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EVALUATION OF THE SOLAR BUILDING,
ALBUQUERQUE, NEW MEXICO: ##

INSTRUMENTATION OF BUILDING AND SYSTEM

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INTRODUCTION

The purpose of this report is to describe the instrumentation used to obtain data on the Solar Building, Albuquerque, New Mexico during the period November, 1974, through April, 1976. In this report, attention is focused on the types of instrumentation used: their principles of operation, sensitivity, range and where pertinent, installation. Locations of sensors are identified, so far as this pertains to obtaining accurate and adequate data. Detailed lists of locations of each type of sensor for each of three major data acquisition periods are contained in a separate report. A list of sensors monitored in the third period is presented, as an example in Appendix A. But it may be noted that the instrumentation to be described was used to obtain information on solar energy, both incident and collected, on energy flow and operating characteristics of the solar-assisted heat pump heating and cooling system and on almost all forms of energy use in the building except the personal energy of the occupants.

For convenience, the physical quantities measured and the type of instrument used to measure each are presented in Table 1, on the following page. The nature of the output from the instrument and the normal method of recording that output are also given in Table 1.

DESCRIPTION OF INSTRUMENTATION¹

Temperature Measurements

Thermistor Sensors

Thermistors were employed to measure all air and water temperatures that were continuously monitored by the System 7 data acquisition computer. The principal reason for selection of thermistors was that they would satisfy the input voltage requirements of the System 7. However, the thermistors employed also have the advantage of exhibiting high precision, as discussed later in this section.

The thermistors were composite pairs encapsulated in epoxy to form a probe and attached to ten-foot vinyl-jacketed lead wires having a phone plug on the far end. The three-section phone plug is used to connect each thermistor to a shielded three-wire cable to the power supply and output terminals. A nominal two-volt DC power supply is connected to each thermistor through a network containing two fixed resistors. The combination of fixed resistors in the power supply network and variable resistors in the probe produces an output that is linear within a given tolerance for a particular temperature range. The general form of the relation between input and output voltage is $E_{out} = E_{in} [C_1 T + C_2]$, where C_1 and C_2 depend on the range and temperature scale, and T is temperature. The specific thermistors used were number 44018 composites made by Yellow Springs Instruments Company. For all water and indoor air temperatures, including dew point, number 44301 resistor composites (pairs) were used to cover the range from 0C to 100C (32°F to 212°F) with a maximum deviation from linearity of not more than $\pm 0.22C$ ($\pm 0.39^\circ F$). Number 44303 resistor composites were used for outdoor temperatures, including dew point, to cover the range from -30C to +50C (-22°F to 122°F) with a maximum deviation from linearity of $\pm 0.16C$ ($\pm 0.29^\circ F$).

¹To aid in identifying instruments, the manufacturer's name is sometimes given. No endorsement of any product is implied.

TABLE 1
LIST OF INSTRUMENTS

<u>Physical Quantity Sensed</u>	<u>Type of Instrument</u>	<u>Output Form</u>	<u>Recording Method</u>
Temperature	Thermistor Pair	Voltage	Computer Digitization and Storage
Temperature	Thermocouple	Voltage	Self-balancing Potentiometer with Strip Chart or Manual
Temperature (Dew Point)	Dual Spool with Thermistor Pair	Voltage	Computer Digitization and Storage
Solar Flux	Pyranometer	Voltage	Computer Digitization and Storage
Electric Energy	Watt hour Meter	Change in State of Contact Closure	Computer Count and Storage
Flow Rate (Water)	Rotameter	Linear Displacement	Manual
Flow Rate (Air)	Pitot-Static Tube	Linear Displacement	Manual
Flow Rate (Air)	Anemometer	Dial Indicator	Manual
Flow Rate (Air)	Duct Air Monitor Device	Linear Displacement	Manual
Operating Mode	Relay	Change in State of Contact Closure	Computer Count and Storage
Door Open	Reed Switch	Change in State of Contact Closure	Computer Count and Storage
Infiltration Rate	Gas Chromatograph (Tracer Gas)	Voltage	Strip Chart
Supply Voltage	Power Supply	Voltage	Computer Digitization and Storage

In addition to the linearity deviation, there is also an error due to manufacturing tolerances of $\pm 0.15^{\circ}\text{C}$ ($\pm 0.27^{\circ}\text{F}$) for both resistor composites. Thus the maximum error specified by the manufacturer is $\pm 0.37^{\circ}\text{C}$ ($\pm 0.66^{\circ}\text{F}$) for the 0°C to 100°C range and $\pm 0.31^{\circ}\text{C}$ ($\pm 0.56^{\circ}\text{F}$) for the -30°C to $+50^{\circ}\text{C}$ (-22°F to $+122^{\circ}\text{F}$) range.

In practice, it was found that two probes inserted in the same water stream at different locations not separated by a heat exchanger or other heat transfer element frequently agreed within much less than the nominal uncertainty stated above. In fact, our normal practice was to replace a thermistor if it was found to disagree by more than $\pm 0.19^{\circ}\text{C}$ (0.33°F) with another thermistor located in the same stream. Visual inspection of data output locally and of computer-acquired data returned from Penn State University was used to detect thermistors whose outputs exceeded the $\pm 0.19^{\circ}\text{C}$ (0.33°F) tolerance. Normal operational data for periods with negligible heat flow through a given component and data from test runs involving special operating modes were both used to detect out-of-tolerance thermistors. These techniques were applied regularly to check thermistors whose readings were used in computing energy flow rates for energy balances or for evaluating energy flow to and from storage, the collectors and the building, via the main air handling unit.

Another procedure employed occasionally to check the accuracy of some of the more critical thermistors involved use of a constant temperature bath. The thermistors were inserted in a bath whose temperature was measured independently with a high-resolution mercury-in-glass thermometer. The output voltage of a thermistor in the bath was always monitored locally with a digital multimeter or a data logger. Usually it was also monitored with the data acquisition computer by keeping each thermistor in the bath for at least two averaging periods (twelve minutes). The first such check was carried out about half-way through the first major period of data acquisition. It confirmed agreement between computer-sampled, and -calculated, temperatures obtained from thermistor outputs and the independently-measured bath temperature to within both the uncertainty given by the manufacturer and the desired tolerance of $\pm 0.19^{\circ}\text{C}$. It also provided a check on the accuracy of a number of critical thermistors, such as at the inlet and outlet of the water-to-water heat pump evaporator and condenser and the collector system heat exchanger. Additional checks using the constant temperature bath were carried out near the end of the final major data acquisition period. All new thermistors used for the second and third periods of data acquisition were checked using the bath prior to installation.

Thermistors used to sense water temperatures were inserted in oil-filled thermal wells which, in turn, were inserted in the flow stream through compression fittings. The thermal wells were made from nominal 1/2-inch diameter copper tubing with a soldered cap on one end. These wells were inserted into the flow stream as far as possible, normally three to four inches; but in two locations the insertion length was only about 2 inches. Preliminary tests pertinent to thermal well performance were performed in a laboratory at the University of New Mexico using a thermocouple sensor in a thermal well oriented at various angles relative to the direction of flow and inserted into the flow stream to various depths. The results indicated good agreement with a thermocouple sensor in a well inserted deep into the flow stream in an upstream direction, for all angles of insertion and for insertion depths as small as one inch. The flow rates used in these tests were in the range which occurred during system operation.

Thermistors used to measure air temperatures were simply placed at the desired location in the air stream or the space to be monitored. If the temperature was expected to vary across an air flow stream, such as at the outlet or inlet of a heat exchanger, the temperature distribution in the stream was surveyed by means of a thermocouple connected to a digital voltmeter, and the thermistor probe was located so as to read a temperature approximating an average. Such measurements were not claimed to be of high precision; hence, such air temperatures were normally used only to verify modes of operation, rather than to determine energy flow rates.

The locations of all indoor temperature sensors are shown in Figure 1, attached.

The thermistor and dew point probes used to monitor ambient outdoor conditions were located inside a well-ventilated box with a double roof, in general accord with a U.S. Weather Bureau specification.

Thermocouple Sensors

In addition to the computer-recorded temperature measurements using thermistors, copper-constantan thermocouples were used to measure some selected collector fluid temperatures. The mixed supply and return fluid temperatures were measured using thermocouples, for comparison with corresponding thermistor-measured temperatures. Thermocouples were also used to measure return temperatures from several groups of collectors, to determine what fluid temperature each group was delivering. Each group of collectors was connected to one supply and one return line. If the radiation incident on each group of collectors of a given total exposed area were the same and the flow rate through, and the efficiency of, each such group were the same, the return temperature would be the same. The fact that the return temperatures from the groups were normally not the same indicated various combinations of differences in these quantities. The principal factor producing a difference was the flow rate; hence different return temperatures were used primarily as an indicator of unbalanced flow rates. The thermocouple outputs were sampled, converted to temperatures and recorded by means of a Honeywell "Brown" recorder.

A thermocouple was also used to survey the temperature distribution in the heat pump supply and return air ducts, as stated above. Temperature differences, not absolute levels, were of interest, so a digital voltmeter was used for output.

Dew Point Sensors

Moisture content of indoor and outdoor air was determined by measuring dew point temperature. Dew point temperature was determined by using dew point probes comprised of two concentric, electrically-heated bobbins with a thermistor at the center of the inside bobbin, to measure the bobbin temperature. Both bobbins are comprised of spools covered with a wick impregnated with Lithium Chloride, on top of which gold bifilar electrodes are wound. As the moisture content of the surrounding air increases, the water content of the LiCl solution also increases. This produces larger currents through the wicks and the electrodes and raises the bobbin temperature until equilibrium is achieved. Dew point temperature is determined by measuring bobbin temperature, using the thermistor in the center, and employing calibration data supplied by the

manufacturer to convert bobbin temperature to dew point temperature. Resulting values are accurate to within $\pm 1.2^{\circ}\text{C}$ (2.2°F) for a dew point temperature range from -40°C to $+42^{\circ}\text{C}$ (-40°F to $+100^{\circ}\text{F}$), if no correction for ambient conditions is employed, according to the manufacturer, Yellow Springs Instrument Company. The response time of the dew point probe is about 1C (1.8°F) per minute.

Since only one channel each for indoor and outdoor dew point temperature was provided, redundant measurements were not possible. Occasional checks were made with hourly dew point temperature measurements at the local National Weather Service Station and usually exhibited agreement to within five degrees F.

The dew point probes require that 24V AC power be supplied to the bobbin filament windings, in addition to the 2V DC supply to the thermistor. To prevent possible damage to the probe in the event of loss and subsequent restoration of building AC power, a latching relay was employed. If AC power was lost temporarily, the relay's solenoid de-energized and the relay latched on the open position. Power could be restored to the probe only by manually resetting the relay after the main AC power had been restored. A shielded, four-wire cable was used to supply both AC and DC power to the dew point probe. One of the two leads to the bobbin filaments was common with one of the three leads to the thermistor.

During the first data collection period, erratic variations in outdoor dew point temperature were noted from the six-minute average data. Inspection of the surroundings revealed a nearby plumbing vent. Capping of this vent eliminated the erratic behavior.

THERMISTOR SUPPLY VOLTAGE

Since thermistor output voltage is directly proportional to supply voltage, and since drift of the supply voltages could not be reduced to negligible proportions, the three supply voltages were each sampled regularly at six minute intervals. The value of a given supply voltage measured at one time was used to reduce the outputs of all thermistors connected to that supply during the following six minutes.

Separate two-volt DC power supplies were used for the thermistor probes in the HVAC system, for the probes in the underground tank (Tank No. 1) and for the probes in the two above-grade tanks (Tank No's. 2 and 3) plus some HVAC system probes. Thus a total of three power supplies was used.

TIME SHARING AND INDEXING

The thermistor supply voltages were sampled at six minute intervals, in association with a procedure developed to sample and record several thermistor outputs by means of one input channel to the data acquisition computer. The technique of inputting several sensors on one channel was termed "time sharing" and the technique used to order and distinguish between the sensors was termed "indexing". These techniques were employed only for thermistors whose outputs could be expected to change slowly, such as room air temperatures and storage tank temperatures.

Time sharing was achieved by connecting several thermistors and the 2V power supply output to the input terminals of a Honeywell "Brown" recorder, and by connecting the recorder output to one channel of the System 7. The recorder served only as an automatic, precisely-timed switch; the measuring circuit was disconnected at all times. Since the "indexing period" of the recorders, i.e., the time elapsed between switching from one input channel to the next, was very precise, it was possible to reliably use an independent time base generated by the data acquisition computer to determine the times to index from one sensor reading to the next, once the initiation of a cycle of readings had been detected. The initiation of a cycle of readings was determined by sensing the DC power supply voltage, which was input to the Brown recorder with reverse polarity and was also considerably larger in absolute value than all other inputs. This "index voltage" was sensed by seeking for it at a relatively rapid sampling rate and by sampling it twice in order to "lock in" on the input signal near the center of an indexing period on the Brown recorder. Once the index voltage had been detected, the rate of sampling was reduced to correspond to the indexing period of the Brown recorder. Thus the desired thermistor outputs were sampled and recorded in a prearranged order.

These techniques were used to sample a set of five room temperatures and two sets of tank temperatures, in addition to the three DC power supply voltages.

ELECTRICAL ENERGY

Watt hour meters were used to measure the electrical energy supplied to all major and minor items of equipment in the HVAC system. These items included all heat pump compressors and blowers, all water pumps and the evaporative water cooler. In addition, total single phase and three phase energy supplied to the building was monitored, as well as the energy supplied to equipment producing significant internal loads, such as computers. Individual lighting circuits were not separately metered. The meters were all manufactured by the General Electric Company. Type I-70-S meters were used for all single phase circuits and Type V-62 meters were used for all three phase circuits. One hundred ampere class meters were used for all connections except total building single-phase and three phase energy, for which two hundred ampere class meters were used. Meter constants ranged from 3.6 to 14.4 watt hours per disk revolution. The stated accuracy of the Type I-70-S meters is well within $\pm 1\%$ for a current range from about 4 to 110 amperes, a voltage range from 120 to 260 volts and a temperature range from -20 to $+50^{\circ}\text{C}$ (-4°F to $+122^{\circ}\text{F}$).

All watt hour meters which were continuously monitored came equipped with a D-30 contact device. This is a three-element switch having a common blade and two "lower" blades which are displaced by two cams on a common shaft that rotates whenever the meter disk rotates. Each of the lower blades alternately makes contact with the common blade. A very short "open" interval occurs between breaking contact with one lower blade and making contact with the other lower blade. In this manner, a certain number of contacts is produced per revolution of the meter disk, which number is termed the contact ratio. By counting the number of contacts and knowing the contact ratio and the meter constant, energy consumption can be evaluated. Measurement of the time interval in which a given number of contacts occurs, enables determination of average power consumption during that interval.

The data acquisition computer was programmed to sample each watt hour meter contact device once per second, which was sufficient to detect each change from the open to closed mode, or vice-versa, of one side of the switch in the contact device. By counting the number of changes in mode of one side on each switch, the number of contacts was determined. Average power consumption during each six-minute averaging period was determined by inputting values of the contact ratio and the meter constant to the computer and by using the time base generated on the computer.

Two of the Type I-70-S meters equipped with D-30 contact devices were tested at no charge by the Meter Department of Public Service Company of New Mexico. The primary purpose was to assess the effects on meter accuracy of the contact devices, particularly at low current levels. The meters were tested at 240V and at currents corresponding to 5% and 50% of nominal full load current. Both meters were found to be accurate within $\pm 0.2\%$ of both currents.

SOLAR RADIATION

Incident solar radiation, or insolation, was measured at essentially one location, in both the plane of the collectors and in the horizontal plane, by means of three Eppley pyranometers. Two pyranometers were oriented parallel to the plane of the collectors. They were located above and to the side of the collector array in order not to shade the collectors nor to receive energy reflected or emitted from them. One of these pyranometers received all the radiation incident at that location, including direct radiation and reflected radiation. The other pyranometer received only diffuse incident radiation, due to a shadow band mounted above the sensor disk. This shadow band was adjusted regularly by manual means, to minimize incidence of direct radiation on the sensor. The pyranometer used to measure total radiation in the horizontal plane was located on top of the weather box identified in Section 2.1, in order to avoid reflections and shadows from adjacent objects.

The pyranometers employed at the start of the first major data acquisition period were of the older, bulb-shaped type. Two of them had 50 junction thermopiles, producing sensitivities on the order of 9 millivolts per Langley per minute; the third had a 10 junction thermopile with a sensitivity of 2.26 millivolts per Langley per minute. These pyranometers were checked for consistency during the first month of data acquisition and found to agree within about 10% except at large angles of incidence. However after about two months of data collection, it was noted that the pyranometer measuring insolation in the horizontal plane was producing unreasonably high readings. Hence three new Eppley Model 8-48 "Black and White" pyranometers were ordered. All had sensitivities of about 9 millivolts per Langley per minute. They were placed in operation during the first week in March of 1975.

As part of the process of interchanging the old and new pyranometers, an Eppley PSP "Precision Spectral Pyranometer" was borrowed from Sandia Laboratories and used as a reference to check readings from both the old and new pyranometers. First, the PSP and the new Black and White pyranometers were all placed in a horizontal plane on the roof in a location where little reflected radiation would be received. Their outputs were monitored by means of a data logger, also borrowed from Sandia Laboratories. One day of data acquisition established that good agreement existed between all these pyranometers over a wide range of

solar angles. Then, one-by-one, the original bulb-type pyranometers were interchanged with Black and White pyranometers. The outputs from the original pyranometers continued to be input to the System 7, in order to check agreement of the computer output for solar insolation from the old instruments with the locally-recorded output from the new pyranometers. This provided a check on computer-implemented data acquisition and reduction, as well as a check on the accuracy of each pyranometer. Once the pyranometers had all been interchanged, and readings in the new locations checked for consistency, the new pyranometers were connected to the data acquisition computer. In this manner it was found that the original pyranometers measuring total horizontal insolation and diffuse insolation on the plane of the collectors were badly out of calibration. However the pyranometer originally used to measure total insolation in the plane of the collectors was found to agree with the PSP within about 10%, when oriented with the sensor in the horizontal plane.

A similar check procedure was employed near the end of the final month of data acquisition. A PSP pyranometer subsequently purchased by the Mechanical Engineering Department at The University of New Mexico was used as a reference instrument. It was located on the roof in a horizontal plane, and the Black and White pyranometers were transferred one-by-one from their normal locations to the same location and plane as the reference instrument. For the purpose of checking, all outputs were sampled and recorded using a data logger. In this manner it was determined that all three pyranometers agreed with the reference within 5% when oriented with their sensors horizontal.

The serial number of the pyranometers and their normal orientations and applications are presented in Table 2.

TABLE 2
PYRANOMETER IDENTIFICATION

<u>Serial Number</u>	<u>Type, or Model</u>	<u>Orientation</u>	<u>Insolation Measured</u>
4025	Bulb, 50 Junction	Collector Plane	Total
4046	Bulb, 50 Junction	Collector Plane	Diffuse
767	Bulb, 10 Junction	Horizontal	Total
13750	8-48	Collector Plane	Total
13749	8-48	Collector Plane	Diffuse
13748	8-48	Horizontal	Total
13011F3	2	Horizontal (Reference)	Total
13690F3	PSP	Horizontal (Reference)	Total

FLOW MEASUREMENTS

Water Flows

Water flow measurements were accomplished by means of rotameters, which measure volumetric flow rate, and water meters, which measure total volume of flow. Rotameters were used to measure water flow rates through the evaporator and condenser of the water-to-water heat pump, through the heat exchanger in the air handling unit, through the water side of the heat exchanger between the collectors and storage and, during the second and third periods of data acquisition, through the evaporative water cooler, independently. It was possible to measure all the necessary water flow rates during the first two periods with three rotameters, due to interconnections between the various items of equipment, such as the heat pump condenser and the air handling unit during heat pump heating operation. During the third period, four rotameters were required. All rotameters had ranges from about 3.2×10^{-4} through 2.2×10^{-3} cubic meters per second (5 through 35 gallons per minute), which was adequate to handle the normal range of flow rates encountered. The rotameters were manufactured by Brooks Instrument Company and Fischer and Porter Company.

Three of the rotameters were calibrated by discharging them into a weigh tank, using a fluid friction test apparatus at The University of New Mexico. Two of these, whose scales read in millimeters, were also tested at The Pennsylvania State University, using a similar technique. The results of the two tests were found to agree closely, within about 1%, except at the upper end of the range of one rotameter, where the difference increased to 5%. The results for the third rotameter indicated agreement with the direct-reading scale within about 1%.

The rotameters were observed visually and readings were recorded manually. Although it was originally intended that turbine meters be used, together with computer monitoring of turbine meter output, to continuously monitor and record flow rates, severe difficulties were encountered in obtaining turbine meters with suitable port sizes and accuracies. Furthermore, the rotameters were observed visually at one hour intervals ten times per day during daytime hours for about six weeks at the start of data acquisition in 1974. These observations indicated consistent, steady flow rates for each flow stream associated with a given mode of operation, within the limits of accuracy of rotameter scale resolution and minor fluctuations in flow rate. Hence the need originally felt for turbine meters was tempered, although there were circumstances in which use of turbine meters would have been very beneficial. One such meter was eventually procured and installed; but its readings were redundant to those obtained from a rotameter; and since the two readings agreed closely, use of the rotameter readings continued.

Water flow rates to each of the water-to-air heat pumps was measured by means of recording water meters with dial indicators for fine resolution and decimal registers for longer-term totals. The meters used were Model 25's manufactured by Badger Meter Company. These meters have a nominal accuracy of $\pm 1.5\%$ in terms of flow rate. Visual Readings from these meters were manually recorded. Such readings were taken hourly ten times per day each day for about six weeks at the start of data acquisition. Week-long and overall average flow rates were computed from these readings. The week-long averages exhibited good

agreement. Short-term flow rates were calculated from readings of the dial indicator on the water meters, and from elapsed times measured by means of a watch with a sweep second hand. The short-term averages exhibited greater variability and therefore less consistency and poorer agreement with the long-term averages. However, in general they confirmed the averages. Therefore long-term average flow rates were used to calculate thermal energy flows between individual heat pumps and the pipe loop connecting them, as well as the net energy flow to or from the loop as a whole. In this regard, the total loop flow rate was taken simply as the sum of the flow rates to the individual heat pumps. Occasional checks of both short-term and long-term average flow rates were made subsequently through the three data collection periods. Checks were performed particularly when adjustments to flow rates were made, or when there was other reason to expect changes in individual or total flow rates.

Validity of the water flow rates to the water-to-air heat pumps obtained in the manner just described was supported by results of comparing: 1) net energy flow to storage from the water-to-air heat pump loop, calculated from total flow rate and temperature difference across the entire loop, with 2) the algebraic sum of thermal energy flows from the individual heat pumps, calculated from individual heat pump flow rates and temperature differences. These results normally exhibited agreement within $\pm 5\%$ or better.

Air Flows

Air flow rates were measured: 1) through the water-to-air heat pumps, 2) at each supply register connected to the main air handling system and 3) at the discharge of the outdoor air supply fan. To measure air flow rates through the heat pumps, the inlet and outlet ducts were traversed with a pitot-static tube. Because of large variations in velocities across the ducts, they were subdivided into relatively small area increments; comparison of total inlet and outlet volumetric flow rates permitted redundancy checks or identified serious discrepancies. The pitot-static tube used was 1/8 inch in outside diameter, which permitted measurements in close proximity to duct walls. An absolute micromanometer was used to sense the differential pressure output from the pitot-static tube. The resolution of this instrument was 0.005 inches of water. The pitot-static tubes were made by Dwyer Instrument Company and the micromanometer was supplied by E. Vernon Hill, Incorporated.

Air flow rates through the discharge registers of the main air handling system were measured by means of an Alnor velometer Type 6000, and a Davis anemometer, Type A-2/A/-3. These measurements were performed, free of charge, by the operator of a local testing and balancing firm, who also advised us on all the air flow measurements we performed. (His assistance was greatly appreciated.) An initial set of discharge flow rate measurements revealed significant departures from standard air supply rates, for some spaces. Hence dampers on most supply registers were adjusted and the measurements repeated.

The volume rate of flow through the outside air supply blower was measured using a duct air monitoring device located near the blower outlet. This device, produced by Air Monitor Corporation, uses a manifolded array of total pressure tubes and a manifolded pair of static pressure tubes, to sense velocity pressure differentially. The total and static pressure tubes are located downstream of a honeycomb core, to reduce velocity variation across the duct to a small fraction of mean velocity, thus permitting accurate measurements of average velocity

using manifolded tubes. Output from this device was sensed with an Ellison inclined manometer having a minimum resolution of 0.02 inches of water.

OPERATING MODE AND DOOR CLOSURE SENSORS

The modes of operation of the main (water-to-water) heat pump system, e.g., heat pump heating, direct heating, heat pump cooling, and the operating modes of the solar collectors, were determined by sensing relay-controlled switch closures. The status of each switch was sensed once per second by means of a digital input channel to the data acquisition computer. If the relay corresponding to a particular mode was closed, for example, the system was assumed to be in that mode for one second. This provided an accurate accounting of the time spent in each operating mode.

A similar method was employed to detect the open or closed status of each door leading to the outdoors or to portions of the building that were not monitored. The sensors used were magnetic reed switches, such as those employed in security alarm systems. The status of each switch was sampled once per second, thus providing a count of the total number of seconds a given door was open during a period of time. These sensors did not operate reliably unless the door closed tightly.

INFILTRATION RATE

The rate of air change in the building, both with and without operation of the outside air blower, was measured using a tracer gas technique. A technique similar to that developed at the National Bureau of Standards, using sulphur hexafluoride as the tracer gas, was employed. However, a two-point calibration technique with frequent, automated sampling of two specially-prepared calibration gases was developed. It was also discovered that single-point sampling of return air was sufficient to accurately detect concentration. These developments, and the associated testing procedures and test results are described in a thesis titled: "Air Change Measurements Using a Tracer Gas Technique," submitted to the Department of Architectural Engineering at The Pennsylvania State University by Robert C. Doeffinger. Expected trends in variation of infiltration rate with interior-exterior temperature and pressure differences were observed in the results; but correlations were impossible, due to limited results.

WIND SPEED AND DIRECTION

The local speed and the direction of the wind were measured with a Taylor Instruments wind measurement apparatus mounted on top of the weather box identified in Section 2.1. Speed was indicated by the voltage output from a DC generator attached to a cup anemometer. Direction was indicated by a potentiometer attached to a vane. The range of both outputs was 0 to 100 millivolts.

LOCAL AUTOMATED DATA SAMPLING AND RECORDING

Although it is not related to instrumentation in the strict sense, the use of a data logger to sample and record outputs from selected thermistors is noteworthy. Since possibilities for local output of data from the System 7 computer were extremely limited and since receipt of data transmitted to The Pennsylvania State University required several days for printed output, local output was extremely desirable. Furthermore, instantaneous data is indispensable for system checkout and diagnostic work on instrumentation and the system. The data logger employed was a Kaye Instruments Model 8000, which could be programmed to scan inputs continuously or at pre-set intervals. Both types of scanning proved very helpful at times; but normal scan intervals were 1/2 hour, unless special conditions warranted more frequent sampling. Such scan intervals provided a running picture of the operating modes of the system, and they helped identify malfunctions of most critical temperature sensors. In short, the use of a local data sampling and recording device proved to be invaluable.