=DIG(0,3,5)  SKIP:NO
234 EU=47  E=DIG(0,4,5)  SKIP:NO
235 EU=47  E=DIG(0,5,5)  SKIP:NO
236 EU=47  E=DIG(0,6,3)  SKIP:NO
237 EU=47  E=DIG(0,7,4)  SKIP:NO
238 EU=47  E=DIG(0,8,4)  SKIP:NO
239 EU=47  E=DIG(0,9,4)  SKIP:NO
240 EU=47  E=DIG(1,0,3)  SKIP:NO
241 EU=47  E=DIG(1,1,3)  SKIP:NO
242 EU=47  E=DIG(1,2,3)  SKIP:NO
243 EU=47  E=DIG(1,3,3)  SKIP:NO
244 EU=47  E=DIG(1,4,3)  SKIP:NO
250 EU=47  E=DIG(0,9,3)  SKIP:NO    LIMITS 01/00/00/00
251 EU=25  E=CN+C250L1  SKIP:NO
```

Scan Intervals:

SCAN NO.	CHANNELS	INTERVAL	ENABLE CHNL
1	000/138	00:01:00	---
2	200/217	00:01:00	---
3	140/186	00:02:00	079
4	230/251	00:02:00	079

Netpac Status:

NETPAC	DEAD	FAILED
1/00	-	-
2/00	-	-

History Files:

FILE	SOURCE	RATE	SIZE	WRAP	DATE
1		01	0	NO	YES
2	2	03	207008	NO	YES
3	3	01	40000	NO	YES
4	4	01	15008	NO	YES
5		01	0	NO	YES

Alarms Enabled

Limits table:

01=2.50000 H   05=5.00000 L   06=5.00000 H   07=.500000 L

08=.500000 H

OUTPUT TABLES:

```
    DATA SOURCE:1     Devices  Suppress limits:NO   Alarms only:NO
                      Alarms once:NO     B.O.S. messg:
                      Data field size:12   Print chnl no.:YES
                      Print units:YES      Fields/line:02

    DATA SOURCE:2     Devices  Suppress limits:NO   Alarms only:NO
                      Alarms once:NO     B.O.S. messg:
                      Data field size:06   Print chnl no.:NO
                      Print units:NO       Fields/line:20

    DATA SOURCE:3     Devices  Suppress limits:NO   Alarms only:NO
                      Alarms once:NO     B.O.S. messg:
                      Data field size:06   Print chnl no.:NO
                      Print units:NO       Fields/line:20

    DATA SOURCE:4     Devices  Suppress limits:NO   Alarms only:NO
                      Alarms once:NO     B.O.S. messg:
                      Data field size:06   Print chnl no.:NO
                      Print units:NO       Fields/line:20

    DATA SOURCE:L     Devices  Suppress limits:NO   Alarms only:NO
                      Alarms once:NO     B.O.S. messg:
                      Data field size:12   Print chnl no.:YES
                      Print units:YES      Fields/line:02
```

PROGRAM DUMP/LOAD TO: INTERNAL EEPROM
DAC - BCD OUTPUT PROGRAMING:

```
    Board/Channel     Source
```

Table B.3 Sensor Channel Locations - Building 8390

Sensor	Channel(s)
Vertical String 1	0-7
Vertical String 2	20-27
Globe Thermometer 1	8-13
Globe Thermometer 2	30-35
Ceiling Thermocouples	15-17
Dew Point Sensor	14
Air Velocities	18-19
MAU Inlet Temperature	36
MAU Outlet Temperature	37
Exhaust Fans	38-39
Ceiling Fans	46-49
Bay Doors	50-55
North Supply Water Temp	40
North Return Water Temp	41
South Supply Water Temp	43
South Return Water Temp	42
North Water Flow Rate	44
South Water Flow Rate	45
North Bay Energy Calculation	57
South Bay Energy Calculation	58
Bay Door Data - Conversion to Integer Number	96-107
Digital Input - Bay Door Time Open	240-245

```
Channel programming:
000 EU=09   NETPAC:1/00/00   RES:H   SKIP:NO
001 EU=09   NETPAC:1/00/01   RES:H   SKIP:NO
002 EU=09   NETPAC:1/00/02   RES:H   SKIP:NO
003 EU=09   NETPAC:1/00/03   RES:H   SKIP:NO
004 EU=09   NETPAC:1/00/04   RES:H   SKIP:NO
005 EU=09   NETPAC:1/00/05   RES:H   SKIP:NO
006 EU=09   NETPAC:1/00/06   RES:H   SKIP:NO
007 EU=09   NETPAC:1/00/07   RES:H   SKIP:NO
008 EU=09   NETPAC:1/00/08   RES:H   SKIP:NO
009 EU=09   NETPAC:1/00/09   RES:H   SKIP:NO
010 EU=09   NETPAC:1/00/10   RES:H   SKIP:NO
011 EU=09   NETPAC:1/00/11   RES:H   SKIP:NO
012 EU=09   NETPAC:1/00/12   RES:H   SKIP:NO
013 EU=09   NETPAC:1/00/13   RES:H   SKIP:NO
014 EU=21   NETPAC:1/00/14   RES:H   SKIP:NO
015 EU=09   NETPAC:1/00/15   RES:H   SKIP:NO
016 EU=09   NETPAC:1/00/16   RES:H   SKIP:NO
017 EU=09   NETPAC:1/00/17   RES:H   SKIP:NO
018 EU=06   NETPAC:1/00/18   RES:H   MX+B=01   SKIP:NO
019 EU=06   NETPAC:1/00/19   RES:H   MX+B=01   SKIP:NO
020 EU=09   NETPAC:1/00/20   RES:H   SKIP:NO
021 EU=09   NETPAC:1/00/21   RES:H   SKIP:NO
022 EU=09   NETPAC:1/00/22   RES:H   SKIP:NO
023 EU=09   NETPAC:1/00/23   RES:H   SKIP:NO
024 EU=09   NETPAC:1/00/24   RES:H   SKIP:NO
025 EU=09   NETPAC:1/00/25   RES:H   SKIP:NO
026 EU=09   NETPAC:1/00/26   RES:H   SKIP:NO
027 EU=09   NETPAC:1/00/27   RES:H   SKIP:NO
028 EU=09   NETPAC:1/00/28   RES:H   SKIP:NO
029 EU=09   NETPAC:1/00/29   RES:H   SKIP:NO
030 EU=09   NETPAC:1/00/30   RES:H   SKIP:NO
031 EU=09   NETPAC:1/00/31   RES:H   SKIP:NO
032 EU=09   NETPAC:1/00/32   RES:H   SKIP:NO
033 EU=09   NETPAC:1/00/33   RES:H   SKIP:NO
034 EU=09   NETPAC:1/00/34   RES:H   SKIP:NO
035 EU=09   NETPAC:1/00/35   RES:H   SKIP:NO
036 EU=09   NETPAC:1/00/36   RES:H   SKIP:NO
037 EU=09   NETPAC:1/00/37   RES:H   SKIP:NO
038 EU=24   NETPAC:1/00/38   RES:D   SKIP:NO    LIMITS 03/00/00/00
039 EU=24   NETPAC:1/00/39   RES:H   SKIP:NO    LIMITS 03/00/00/00
040 EU=21   NETPAC:1/00/40   RES:H   MX+B=03   SKIP:NO
041 EU=21   NETPAC:1/00/41   RES:H   MX+B=03   SKIP:NO
042 EU=21   NETPAC:1/00/42   RES:H   MX+B=03   SKIP:NO
043 EU=21   NETPAC:1/00/43   RES:H   MX+B=03   SKIP:NO
044 EU=21   NETPAC:1/00/44   RES:H   MX+B=02   SKIP:NO
045 EU=21   NETPAC:1/00/45   RES:H   MX+B=02   SKIP:NO
046 EU=24   NETPAC:1/00/46   RES:D   E=128*C46L1   SKIP:NO    LIMITS 03/
```

```
047 EU=24  NETPAC:1/00/47  RES:D  SKIP:NO    LIMITS 03/00/00/00
048 EU=24  NETPAC:1/00/48  RES:D  SKIP:NO    LIMITS 03/00/00/00
049 EU=24  NETPAC:1/00/49  RES:D  SKIP:NO    LIMITS 03/00/00/00
050 EU=06  NETPAC:1/00/50  RES:D  SKIP:NO    LIMITS 05/00/00/00
051 EU=06  NETPAC:1/00/51  RES:D  SKIP:NO    LIMITS 05/00/00/00
052 EU=06  NETPAC:1/00/52  RES:D  SKIP:NO    LIMITS 05/00/00/00
053 EU=06  NETPAC:1/00/53  RES:D  SKIP:NO    LIMITS 05/00/00/00
054 EU=06  NETPAC:1/00/54  RES:D  SKIP:NO    LIMITS 05/00/00/00
055 EU=06  NETPAC:1/00/55  RES:D  SKIP:NO    LIMITS 05/00/00/00
056 EU=25  E=TOD"**/30/**"  SKIP:NO
057 EU=26  E=(C40-C41)*C44*.5  SKIP:NO
058 EU=25  E=(C43-C42)*C45*.5  SKIP:NO
060 EU=25  E=AVT(C0,C56)  SKIP:NO
061 EU=25  E=AVT(C1,C56)  SKIP:NO
062 EU=25  E=AVT(C2,C56)  SKIP:NO
063 EU=25  E=AVT(C3,C56)  SKIP:NO
064 EU=25  E=AVT(C4,C56)  SKIP:NO
065 EU=25  E=AVT(C5,C56)  SKIP:NO
066 EU=25  E=AVT(C6,C56)  SKIP:NO
067 EU=25  E=AVT(C7,C56)  SKIP:NO
068 EU=25  E=AVT(C8,C56)  SKIP:NO
069 EU=25  E=AVT(C9,C56)  SKIP:NO
070 EU=25  E=AVT(C10,C56)  SKIP:NO
071 EU=25  E=AVT(C11,C56)  SKIP:NO
072 EU=25  E=AVT(C12,C56)  SKIP:NO
073 EU=25  E=AVT(C13,C56)  SKIP:NO
074 EU=25  E=AVT(C14,C56)  SKIP:NO
075 EU=25  E=AVT(C15,C56)  SKIP:NO
076 EU=25  E=AVT(C16,C56)  SKIP:NO
077 EU=25  E=AVT(C17,C56)  SKIP:NO
080 EU=25  E=AVT(C20,C56)  SKIP:NO
081 EU=25  E=AVT(C21,C56)  SKIP:NO
082 EU=25  E=AVT(C22,C56)  SKIP:NO
083 EU=25  E=AVT(C23,C56)  SKIP:NO
084 EU=25  E=AVT(C24,C56)  SKIP:NO
085 EU=25  E=AVT(C25,C56)  SKIP:NO
086 EU=25  E=AVT(C26,C56)  SKIP:NO
087 EU=25  E=AVT(C27,C56)  SKIP:NO
088 EU=25  E=AVT(C28,C56)  SKIP:NO
089 EU=25  E=AVT(C29,C56)  SKIP:NO
090 EU=25  E=AVT(C30,C56)  SKIP:NO
091 EU=25  E=AVT(C31,C56)  SKIP:NO
092 EU=25  E=AVT(C32,C56)  SKIP:NO
093 EU=25  E=AVT(C33,C56)  SKIP:NO
094 EU=25  E=AVT(C34,C56)  SKIP:NO
095 EU=25  E=AVT(C35,C56)  SKIP:NO
096 EU=25  E=C38L1  SKIP:NO
097 EU=25  E=C39L1*2  SKIP:NO
```

```
098 EU=25  E=C46L1*4  SKIP:NO
099 EU=25  E=C47L1*8  SKIP:NO
100 EU=25  E=C48L1*16  SKIP:NO
101 EU=25  E=C49L1*32  SKIP:NO
102 EU=25  E=C50L1*64  SKIP:NO
103 EU=25  E=C51L1*128  SKIP:NO
104 EU=25  E=C52L1*256  SKIP:NO
105 EU=25  E=C53L1*512  SKIP:NO
106 EU=25  E=C54L1*1024  SKIP:NO
107 EU=25  E=C55L1*2048  SKIP:NO
108 EU=25  E=AVG(C96,C107)  SKIP:NO
109 EU=25  E=AVT(C57,C56)  SKIP:NO
110 EU=25  E=AVT(C58,C56)  SKIP:NO
111 EU=25  E=AVT(C40,C56)  SKIP:NO
112 EU=25  E=AVT(C41,C56)  SKIP:NO
113 EU=25  E=AVT(C42,C56)  SKIP:NO
114 EU=25  E=AVT(C43,C56)  SKIP:NO
115 EU=25  E=AVT(C44,C56)  SKIP:NO
116 EU=25  E=AVT(C45,C56)  SKIP:NO
150 EU=25  UNITS=GT1   E=AVG(C8,C13)  SKIP:NO
151 EU=25  UNITS=GT2   E=AVG(C30,C35)  SKIP:NO
152 EU=27  UNITS=AV1   E=C18  SKIP:NO
153 EU=27  UNITS=AV2   E=C19  SKIP:NO
154 EU=25  UNITS=MAU1  E=C36  SKIP:NO
155 EU=25  UNITS=MAU2  E=C37  SKIP:NO
156 EU=25  E=C108*12  SKIP:NO
157 EU=25  E=AVG(C4,C5)  SKIP:NO
158 EU=25  E=AVG(C24,C25)  SKIP:NO
159 EU=25  E=C14  SKIP:NO
200 EU=25  E=C60  SKIP:NO
201 EU=25  E=C61  SKIP:NO
202 EU=25  E=C62  SKIP:NO
203 EU=25  E=C63  SKIP:NO
204 EU=25  E=C64  SKIP:NO
205 EU=25  E=C65  SKIP:NO
206 EU=25  E=C66  SKIP:NO
207 EU=25  E=C67  SKIP:NO
208 EU=25  E=C68  SKIP:NO
209 EU=25  E=C69  SKIP:NO
210 EU=25  E=C70  SKIP:NO
211 EU=25  E=C71  SKIP:NO
212 EU=25  E=C72  SKIP:NO
213 EU=25  E=C73  SKIP:NO
214 EU=25  E=C74  SKIP:NO
215 EU=25  E=C75  SKIP:NO
216 EU=25  E=C76  SKIP:NO
217 EU=25  E=C77  SKIP:NO
218 EU=25  E=C78  SKIP:NO
```

```
219 EU=25  E=C79  SKIP:NO
220 EU=25  E=C80  SKIP:NO
221 EU=25  E=C81  SKIP:NO
222 EU=25  E=C82  SKIP:NO
223 EU=25  E=C83  SKIP:NO
224 EU=25  E=C84  SKIP:NO
225 EU=25  E=C85  SKIP:NO
226 EU=25  E=C86  SKIP:NO
227 EU=25  E=C87  SKIP:NO
228 EU=25  E=C88  SKIP:NO
229 EU=25  E=C89  SKIP:NO
230 EU=25  E=C90  SKIP:NO
231 EU=25  E=C91  SKIP:NO
232 EU=25  E=C92  SKIP:NO
233 EU=25  E=C93  SKIP:NO
234 EU=25  E=C94  SKIP:NO
235 EU=25  E=C95  SKIP:NO
236 EU=25  E=C109  SKIP:NO
237 EU=25  E=C110  SKIP:NO
240 EU=47  E=DIG(0,0,3)  SKIP:NO
241 EU=47  E=DIG(0,1,3)  SKIP:NO
242 EU=47  E=DIG(0,2,3)  SKIP:NO
243 EU=47  E=DIG(0,3,3)  SKIP:NO
244 EU=47  E=DIG(0,4,3)  SKIP:NO
245 EU=47  E=DIG(0,5,3)  SKIP:NO
246 EU=25  E=C111  SKIP:NO
247 EU=25  E=C112  SKIP:NO
248 EU=25  E=C113  SKIP:NO
249 EU=25  E=C114  SKIP:NO
250 EU=25  E=C115  SKIP:NO
```

Scan Intervals:

SCAN NO.	CHANNELS	INTERVAL	ENABLE CHNL
1	000/116	00:01:00	---
2	150/159	00:01:00	---
3	200/251	00:01:00	056

Netpac Status:

NETPAC	DEAD	FAILED
1/00	-	-

History Files:

FILE	SOURCE	RATE	SIZE	WRAP	DATE
1		01	0	NO	YES
2	2	03	212000	NO	YES
3	3	01	50000	NO	YES
4		01	0	NO	YES
5		01	0	NO	YES

Alarms Enabled

Limits table:
01=60.0000 H   03=.500000 H   05=5.00000 H

MX+B table:
01= M-1.00000   , B0.00000   02= M2.50000   , B0.00000
03= M2.00000   , B0.00000

APPENDIX C

DAILY AVERAGE DATA TABLES

This appendix contains the daily average values of the data used iin this study. The column headings used for these tables are defined in Table C.1 below.

Table C.1 Data Headings Definitions

Heading	Definition
JULIAN	Julian Date (32=1 Feb)
70 ENER	Total KBTUs consumed 8370
90 ENER	Total KBTUs consumed 8390 75% Boiler Eff
70 NITE	KBTUs consumed 8370 0001-0600, 1800-2400
70 DAY	KBTUs consumed 8370 0600-1800
90 NITE	KBTUs consumed 8390 0001-0600, 1800-2400
90 DAY	KBTUs consumed 8390 0600-1800
TEMP	Average Outside Air Temperature
GLOBE 1	Average Temperature Globe 1 - 8370
GLOBE 2	Average Temperature Globe 2 - 8370
GLOBE 3	Average Temperature Globe 3 - 8370
GLOBE 4	Average Temperature Globe 1 - 8390
GLOBE 5	Average Temperature Globe 2 - 8390
70 AIR	Average Space Air Temperature - 8370
70 OCC	Average Temperature 0.5' - 6.0' 8370
70 TOP	Average Temperature 22' Elevation 8370
70 6IN	Average Temperature 0.5' Elevation 8370
70 STRAT	70 TOP) - (70 6IN)

Heading	Definition
70 GLOBE	Average of GLOBE 2 and GLOBE 3
90 AIR	Average Space Air Temperature - 8390
90 OCC	Average Temperature 0.5' - 6.0' 8390
90 TOP	Average Temperature 22' Elevation 8390
90 6IN	Average Temperature 0.5' Elevation 8390
90 STRAT	(90 TOP) - (90 6IN)
90 GLOBE	Average of GLOBE 4 and GLOBE 5
70 DOORS	Bay Door Percent Time Open - 8370
70 CF	Ceiling Fan Percent Time On - 8370
70 EF	Exhaust Fan Percent Time On - 8370
90 DOORS	Bay Doors Percent Time Open - 8390
90 CF	Ceiling Fan Percent Time On - 8390
90 EF	Exhaust Fan Percent Time On - 8390

JULIAN	70 ENER	90ENER	70 NITE	70 DAY	90 NITE	90 DAY
32	13480.88	4696.917	6439.58	7041.3	1675.797	3021.12
33	13592.6	5901.052	6664.98	6927.62	1747.321	4153.731
34	10804.5	4391.886	4363.94	6440.56	1101.733	3290.153
35	10666.32	6951.588	4906.86	5759.46	1419.175	5532.413
36	13691.58	6903.955	6467.02	7224.56	2040.248	4863.707
37	14484.4	8374.022	7247.1	7237.3	3368.506	5005.516
38	12600.84	6528.178	6382.74	6218.1	3270.606	3257.572
39	11857.02	5211.555	5375.3	6481.72	1976.48	3235.075
40	8867.04	5141.117	4635.4	4231.64	1164.26	3976.857
41	13139.84	7159.801	5580.12	7559.72	1965	5194.801
42	16305.24	8012.207	8179.08	8126.16	1893.785	6118.422
43	12864.46	4895.821	5832.96	7031.5	1565.638	3330.183
44	4678.52	1927.452	2227.54	2450.98	335.1284	1592.324
45	9318.82	3406.052	4314.94	5003.88	247.1572	3158.895
46	8123.22	3694.170	4027.8	4095.42	990.1802	2703.99
47	5742.8	3928.139	2912.56	2830.24	855.3534	3072.786
48	4613.84	3485.179	2631.3	1982.54	1001.66	2483.519
49	7929.18	2099.206	3596.6	4332.58	732.3177	1366.889
50	7460.74	2893.275	3696.56	3764.18	683.9103	2209.365
51	7523.46	2956.577	3713.22	3810.24	350.4884	2606.089
52	4848.06	2479.794	2246.16	2601.9	576.8554	1902.939
53	5850.6	3083.336	3911.18	1939.42	837.0454	2246.291
54	12529.3	3124.141	5360.6	7168.7	698.4946	2425.647
55	10295.88	4329.672	4276.72	6019.16	1026.485	3303.187
56	2739.1	4969.984	1762.04	977.06	1026.64	3943.344
57	2967.44	2942.612	915.32	2052.12	501.7618	2440.851
58	3736.74	555.5993	1898.26	1838.48	189.7509	365.8484
59	3719.1	628.5209	1902.18	1816.92	172.6842	455.8367
60	5420.38	2877.138	1782.62	3637.76	564.4432	2312.695
61	3046.82	744.8849	1298.5	1748.32	444.0452	300.8397
62	12142.2	3355.161	5148.92	6993.28	901.8981	2453.263
63	13585.74	5172.149	7019.74	6566	1239.82	3932.329
64	8789.62	2740.138	4662.84	4126.78	902.3635	1837.775
65	8186.92	1952.431	4262.02	3924.9	645.5878	1306.844
66	6963.88	2039.161	3514.28	3449.6	830.0637	1209.098
67	4403.14	5020.563	2944.9	1458.24	1462.307	3558.256
68	7114.8	5577.561	2664.62	4450.18	1228.804	4348.757
69	3634.82	3175.029	1668.94	1965.88	979.7847	2195.245
70	1774.78	3530.019	1460.2	314.58	836.8903	2693.129
71	2903.74	5495.95	659.54	2244.2	1344.237	4151.713
72	8317.26	7156.387	4103.26	4214	1178.533	5977.854
73	6572.86	4047.916	3797.5	2775.36	877.2299	3170.687
74	9122.82	7233.188	3571.12	5551.7	2213.088	5020.1
75	7628.32	9925.696	3489.78	4138.54	4815.609	5110.087
76	7553.84	9426.728	3015.46	4538.38	4534.939	4891.789

JULIAN	70 ENER	90ENER	70 NITE	70 DAY	90 NITE	90 DAY
77	8278.06	7523.166	2978.22	5299.84	2610.587	4912.579
78	6988.38	7035.058	3785.74	3202.64	2811.975	4223.083
79	4636.38	4700.174	1949.22	2687.16	1656.247	3043.927
80	1819.86	2931.907	736.96	1082.9	1697.363	1234.544
81	1946.28	1774.006	641.9	1304.38	1297.845	476.1617
82	246.96	759.4693	0	246.96	688.72	70.74935
83	0	3154.24	0	0	1587.204	1567.036
84	0	2531.149	0	0	1133.074	1398.075
85	0	3161.687	0	0	1933.349	1228.338
86	0	4056.759	0	0	1450.515	2606.244
87	0	1076.29	0	0	806.3254	269.9646
88	2732.24	4305.934	2003.12	729.12	839.9934	3465.941
89	5293.96	6733.753	1658.16	3635.8	2222.087	4511.666
90	1497.44	3807.585	1053.5	443.94	1865.703	1941.882
91	2350.04	7182.918	1866.9	483.14	2352.104	4830.814
92	5025.44	7209.605	2225.58	2799.86	2450.471	4759.134
93	2878.26	4566.899	1459.22	1419.04	1872.995	2693.904
94	2777.32	3283.326	1278.9	1498.42	1686.347	1596.979
95	1142.68	1061.395	712.46	430.22	914.3112	147.0841
96	2054.08	4940.35	966.28	1087.8	1907.128	3033.222
97	3429.02	2606.708	705.6	2723.42	1474.409	1132.299
98	1712.06	1344.391	631.12	1080.94	1108.095	236.2966
99	0	10.24003	0	0	4.49941	5.740627
100	0	6197.858	0	0	1657.799	4540.059
101	0.98	4718.95	0.98	0	1795.73	2923.22
102	485.1	6047.98	0	485.1	1998.202	4049.778
103	284.2	2170.109	0	284.2	1527.78	642.3296
104	0	1573.086	0	0	1182.879	390.2074
105	0	6700.085	0	0	1788.436	4911.649
106	0	1769.818	0	0	1003.367	766.4513
107	0	0.465455	0	0	0.310304	0.155151
108	0.98	0	0	0.98	0	0
109	1182.86	0	0	1182.86	0	0
110	3304.56	0	133.28	3171.28	0	0
111	1508.22	1.086063	735.98	772.24	0.930912	0.155151
112	1309.28	2.947889	424.34	884.94	1.861825	1.086064
113	438.06	0.77576	46.06	392	0.77576	0
114	1684.62	0	711.48	973.14	0	0
115	0.98	0	0	0.98	0	0
116	0	0	0	0	0	0
117	5920.18	0	713.44	5206.74	0	0
118	8388.8	0	2659.72	5729.08	0	0
119	1448.44	1.086063	1410.22	38.22	0.930912	0.155151
120	0	0.620608	0	0	0.620608	0
121	0.98	0	0.98	0	0	0
122	0	1.55152	0	0	1.55152	0

JULIAN	TEMP	GLOBE1	GLOBE2	GLOBE3	GLOBE4	GLOBE5
32	13.9	69.49166	67.20416	68.91875	66.275	63.6993
33	15.4125	69.11805	67.34583	69.71805	64.38819	63.92361
34	18.41666	74.825	72.29583	73.14166	65.20416	65.6125
35	11.1125	70.2856	68.91742	68.47121	61.35069	62.37777
36	5.025	63.69444	62.29375	63.33055	57.98712	57.93484
37	11.625	69.71666	67.85416	69.99444	68.75138	67.94791
38	24.19583	78.06944	76.40486	76.50347	77.01944	76.4118
39	31.76666	77.53472	77.00416	76.21736	76.73263	74.98125
40	27.5125	72.79375	72.78541	70.45208	67.37708	67.03472
41	13.6875	66.18125	65.23888	66.23125	63.88263	61.66527
42	-0.18333	66.82291	66.92777	70.31875	61.87291	59.77361
43	26.15	74.45625	72.93125	73.53819	66.92777	65.53819
44	46.20833	73.75347	72.25972	69.99236	72.58819	71.73611
45	33.57083	70.58055	69.50416	67.68611	66.80902	66.65138
46	28.5375	71.27361	71.03819	67.80138	68.62083	68.19861
47	42.02916	72.5875	73.01527	69.08819	69.63819	69.03402
48	38.575	72.72013	71.40277	68.86666	71.37152	70.79097
49	35.84583	71.87361	70.66805	67.20555	75.01041	74.14236
50	38.02916	73.71527	71.775	67.87708	70.19375	70.4868
51	35.2	75.63958	73.57708	68.82916	71.74583	71.53055
52	48.1625	75.65069	73.95625	70.65972	75.09652	74.99027
53	45.28333	72.12986	71.2993	69.70486	74.10347	74.00972
54	31.67916	79.40694	78.01388	76.99166	68.41319	68.22986
55	30.51666	82.47291	80.27222	78.31944	65.04027	66.08611
56	38.3125	72.21388	70.32777	70.06527	65.90625	65.68263
57	50.73333	69.84097	69.64236	69.58263	67.81805	67.66388
58	45.8875	73.31458	74.83611	75.84027	69.9618	69.35555
59	45.9875	72.93333	74.47708	75.46111	69.60763	69.00555
60	41.79583	71.81805	72.13194	70.83055	67.30902	67.63958
61	50.5	73.83541	74.30694	72.175	70.24375	70.45069
62	36.65	73.49305	70.14444	71.67569	65.43472	64.33194
63	32.20416	76.93541	73.04027	75.34027	64.83611	64.11527
64	30.89166	83.12569	79.55625	78.45625	67.39444	66.57638
65	32.5125	85.06527	81.33194	80.03888	68.22638	67.88055
66	39.07916	83.81319	79.65069	78.97361	69.23472	69.00902
67	48.70416	75.77569	73.14375	71.61388	68.48888	67.99791
68	39.86666	73.52777	71.62083	70.59583	67.08125	67.80486
69	42.7875	73.44027	71.82847	69.7618	69.23819	69.05208
70	51.02916	69.37152	68.14236	67.91041	69.74861	69.03125
71	45.63333	64.74861	64.46111	65.18819	67.30972	66.8743
72	27.17083	55.70625	60.76666	60.72638	60.01736	60.31875
73	21.65	56.30138	60.14097	61.41111	62.91527	63.16944
74	22.85416	67.28333	66.80208	68.73333	64.71527	64.55625
75	27.2625	68.37083	66.57638	67.31458	62.36666	61.70277
76	28.14583	75.1	72.15555	69.9743	64.56944	64.30625

JULIAN	TEMP	GLOBE1	GLOBE2	GLOBE3	GLOBE4	GLOBE5
77	28.37083	73.06458	69.90763	69.28958	65.33472	65.44583
78	31.525	70.36666	67.46527	66.31458	61.04513	60.59027
79	45.65	72.15347	67.55625	66.12013	69.53194	68.95902
80	58.07916	73.73055	69.41458	68.93125	72.21319	71.90972
81	63.50416	75.37916	72.73819	73.5118	76.65208	75.33125
82	65.00416	73.6618	72.56736	72.44652	76.42083	76.15416
83	54.79583	67.3743	66.47152	66.54861	69.72708	70.10555
84	57.64166	64.99166	64.52152	64.26944	70.86597	71.21388
85	51.16666	61.63194	61.61597	60.95625	68.07708	68.26388
86	50.95	60.32708	60.23819	59.57916	70.82638	71.35763
87	62.36666	64.21527	63.89652	63.42291	73.27013	73.7125
88	55.25833	66.37013	65.68055	66.86527	72.2375	71.84791
89	43.98333	66.99375	66.74166	68.12638	69.30972	69.21805
90	47.5125	63.3625	60.94722	60.72569	69.60277	69.12916
91	45.12083	65.82291	64.36666	63.39166	68.76666	68.70694
92	44.67083	63.14236	61.84583	60.50138	67.85486	67.08402
93	44.53333	67.29583	69.37083	66.54722	71.21319	70.91111
94	52.90833	70.46319	70.77986	68.51458	72.84791	72.85833
95	64.45416	71.38611	72.675	71.29027	73.7625	74.09236
96	53.0125	66.14513	66.54236	65.34791	70.79027	70.84861
97	50.45	69.43958	69.29097	68.95763	70.49722	69.7875
98	63.35	73.34305	73.68819	72.7625	74.83333	74.31041
99	69.14	75.57222	74.60763	73.79236	76.5243	76.37986
100	44.29	65.63958	64.68541	64.875	66.43611	68.25486
101	46	61.24444	60.43472	60.38888	72.8	71.59027
102	50.93529	61.72847	60.85	60.09166	71.22222	70.47708
103	53.62916	64.00763	62.61458	62.24027	70.21527	69.81805
104	60.75833	67.22916	66.62361	66.91527	73.7875	73.57708
105	48.175	64.17847	63.37638	63.3	70.00972	69.53819
106	50.9125	62.1375	61.40138	60.94236	67.3625	66.85486
107	52.57916	62.96805	62.25486	61.93958	67.21388	67.08194
108	52.32916	63.26041	62.55972	62.26527	67.67916	67.40277
109	49.52666	60.84375	59.39097	58.99722	60.96736	60.19305
110	48.988	68.68125	65.63819	64.56944	63.07222	62.53819
111	57.896	73.39791	69.15833	68.55	67.39444	67.63263
112	63.225	72.65208	71.08055	70.40138	69.18402	71.02708
113	51.7625	63.61458	62.57916	62.33472	63.35625	63.65486
114	47.35	61.8118	62.16944	61.14513	60.39652	60.53958
115	51.8375	63.67916	63.01805	62.68333	62.28402	62.75902
116	55.55416	65.36875	64.72777	64.27916	64.0243	63.80416
117	49.34166	68.12638	66.10277	66.59583	61.14305	60.51527
118	52.5875	72.66805	69.60902	71.69444	60.02777	60.69097
119	62.51666	71.6868	71.16458	72.36388	65.97569	67.06805
120	60.2958	67.17916	66.29583	66.34791	66.53541	66.55138
121	65.404	68.27847	67.62777	67.45347	67.53125	68.07361
122	66.84166	69.1625	68.55138	68.35	70.29513	70.0993

JULIAN	70 AIR	70 OCC	70 TOP	70 6IN	70STRAT	70GLOBE
32	70.71815	63.17083	86.47916	62.38125	24.09791	68.06145
33	70.77172	65.18958	82.375	63.725	18.65	68.53194
34	73.24494	70.64513	79.20625	69.5875	9.61875	72.71874
35	70.36915	65.22803	80.05681	63.06363	16.99318	68.69431
36	68.20833	56.6868	86.16666	51.52291	34.64375	62.81215
37	72.93363	62.55416	91.17291	57.87708	33.29583	68.9243
38	80.02678	71.32361	94.96666	67.01666	27.95	76.45416
39	80.31118	72.10652	93.77826	67.52826	26.25	76.61076
40	73.65297	67.92638	83.97083	64.83333	19.1375	71.61874
41	65.99434	62.0625	74.2875	60.70416	13.58333	65.73506
42	69.29404	65.44375	76.18541	62.49375	13.69166	68.62326
43	75.49596	70.40724	84.24565	67.66739	16.57826	73.23472
44	72.32113	69.01736	78.76875	67.85625	10.9125	71.12604
45	69.8744	65.49305	80.08333	64.69583	15.3875	68.59513
46	71.19821	65.48541	82.14791	63.82083	18.32708	69.41978
47	71.88809	68.53819	78.8375	67.70833	11.12916	71.05173
48	72.04968	67.66666	78.93913	65.8413	13.09782	70.13471
49	71.86607	65.60208	82.43333	63.20625	19.22708	68.9368
50	71.36273	66.58405	80.13043	64.47391	15.65652	69.82604
51	72.97916	67.76527	82.34583	65.49375	16.85208	71.20312
52	73.22261	70.1368	79.44791	68.69166	10.75625	72.30798
53	70.69161	68.96594	74.67608	68.32391	6.352173	70.50208
54	77.81071	75.49652	83.24583	74.30625	8.939583	77.50277
55	79.42619	77.70833	83.50208	76.50625	6.995833	79.29583
56	70.28869	68.81875	73.0875	67.88333	5.204166	70.19652
57	69.30544	68.6873	71.22619	68.34523	2.880952	69.61249
58	75.80625	75.05277	78.94791	74.65	4.297916	75.33819
59	75.36398	74.74652	78.31458	74.66041	3.654166	74.96909
60	73.22049	69.80724	80.18913	68.17173	12.01739	71.48124
61	74.09285	71.56875	79.55416	69.89583	9.658333	73.24097
62	71.81815	68.26875	79.86666	67.60625	12.26041	70.91006
63	75.20386	71.65972	82.46458	69.8875	12.57708	74.19027
64	79.33541	77.84722	82.65	76.9	5.75	79.00625
65	80.8866	79.77777	83.60833	79.28541	4.322916	80.68541
66	79.34196	78.69236	81.34166	78.53958	2.802083	79.31215
67	72.2236	70.7884	75.88043	70.49565	5.384782	72.37881
68	72.69553	68.82152	81.45416	67.83958	13.61458	71.10833
69	71.88839	69.14375	77.80416	68.1625	9.641666	70.79513
70	68.29672	67.03958	71.10625	66.52083	4.585416	68.02638
71	64.45869	62.26666	69.27826	61.41086	7.867391	64.82465
72	60.36636	57.06666	69.875	56.39791	13.47708	60.74652
73	61.94017	57.18125	73.12291	56.7	16.42291	60.77604
74	68.64553	65.23125	77.06666	64.44583	12.62083	67.7677
75	67.40446	65.21527	71.96666	64.04583	7.920833	66.94548
76	72.09434	69.17638	77.00208	66.375	10.62708	71.06492

JULIAN	70 AIR	70 OCC	70 TOP	70 6IN	70STRAT	70GLOBE
77	71.10297	66.7625	78.64166	64.39166	14.25	69.5986
78	68.30892	63.73333	77.69166	62.45416	15.2375	66.88992
79	67.66696	65.15277	72.62916	64.27083	8.358333	66.83819
80	69.91934	68.45069	72.52291	67.49166	5.03125	69.17291
81	74.0267	72.39782	76.85217	71.3	5.552173	73.12499
82	72.73809	72.20902	73.53958	71.79583	1.74375	72.50694
83	66.37083	65.63194	67.61458	64.9625	2.652083	66.51006
84	64.30535	63.76666	65.18958	63.29791	1.891666	64.39548
85	60.9854	60.37173	61.95217	59.76086	2.191304	61.28611
86	59.82232	59.3375	60.64166	59.05833	1.583333	59.90867
87	64.2738	63.23472	65.35208	62.41041	2.941666	63.65971
88	66.55124	64.76521	70.46739	64.31521	6.152173	66.27291
89	68.81547	65.02708	77.30208	64.33125	12.97083	67.43402
90	61.17202	59.63958	63.65833	58.90833	4.75	60.83645
91	64.57414	62.06428	69.31666	60.90238	8.414285	63.87916
92	61.54732	59.74583	65.45	58.87083	6.579166	61.1736
93	69.14791	66.49166	75.47708	65.42916	10.04791	67.95902
94	70.73065	68.55902	75.75416	67.71458	8.039583	69.64722
95	72.93095	71.3243	75.98958	70.28958	5.7	71.98263
96	66.48636	65.22424	69.40227	65.06136	4.340909	65.94513
97	70.14702	67.57222	75.27291	66.45625	8.816666	69.1243
98	73.89017	72.44166	76.80833	71.57291	5.235416	73.22534
99	74.74642	73.44375	75.975	71.60833	4.366666	74.19999
100	64.63511	64.11597	65.61875	64.0125	1.60625	64.7802
101	60.09375	59.80486	60.7875	59.80625	0.98125	60.4118
102	60.35031	59.5355	61.75869	59.00434	2.754347	60.47083
103	62.80565	61.51527	64.4	59.99583	4.404166	62.42742
104	67.31934	66.23402	68.58541	65.02916	3.55625	66.76944
105	63.27946	62.60833	64.5	62.225	2.275	63.33819
106	61.26459	60.43405	62.37826	59.47826	2.9	61.17187
107	62.44464	61.69722	63.33333	61.08125	2.252083	62.09722
108	62.45952	62.11597	63.22916	62.06458	1.164583	62.41249
109	59.30186	57.8442	61.99347	57.32826	4.665217	59.19409
110	66.42202	63.35902	71.45833	61.41666	10.04166	65.10381
111	69.95803	67.9868	73.02291	66.175	6.847916	68.85416
112	71.31428	69.48055	74.45416	67.91666	6.5375	70.74096
113	62.86149	61.69347	65.03913	60.92826	4.110869	62.45694
114	62.44226	60.6375	66.5125	59.58958	6.922916	61.65728
115	63.15863	62.40555	64.075	61.79583	2.279166	62.85069
116	64.69906	63.96594	65.76956	63.08913	2.680434	64.50346
117	67.83571	64.62569	74.16041	63.24166	10.91875	66.3493
118	74.38422	67.63333	86.31666	64.83333	21.48333	70.65173
119	72.75446	70.34583	77.50416	68.92916	8.575	71.76423
120	66.78012	66.06086	67.87391	65.28043	2.593478	66.32187
121	67.94017	67.19791	68.775	66.46666	2.308333	67.54062
122	68.85595	68.15972	69.65416	67.50625	2.147916	68.45069

JULIAN90	AIR	90 OCC	90 TOP	90 6IN	90 STRAT	90GLOBE
32	66.2994	64.50972	67.87291	63	4.872916	64.98715
33	66.65744	63.74861	69.26458	61.475	7.789583	64.1559
34	67.96666	65.16319	70.50208	63.46666	7.035416	65.40833
35	64.65684	60.74305	68.50625	58.10625	10.4	61.86423
36	61.27792	57.34545	65.28409	54.4409	10.84318	57.96098
37	70.64791	68.08541	72.56041	65.725	6.835416	68.34964
38	78.8747	76.18888	80.7	73.80416	6.895833	76.71562
39	77.75952	75.33125	79.82916	73.68125	6.147916	75.85694
40	70.96398	67.80069	73.89791	66.25208	7.645833	67.2059
41	65.36875	62.57708	68.20416	61.48333	6.720833	62.77395
42	64.25565	60.74861	67.42916	57.3125	10.11666	60.82326
43	68.50505	65.32916	71.15208	61.46666	9.685416	66.23298
44	73.85535	71.40416	76.19375	68.66041	7.533333	72.16215
45	68.30148	65.86666	71.25833	64.4	6.858333	66.7302
46	70.32083	67.65208	72.77708	64.07916	8.697916	68.40972
47	71.13541	68.39444	73.89791	65.76666	8.13125	69.3361
48	73.45465	70.47971	76.11956	67.1826	8.936956	71.08124
49	76.83065	73.96805	79.18333	70.35625	8.827083	74.57638
50	72.38074	69.43985	74.99565	66.10869	8.886956	70.34027
51	73.62083	70.81666	76.17916	67.62291	8.55625	71.63819
52	76.99375	74.41666	79.14375	71.40416	7.739583	75.04339
53	76.25029	73.67152	78.50208	71.10416	7.397916	74.05659
54	70.78541	67.37083	73.91875	64.35	9.56875	68.32152
55	68.89613	64.38263	72.63333	59.97708	12.65625	65.56319
56	68.76369	64.23472	72.56666	59.42708	13.13958	65.79444
57	69.18819	67.01376	71.31739	65.18043	6.136956	67.74096
58	71.20744	68.90347	73.36666	67.21666	6.15	69.65867
59	70.56994	68.52777	72.77916	67.22708	5.552083	69.30659
60	70.40714	66.51739	73.82173	63.65652	10.16521	67.4743
61	72.08452	69.64722	74.38541	67.73541	6.65	70.34722
62	67.07321	64.11666	70.15833	63.05416	7.104166	64.88333
63	67.18988	63.71041	70.3	61.04375	9.25625	64.47569
64	69.28184	66.02986	72.20833	62.525	9.683333	66.98541
65	69.59523	67.03055	71.99375	64.38333	7.610416	68.05346
66	70.56607	68.10138	72.85416	65.6625	7.191666	69.12187
67	69.12023	67.49166	70.89583	66.23333	4.6625	68.24339
68	69.37083	66.68263	71.97708	64.3625	7.614583	67.44305
69	70.96755	68.19166	73.66041	65.57916	8.08125	69.14513
70	70.8497	68.74861	72.91666	67.20625	5.710416	69.38993
71	68.81488	66.44722	71.27291	64.6875	6.585416	67.09201
72	61.30982	59.03472	63.825	58.11666	5.708333	60.16805
73	64.72767	62.36666	66.90208	60.16666	6.735416	63.04235
74	67.64223	63.97971	70.55869	59.92391	10.63478	64.63576
75	66.75595	61.76944	71.28125	57.68541	13.59583	62.03471
76	68.95833	64.21527	72.67708	58.98541	13.69166	64.43784

JULIAN	90 AIR	90 OCC	90 TOP	90 6IN	90 STRAT	90GLOBE
77	68.87113	64.51875	72.78541	60.32708	12.45833	65.39027
78	66.5672	62.42348	70.51363	58.775	11.73863	60.8177
79	71.36309	68.39583	74.00833	65.06458	8.94375	69.24548
80	73.92291	71.46805	76.24166	68.95833	7.283333	72.06145
81	76.0872	74.30347	77.9875	72.6625	5.325	75.99166
82	76.25089	75.1743	77.47708	74.29166	3.185416	76.28749
83	71.38214	69.48125	73.54791	68.81041	4.7375	69.91631
84	72.28452	70.68888	73.83541	69.44375	4.391666	71.03992
85	69.45357	67.55	71.50833	66.18125	5.327083	68.17048
86	73.19642	70.64444	75.61458	68.81041	6.804166	71.092
87	74.55208	72.97013	76.38958	71.71041	4.679166	73.49131
88	72.24902	70.43939	74.26363	69.14772	5.115909	72.0427
89	72.06696	68.62569	75.14375	66.10625	9.0375	69.26388
90	70.73601	68.64513	73.04166	67.12916	5.9125	69.36596
91	70.92738	68.30416	73.78958	66.36041	7.429166	68.7368
92	69.24732	67.2125	71.6	65.89166	5.708333	67.46944
93	72.43333	70.59722	74.15416	68.82291	5.33125	71.06215
94	73.99613	72.40208	75.58541	70.93125	4.654166	72.85312
95	75.31038	74.14772	76.72954	73.22045	3.50909	73.92743
96	71.7369	69.91875	73.4875	68.99791	4.489583	70.81944
97	71.08244	69.25347	73.31666	68.17291	5.14375	70.14236
98	75.2247	73.89583	77.08541	72.9875	4.097916	74.57187
99	76.52678	75.86944	77.75625	75.51875	2.2375	76.45208
100	69.34494	66.83263	72.175	65.98958	6.185416	67.34548
101	73.2738	71.30347	75.0125	69.9625	5.05	72.19513
102	72.73928	70.23055	75.025	68.41041	6.614583	70.84965
103	71.29404	69.28541	74.23541	68.16666	6.06875	70.01666
104	74.69672	73.09861	76.58125	71.90208	4.679166	73.68229
105	71.18809	68.85833	73.56041	67.40208	6.158333	69.77395
106	67.43975	66.25289	68.99347	65.54565	3.447826	67.10868
107	67.19226	66.61875	68.21041	66.41041	1.8	67.14791
108	67.57589	67.19513	68.25833	67.11041	1.147916	67.54096
109	60.40465	60.05144	61.20217	60.22608	0.976086	60.5802
110	62.62083	62.2375	63.35625	62.19166	1.164583	62.8052
111	67.65892	66.93055	68.67708	66.43541	2.241666	67.51353
112	69.98571	69.1368	71.31875	68.78541	2.533333	70.10555
113	63.55	62.88333	64.85652	62.72826	2.12826	63.50555
114	60.48363	59.99791	61.3125	59.85416	1.458333	60.46805
115	62.81785	62.28472	63.53958	61.89375	1.645833	62.52152
116	63.96279	63.48888	64.78333	63.22083	1.5625	63.91423
117	60.96011	60.5368	61.73541	60.32083	1.414583	60.82916
118	60.35119	60.06111	61.05833	59.95208	1.10625	60.35937
119	66.65952	66.10486	67.54791	65.49375	2.054166	66.52187
120	66.57559	66.34166	67.09791	66.16041	0.9375	66.54339
121	68.07142	67.66875	68.64375	67.31666	1.327083	67.80243
122	70.30982	70.27847	70.36875	70.04583	0.322916	70.19721

JULIAN	70 DOORS	70 CF	70 EF	90 DOORS	90 CF	90 EF
32	0.234375	0	0	0.228202	75	0
33	0.885416	52	15.07692	15.94714	75	0
34	0	75	0	33.13599	75	0
35	0.130208	5.777777	3.444444	26.40702	75	0
36	1.5625	10.75	5.75	12.72878	73.77272	0.136363
37	0	0	0	0	75	0
38	0	0	0	0.010416	75	0
39	0.729166	16.83333	14.08333	13.11439	75	0
40	1.458333	43.75	18.04166	13.56192	73.125	0
41	0.286458	72.5	7.208333	0.658564	75	0
42	1.09375	100	12	0.882137	65.95833	0
43	2.03125	55.625	8.666666	1.168209	24.29166	0
44	0	0	0	0.765817	25	0
45	0	0	0	0.101851	25	0
46	0	0	0	0.458719	25	0
47	0	0	0	4.8152	25	0
48	0.078125	0	0	2.351465	24.60869	0
49	3.229166	0	1.375	0.831982	25	0
50	1.354166	6.913043	0.782608	2.76466	24.56521	0
51	4.739583	0	0	0.04591	16.875	0
52	0.494791	0	0	0	0	0
53	1.953125	35.04347	0	2.335262	0	0
54	4.114583	100	3.875	6.847993	0	0
55	1.328125	100	2.833333	3.478781	0	0
56	4.869791	62.5	1.583333	8.502122	0	0
57	5.234375	60.42857	0	19.01195	0	0
58	0	100	0	0	0	0
59	0.651041	100	0	0.41493	0	0
60	5.390625	52.17391	20.17391	8.549381	0	0
61	1.822916	0	0	0.065393	0	0
62	1.09375	50.66666	2.916666	0.471836	0	0
63	1.484375	96.95652	17.60869	1.651234	0	0
64	0.026041	100	0	0.23341	0	0
65	0	100	0	0	0	0
66	1.302083	100	0	0	0	0
67	1.510416	33.43478	0	7.922067	0	0
68	0.15625	0	2.833333	4.426697	0	0
69	0.104166	0	0	4.690972	0	0
70	9.739583	0	3.041666	5.648919	0	0
71	3.515625	0	0	8.969714	0	0
72	0.755208	0	0	0	0	0
73	0	0	0	0.318865	0	0
74	0.260416	66.29166	2.833333	4.198303	0	0
75	5.520833	92.08333	0	6.938078	0	0
76	10.52083	75	0	3.030671	0	0

JULIAN

	70 DOORS	70 CF	70 EF	90 DOORS	90 CF	90 EF
77	3.90625	49.79166	5.583333	1.404706	0	0
78	1.276041	10.625	0.833333	4.976465	0	53.125
79	9.270833	21.79166	0	0	0	100
80	0	0	0	0	0	100
81	9.505208	14.30434	0	16.2826	0	96.66666
82	20.59895	25	0	6.01929	0	100
83	13.02083	17.20833	0	19.24614	0	100
84	2.838541	0	0	7.499807	0	100
85	3.046875	0	0	9.862461	0	100
86	0.104166	0	0	0	0	100
87	2.03125	0	0	0	0	100
88	11.79687	4.043478	2.652173	6.060571	9.045454	63.63636
89	3.697916	0	17	5.517361	25	0
90	9.557291	0	0	6.412422	25	5.083333
91	2.786458	0	15.19047	5.864776	25	34.5
92	2.447916	0	0	0.966821	25	24.70833
93	3.567708	0	0	0	25	0
94	0.234375	0	0	0.012538	25	0
95	5.729166	0	0	7.970486	23.90909	0
96	5.46875	0	7.318181	8.113426	25	3.875
97	1.5625	7.166666	1.5	10.7444	25	13.04166
98	22.5	0	0	27.30092	25	82.625
99	8.072916	0	0	23.09355	24.20833	26.25
100	0	0	0	12.71952	25	0
101	0	0	0	0	25	0
102	2.864583	0	4.043478	5.297454	25	0
103	7.682291	0	5	9.90027	24	0
104	3.489583	0	0	6.578318	25	0.458333
105	1.40625	17.04166	3.666666	15.2253	25	0
106	5.46875	7.304347	2.086956	11.90625	24.91304	0
107	0	0	0	3.561342	25	0
108	0	0	6.375	0.040895	20.66666	0
109	3.177083	0	0	3.555941	0	0
110	6.119791	0	4.833333	6.176889	14.79166	0
111	2.916666	0	2	9.386574	25	0
112	14.40104	0	4.625	19.70254	10.45833	0
113	2.864583	0	0.565217	3.488425	0	0
114	0	0	0	0	0	0
115	0	0	0	0	0	0
116	7.369791	0	3.043478	18.4454	0	0
117	1.640625	8.5	6.708333	3.281828	0	0
118	10.67708	0	0	19.22839	0	50.625
119	23.93229	0	0	23.37326	0	53.16666
120	3.932291	0	0	3.394675	0	0
121	0	0	0	0	0	0
122	0	0	0	5.576389	0	0

A FIELD COMPARISON OF RADIANT AND CONVECTIVE HEATING SYSTEMS IN ARMY MAINTENANCE FACILITIES

by

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AN ABSTRACT OF A MASTER'S THESIS

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ABSTRACT

The U.S. Army Construction Engineering Research Laboratory initiated a program entitled "Radiant Heat Effectiveness" at Fort Riley, Kansas. The purpose of this project was to compare the performance of the heating systems in two Tactical Equipment Maintenance Facilities. The two buildings selected are of similar construction, and differ most significantly in their heating systems. One building is heated by gas-fired, tube type infrared radiant heaters while the other is heated by a forced-air convection system consisting of finned-tube unit heaters operating on a hot-water system. Both buildings are located on the same area of the post amid similar surroundings.

The buildings were monitored continuously for a period of three months (February - April 88). The energy consumption of each building was monitored, as were several aspects of the buildings' thermal environments. These included air temperatures at different levels and locations in the buildings, air velocity, dew point temperature, and operative temperature. The operative temperatures were measured using segmented globe thermometers. In addition to thermal conditions and heater operation, the operation of equipment likely to have an effect on the heating systems' performance was monitored. This equipment included the

garage doors, ceiling fans, and vehicle exhaust fans. Outside weather conditions were measured at a nearby weather station.

Comparison of the energy consumption data revealed that the radiant heating system used more energy during the study period. This appears to have been the result of an inadequate control system. The radiant system had no nighttime setback, while the convective system did. As a result, the radiant system consumed far more energy at night than did the convective system. In terms of thermal conditions, the radiant system maintained a greater difference between the opeative temperature and the air temperature at the occupied levels than did the convective system.

Both buildings demonstrated a problem with thermal stratification, with temperature differences of 20F or greater between floor level and ceiling level. The ceiling fans in the radiant building were somewhat effective in dealing with this, while those in the convective building had little effect.