MASTER

COO/2704-20
Distribution Category UC-59a

EVALUATION OF THE SOLAR BUILDING
ALBUQUERQUE, NEW MEXICO

DATA LOSSES AND SENSOR FAULTS

M. W. WILDIN
D. E. SWICK
S. F. GILMAN

SEPTEMBER 1976

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

THE PENNSYLVANIA STATE UNIVERSITY
UNIVERSITY PARK, PENNSYLVANIA 16802

PREPARED FOR THE
U.S. DEPARTMENT OF ENERGY
SOLAR ENERGY
UNDER CONTRACT EY-76-S-02-2704

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

NOTICE

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for any third party's use or the results of such use of any information, apparatus, product or process disclosed in this report, or represents that its use by such third party would not infringe privately owned rights.

INTRODUCTION

During the data acquisition phase of this project, significant quantities of data were "lost" due to data acquisition equipment failures and malfunctions, operator errors and sensor faults. In this report the term "data losses" is reserved for two types of events: 1) those in which data that had been recorded by the on-site computer were not committed to "permanent" storage on magnetic tape at The Pennsylvania State University, and 2) those in which there was a failure to record data on the computer due to malfunctions or modifications of the data acquisition hardware or software. The term "sensor faults" is used to denote events in which the sensors did not satisfy either the manufacturer's tolerance on accuracy or an arbitrary tolerance specified by project personnel to help insure adequate accuracy in critical temperature measurements. This tolerance was less than that of the manufacturer.

It is not difficult to develop a catalog of data losses, due to permanent files of data, including the times to which the data correspond. However, it is virtually impossible at this point in time to catalog all sensor faults for two major reasons: 1) Not all sensor faults were recorded, particularly during the first 45 days (approximately) of data collection when on-site personnel were busy with a great variety of problems and did not yet understand the operating characteristics of either the heating and cooling system or the data acquisition system. Even after initiating maintenance of a daily log of actions and events that seemed worthy of note, there were occasional failures to record sensor faults or replacements of sensors thought to be faulty. 2) Some sensor faults undoubtedly remained unnoticed and therefore unrecorded. In some cases, adequate redundancy in the instrumentation to facilitate checking for sensor faults on a regular schedule was either not provided or not possible; and, of course, those sensors which were not easily checked were not checked as frequently. For example, it was not possible, with the equipment available to us to obtain good energy balances on the water-to-air heat pumps. This was probably due to non-uniformity of the temperature and velocity distributions in the inlet and outlet air streams; but the number of channels available on the data acquisition computer, together with the instrumentation employed, did not permit the detailed measurements required to thoroughly analyze and resolve this problem. However, the lack of a good energy balance on these units was not considered essential as long as the total energy flow from all of them to storage was accurately determined. For measurements which were considered essential, it was found necessary to continually maintain an effort to detect sensor faults. The major tools used to this end were energy balances and comparison of redundant measurements. Despite diligent exercise of these tools, there were several occasions in which on-site personnel were surprised to learn that sensors which had been thought to be operating properly were found to be out of tolerance. So it is possible that other sensor faults were not detected or recorded, although it is thought that such failures were relatively few in number.

Although simply cataloging data losses and sensor faults may be of limited and transitory utility, information on the major reasons for failures to acquire or to permanently record useful data and on methods used to reduce such failures appears to have potential for widespread utility to other projects involving monitoring of buildings. Hence, this report presents discussions of both known data losses and how they occurred, and of diagnostic methods used to detect sensor faults. Measures taken to reduce both data losses and sensor faults are also discussed.

DATA LOSSES

Appendix A presents: 1) lists of dates for which twenty-four hours of data were recorded, 2) lists of dates and hours for which data is missing and 3) lists of dates and hours for which partial sets of data were obtained due to failure of the data acquisition system. There are separate lists for the 1974-75 and 1975-76 winter heating seasons.

As indicated in the introduction, two major types of events occurred which led to what is herein termed data losses. One was the failure to commit to permanent magnetic tape storage at The Pennsylvania State University data that had been temporarily recorded on magnetic disk storage by the on-site data acquisition computer, an IBM System 7. Since the computer demonstrated the ability to save data and programs in process of execution when an electric power failure occurred, data was lost as a result of such failures only due to the lack of provision of an auxiliary power supply or a self-starting feature on the computer, both of which would have been expensive. The major reason for failure to commit locally-recorded data to permanent storage was termination of computer operation prior to completing a file, together with a decision not to save incomplete files. A data file was complete only after continuous data collection for a fixed period of time. A decision was made early in the planning phase of the project not to save incomplete files, due to the complexities involved in their cataloging and subsequent use. The effects of this decision were compounded during 1974-75 heating season data collection by use of twelve-hour file lengths. Thus, if computer operation ceased any time during a twelve-hour period after the start of a file, all the computer-recorded data collected after the start of that file were lost. Although it would seem possible to minimize the effects of such losses by manually stopping the computer only during nighttime, this proved to be impossible due to the frequent need for diagnostic work on computer hardware or software at the site or at The Pennsylvania State University, and this normally was accomplished in the daytime, due to availability of key personnel. The need for daytime manual stops was particularly great during the initial part of each major data acquisition period, but it continued throughout each period. Additional, machine-initiated, stops occurred during transmission of data from the site to PSU. These stops occurred particularly frequently during approximately the first three months of the 1974-75 period. For example, these stops and the diagnostic work performed to detect and correct them caused loss of considerable daytime data for 26 days during the first 9 weeks of 1975. The problems producing the stops during this period were solved by repeatedly bringing representatives of the computer manufacturer and the telephone company together, which led to identification and correction of telephone hardware malfunctions and deficiencies of the interface between the computer and telephone companies' equipment. Diagnosis of the factors which produced these stops were complicated by the several items of equipment at both ends of the communication line and the interaction between the lines.

Although these measures greatly reduced machine-initiated stops during transmission, such stops continued through the data acquisition phase. It was found that the stops were much more frequent after a number of files had been transmitted, apparently due to the necessity to search for files located further from the initial location on the disk. To alleviate this problem, a practice was established of regularly executing a process termed "cleaning and reorganizing the disk." Execution of this process required a manual computer stop, so care was taken to initiate this process immediately after completion of a file.

Since the amount of data lost due to computer stops prior to completion of a file was strongly dependent on the time length of a file, this length was reduced from twelve hours to three hours following the first heating season. While this step significantly reduced the proportion of data lost, it required slightly more time to transmit a given amount of data and modest additional down time of the computer to clean and reorganize the disk.

Although some data was lost as a result of the transmission process, such losses were relatively quite small. This was principally due to provision of a mechanism by which files could be saved by redesignating them at the sending end if difficulties occurred during transmission that indicated possible loss of transmitted data. While this mechanism was exercised beneficially on a number of occasions, there were occasions in which losses were incurred due to failure to identify circumstances that produced data loss. More commonly, these circumstances were identified; but it was not possible to exercise the save mechanism in a timely manner. This resulted from the requirement that this mechanism must be used during normal operation of the data collection program, but not during transmission, and that it must be exercised prior to a computer stop in order to save the data. Since circumstances which might result in loss of data were normally detected during transmission and since machine-initiated stops sometimes occurred during the same transmission, it was not possible to utilize the save mechanism in this combination of circumstances.

The second type of data loss was a failure to record data on the System 7 computer, due to malfunctions or modifications of the data acquisition system or the computer software. Obviously, data were not recorded any time a computer stop occurred. Despite a continual effort to reduce down time, both manual and machine-initiated stops occurred frequently. It may seem paradoxical, but the down time was frequently greater during periods of heightened activity by on-site personnel. This was a result of a higher rate of computer stops associated with diagnostic work and data transmission. Conversely, during vacation periods of the regular on-site personnel, data were recorded with relatively few interruptions. But there is less confidence in the data obtained during the latter periods, due to the reduced amount of diagnostic work done during these periods.

Most of the stops were manually-initiated, and they were necessary for a wide variety of purposes, such as modifications to computer software, cleaning and reorganizing the disk and trouble-shooting. A number of machine-initiated stops occurred, aside from those mentioned previously, during transmission; but these stops were generally bunched together in time. They usually resulted from weaknesses or failures in the computer hardware and were normally readily corrected by actions of IBM Customer Engineers.

Aside from machine stops, there were also failures to record data due to malfunctions of portions of the data acquisition system. The major loss of this type was associated with an indexing method used to input data from several sensors to a single computer data channel. During the 1974-75 heating season, an array of five room temperatures was sampled and recorded using this method; and during 1975-76, three tank temperature arrays with 24 sensors each, were added. The method involved use of an electrically-driven, precisely-timed switch in a Honeywell "Brown" Recorder, operating on a separate time base from that of the computer. The principal difficulty in making this method operate satisfactorily was related to the necessity to identify the first channel of a sequence and then "locking-in" on the sequence. After the "bugs" had been

worked out of this scheme during the first period of data collection, it performed satisfactorily. But the time required to obtain satisfactory operation was rather long, as indicated in Appendix A, for 1974-75. Application of this method to the three tank temperature arrays in addition to the room temperature array during the second heating season introduced additional difficulties related to the fact that the various electrically-driven switches were not always sampled in the same sequence by the computer. Resolution of these problems consumed considerable time and caused additional data losses, identified in Appendix A.

Absence of sensors also caused data losses of the type under discussion. The most significant example of this was delivery of single phase watt-hour meters from one and a half to two months late in the first heating season. Loss of detailed data on electrical energy use was averted by manually-recorded visual readings of common dial-type watt-hour meters obtained on loan from Public Service Company of New Mexico. These readings were recorded hourly from 800 to 1800 each weekday for approximately six weeks at the start of the first period of data acquisition.

Instantaneous water flow rates through the piping loops associated with water-to-water heat pump operation and solar energy collection and total amounts of water flow through the water-to-air heat pumps were also recorded in this manner. It was these detailed observations of flows and flow rates for the various modes of operation which led to the conclusion that turbine meters were not an absolute requirement for monitoring water flow rates, due to the relative constancy of flow rates during each operating mode. However, circumstances arose during both seasons, such as gradual changes in flow rates, which would have made use of turbine meters desirable. Eventually one such meter was acquired and installed, but a complete set of such meters was never obtained. The major data losses incurred by the absence of turbine meters were due to incomplete information during system transients and lack of sufficient flow rate information to perform an energy balance on the heat exchanger between the collector loop and the main system.

A decision was made early in the planning of this project not to output data from the data acquisition computer in engineering units at the site. To do so would have entailed significantly higher computer rental costs. It was quickly recognized during the initial system "shake-down" that such an arrangement was inadequate for diagnostic work and for analysis of system operation. Use of digital multimeters provided some aid to diagnostics, but a continuous record of outputs from various channels was needed. To fill this gap in the data acquisition equipment, a Kaye Instruments System 8000 data logger was borrowed from the Mechanical Engineering Department at The University of New Mexico and installed at the site. At first, ten temperature measurement channels were monitored locally by this means, but the number of channels was subsequently expanded, first to twenty channels, then to thirty channels. The inputs to the data logger paralleled those to the IBM System 7, but they comprised a relatively small subset of the channels monitored by the data acquisition computer. The data logger was used to continuously monitor a few temperature channels which yielded valuable information on operation of important components such as the collector array, the storage tank and the water-to-water heat pump. The data on these channels was normally sampled and recorded on paper tape every half hour, except during special tests, when more frequent sampling was employed.

The reason for noting these provisions for local data acquisition is that the data thus obtained were very helpful in filling the gaps in the computer-recorded data, for diagnostic and system analysis purposes. This data was useful in trouble-shooting both the heating and cooling system and the data acquisition system, because: 1) in the case of the former system it provided immediate readout of instantaneous data, and immediate output of instantaneous data was very much more useful for trouble-shooting than the two- or three-day old average data provided by the computer system, and 2) in the case of the latter system, it provided an alternate set of data for comparison with the computer-recorded data. With regard to system analysis, the locally-recorded data were very useful despite the relatively long periods between samples, once normal operating patterns of the system had been recognized. The locally-output data was usually scanned at least once a day to determine whether the system's operation had been normal. It was also very useful in executing redundancy checks on the more important temperature measurements, as described in the following section.

SENSOR FAULTS

Appendix B contains lists of observations and actions pertinent to sensor faults. There are separate lists for the 1974-75 and 1975-76 heating seasons.

In maintaining the instrumentation, efforts were concentrated on sensors pertinent to energy flows to, and through, major components and subsystems, including the storage tanks, the water-to-water heat pump, the water-to-air heat pump loop, the collector array, the evaporative water cooler and the air handling unit. These efforts dealt principally with temperature sensors, watt-hour meters, water flow and flow rate meters and solar flux meters (pyranometers), but they also extended to mode sensors, door position sensors and air flow rate measurements with pitot-static tubes.

It may be implied from the length of the list for thermistors, that a large portion of the effort focused on these sensors (which were used to sense all the temperatures monitored by the data acquisition computer). This concentration of effort was the result of experience gained during the first heating season. As a result of discussion at an Advisory Committee meeting in December 1974, approximately one month after system startup, a constant temperature bath and a precision mercury-in-glass thermometer were obtained and used to check outputs from several of the more important thermistors located in the equipment room. The agreement between the readings from the thermistors and the mercury-in-glass thermometer was well within the manufacturer's tolerance. Several of these thermistors either directly measured temperatures at the water side inlets and outlets of the heat exchangers on the water-to-water heat pump or provided redundancy checks on these measurements. Nevertheless, repeated efforts to obtain an energy balance on the water-to-water heat pump failed, despite the good results obtained from the constant temperature bath check and despite repeated checks on the electrical energy flow and the water flow rates through the evaporator and condenser of this heat pump. In the process of resolving this problem, it was found to be desirable to enforce a tolerance during conditions involving negligible heat flow, of $\pm 0.33^{\circ}\text{F}$ on the difference between two sensors used to measure the temperature difference across a heat exchanger. This tolerance is significantly below the tolerance of $\pm 0.90^{\circ}\text{F}$ obtained by combining the manufacturer's tolerance on individual sensors. In other words,

it was found to be necessary to use essentially matched thermistors to determine temperature differences pertinent to energy balances and to important energy flow rates. Although the major problem with the above-mentioned energy balance was traced to a previously undetected recirculating flow and not to sensor faults, this experience drilled home the importance of making regular checks on the consistency of readings obtained from redundant temperature sensors.

Regular checks were performed on redundant water temperature sensors by checking the consistency of readings obtained from these sensors when there was no significant heat transfer through the piping or heat exchangers separating them. These conditions existed when either steady state operation was approached or when an item of equipment, such as a heat pump compressor, was inoperative. Therefore, data obtained for both normal system operation and for special test periods were useful in executing redundancy checks. The output of the on-site data logger was scanned at least once daily, as indicated previously, to execute redundancy checks using normal operating data. Starting late in the first heating season, thorough-going tests were executed every week or two by: 1) adjusting the main system thermostat to drive that system into a desired mode of operation, normally heat pump heating in the winter and heat pump cooling in the summer, 2) shutting off electric power to all heat pump compressors while leaving all blowers and pumps operating, 3) observing redundant temperature readings across heat exchangers to see whether they agreed within the desired tolerance as steady state with zero heat flow was approached and, if the agreement was not satisfactory, carrying out further checks until either the problem was resolved or the offending sensor was replaced, and 4) restoring electric power to all compressors and observing temperatures, flow rates and electric energy readings as the various subsystems approached steady state. It was possible to observe instantaneous temperatures and flow rates on-site by means of the data logger and visual observation of flow meters, while information on electric energy use required return of six-minute average data from The Pennsylvania State University. To assure correspondence between instantaneous and average values, essentially steady state values were normally observed for at least three six-minute averaging periods, i.e., eighteen minutes. Simultaneous temperature, electric energy and flow rate values were used to perform energy balances on the water-to-water heat pump. Simultaneous temperature differences across the water sides of individual water-to-air heat pump heat exchangers were used, together with flow rates obtained from long term observations of integrating water flow meters for each such heat pump, to check the temperature difference across the entire water-to-air heat pump piping loop during the test runs under consideration. This check was considered essential because the water-to-air heat pump loop subsystem was a major source of thermal energy for the original 6000 gallon storage tank and the temperature difference across this loop was often about 1.5°F.

Some simultaneous temperature sensor outputs during the test runs were useful in performing redundancy checks. For example, in the heat pump heating mode the water-to-water heat pump condenser was connected in series with the air handling unit heat exchanger. As steady state operation was approached, the condenser outlet and air handling unit inlet temperatures were checked for consistency, as were the air handling unit outlet and condenser inlet temperatures. If these temperatures did not agree within 0.33°F, as sometimes occurred when a reduced steady-state period was necessary or when transients were slow in

disappearing, an alternate requirement was imposed of agreement within 0.33°F between the temperature difference across the condenser and that across the air handling unit.

Despite frequent redundancy checks on temperature sensors, the energy balance checks revealed faults that had not been previously detected. Thus, the importance of performing energy balances was established.

The stringent tolerance adopted for water temperature measurements was not applied to air temperature measurements because accurate measurements of average air temperatures during normal system operation were not possible. This was due to the facts that air stream temperatures were nonuniform and available computer inputs permitted only one air temperature sensor at each location. Hence, only redundancy checks were performed on air temperature sensors, and these were executed only under conditions of zero heat flow, so that inlet and outlet temperatures could be compared. Such redundancy checks were useful primarily for the water-to-air heat pumps, since most of them operated cyclically.

The thermistors used to sample indoor temperatures were occasionally checked by comparison with readings from a precision mercury-in-glass thermometer. Since high accuracy in these temperatures was not necessary, agreement within 1°F was acceptable.

Outdoor dry bulb and dewpoint temperature readings were compared occasionally against simultaneous values obtained from the local office of the National Weather Service. No tolerance was imposed on the agreement between these values, since no basis for such a tolerance was identified.

The temperature sensors used in the tank temperature probes could not be readily checked in a rigorous manner. Their readings could be compared at times when the tank temperature distribution appeared nearly uniform, but if a reading appeared to be out of line with the others, one could only speculate as to the cause. However, grossly inconsistent readings were disregarded. All these sensors were checked in the constant temperature bath against a precision mercury-in-glass thermometer prior to installation. But it was physically impossible to remove the sensors and check them in the same manner after the probes had been assembled, due to friction between the sensor leads and the walls of the PVC tubes used to construct the probes.

Electric energy use was monitored by watt-hour meters equipped with contact devices, or pulse initiators, to permit automated readout of the meter readings, as described in the earlier report on Instrumentation of Building and System (COO/2704-20). These meters required relatively infrequent attention, since their outputs usually appeared to be very reliable. Because of the manually-recorded data on electrical energy use, identified previously in this report, the outputs from the automated meters were checked early in the first heating season. The questions and problems which arose at that time were all resolved, and were mainly due to a misunderstanding of the operating characteristics of the input cards on the data acquisition computer. However, a question arose about the accuracy of readings from watt-hour meters monitoring very low rates of energy use, i.e., on circuits with low current flow. This question occurred because the meter on water-to-air heat pump No. 5 consistently indicated about half the power specified by the manufacturer. This low value resulted in poor

energy balances on heat pump No. 5, thus tending to confirm its inaccuracy. At our request, two 100-amp class watt-hour meters with contact devices were calibrated by the Metering Department of Public Service Company of New Mexico at 1.5 and 15 amperes and found to be accurate within 0.2 percent. This resolved the questions about accuracy of watt-hour meters with contact devices at low rates of energy use, but the low readings obtained from the meter on heat pump No. 5 continued, despite repeated checks by project personnel and by an electrician to determine that the meter was wired properly. Some useful data on the electrical energy flow to this unit was obtained by using a portable Amprobe meter with a clamp-on sensor.

During the entire data collection phase, lasting about 18 months, only two watt-hour meters and two contact devices are known to have failed. However, efforts to obtain reasonable agreement between measured and estimated single phase building power, including lights, utility outlets and miscellaneous equipment failed. The meter reading was consistently above the estimate, but repeated attempts did not resolve the discrepancy. Through subsequent experience with the same type watt-hour meters equipped with the same type contact devices, it has been learned that the pulses produced by these devices may be far from the anticipated square wave, that is, the signals may be very "noisy". So it is possible that, even though the computer sampled these devices discretely rather than continuously, false readings were obtained. This is particularly possible in the case of the building single phase watt-hour meter, since the disk on it rotated relatively rapidly.

Problems encountered with the pyranometers and the methods used to check their outputs are discussed in the Solar Radiation section of the report on Instrumentation of Building and Systems (C00/2704-20). Two of the first three pyranometers used on the project failed during the first two months of data collection. Another six weeks of time were required to acquire, install and check out the replacements for all three pyranometers. The replacements apparently continued to operate reliably through the remainder of the data acquisition period, as indicated by a comparison check performed during the final month of data collection.

Two of the four rotameters used to measure instantaneous water flow rates were calibrated using a weigh tank at The Pennsylvania State University prior to shipment to Albuquerque and subsequent installation in the system. These, along with an existing rotameter, were recalibrated during the first heating season at The University of New Mexico in the effort described earlier to resolve the problems with the energy balance on the water-to-water heat pump. These meters appeared to give consistently reliable readings. It was possible to perform redundancy checks on two of them, and this was done repeatedly during the first heating season. The total flow meters used on the water-to-air heat pumps were not checked individually, but their sum was checked against a difference in the readings obtained from two rotameters. One of these meters, on water-to-air heat pump No. 2, failed during the second season; but by the time the failure occurred, the heat pump had ceased to function and the space it conditioned was not currently in use, so it was not repaired.

APPENDIX A

TABLE A

INCLUSIVE DATES OF DATA COLLECTION

1. 1974-75 Heating Season
Data Collection Initiated: November 15, Julian date 318, 1974.
Data Collection Terminated: June 5, Julian date 156, 1975.
2. 1975-76 Heating Season
Data Collection Initiated: December 16, Julian date 350, 1975.
Data Collection Terminated: April 30, Julian date 121, 1976.

APPENDIX A

TABLE B

DATES WITH 24 HOURS OF DATA
COLLECTION AND PERMANENT STORAGE

1. 1974-75 Heating Season

Julian Dates

318 105
319 108
322 114 - 117
325 - 327 122 - 125
329 128 - 134
330 136 - 140
332 142
334 143
336
340 - 342
348
359
353 - 364

1
4 - 8
11
12
15
18
22
25
26
28
34
35
37 - 43
46
47
53
54
57
58
60
68
69
71
73 - 75
77
80 - 83
86 - 89
93 - 95
97
99
101
103

2. 1975-76 Heating Season

Julian Dates

351
354
355
357 - 362
1
3 - 5
8 - 11
13
14
16 - 19
22 - 25
27 - 32
34 - 36
40
41
43
45
46
48
50 - 54
57
58
60
62
63
65 - 67
73 - 76
79
80
85
87 - 89
91
94
95
97
98
101
102
104
106 - 109
112
113
118 - 120

APPENDIX A

TABLE C

DATES OF INCOMPLETE DATA COLLECTION
AND HOURS OF MISSING DATA

1. 1974-75 Heating Season

	Date	Hours of Missing Data		Date	Hours of Missing Data
1974	320	10:36 - 13:56		33	14:36 - 17:39
	321	1:56 - 14:41		36	5:39 - 18:09
	323	14:41 - 17:01		44	6:09 - 15:12
	324	5:01 - 15:28		45	3:12 - 13:42
	328	15:28 - 17:16		48	1:42 - 10:56
	331	5:16 - 14:44		48	22:56 - 24:00
	333	14:44 - 15:36		49	00:00 - 11:49
	335	3:36 - 16:22		49	23:49 - 24:00
	337	4:22 - 9:38		50	00:00 - 16:51
	338	9:38 - 21:36		51	4:51 - 14:58
	339	9:36 - 15:29		52	2:58 - 7:56
	343	3:29 - 16:33		55	7:56 - 15:30
	344	4:33 - 18:12		56	3:30 - 15:00
	345	4:33 - 18:12		59	3:00 - 16:52
	346	4:50 - 16:54		62	4:52 - 15:49
	347	4:54 - 14:41		63	3:49 - 16:19
	350	2:41 - 24:00		64	4:19 - 24:00
	351	00:00 - 24:00		65	00:00 - 13:54
	352	00:00 - 20:36		66	20:07 - 24:00
	364	20:36 - 24:00		67	00:00 - 9:36
	365	00:00 - 8:36		70	9:36 - 15:25
				72	3:25 - 8:31
1975	1	20:36 - 24:00		76	8:31 - 9:01
	2	00:00 - 15:36		78	9:01 - 15:17
	3	3:36 - 20:44		79	3:17 - 9:06
	9	8:44 - 12:19		79	21:06 - 21:37
	9	23:19 - 24:00		84	9:37 - 24:00
	10	00:00 - 8:37		85	00:00 - 8:36
	13	10:37 - 24:00		90	8:36 - 24:00
	14	00:00 - 12:05		92	00:00 - 8:58
	16	12:05 - 17:21		96	8:58 - 14:57
	17	5:21 - 17:06		98	14:57 - 18:37
	19	5:06 - 16:54		100	6:37 - 8:36
	20	4:54 - 18:49		102	8:36 - 16:39
	21	6:49 - 9:26		104	4:39 - 9:50
	22	21:26 - 24:00		106	9:50 - 24:00
	23	00:00 - 9:26		107	00:00 - 9:36
	24	9:26 - 12:10		109	21:36 - 24:00
	27	12:10 - 12:21		110	00:00 - 9:36
	29	0:21 - 12:44		111	9:36 - 24:00
	30	12:44 - 13:30		112	00:00 - 24:00
	31	1:30 - 3:36		113	00:00 - 13:26
	32	12:36 - 14:36		118	13:26 - 17:39

APPENDIX A

TABLE C (cont'd)

1. 1974-75 Heating Season

	Date	Hours of Missing Data		Date	Hours of Missing Data
1975	119	5:39 - 8:43		47	7:24 - 11:36 and
	119	20:43 - 23:05			11:36 - 12:12
	120	11:05 - 24:00		55	6:12 - 10:11
	121	00:00 - 19:40		56	7:11 - 9:30
	126	7:40 - 24:00		59	9:30 - 10:22
	127	00:00 - 9:46		61	10:22 - 11:00
	135	9:46 - 22:15		64	11:00 - 12:19
	141	10:15 - 15:58		68	11:26 - 15:35
	144	15:58 - 24:00		69	11:48 - 24:00
	145	00:00 - 24:00		70	24:00 - 10:50 and
	146	00:00 - 14:01			13:50 - 14:53
	147	2:01 - 13:31		71	11:06 - 12:58
	148	13:31 - 15:36		72	9:11 - 9:36
	149	15:36 - 24:00		77	10:43 - 16:17
	155	00:00 - 16:31		78	13:29 - 16:38
	156	4:31 - 24:00		81	19:42 - 24:00
				82	24:00 - 14:47
				83	8:08 - 10:22 and
					19:03 - 22:21
				84	9:56 - 10:42
				86	8:54 - 12:06
				90	9:25 - 13:17
				92	11:29 - 16:17
				93	9:38 - 11:07 and
					14:03 - 14:44
				96	7:13 - 10:16
				99	8:30 - 11:45 and
					20:27 - 23:45
				100	8:27 - 9:21
				103	9:32 - 11:18
				105	6:37 - 12:16
				110	7:43 - 10:36
				111	9:43 - 12:34
				114	6:57 - 24:00
				115	00:00 - 12:56
				116	6:17 - 9:56
				117	11:57 - 13:16
				121	9:38 - 11:57

2. 1975-76 Heating Season

	Date	Hours of Missing Data		Date	Hours of Missing Data
1975	352	10:18 - 10:51			
	353	13:51 - 16:47			
	356	7:47 - 9:21 and			
		12:21 - 14:39			
	363	23:39 - 8:47			
	364	11:47 - 11:54			
	365	8:54 - 13:28			
1976	2	13:28 - 14:16			
	6	14:16 - 17:12			
	7	11:12 - 18:07			
	12	9:07 - 11:18			
	15	14:18 - 16:30			
	20	10:30 - 11:29			
	21	8:29 - 14:36			
	26	8:36 - 11:54			
	33	8:54 - 13:36			
	37	10:36 - 16:08			
	38	7:08 - 9:26 and			
		12:26 - 12:49			
	39	15:49 - 18:53			
	42	6:53 - 10:42 and			
		13:42 - 15:12 and			
		18:12 - 18:36			
	44	12:36 - 13:24			

END

APPENDIX B

LIST OF RECORDED SENSOR FAULTS

Note: Refer to lists of channel designations later in this appendix for identification of sensor function.

I. Thermistor and Dew Point Probe Faults

A. 1974-75

<u>Date</u>	<u>Item</u>
2/8/75	Replaced AI-12 and AI-17 at 9:00 after constant temperature bath check.
3/23/75	AI-21 out of tolerance until 3/31/75.
3/31/75	AI-21 replaced.

B. 1975-76

12/17/75	AI-18 replaced.
12/20/75	AI-09 replaced.
1/6/76	AI-17 replaced.
1/7/76	AI-26 } Dew point probes removed from AI-27 } position for bake-out.
1/8/76	AI-26 } Dew point probes returned to AU-27 } position.
1/20/76	AI-27 replaced.
1/28/76	AI-23 failed at 13:54.
2/2/76	AI-23 replaced.
	AI-24 (Reception Room) replaced.
	AI-17 out of tolerance until 3/3/76.
2/7/76	AI-18 failed at 12:49 AI-11 failed at 12:49
2/16/76	AI-18 replaced at 13:50, but out of tolerance rest of & data collection period, due to bad thermal well. AI-11 (H.P. #2 inoperative, H.P. #4 operative on cooling only.)
3/3/76	AI-17 replaced.
4/6/76	AI-57 failed at 1:10 (bad rest of data collection period)
4/21/76	Constant temperature bath check of equipment room thermistors 9:30 to 13:30.

II. Watt-hour Meter Faults

A. 1974-75

<u>Date</u>	<u>Item</u>
1/7/75 to 1/8/75	DI-18 not operating continuously H.P. #6

APPENDIX B

II. Watt-hour Meter Faults (cont'd)

B. 1975-76

<u>Date</u>	<u>Item</u>
1/2/76	Meter on DI-13 failed.
1/8/76	Meter on DI-13 replaced.
1/9/76	Meter on DI-12 removed; but in position for DI-19.
1/21/76	Meter on DI-21 now operating.
2/4/76	Meter on DI-11 removed; but in position for DI-12.
2/6/76	Meter on DI-12 removed; but in position for DI-11.
2/9/76	Meter on DI-04 removed for rest of data collection period; but in position for DI-12.
4/23/76	Meter on DI-17 replaced.

III. Pyranometer Faults

A. 1974-75

1/75	AI-02, AI-03, noted unusually high readings. Ordered replacement pyranometers.
2/28/75 to 3/11/75	Installed and compared new pyranometers with PSP from Sandia.

B. 1975-76 No faults. Pyranometers rechecked against an Eppley PSP in April 1976.

IV. List of Input Channels

A. 1974-75

	<u>Input Channel No.</u>	<u>Description</u>
<u>Analog</u>	AI-01	Collector Solar
	AI-02	Diffuse Solar
	AI-03	Horizontal Solar
	AI-04	Wind Direction
	AI-06	Evap. Water Cooler EWT*
	AI-07	Evap. Water Cooler LWT
	AI-08	W/W HP Chiller EWT
	AI-09	W/W HP Chiller LWT
	AI-10	Condenser EWT
	AI-11	Condenser LWT
	AI-12	Storage Tank EWT
	AI-13	Storage Tank LWT
	AI-14	W/A HP Loop EWT
	AI-15	W/A HP Loop LWT
	AI-16	Air Handling Unit EWT
	AI-17	Air Handling Unit LWT

*List of Abbreviations at end of listing

APPENDIX B

IV. List of Input Channels (cont'd)

<u>Input Channel No.</u>	<u>Description</u>
AI-18	HX Glycol Side EGT
AI-19	HX Glycol Side LGT
AI-20	HX Water Side EWT
AI-21	HX Water Side LWT
AI-22	Coll. Air Temp.
AI-23	Coll. Surface Temp.
AI-29	Wind Velocity
AI-25	Outdoor Dry Bulb Temp.
AI-26	Outdoor Dew Pt. Temp.
AI-27	Indoor Dew Pt. Temp.
AI-28	Voltage Source (Thermistor)
AI-30	Voltage Ref. (Computer)
AI-05	{ Reserved for turbine meter output
AI-05	
AI-05	
AI-05	
AI-24	Draft Room North Temp.
AI-24	Draft Room Attic Temp.
AI-24	Print Room Temp.
AI-24	Computer Room Temp.
AI-24	Reception Room Temp.
AI-24	Ignore
<u>Digital</u>	
DI-02	Whr-Mtr Bldg. 3 Phase
DI-02	Whr-Mtr Water Heater
DI-03	Whr-Mtr Bldg. 1 Phase
DI-04	Whr-Mtr B&P IBM 1130
DI-05	Whr-Mtr System 7
DI-06	Whr-Mtr AHU
DI-07	Whr-Mtr EWC
DI-08	Whr-Mtr Pump #1 - DH, Chiller
DI-09	Whr-Mtr Pump #2 - Condenser
DI-10	Whr-Mtr Pump #3 - H.P. Loop
DI-11	Whr-Mtr Pump #4 - Collectors
DI-12	Whr-Mtr Pump #5 - EWC
DI-13	Whr-Mtr PH #1 W/W
DI-14	Whr-Mtr HP #2 W/A
DI-15	Whr-Mtr HP #3 W/A
DI-16	Whr-Mtr HP #4 W/A
DI-17	Whr-Mtr HP #5 W/A
DI-18	Whr-Mtr HP #6 W/A
DI-19	Whr-Mtr B&P Gen Auto
DI-20	Front Ext Door Open
DI-21	Elec Eng Off Door Open
DI-22	Center Ext Door Open
DI-23	E.E. Print Room Door Open
DI-24	Draft Room Ext Door Open
DI-25	Direct Heating

APPENDIX B

IV. List of Input Channels (cont'd)

<u>Input Channel No.</u>	<u>Description</u>
DI-26	Winter HP Heating
DI-27	Winter HP Cooling
DI-28	Max Tank Temp. Control
DI-30	Winter Evap. Cooling

B. 1975-76

AI-01	Collector Solar
AI-02	Diffuse Solar
AI-03	Horizontal Solar
AI-04	Wind Direction
AI-05	Tank #1 Temp's (24)
AI-06	HP #6 Delta T a
AI-07	HP Chiller, LWT
AI-08	HP Condenser, LWT
AI-09	Air Handling Unit, LWT
AI-10	HP #2, Delta T w
AI-11	HP #4, Delta T w
AI-12	HP #2, EAT
AI-13	HP #2, Delta T a
AI-14	HP #3, EAT
AI-15	HP #3, Delta T a
AI-16	HP #4, EAT
AI-17	Evap. Water Cooler, LWT
AI-18	HP #4, EWT
AI-19	HP Chiller, EWT
AI-20	HP #3, Delta T w
AI-21	HP Condenser EWT
AI-22	HP #5, Delta T w
AI-23	HP #6, Delta T w
AI-24	Drafting Room Temp.
AI-24	Attic Space Temp.
AI-24	Print Room Temp.
AI-24	Reception Room Temp.
AI-24	Computer Room Temp.
AI-24	Brown Recorder Ref. Voltage
AI-25	Outdoor Dry Bulb
AI-26	Outdoor Dew Point
AI-27	Indoor Dew Point
AI-28	Voltage Source
AI-29	Wind Velocity
AI-30	Voltage Reference
AI-31	Tank #2 Temp (24)
AI-32	Tank #3 Temp (24)
AI-33	Storage Tank, EWT
AI-34	Storage Tank, LWT
AI-35	W/A HP Loop, EWT
AI-36	W/A HP Loop, LWT
AI-37	Air Handling Unit, EWT
AI-38	HP #4, Delta T a

APPENDIX B

IV. List of Input Channels (cont'd)

<u>Input Channel No.</u>	<u>Description</u>
AI-39	HP #5, EAT
AI-40	HP#5, Delta T a
AI-41	HP #6, EAT
AI-42	Evap. Water Cooler, EWT
AI-43	Air Handling Unit, EAT
AI-44	Air Handling Unit, LAT
AI-45	Static Pressure
AI-46	W/A HP #6 DHC EWT
AI-47	W/A HP #6 DHC LWT
AI-48	Storage Tank 2 & 3, EWT/AHU
AI-49	Storage Tank 2 & 3, LWT/AHU
AI-50	Storage Tank 2 & 3, EWT/EGX
AI-51	Storage Tank 2 & 3, LWT/EGX
AI-52	Flowmeter 1 Tank 2 & 3 LWT/AHU
AI-53	Flowmeter 2 Tank 2 & 3, LWT/EGX
AI-54	HX Glycol Side EGT
AI-55	HX Glycol Side LGT
AI-56	HX Water Side EWT
AI-57	HX Water Side LWT
DI-03	Whr-Mtr Bldg. 3 phase
DI-02	Whr-Mtr Water Heater
DI-03	Whr-Mtr Bldg. 1 phase
DI-04	Whr-Mtr B&P Gen. Automation Computer
DI-05	Whr-Mtr System 7
DI-06	Whr-Mtr AHU
DI-07	Whr-Mtr EWC
DI-08	Whr-Mtr Evaporator Pump W/W HP
DI-09	Whr-Mtr Condenser Pump W/W HP
DI-10	Whr-Mtr W/A HP Loop Pump
DI-11	Whr-Mtr Collector Pump
DI-12	Whr-Mtr Evaporative Water Cooler Pump
DI-13	Whr-Mtr W/W HP #1
DI-14	Whr-Mtr W/A HP #2
DI-15	Whr-Mtr W/A HP #3
DI-16	Whr-Mtr W/A HP #4
DI-17	Whr-Mtr W/A HP #5
DI-18	Whr-Mtr W/A HP #6
DI-19	Whr-Mtr Storage Tank 2 & 3 Pump to EGX
DI-20	Whr-Mtr Direct Heating Coil Pump
DI-21	Whr-Mtr Fresh Air Fan
DI-22	Collection to New Tanks
DI-23	Override to HP Heating
DI-24	Draft Room Ext. Door Open
DI-25	Direct Heating
DI-26	Winter HP Heating
DI-27	Winter HP Cooling
DI-28	Collector Operation

APPENDIX B

IV. List of Input Channels (cont'd)

<u>Input Channel No.</u>	<u>Description</u>
DI-29	Max. Tank Temp. Control
DI-30	Winter Evap. Cooling
DI-31	W/W HP Operation
DI-32	Directing Heating T2 & T3

LIST OF ABBREVIATIONS

EAT	Entering air temperature
EWI	Entering water temperature
LAT	Leaving air temperature
LWT	Leaving water temperature
AHU	Air Handling Unit
HP	Heat Pump (water-to-water)
W/A HP	Water-to-air heat pump
HX	Heat Exchanger
Delta T a	Air temperature differential
Delta T w	Water temperature differential
EGX	Ethylene-Glycol Side of Heat Exchanger