AD-A154 651 EVALUATION OF A COMMERCIALLY AVAILABLE SINGLE BUILDING EMCS (ENERGY MONITORING CONTROL SYSTEM)(U) NAVAL CIVIL ENGINEERING LAB PORT HUENEME CA I SANCHEZ ET AL. FEB 85 NCEL-TR-914 1/1

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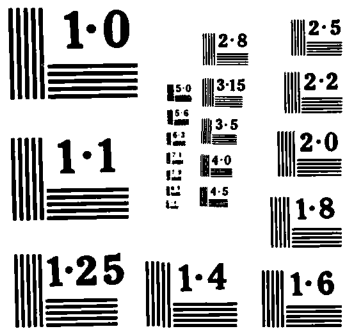

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Technical Report R-914

Evaluation of a Commercially Available Single Building EMCS

By Ivan Sanchez, John Franchi and Karlin Canfield

Sponsored by Naval Material Command

February, 1985

DEPARTMENT OF THE NAVY
NAVAL CIVIL ENGINEERING LABORATORY

NAVAL CIVIL ENGINEERING LABORATORY
PORT HUENEME, CALIFORNIA 93043

METRIC CONVERSION FACTORS

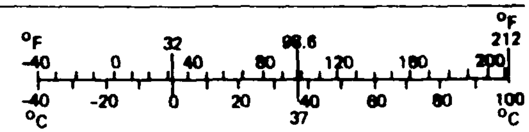
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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Naval Civil Engineering Laboratory
EVALUATION OF A COMMERCIALLY AVAILABLE SINGLE BUILDING EMCS (SBEMCS), (Final) by Ivan Sanchez and John Franchi

TR-914 29 pp illus February 1985 Unclassified

1. EMCS 2. Energy conservation I. ZO371-01-221C

The Navy is investigating new ways to reduce energy consumption at Naval bases throughout the world. At the Naval Weapons Center, China Lake, Calif., 75% energy savings were achieved at the Thompson Laboratory by installing a commercially available single building energy monitoring control system (SBEMCS). Part of these savings was the result of identifying other problem areas during the installation such as broken ducting in the attic, stuck dampers, and faulty thermostats. The enormous savings realized after the installation of the SBEMCS resulted in a payback period of 6 months. Prior to this installation, the air handler units ran 24 hours a day, 365 days a year while the boiler and chiller ran continuously during their seasonal operation. It took the coordinated efforts of four people (two public works engineers from the NWC and an engineer and a technician from NCEL) to install and program the SBEMCS. The installation of this system took less than 2 weeks and energy savings started immediately. This report documents the installation and evaluation of the SBEMCS installed at the Thompson Laboratory.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER TR-914	2. GOVT ACCESSION NO. DN387288	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) EVALUATION OF A COMMERCIALLY AVAILABLE SINGLE BUILDING EMCS (SBEMCS)		5. TYPE OF REPORT & PERIOD COVERED Final; Oct 1981 – Sep 1984 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Ivan Sanchez, John Franchi and Karlin Canfield		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS NAVAL CIVIL ENGINEERING LABORATORY Port Hueneme, California 93043		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 64710N; ZO371-01-221C
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Material Command Washington, DC 20360		12. REPORT DATE February 1985 13. NUMBER OF PAGES 29
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

EMCS single building controller, energy conservation, energy savings, SBEMCS - single building energy monitoring control system.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Navy is investigating new ways to reduce energy consumption at Naval bases throughout the world. At the Naval Weapons Center, China Lake, Calif., 75% energy savings were achieved at the Thompson Laboratory by installing a commercially available single building energy monitoring control system (SBEMCS). Part of these savings was the result of identifying other problem areas during the installation such as broken ducting in

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CONTENTS

INTRODUCTION

The Navy is investigating new ways to reduce energy consumption at Navy Bases throughout the world. At the Naval Weapons Center, China Lake, Calif., 75% energy savings were achieved at the Thompson Laboratory by installing a commercially available single building energy monitoring control system (SBEMCS). Part of these savings was the result of identifying other problem areas during the installation such as broken ducting in the attic, stuck dampers, and faulty thermostats. The enormous savings realized after the installation of the SBEMCS resulted in a payback period of 6 months. Prior to this installation the air handler units ran 24 hours a day, 365 days a year while the boiler and chiller ran continuously during their seasonal operation.

It took the coordinated efforts of four people, two public works engineers from the NWC and an engineer and a technician from NCEL, to install and program the SBEMCS. The installation of this system took less than 2 weeks and energy savings started immediately. This report documents the installation and evaluation of the SBEMCS installed at the Thompson Laboratory. Results such as these can be achieved at most facilities.

BACKGROUND

As a result of the energy crisis of 1973, energy conservation targets were established for Navy shore activities. To meet these targets, many large activities are considering the installation of computerized energy monitoring and control systems (EMCS). These systems promise long term energy controls with limited manpower resources, but have the disadvantage of high initial costs and are primarily feasible for large installations only. Smaller activities have the option of utilizing single building EMCS (SBEMCS). (See Reference 1 for guidelines on the selection and implementation of SBEMCS.) These smaller systems have the advantage of lower initial costs, and the ability to be integrated into a larger EMCS network if one is to be installed at a later date.

The Naval Civil Engineering Laboratory (NCEL) has been furthering the development of SBEMCS. Their first effort, an intelligent building controller (ITC), was described in Reference 2. The original ITC validated the basic concepts of a SBEMCS, but unfortunately the unit was not as reliable or maintainable as desired, and the decision was made to replace the ITC with an NCEL assembled unit using single board computer technology. The development, installation, and resultant performance of this unit is described in Reference 3. Reference 4 documents the use of one of the first commercially available SBEMCS, the Andover Controls "Sunkeeper."*

*The selection of Andover Controls does not imply endorsement by the government. Andover Controls is one of many different single building controller manufacturers (see Reference 5) and may not be better or worse than any other controller with similar characteristics.

Numerous manufacturers are presently supplying SBEMCS. The recently developed SBEMCS are very versatile and efficient energy management systems. NCEL was tasked to buy, install, and evaluate at selected sites two of the recently developed commercially available SBEMCS. NCEL personnel then were to determine the capability of these systems in assisting the Navy to meet the energy conservation targets. The Naval Weapons Center (NWC) at China Lake, California, is the location where the first SBEMCS was installed under this effort. The Trident Submarine Base in Georgia is the next location where a SBEMCS is scheduled to be installed. NWC, China Lake (a high desert location) and the Navy base in Georgia (a high humidity area) were selected based on their different temperature and humidity demands on the SBEMCS.

DISCUSSION

NCEL and NWC, China Lake, in this joint effort selected Building 31433, the Thomspon Laboratory, as the evaluation site. This building is 20,000 square feet in size. The air-water Heating, Ventilation, and Air Conditioning (HVAC) system consists of:

1. One 160-ton Chiller, model no. 19DG160, manufactured by the Carrier Air Conditioning Company (Figure 1).

2. One boiler, model no. 309, manufactured by National (Figure 2).

3. Four air handler units (AHUs), with 20-, 20-, 15-, and 10-hp electric motors, respectively (Figures 3 and 4).

The Thompson Laboratory has two methods of controlling the temperature requirements: (1) AHUs and a chiller during the hot weather from May through September, and (2) AHUs and a boiler during the cold weather from November through April.

The AHUs have to be operational year-round to circulate outside air into the occupied building in accordance with ASHRAE standards. NWC, before the installation of the SBEMCS, allowed NCEL to install an energy data acquisition system (DAS) in FY82. Using the accumulated data, NCEL was able to compare the usage before and after the installation of the SBEMCS. The installation of the SBEMCS and the DAS was performed by NCEL personnel. All of the specifications for the control strategies were done by NWC.

Before the installation of the SBEMCS, the HVAC system was in operation 24 hours a day. An energy profile of the AHUs prior to conservation action is shown in Figure 5. At the time these data were gathered, the average daily energy consumption by the AHUs was 700 kW-hr. The first energy conservation effort at the Thompson Laboratory by NWC consisted of changing the pulley ratio on the four AHUs electric motors. The AHU's fan speed was decreased and consequently the AHU's energy usage was reduced as shown in Figure 6. The air volume rate per unit of time (cfm) decreased by 30% and the energy consumption by 43%. NWC was careful to maintain the circulating air volume necessary to comply with the requirements as stated in the ASHRAE standards.

The second energy conservation effort at the Thompson Laboratory consisted of the installation by NCEL personnel of a SBEMCS (an Andover Controls AC256M master unit) (Figures 7 and 8). Details on the hardware and software are given in the Appendix.

On January 28, 1983, the AC256M began controlling the four AHUs at the Thompson Laboratory (Figure 9) with a simple program similar to the one shown in the Appendix. Four sensors (Figure 10) were mounted in the hallway of the laboratory to measure the temperature in the four different zones of the building. An indoor/outdoor sensor (Figure 10) was mounted outside the Thompson Laboratory behind air handler unit No. 1 to monitor outside air temperature. Solid state relays (Figure 11) were used to control the AHUs, chiller and boiler. Instead of the AHUs running 24 hours a day, 365 days a year, they were allowed to run for only 10 hours a day, and were shut off on weekends as well as holidays. Four auxiliary switches were mounted in the hallway of the Thompson Laboratory to control the four AHUs individually in the event personnel wished to work overtime or on weekends. By depressing the momentary-on switch the respective AHU will run for an additional hour. If you depress the switch three times, the AHU will run for an additional 3 hours, etc.

The AHU's resultant energy usage was reduced further as shown in Figure 12. Table 1 shows the energy savings accomplished by doing a scheduled start/stop control on the AHU before and after replacing the pulleys.

Table 1. Thompson Laboratory Electric Consumption/Cost: Four Air Handler Units

Action	Average Usage (kW-hr/yr)	Percentage Energy Saved (%)	Annual Dollar Savings ($)
Original (continuously running)	255,500		[a]
After fan pulley change	150,380	43	10,965
After EMCS and pulley change	49,640	80	20,400

[a]Original cost was $25,500 annually

Energy conservation with the SBEMCS controlling the AHUs is limited due to the air circulation requirements of the outside air. Another control strategy that could be implemented is an economizer. An economizer will work in conjunction with the AHUs and the outside air dampers. Basically the AC256M will sense the inside and outside air temperatures and determine if the cooling or heating requirement can be satisfied with the outside air. The AC256M will send a control signal to position the dampers fully open when the outside air is sufficient to warm or cool the building. Using this strategy, the chiller or boiler could stay off for longer periods of time when the weather conditions are favorable, such as in the transition period between seasons when mild temperatures occur.

BOILER CONTROL

In the past it was thought that cycling a boiler on and off would have an adverse effect on the boiler's life expectancy. Recent information obtained by boiler experts at NWC has determined that cycling the boiler once a day would not affect in any way the operation of the boiler. Samuel G. Dukelow, an instructor in boiler control for the Instrument Society of America, has also emphasized that it does not affect a boiler to be shut down periodically, and cites the fact that many utility companies shut down their boilers every day to save energy. Mr. Dukelow's expertise is backed up by 38 years of experience with Bailey Controls Company, a subsidiary of Babcock and Wilcox Company.

By April of 1983, the boiler at the Thompson Laboratory was under a scheduled start/stop control strategy. The boiler is operated by propane gas (Figure 13). Table 2 compares the last 3 years of propane usage. It can be observed that in the month of April, when the boiler was under computer control, a lower amount of propane was used. This was achieved in spite of the higher heating degree days as compared with the previous 2 years.

Table 2. Thompson Laboratory Heating Fuel Usage

Year	Heating Degree Days	Propane Usage (gallons)
1981	1341	25,100[a]
1982	1715	12,800[b]
1983	1707	9,000[c]

[a]Original pneumatic system

[b]With new pneumatic system

[c]After installing EMCS/last 2 months of heating season (April and May)

CHILLER CONTROL

An energy profile of the chiller is shown in Figure 14. The chiller was allowed to run 24 hours/day with the AHUs before the installation of the SBEMCS. The installed SBEMCS (AC256) controls the chiller with an optimum start/stop control strategy. Running the chiller in an optimum start/stop control strategy results in turning the chiller off in the afternoon, and on early the next morning. When the chiller is turned on early in the morning, additional work is necessary to cool the water in the system. The chiller will load to a point close to its maximum capacity in order to satisfy the higher cooling demand. At this point the chiller at the Thompson Laboratory is drawing approximately 250 amps at 208 VAC. The chiller efficiency decreases as the overall result of sudden chiller loading.

The AC256 can implement a soft-loading sequence for solving the sudden demand created by the chiller. This is done by locating two load limit switches on the chiller vanes. These switches tell the AC256 when the chiller has been loaded to a specific level. The two settings selected were at 160 amps and 210 amps. By reading the vane limit switches, the AC256 can now tell how much the chiller is loaded. As soon as the AC256 detects the first switch closure the chiller is using about 160 amps. The vane stepper motor is disabled and the chiller is forced by the AC256 to stay at that constant load for a programmable amount of time. A similar condition occurs for the second limit (210 amps). In about 1-1/2 hours the "soft-loading" sequence is over and the AC256 returns to the chiller the capability to load by itself. After contacting several chiller manufacturers, it was determined that there is no soft-loading system available on the market. A patent application has been filed at NWC for the soft-loading system developed at the Thompson Laboratory.

An energy profile of the chiller under an optimum start/stop control strategy and the newly developed soft-loading sequence is shown in Figure 15. Original energy consumption and cost is compared in Table 3 to energy consumption and cost savings after installation of the SBEMCS.

Table 3. Thompson Laboratory Electrical Consumption/Cost Chiller Unit

[Cost saving is approximately 80%]

System	Average Usage (kW-hr/yr)	Annual Dollar Savings ($)
Original	232,800	a
After Installing EMCS	46,400	14,100

[a] Original cost was $17,600.

SYSTEM COST

Table 4 shows a summary of the system cost. A total of approximately $20,000 was expended for the acquisition and installation of the entire system. At the Thompson Laboratory the pay-back period was 6 months. The pay-back period at this site was short because of the tremendous energy savings accomplished. Single building controllers cannot be applied everywhere. Ideally, they should be applied in buildings where there is only one shift and there is no critical equipment conditioning requirements or the electronic equipment in the building has a separate air conditioning system. The one working shift means that the HVAC system is active for less than 10 hours. Maximum energy conservation exists when the HVAC system is shut-off completely.

Table 4. Thompson Laboratory Energy Conservation Efforts Simple Payback Period: 6 Months

Item	Dollars ($)
Systems Costs	
Hardware	9,750
Installation	10,200
Total	19,950
Dollar Savings (annual)	38,300

CONCLUSIONS

Single building controllers make available to the user a wide range of energy management strategies such as scheduling, optimum start/stop, demand control, duty cycling, chiller/boiler optimization, enthalpy, and lighting control. Characteristics of good single building controllers are:

1. Distributed control - buy just the system your building needs.

2. Start with a few inputs and outputs and then expand.

3. Sophisticated computer power that is quick and simple to program.

4. Units are easily set up and programmed by the user.

5. Modular design for proven reliability; easy to install, expand, maintain, and service.

6. Remote communication with the unit over phone lines.

7. Units provide reports such as status, alarms, histories and routine.

8. Direct digital control of temperature, humidity and air movement.

A direct result of the successful application of the SBEMCS in the Thompson Laboratory is the additional installation of SBEMCS throughout the entire NWC at China Lake. With a total energy bill of 10 million dollars a year, public works engineers are estimating savings of 30% annually, 3 million dollars a year, using SBEMCS.

A few basic concepts have been illustrated with the Thompson Laboratory effort:

(1) Determine existing conditions (metering and surveys)

(2) Determine actual needs (ASHRAE standards, Navy guidance)

(3) Repair inoperative equipment (Repairing duct work, dampers and thermostat)

(4) Modify equipment to meet requirements (change AHU's pulleys to provide minimum air recirculation)

(5) Select energy conservation strategies (scheduled start/stop and chiller soft-loading)

(6) Install controller with cooperation of building occupants (installations of AC256)

(7) Monitor operation to determine savings (metering)

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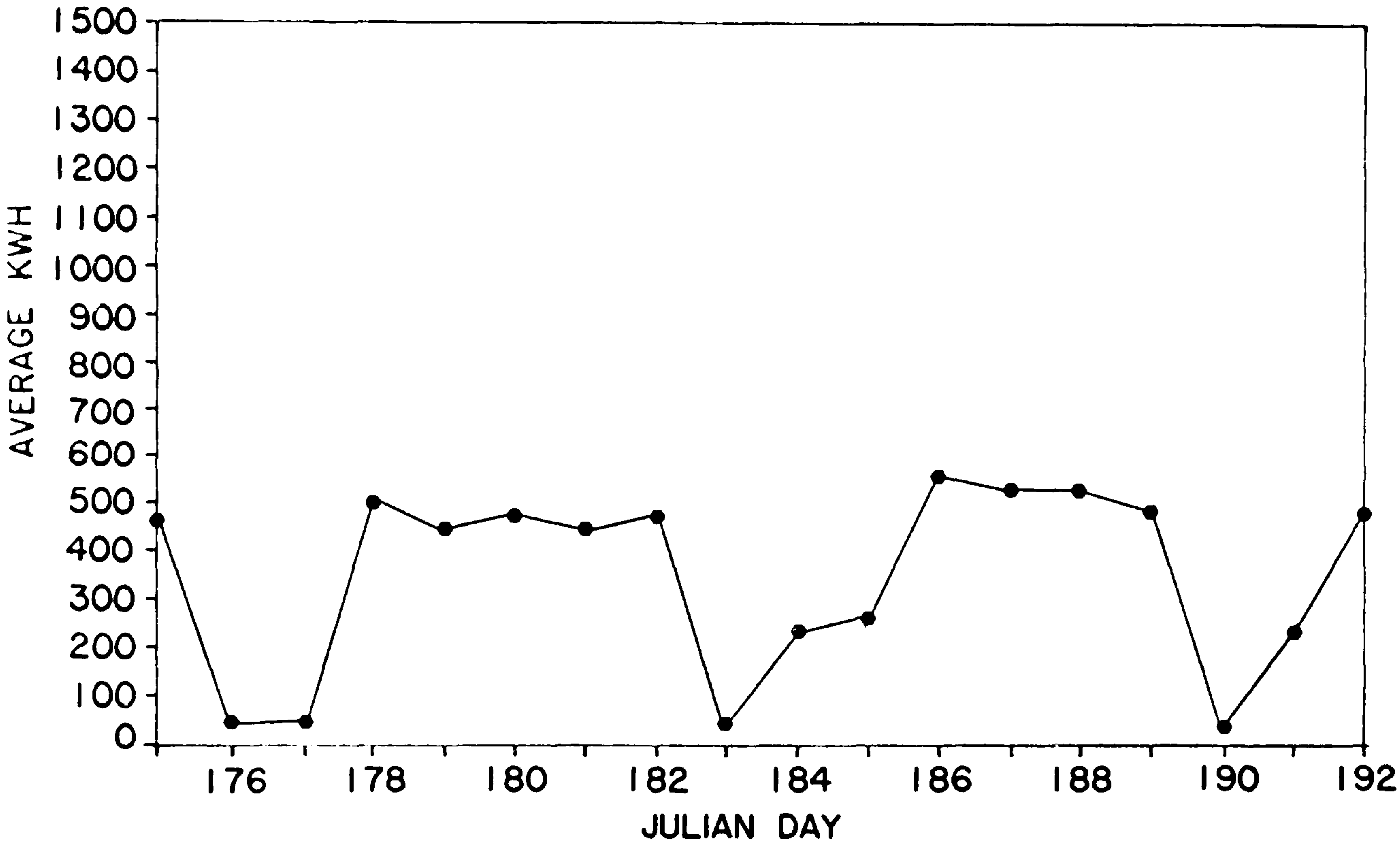

Figure 15. Thompson Laboratory, NWC China Lake AHUS chiller consumption (after EMCS).

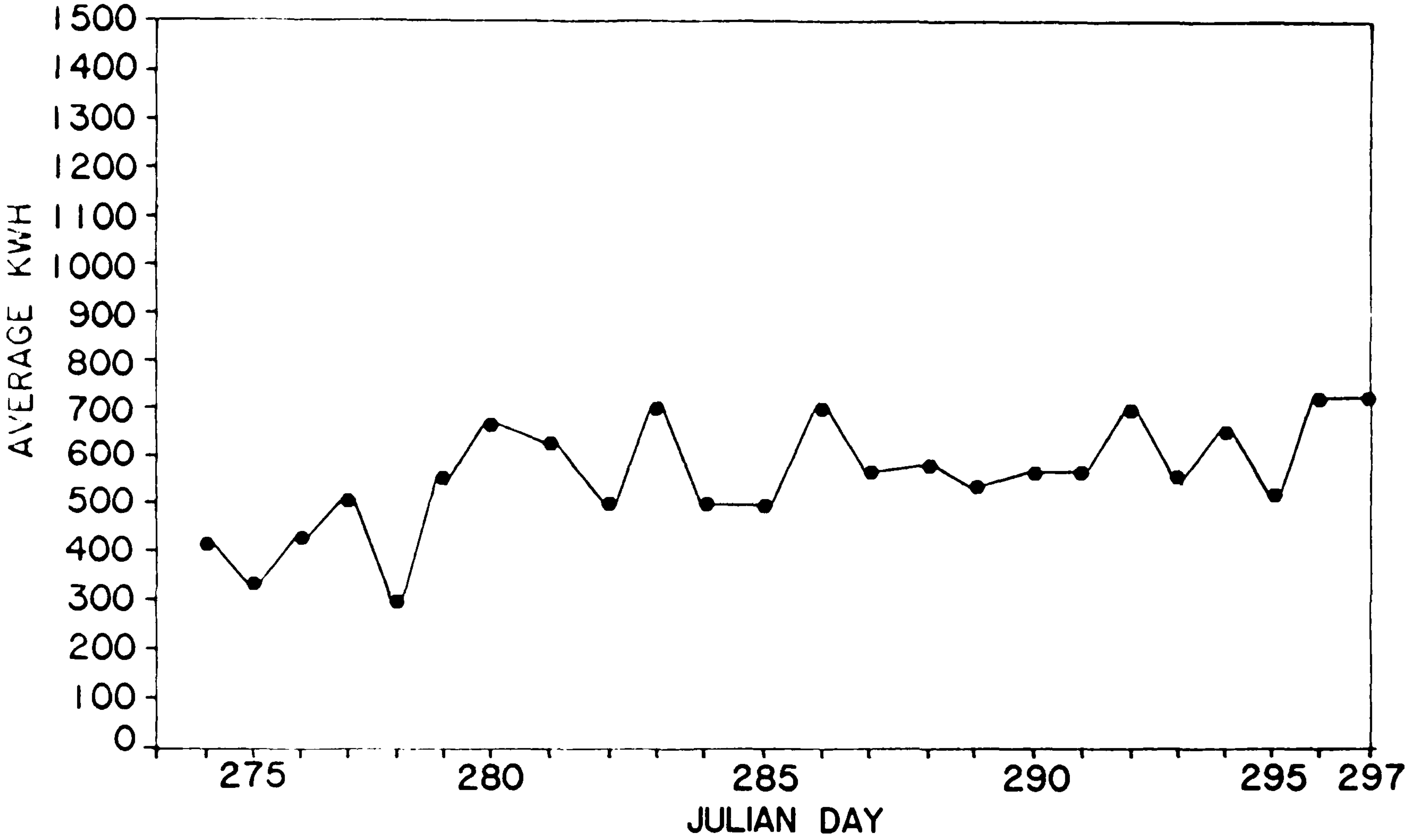

Figure 14. Thompson Laboratory, NWC China Lake AHUS chiller consumption (prior to EMCS).

Figure 13. Gas meter used to measure propane usage of boiler.

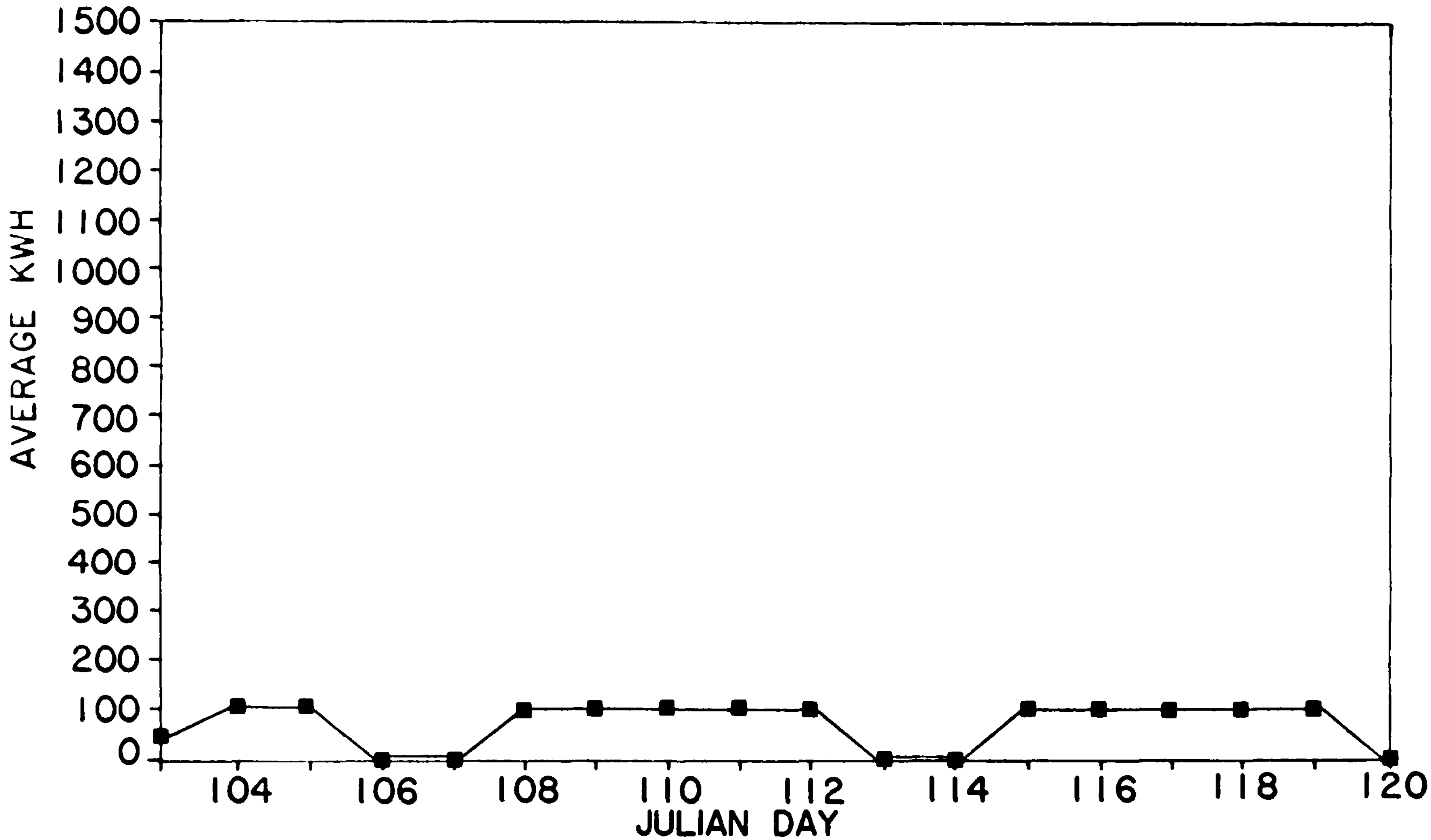

Figure 12. Thompson Laboratory, NWC China Lake AHUS consumption (after pulley change/EMCS installation).

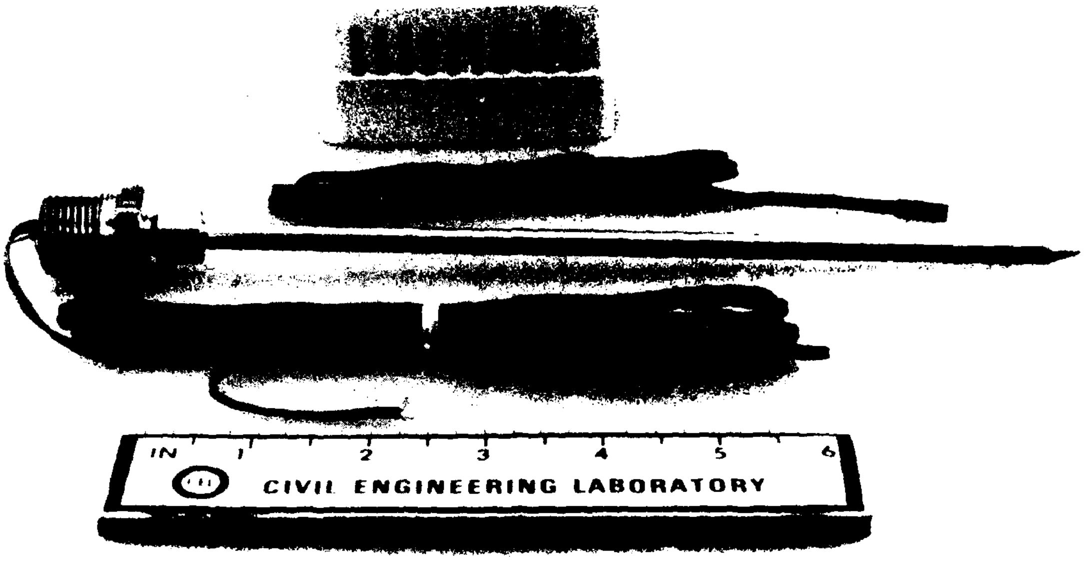

Figure 10. Indoor and outdoor temperature sensors.

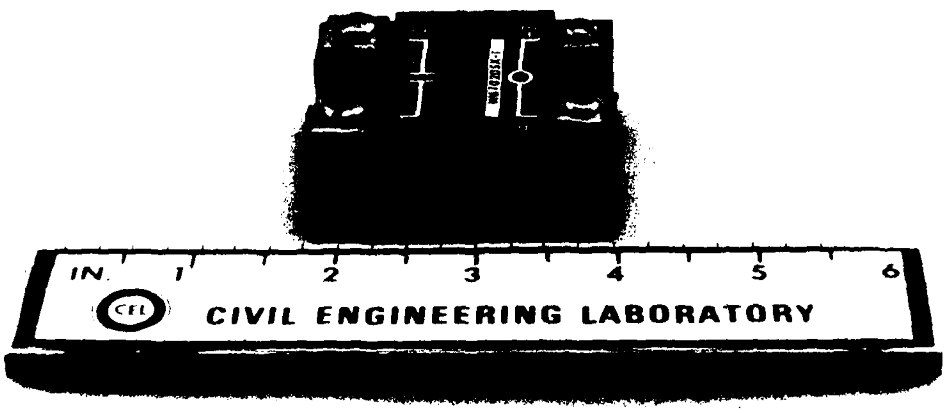

Figure 11. Solid state relay used to control AHUs, chiller and boiler.

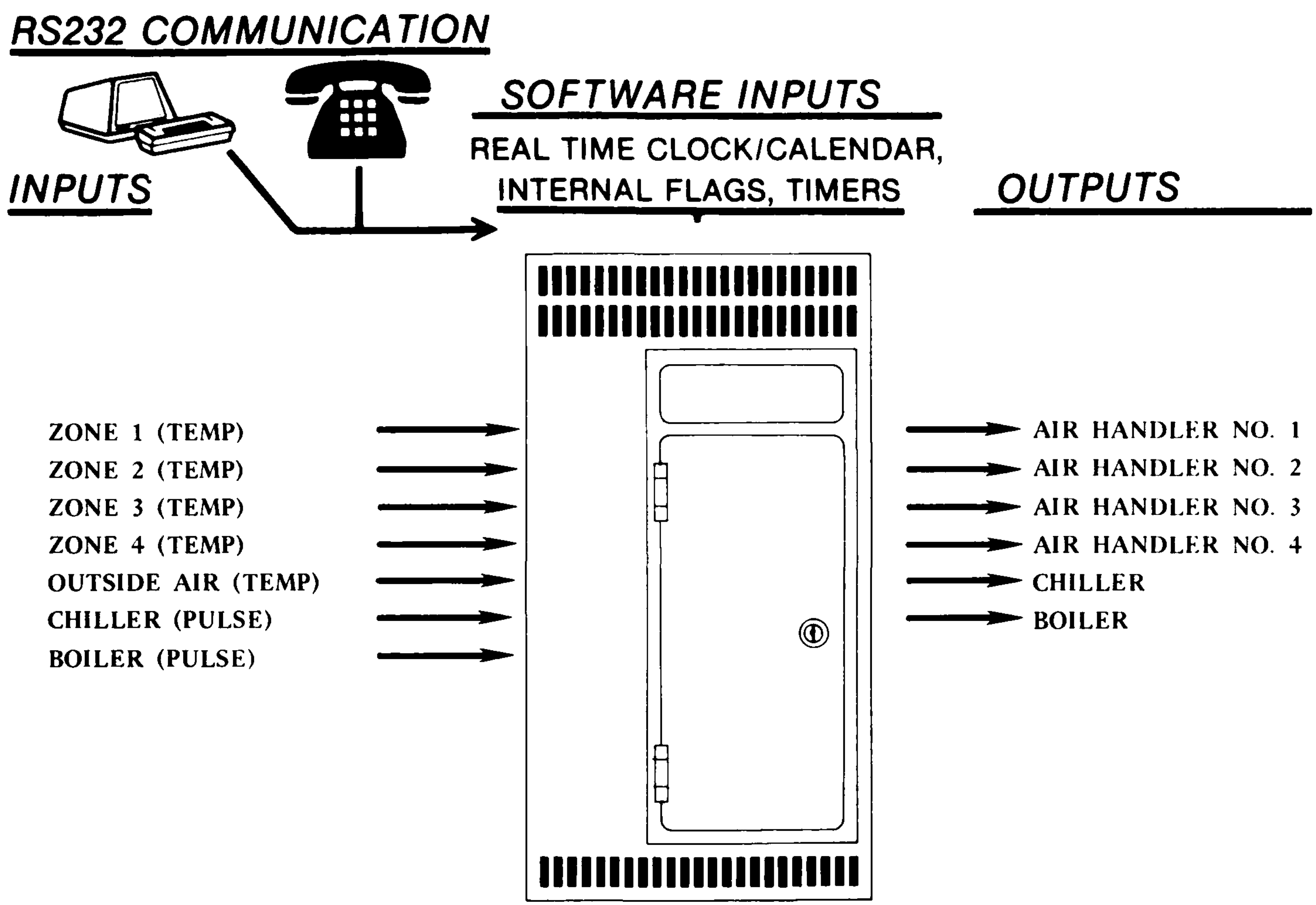

Figure 9. Block diagram of AC 256-M at Thompson Laboratory.

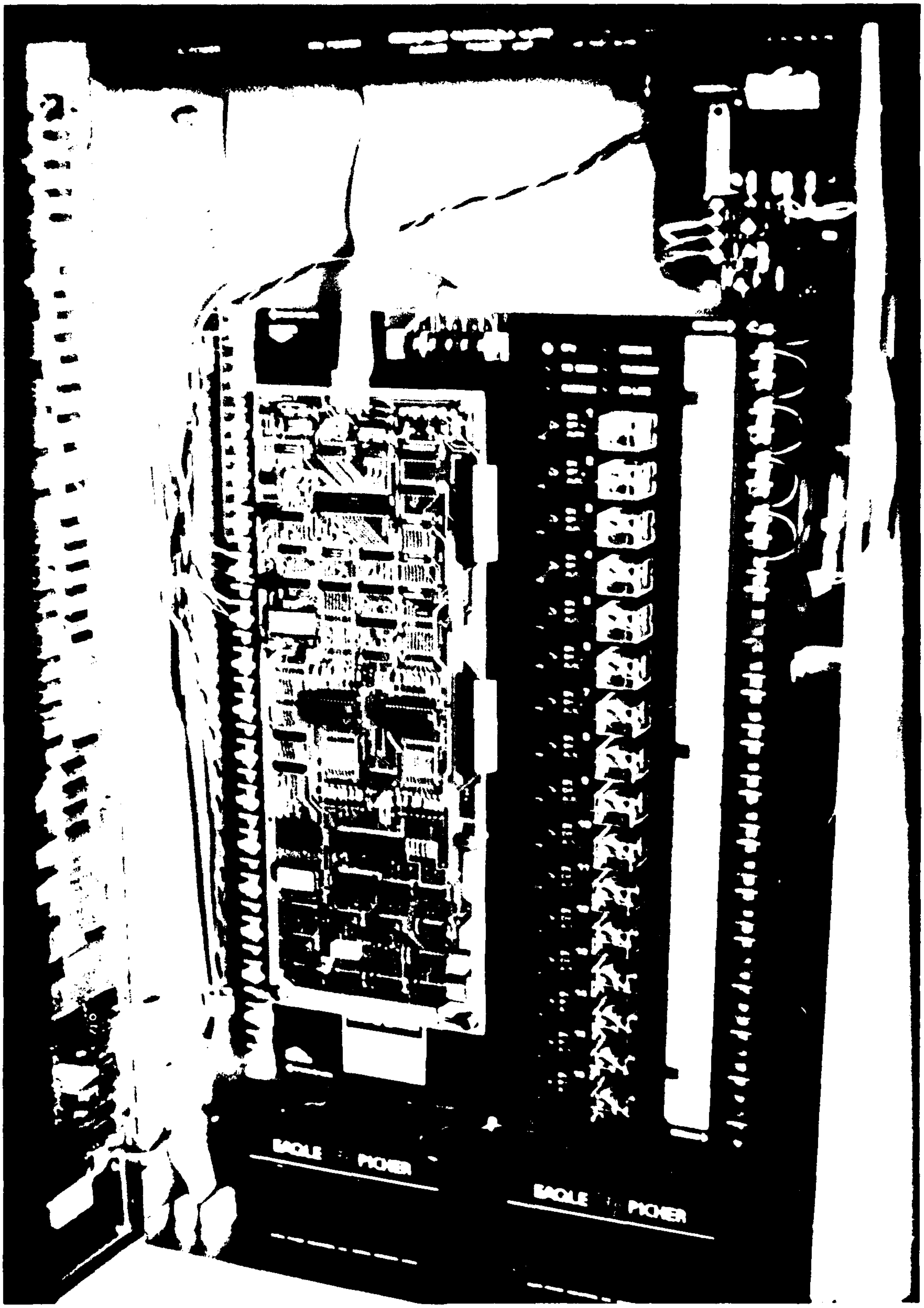

Figure 8. CIU and IOU boards. Andover controls 256-M.

Figure 7. SBEMCS Andover controls 256-M.

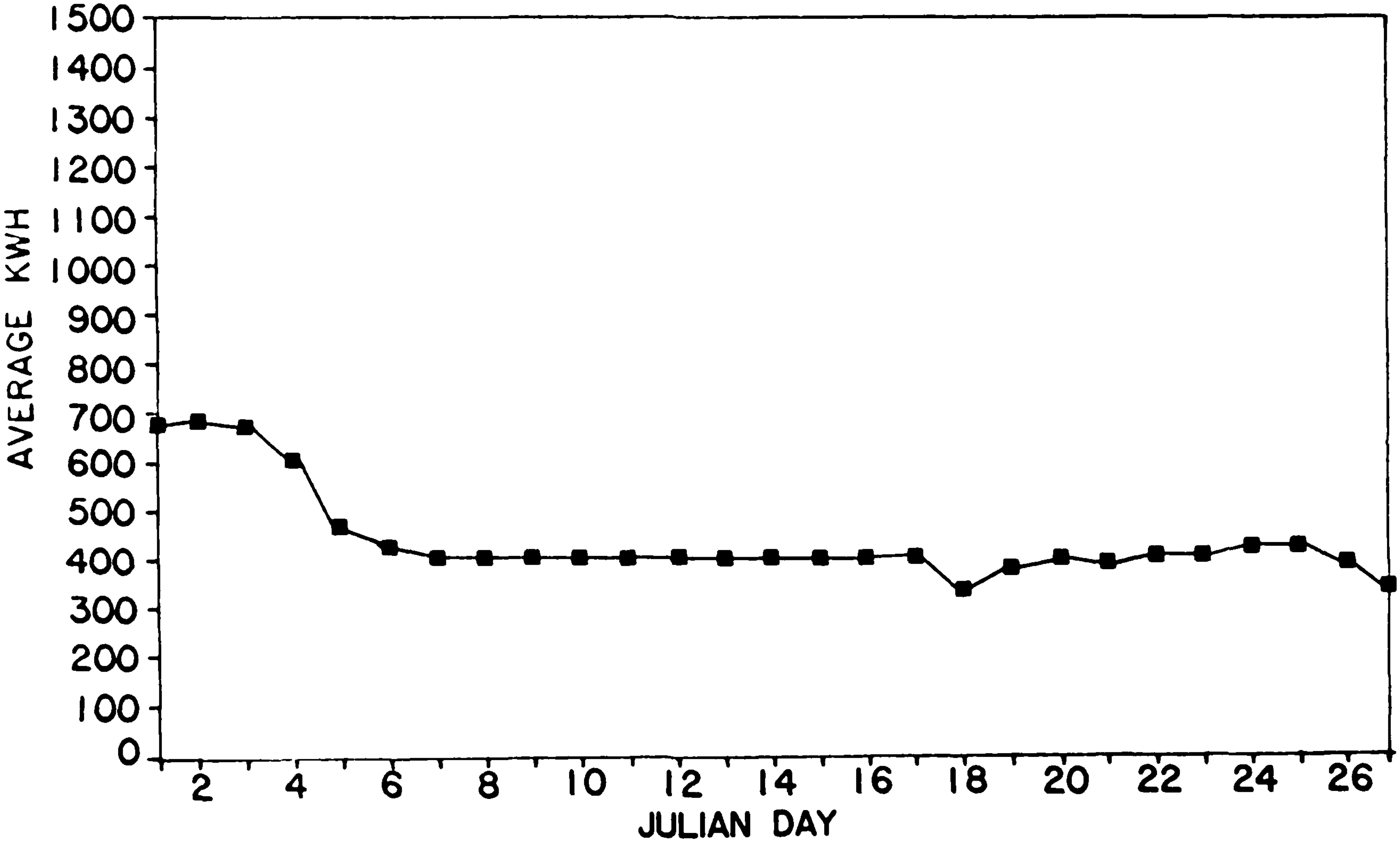

Figure 6. Thompson Laboratory, NWC China Lake AHUS consumption (after pulley change).

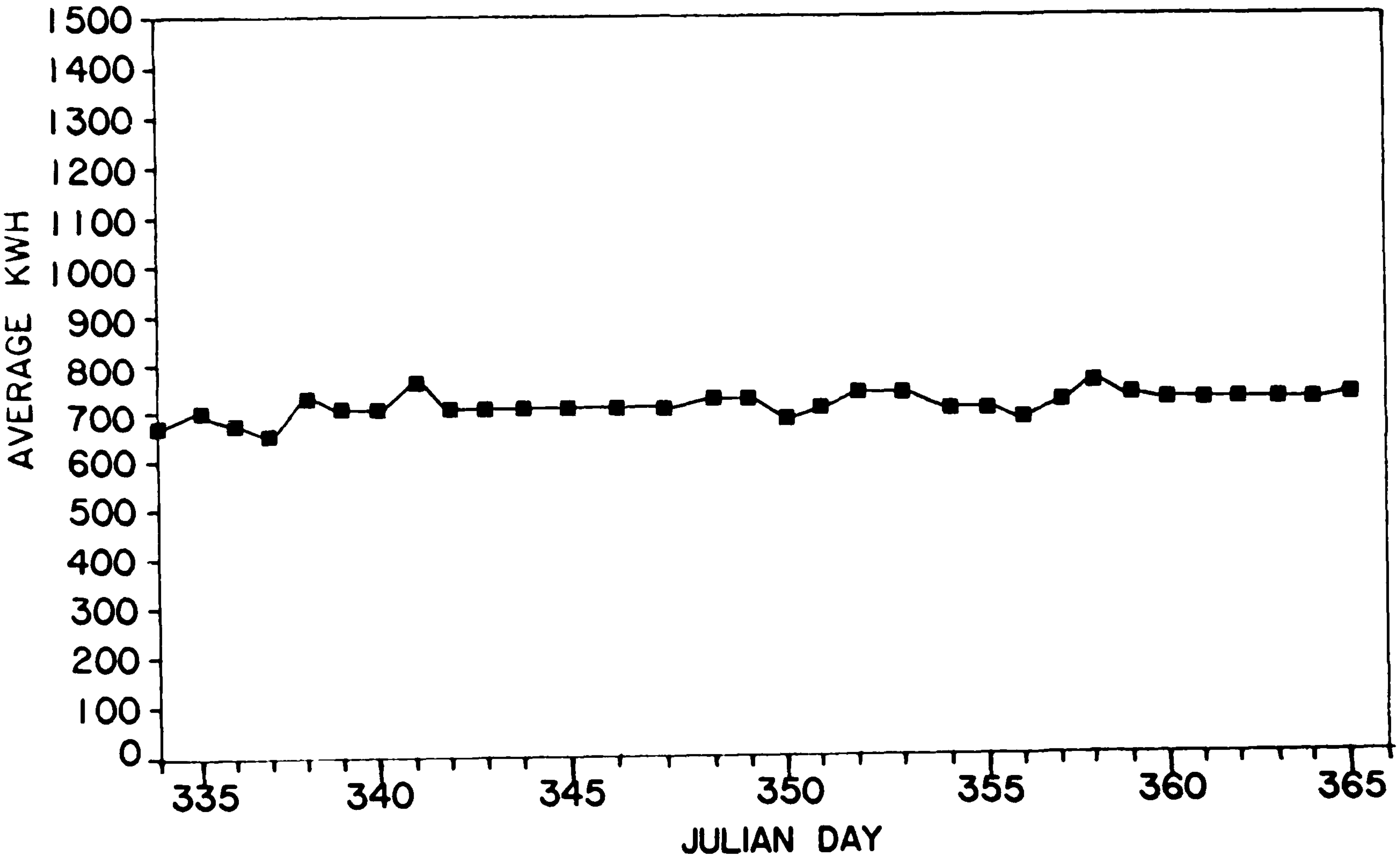

Figure 5. Thompson Laboratory, NWC China Lake AHUS consumption (prior to changes).

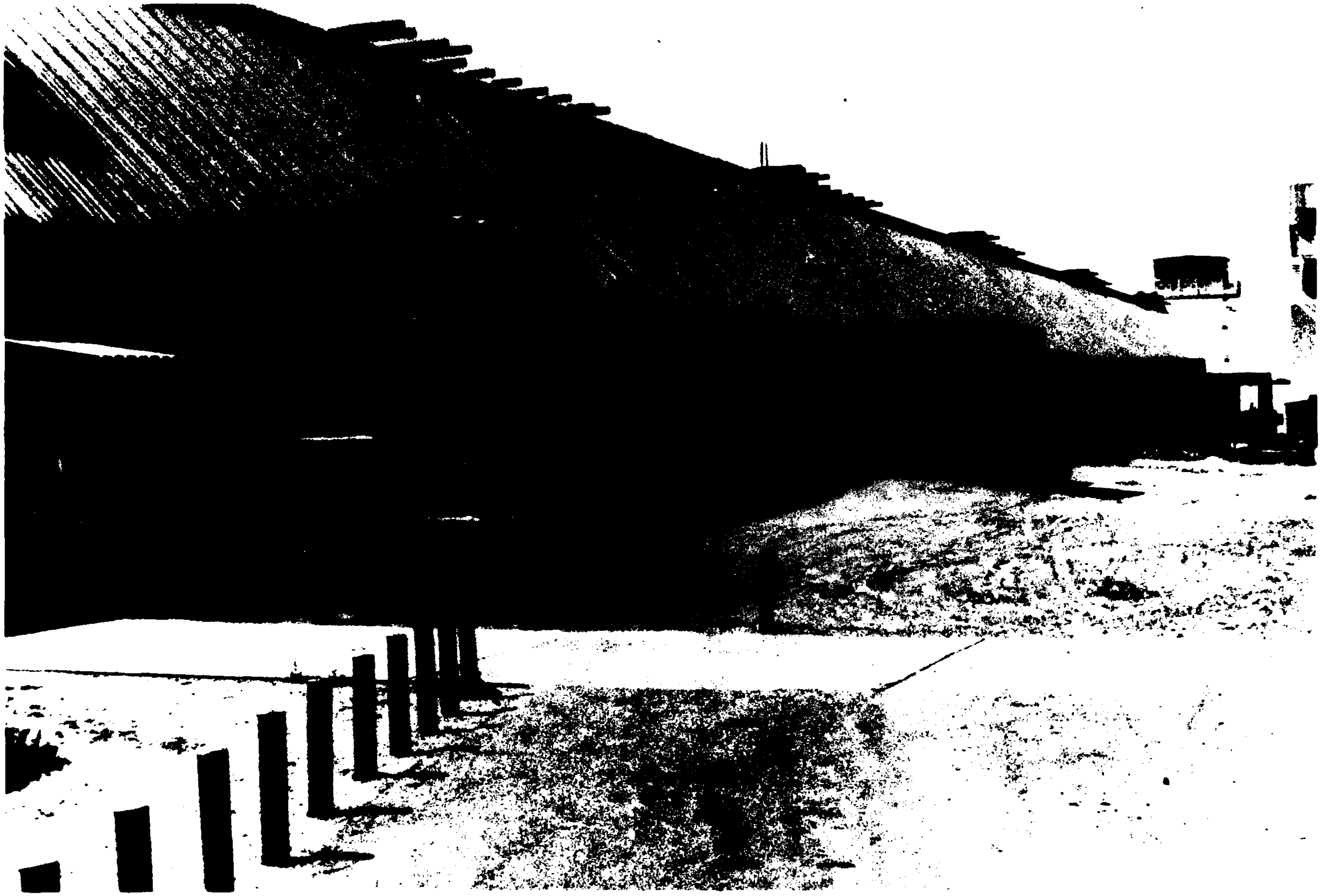

Figure 4. Four air handler units at the Thompson Laboratory.

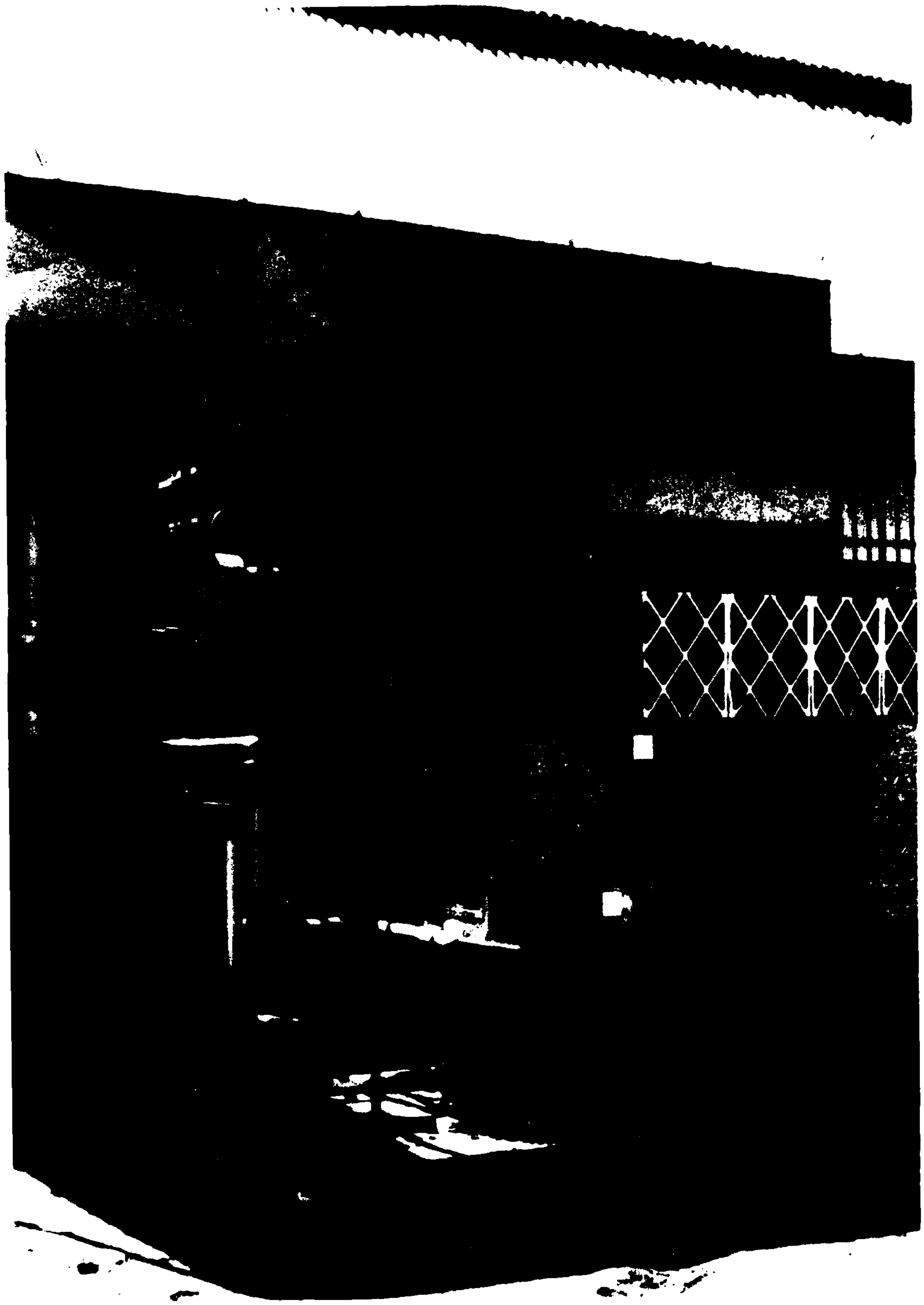

Figure 3. Air handler unit.

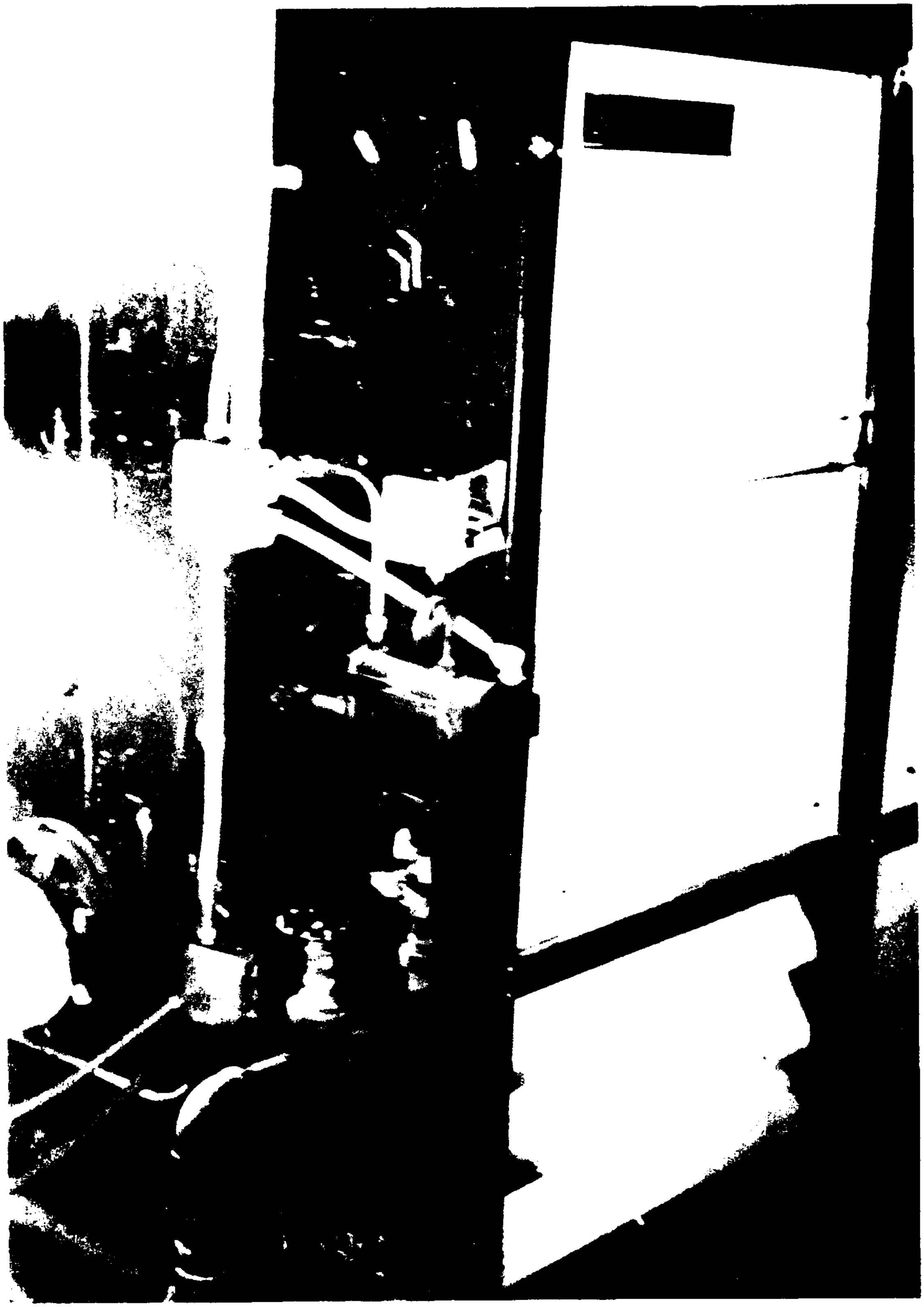

Figure 2. Boiler, model no. 309.

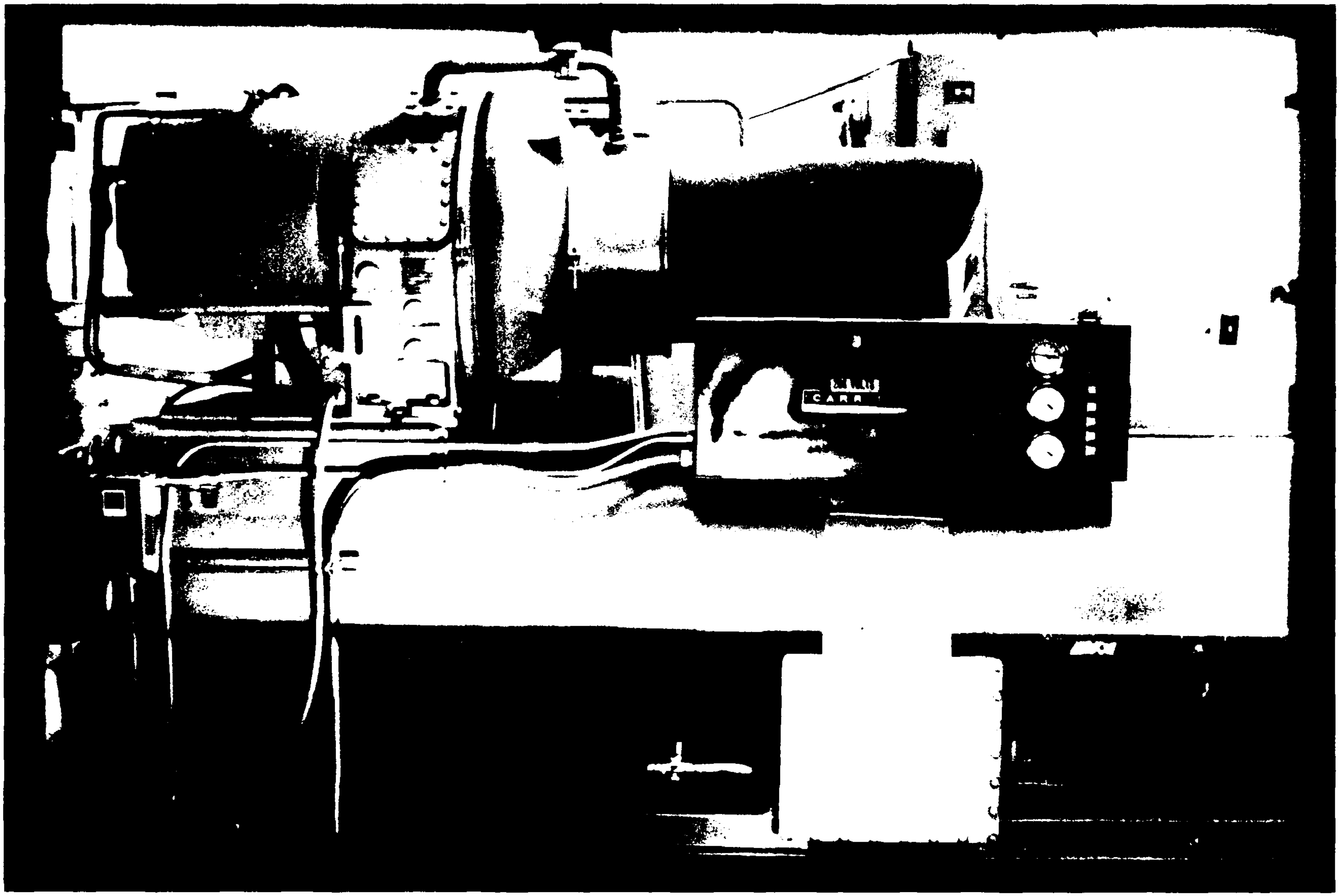

Figure 1. 160-ton chiller, Model no. 19DG160.

Appendix

DETAILS ON THE HARDWARE AND SOFTWARE OF THE AC256

HARDWARE CAPABILITIES

- Thirty-two definable inputs for temperature, pressure, relative humidity or contact closures sensing.
- Sixteen digital outputs (relay closures) to control chillers, AHUs or boilers.
- Each master can control up to 16 slaves. Slaves consist only of an I/O unit with no intelligence. The intelligence is only at the master units.
- The maximum configuration network is a 16 x 16 matrix of masters and slaves. A total of 8,192 inputs and 4,096 outputs.
- The AC256M uses the Motorola family of microprocessor called the 6800 which has been proven to be a very reliable system.
- A battery back-up is included to maintain the programs and the time data for 3 hours during electrical power outages.

SOFTWARE CAPABILITIES

A very simple English control language is used. Each program area is analogous to a cylindrical drum with program lines and a pointer. There is capacity for 320 drums. The user can program the machine to suit his needs. There are no canned control programs. The manufacturer provides an installation guide, if requested, that documents some control programs. With a minimum modification these were applied at the evaluation site.

As an example of the machine flexibility one of the commands will be discussed. The "ASSIGN" command is used to define the inputs and outputs. Inputs and outputs will have a connection and a name assigned.

Command Format for the Outputs

ASSIGN OM,1-16 NAME

OM - is to define an output in master number M
1-16 - is the available outputs in one master
NAME - any eight characters

To define the third output in a system with only one master, the following command is used:

ASSIGN 01,3 CHILLER

Now relay number three in the output will be used to control the chiller and can be referenced in the programs by the new name "CHILLER" (see example in the end of the Appendix).

Examples for the Inputs

You identify the inputs in the same format, although there are 32 inputs. But instead of using the letter O, you must pick one of four letters, indicating the way you will be using the input:

V - to read as a voltage

T - to read it as a temperature (number of degrees fahrenheit)

D - to read it digitally (on or off)

C - to read it as a counter (number of pulses sensed in the most recent interval)

Examples

ASSIGN C1,1 KWPULSE

ASSIGN T1,2 EXT-TEMP

ASSIGN T1,3 INT-TEMP

ASSIGN D1,4 OVERRIDE

In the second example: ASSIGN T1,2 EXT-TEMP, input 2 for master 1 is a temperature sensor measuring external temperature.

This demonstrates the flexibility of the AC256 in which inputs and outputs can be named and categorized in any order.

At the same time there is protection as well flexibility. The AC256M has 3 levels of security. The higher the number the less the restriction. Therefore, level 3 will let the operator use all the AC256's features, even program in or delete personal passwords. Level 2 lets the operator analyze or change the AC256's operation, reprogram it, or erase part or all of its memory. In level 1 the operator can find out what the AC256 is doing but not affect the AC256's operation in any way.

To demonstrate the simplicity in programming the AC256 an actual program in use at the Thompson Laboratory will be shown. The example that follows is currently being used to control the chiller.

```
Drum -- 225    This is controlling the chiller during regular schedule.
               B455  1983  Jun 24 Fri 19 22 54

LINE 1

     1A   OFF > CHILLER                ; turn off chiller
     1X   Exit to line 3 if F4 = ON    ; rotate to line 3 if F4 is "ON"
                                         F4 is a flag and is turned on
                                         in another drum program when
                                         time, temperatures and day of
                                         week meets certain requirements

LINE 3

     1A   ON > CHLERPMP                ; turn on chilled water pump
     1X   Exit to line 5 if TS > 30    ; rotate to line 5 after 30 seconds

LINE 5

     1A   ON > CHILLER                 ; enable the chiller "ON"
     1X   Exit to Line 10 if TS > 2    ; rotate to line 10 after 2 seconds

LINE 10

     1A   ON > CHSTART                 ; start the chiller with a 5 seconds
                                         pulse
     1X   Exit to Line 15 if TS > 5    ; after 5 seconds go to line 15

LINE 15

     1A   OFF > CHSTART                ; turn the pulse off
     1X   Exit to line 20 if F4 = OFF  ; stay here until F4 is off,
                                         than go line 20

LINE 20

     1A   OFF > CHILLER                ; disable the chiller and turn off
     1X   Exit to line 25 if TM > 14   ; go to line 25 after 15 minutes

LINE 25

     1A   OFF > CHLERPMP               ; turn the chilled water pump off
     1X   Exit to line 1 if __?        ; go to line 1 immediately
                                       ; Emergency line

LINE E

     1X   Exit to line 1 if CL = 0     ; to to line 1 if a power failure
```

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