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SOLAR HEATING AND COOLING EXPERIMENT FOR A SCHOOL IN ATLANTA

Performance Report

MASTER

August 1, 1977

Work Performed Under Contract No. EY-76-C-02-2628

Solar Heating and Cooling Systems
Westinghouse Electric Corporation
Falls Church, Virginia

U.S. Department of Energy

Solar Energy

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PERFORMANCE REPORT

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UNDER CONTRACT EY-76-C-02-2628

PREPARED FOR THE
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

BY
WESTINGHOUSE ELECTRIC CORPORATION
SOLAR HEATING AND COOLING SYSTEMS
FALLS CHURCH, VIRGINIA

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1.0 INTRODUCTION

This report documents the performance, and conclusions therefrom, of a 13 month period of monitoring the performance of the experimental solar heating and cooling system installed in the George A. Towns Elementary School, Atlanta Georgia. A Design Report and a Construction Report, published earlier on this project, are referenced at the end of this report and are cited throughout the following text. For the convenience of the reader, the following section contains extracts from these two earlier reports.

1.1 BACKGROUND

In May 1974, Westinghouse Electric Corporation was awarded a contract for the design, construction and performance analysis of a large-scale experimental solar heating and cooling system to be retrofitted to the 13 year-old George A. Towns Elementary School in Atlanta, Georgia. This single-story, 34,000 square foot building has a flat roof, faces within 2 degrees of true South, and has a room unit ventilator system served by a one-pipe loop designed to carry hot or chilled water for space heating or cooling.

The objectives of this project were to:

- Make a significant contribution to solar design, technology and acceptability.
- Conduct an advanced experiment on an integrated large-scale solar heating and cooling system, determine its performance, reliability and maintainability, and compare these actual results with predicted performance.
- Identify subsystem interface problems that cannot adequately be predicted by theoretical analysis.
- Operationally test major components and identify improvements required.
- Identify cost reducing materials and techniques which may improve the economic viability of solar heating and cooling systems.

The principal associated team members in this effort were:

- Burt, Hill & Associates
  Solar Architectural Design
- Dubin-Bloome Associates, P.C.
  Mechanical Engineering Design
- Georgia Institute of Technology
  Instrumentation System Design

The preliminary design effort was completed in July 1974. Construction of the project was completed, and a one-year period of performance monitoring was commenced on 1 February 1976.

1.2 SYSTEM DESIGN SUMMARY

The solar collector system involves 10,360 ft^2 of PPG "Baseline" flat-plate collectors with an ALCOA selective coating, augmented by 10,800 square feet of aluminized Mylar reflectors. Three 15,000 gallon steel storage tanks, a 100-ton Arkla absorption chiller together with its cooling tower, a collector gravity drain system with a 1,600 gallon holding tank and a collector nitrogen purge system, six pumps and 26 pneumatic control valves were installed and interfaced with the pre-existing gas furnace and distribution system. Figure 1 is a simplified schematic of the system, showing the numbered pumps, automatic control valves and storage tanks. Figure 2 is a functional schematic of the closed-loop collector fill and drain subsystem as it exists with valves 2 and 2A open, and valves 3 and 4 closed. A more detailed flow diagram, showing the performance-monitoring sensors, is displayed on page A-21 of Appendix A.

In the winter heating mode, the solar energy is stored in all three tanks, total capacity of 45,000 gallons, between design temperatures of 105° to 140°F. As soon as Tank 1 is brought up to 140°F, the control valves isolate it from the collector loop, and the hot water from the collectors is used to charge Tank 2 and

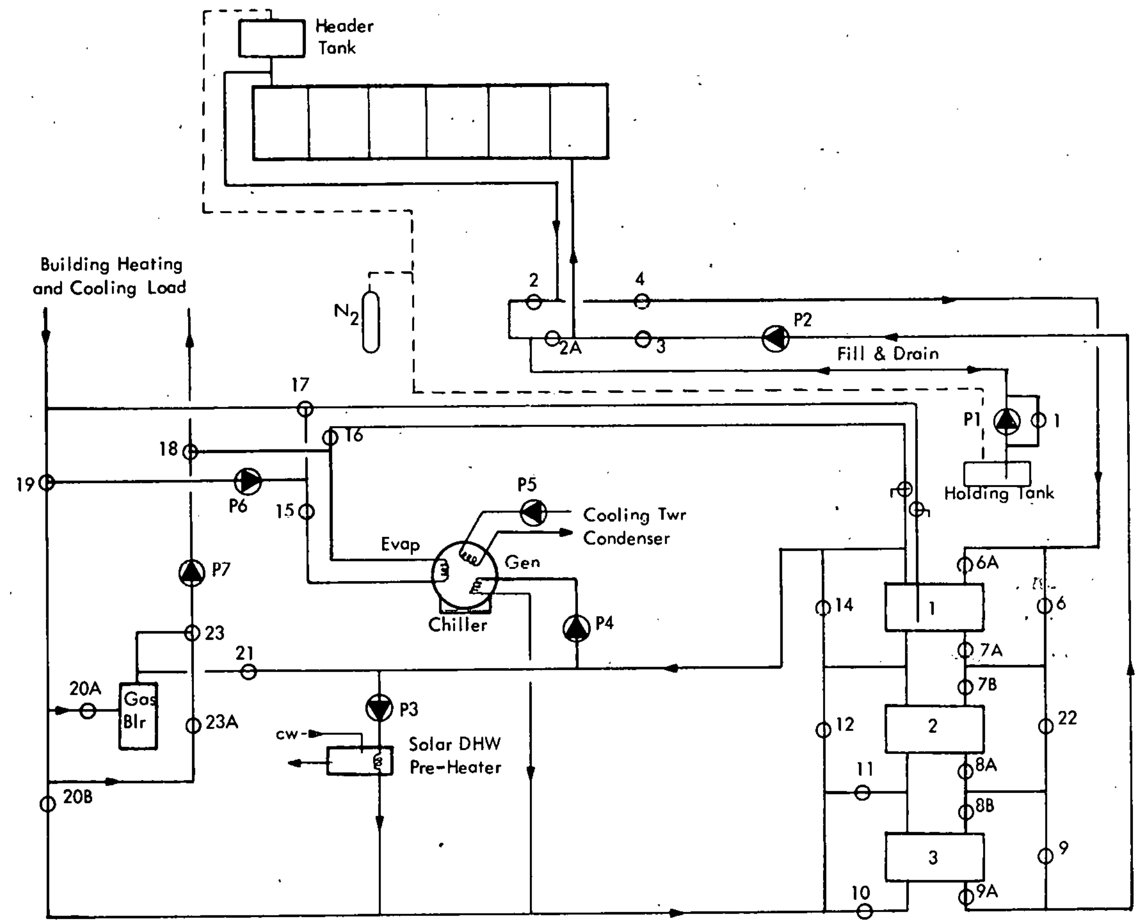


Figure 1. System Flow Diagram

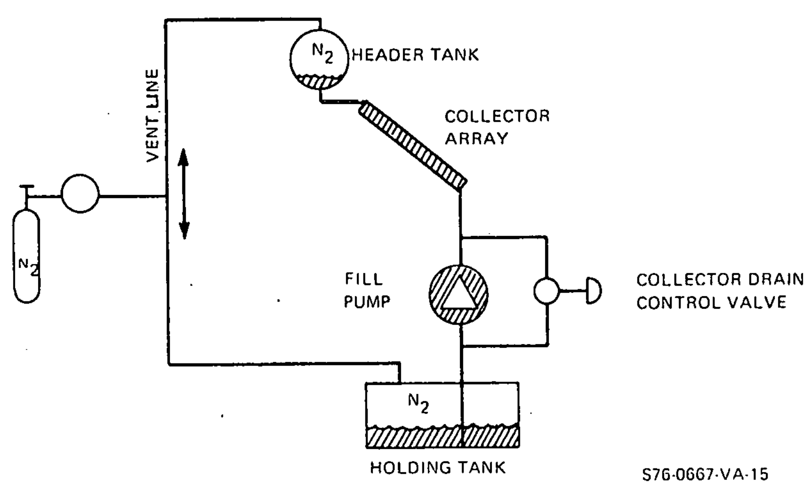


Figure 2. Collector Fill and Drain Subsystem

then Tank 3. Water can be drawn from Tank 1 to heat the school while Tank 2 and 3 are being charged. As a consequence of the flexibility provided by the three tanks, compared to a single tank of equivalent capacity, the thermal lag in the system is reduced. A variable speed pump (P2), in response to sensors at the inlet and outlet of the collectors, modulates the flow of water through each collector from a maximum of .5 gpm to a minimum of .1 gpm, attempting to maintain a temperature rise of about 10°F.

In the summer cooling mode, storage tanks 2 and 3 are designed to store hot water at temperatures between 180° to 200°F, and tank 1 is used to store chilled water.

1.3 SYSTEM COST SUMMARY

Table 1 is a summary of total system costs, in 1975 U.S. dollars, as the system stands today. Costs of changing some components and correcting faults and errors are not included. Therefore, these figures represent the costs to duplicate the present configuration in 1975. Three categories of costs are shown, the first being the solar collector and storage subsystems their associated piping and controls. The second category includes costs for non-solar HVAC components such as the chiller, cooling tower, etc., which were procured for addition to the existing school HVAC plant. Ten spare collectors are included in this category. The third category includes those materials and labor necessary to interface the solar/HVAC system with this 13-year old building, its gas furnace, distribution system and controls.

TABLE 1. SYSTEM COST SUMMARY

Item	Solar System Costs	Non Solar Costs	Interface Costs	
Piping and Wiring	$ 39,505	$ 2,558	$ 2,558	
Absorption Chiller	–	$17,229	–	
Storage Tanks	$ 17,940	–	–	
Holding Tank	$ 1,517	–	–	
Corrosion Inhibitor	$ 6,534	–	–	
Solar DHW Heater	$ 1,176	–	–	
Cooling Tower	–	$ 4,527	–	
Pumps	$ 6,482	$ 430	$ 430	
Reflective Mylar	$ 5,720	–	–	
Collector Framing	$ 15,000	–	–	
Earth Fill	$ 900	–	–	
Solar Collectors	$ 65,927	$ 1,145	–	
Steel Grid	–	–	$19,645	
Control Valves	$ 6,382	–	$ 1,418	
Control Logic Subsystem	$ 5,940	–	–	
Misc. Services & Mat'ls	$ 4,800	–	$ 700	
TOTAL MATERIALS:	$177,823	$25,889	$24,751	$228,463

TABLE 1. SYSTEM COST SUMMARY (cont.)

Labor Category

Item	Solar System Costs	Non Solar Costs	Inter-face Costs	
Mechanical/Electrical	$ 97,480	$13,880	$13,880	
General Construction	$ 52,930	–	–	
Collector Installation	$ 15,500	–	–	
Steel Erection	–	–	$ 7,290	
Controls Design & Install	$ 11,320	$ 1,610	$ 1,610	
TOTAL LABOR	$177,230	$15,490	$22,780	$215,500
TOTALS	$355,053	$41,379	$47,531	$443,963

A General Contractor was not employed to supervise the sub-contractors. This effort was performed as a collateral duty of the Westinghouse Project Manager. The low bid received from a General Contractor for this effort was $20,000, which may be added to the above total at the discretion of the reader.

No figures are readily available on the total man-hours of labor involved in this project. However, the labor to mount the collectors on the erected trusses, and to connect by flexible hose the collectors to the header pipes was monitored. A four-man team averaged 22 minutes per collector, or 691 man-hours for the mounting of 576 collectors over a period of 34 working days. This does not include the labor of unloading the crates of collectors, uncrating, pre-positioning collectors about the roof, trash disposal and collector caulking.

2.0 PERFORMANCE MONITORING AND ANALYSIS

The system performance monitoring and analysis effort was conducted by the Georgia Institute of Technology, under subcontract from the Westinghouse Electric Corporation. The inter-disciplinary team of Georgia Tech researchers, assisted by several graduate students, consisted of:

Dr. Stanley C. Bailey
Aerospace Engineering
Principal Investigator

Dr. Prasana Kadaba
Mechanical Engineering
Co-Principal Investigator

Dr. James I. Craig
Aerospace Engineering
Co-Principal Investigator

Dr. Atif Debs
Electrical Engineering
Co-Principal Investigator

Dr. Frank Clark
Architecture
Co-Principal Investigator

2.1 INSTRUMENTATION

In accordance with the requirements of the prime contract from the U.S. Energy Research and Development Administration, this team was required to design, install and operate an instrumentation system which would measure at least the following:

- Heat collected by the solar energy system
- Heating and cooling delivered to the school
- Energy consumed by the solar system
- Total energy savings as a result of the solar system

The details of the resulting instrumentation system are contained in Appendix A. As may be seen, Georgia Tech has provided a monitoring system which produces considerably more performance data than was contractually required, at no increase in cost to the Government. This was accomplished, in large part, by the no-cost loan of university equipment to the project, and by the contribution of many hours of "free" labor by the research team and their support staff.

2.2 MONITORING PERIODS

A one-year period of performance monitoring commenced on 1 February 1976, and was terminated on 16 February 1977.

On days when school is in session, the building is occupied by faculty and students from 7:30 am to 3:30 pm. At 7:00 am on school days, the pre-existing HVAC system time clock switches to the OCCUPIED mode, enabling the heating and cooling system and the room unit ventilators to be controlled by individual room thermostats. At 4:30 pm on school days, and at all times on non-school days, the time clock is automatically switched to the UNOCCUPIED mode.

During the heating season, the UNOCCUPIED mode disables the room thermostats, and the space heating (gas or solar, if available) is controlled by three zone thermostats at a set-back temperature of 60°F. During the cooling season, the UNOCCUPIED mode disables all space cooling, but enables the use of stored solar hot water to operate the chiller for the production of chilled water into storage. (This feature is intended to use solar heat collected on weekends and holidays for the storage of chilled water for space cooling when the time clock next switches to the OCCUPIED mode. See References 1 and 2.)

The costs of dedicating the Georgia Tech on-campus HP 2100S computer system, employed by the School of Aerospace Engineering, for 24-hour performance monitoring on this project was prohibitive. Therefore, the monitoring system was operated from 6:00 am to 6:00 pm on school days. Periodically each month, the monitoring system was enabled to operate for a 24-hour period to establish a night performance data base. Similarly, an attempt was made to operate the monitoring system continuously over at least one weekend each month.

2.3 MONITORING AND ANALYSIS RATIONALE

The space heating gas furnace is served through a dedicated gas meter, and all electrical equipment associated with the solar system is served through a dedicated KWH meter. These meters are not automated, but their readings were manually recorded at irregular intervals in the early morning and late afternoon on each school day to determine the auxiliary energy usage. To determine *solar* system performance during the unmonitored night hours, it was necessary to perform a heat balance analysis of the three storage tanks for each UNOCCUPIED period. From storage tank performance data gathered over several 24-hour monitor periods, empirical equations were developed to determine tank heat loss rates as a function of average tank temperatures recorded at 6:00 pm, and at 6:00 am on the following morning. These relationships are presented in Section 2 of Appendix C for the heating mode, and have been used in the performance analysis.

It was considered that this procedure would be adequate for analysis of system performance during the relatively inactive night periods. Automated monitoring, starting one hour before commencement of the OCCUPIED period and ending two and one-half hours beyond the end of the OCCUPIED period would record the dominant portion of the solar/HVAC activity.

2.4 CAVEATS

CAVEAT: an explanation to prevent misinterpretation.

Actual conditions rarely coincide with design conditions in the conduct of an experiment. Weather, building loads, sensor and system performance, and people, all have lent a hand in distorting the actual versus design performance of this solar heating and cooling system, for better and for worse. It is well that the reader become familiar with several such biases at this point.

2.4.1. System Heat Balance Calculations

A most important caveat concerning this analysis centers on the method of determining the degree of solar/gas furnace participation in both the heating and cooling processes. The reader is referred to the instrumented flow diagram on page A-21, Appendix A. Note that the temperature/mass flow of hot or chilled water to the building load is measured by T-5, TD-5 and flow meter F 45. Similarly, water temperature/mass flow through the chiller generator is measured by T-3, TD-3 and flow meter F 3. However, no indication was provided to determine the *source* of energy flow, whether gas boiler or solar storage. It was anticipated that the temperature of the source water would clearly identify the heat source. This proved not to be the case. It then became necessary to model the heat exchanges around the thermal storage tanks and the gas furnace and, from the data recorded, determine the solar/gas participation in the heating and cooling processes on a day-by-day basis.

The gas furnace energy input to space heating (or to the chiller generator during the cooling season) is determined from the gas input to the furnace, times the reported heat content of the gas used, times the measured furnace efficiency of 0.75. The solar energy input to space heating (or to the chiller generator) is calculated by a routine which considers measured solar energy input to storage, measured storage tank temperatures, and the estimated heat loss from storage. This latter loss is calculated as a function of storage tank temperatures, using the emperical equations described in Section 2.3, above. System heat losses are calculated as the sum of gas and solar energy input to the heating system, less the measured energy output from the heating system to the load. In retrospect, this heat balance method may penalize the solar participation calculations in at least two respects. At times when the space heating (or chiller generator) load is being satisfied from solar storage, the furnace gas burner cycles to maintain boiler water at a pre-set 180°F (winter), or 210°F (summer). This cycling action consumes a measured 0.331 x 10^6 Btu/day to maintain standby boiler water at 180°F. The pilot light alone consumes a measured 0.181 x 10^6 Btu/day at all times. Such lost gas energy is theoretically included in the system losses, but is charged against the solar system when solar is carrying the load.

2.4.2 Weather and Building Temperatures

2.4.2.1. Heating Season

The monitoring period commenced on February 1, 1976 and terminated on February 16, 1977. Therefore, the heating season reported upon consists of the juxtaposition of the two periods: October 1976 through February 1977, and mid-February 1976 through April 1976. Figure 3 displays comparisons of the actual-versus-design insolation, outside air temperatures and interior building temperatures during the monitored period from 6:00 am to 6:00 pm for this composite heating season. The measured parameters for each are shown as solid lines, while the design conditions are shown as dotted lines. It should be noted that the measured insolation and outside air temperatures are well below design conditions during the early part of this heating season (the coldest in recorded history in Atlanta). The interior building temperatures were maintained well above the design (and Atlanta Public Schools mandated) temperature of 68°F. Unusually low insolation and ambient air temperatures, and the high interior temperatures maintained by teacher-controlled room thermostats, all acted to increase the actual heating load well above the design load, thereby decreasing solar heating participation.

2.4.2.2. Cooling Season

The cooling season reported upon consists of the period from 28 July 1976, through 20 October 1976. Figure 4 displays comparisons of the actual-versus-design insolation, outside air temperatures and interior building temperatures during the monitored period from 6:00 am to 6:00 pm for this cooling season. The measured conditions are shown as solid lines, while the design conditions are shown as dotted lines.

Actual insolation was considerably less than that expected, diminishing the solar heat collected. The above-average cloud cover and precipitation also contributed to the below-average outside air temperatures and resulted in an unusually low cooling load in the school. From our design calculations, it was estimated that the typical cooling load for the months of August and September would average about 80 tons and 50 tons, respectively. The measured cooling loads on the chiller actually averaged 26.1 tons and 22.7 tons in the months of August and September, respectively. The peak day-averaged load observed was 40.1 tons on 13 August. The peak building cooling rate recorded was 62.2 tons on 13 August, at 5:15 pm. (The time clock *should* have terminated building cooling at 4:30 pm, but the data indicates that the night cleaning personnel continued building cooling operations until 5:45 pm on this Friday.)

2.4.3. Transient Effects

2.4.3.1. Heating Season

Recall that the school HVAC system time clock switches to night setback thermostats (60°F) at 4:30 pm. Solar system performance was rather carefully designed to this published condition. By late October, it was discovered that the night cleaning force, which works from 4:30 to 7:30 each school day, surreptitiously switches the time clock back to the OCCUPIED mode to maintain comfortable working temperatures in the building until 7:30 pm, or later. (This procedure was also practiced by teachers and administrative personnel

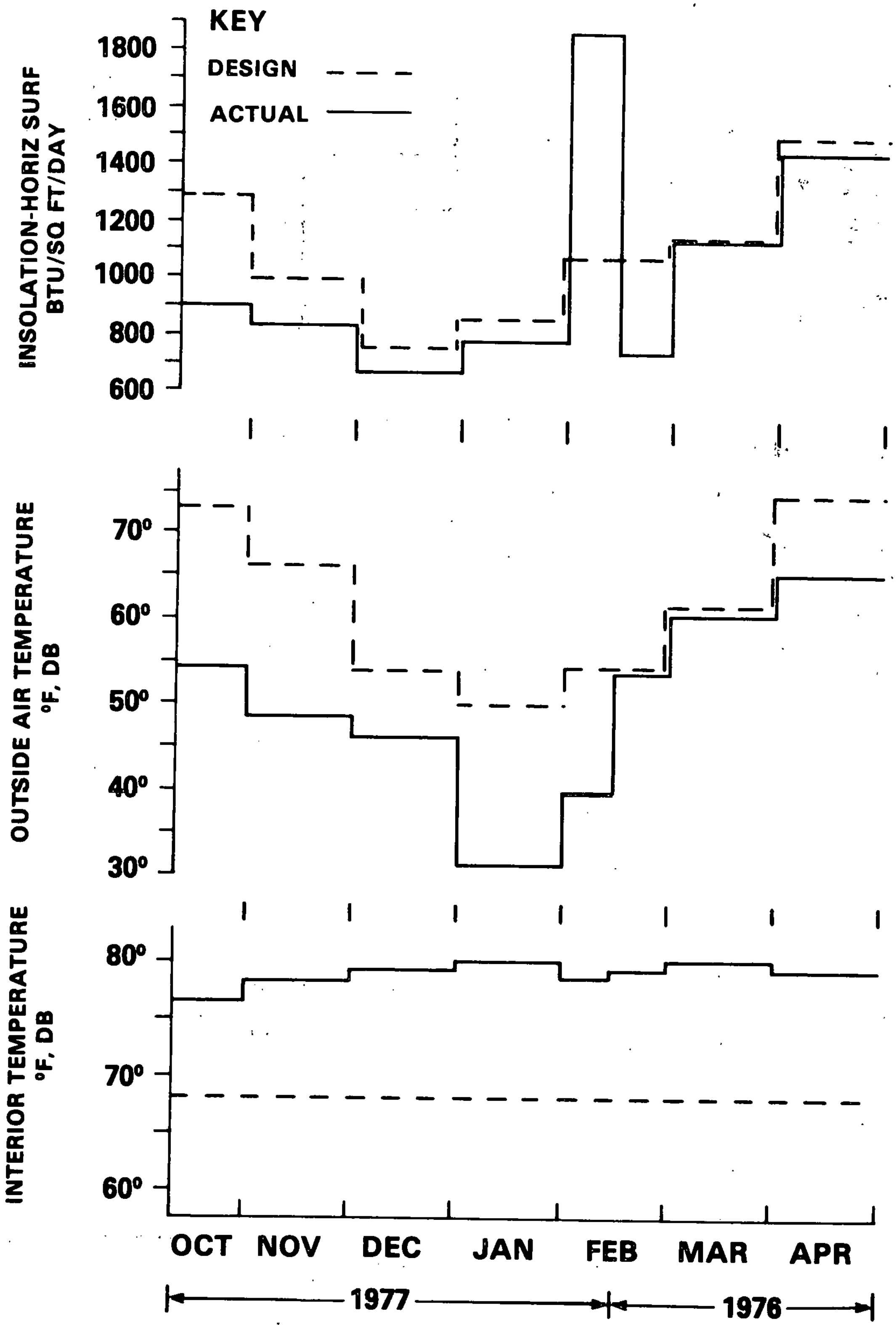


Figure 3. Heating Season Insolation and Temperatures

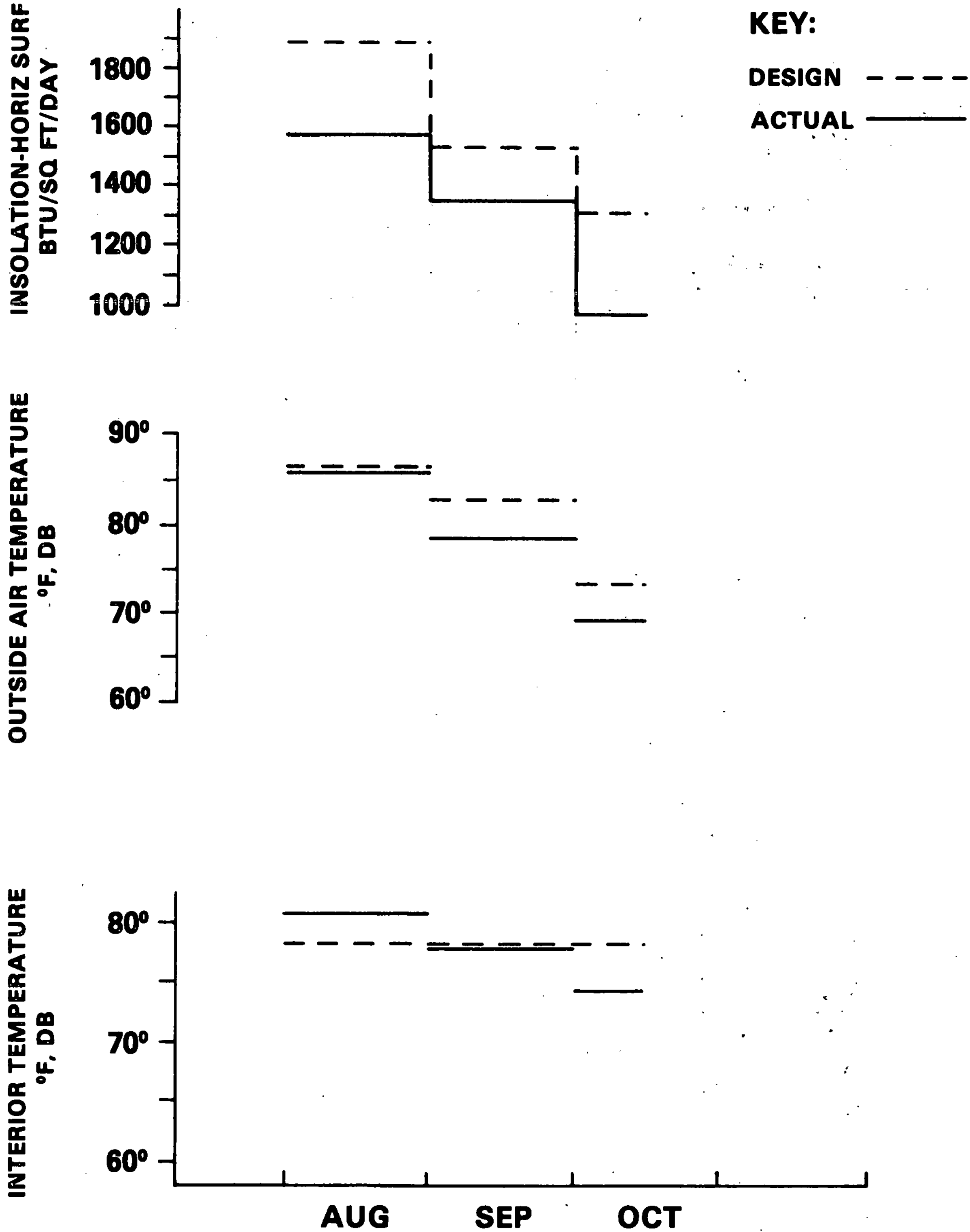


Figure 4. Cooling Season Insolation and Temperatures

who enter the school to work on weekends and holidays.) The extent of this practice could not be determined or measured by the monitoring system, but the effect was to deplete stored solar energy which would otherwise have been available for use on the next school day.

Although stored solar heat at 105° - 115°F is adequate to meet the design heating load, it was also discovered that the school Custodian, during the severe winter of 1976-1977, would surreptitiously switch the HVAC heat source manual control from AUTO to BOILER (180°F) at 6:30 am each morning to hasten the space warm-up process. This practice was discovered when, occassionally, the Custodian would forget to switch the control back to AUTO by 7:30 am, which would permit the solar system to meet the load, if able. On occassion, though solar heat was available, the HVAC system was forced to operate from BOILER, until the situation was discovered by project personnel. Under this circumstance, solar heating participation is forced to zero. (ex: See 29 October and 16 November log entries, Appendix B.)

As an example of the combined effect of the practices cited in the two preceding paragraphs, see the November 29 log entry, Appendix B. 25 and 26 November were Thanksgiving holidays. The monitoring system, left ON over this period, recorded that the HVAC system, left on by the night cleaning force, was running in the OCCUPIED mode 24 hours per day, depleting the solar storage temperatures from 137°, on the morning of 25 November, down to 106° on the morning of Monday, 29 November. At this time the Custodian manually shifted the HVAC control heat source to BOILER to hasten school warm-up, and forgot to shift back to AUTO to enable solar heating participation. This situation was detected and corrected by project personnel at 1630, 29 November. Also see 30 November and 2 December log entries. Solar energy, depleted during such episodes, or not utilized if available, decreased the percentage of solar participation during this heating season.

A drain-down anti-freeze system works. It works well only if (1) all piping is installed with a proper negative slope as designed, (2) no one steps on the piping and alters its slope, (3) all valves are selected and installed to "fail-safe", forcing automatic drain-down in the event of an electrical or air compressor failure, and (4) the collector isolation control valves (valves 2, 2A, 3 and 4, in this case) are bubble-tight.

On system check-out, and during February and March 1976, it was discovered that water under pressure in the main storage tanks could seep back through valves 3 and 4, up into the collectors and, down through valves 2 and 2A, into the small holding tank.

This situation could result in a disastrous collector freeze-up (although this never happened). To preclude such occurance, the collectors were manually filled and drained throughout February, until mid-March, and were left drained on all non-school days. Manually filling and draining the collectors at times convenient to project personnel, and the failure to collect solar heat on weekends and holidays, decreased the percentage of solar heating during that first six week period.

During the summer and fall of 1976, personnel working on the wind vane/anemometer mast habitually used a section of the collector array main supply pipe as a work platform. The pipe bent such that it held a pocket of water after the collectors drained down. On the night of 26 December, this water pocket froze and burst a section of the piping. The break was detected during the next morning fill evolution, and the collector array was immediately drained down. Busy with heating problems at all schools during this coldest winter in Atlanta history, Atlanta Public Schools maintenance personnel did not repair this fault until January 21, 1977. By this date, the solar storage tanks had cooled to about 83°F, and the collector system commenced an uphill struggle during an exceptionally cold, overcast period to achieve useful storage tank temperatures. This was not achieved until the afternoon of 10 February 1977, when storage temperatures first exceeded 105°F. Hence, *no* solar heat was provided to the school from about 26 December 1976 to 10 February 1977.

2.4.3.2. Cooling Season

As displayed in Figure 4, preceding, the mild summer weather imposed a light cooling load on the school, but the HVAC system should have been able to maintain lower classroom temperatures than those actually experienced. In late April 1976, the chiller was checked out in preparation for summer cooling, being fired from 184°F solar storage. Storage Tank No. 1, which was to store chilled water, was used as a load in the absence of a building cooling load. With 15,000 gallons of 100°F water as a load, the chiller produced a 60 ton cooling rate with an evaporator delta-T of 6°-7°F.

During subsequent space cooling operations throughout the summer, the building unit ventilators never imposed an evaporator delta-T in excess of 3°F. In typical space cooling operation, the chiller evaporator sent, say 46.0°F chilled water to the building loop and received in return only 47.2°F from the loop. The unit ventilator filters were cleaned, air dampers were adjusted, faulty fan motors were repaired or replaced, and room thermostats were set down to 65°F. However, the room unit ventilators seldom warmed the chilled water supply by more than 1.5° and imposed an extremely light load on the chiller, even though the classrooms were considerably warmer than the room thermostat settings. In this retrofit project, no funds were provided for improvement of the preexisting unit ventilator system and the inefficient performance of these units have, and will continue to affect adversely the performance of the cooling system and its chiller.

All pumps associated with the chiller operate at constant speed, and relatively steady-state operation is expected of the chiller throughout the OCCUPIED period. However, the chiller's generator by-pass valve, which modulates the generator firing water temperature to accommodate the evaporator delta-T, is observed to be in near-constant operation throughout the day. This frequent modulation, to compensate for an extremely small (1.5°F) evaporator delta-T, results in very erratic sensor readings and chiller performance calculations. These effects are described further in Appendix D, and particularly in Item 26, page D-23.

3.0 SYSTEM PERFORMANCE

3.1 SPACE HEATING

From February to mid-March 1976, the solar collectors were manually filled and drained, and were operated during OCCUPIED periods only, to avoid any possibility of collector freeze. This situation, and its correction, is described in detail in our previous CONSTRUCTION REPORT. The inability to collect solar heat on holidays and weekends, and the requirement to fill and drain the collectors at non-optimum times, severely reduced collection efficiency during this period. However, by 19 March, 1976, the solar system was carrying the full heating load of the school and the gas furnace burner-control solenoid was electrically turned off for the remainder of this heating season.

By mid-May, the school exhibited no demand for space heating or cooling. The solar system was secured on 27 May and allowed to cool down in preparation for mechanical work. The faulty control valves and the collector fill pump were replaced, and the solar system was reactivated in the cooling mode on 28 July 1976.

During February, March and April, 1976, the data acquisition system experienced occasional outages. Table 2, from our monthly reports, displays the system space heating performance during the OCCUPIED periods for those days on which sufficient data was recorded to enable such calculations.

The following heating season commenced on 21 October 1976, and heating performance data was recorded through 16 February 1977. By this time, the data gathering and reporting format had been adjusted to conform to the National Bureau of Standards method described in NBSIR 76-1173. Performance data for this heating period are listed in Tables C-11-a, b and c, Appendix C, for those days on which sufficient data was recorded to enable such calculations. The solar fraction of the total energy consumed to heat the school (N-401) during this period is repeated in Table 3. A value in excess of 100% recorded in October, and a negative value recorded in December, were generated by either computer/sensor error, or statistical scatter, as discussed in Appendix C.

On many days during this composite heating season, a monitor system malfunction precluded a solar participation calculation for the day. On occassion, such data voids conceal truly poor solar performance caused by solar system malfunctions, particularly during February and March, 1976. Conversely, periods of excellent solar system performance went unrecorded, as did solar collection and heating performance on weekends and nights. To place the sparse data available in proper perspective, solar heating percentages from Tables 2 and 3 are plotted in Figure 5. The following chronological summary of events which affected the physical operation of the solar system can be related to Figure 5. Some events are described in greater detail in Appendix B.

TABLE 2. WINTER/SPRING 1976 SOLAR HEATING PERFORMANCE

Month/Date	Solar Fraction of Total Space Heating
February 1976	
1	Commenced monitoring period
9	27.3%
10	62.0%
11	40.1%
19	74.7%
20	69.1%
March 1976	
1	98.7%
2	52.1%
15	61.3%
16	41.1%
18	43.1%
19	73.2%
	Turned off gas furnace. Following solar fractions (which should be 100%) are reported in the interest of scientific accuracy
22	95.8%
23	98.7%
24	99.3%
25	99.2%
29	99.4%
30	99.5%

Month/Date	Solar Fraction of Total Space Heating
April 1976	
7	97.9%
9	98.4%
12	96.0%
13	97.8%
14	98.5%
20	Ceased solar heat collection into Tank 1
27	70.2%
27	Terminated space heating mode

TABLE 3. WINTER 1976-1977 SOLAR HEATING PERFORMANCE

Month/Date	Solar Fraction of Total Space Heating Energy Consumed (N401)
October 1976	
20	Switched to Heating Mode
21	17.0%
22	122.4%
26	79.7%
27	87.6%
28	88.7%
29	29.7%
November 1976	
3	41.5%
4	94.5%
5	7.4%
6	92.0%
7	95.0%
8	93.8%
9	93.6%
11	59.8%
13	93.9%
14	92.6%
15	59.9%
16	2.3%
19	6.1%
22	12.5%
23	1.8%
25	57.1%
26	95.4%
29	0.3%
December 1976	
2	1.9%
3	-31.8%
6	4.0%
7	16.4%
8	44.2%
9	21.3%
10	71.8%
16	17.6%
17	92.6%
19	89.2%
26	Frozen pipe. No solar heat provided until 10 February 1977.
January 1977	No Solar heat could be provided during this month. Following solar fractions (which should be zero) were calculated and are reported in the interest of scientific accuracy.
6	5.40%
10	2.1%
11	1.2%
12	2.8%
17	0.7%
19	2.4%
20	11.9%
21	5.9%
22	12.2%
23	2.9%
24	5.6%
25	0.1%
26	4.1%
February 1977	No solar heat could be provided until 10 February 1977
1	21.6%
3	2.1%
4	9.4%
6	5.7%
7	14.1%
10	55.2%
11	75.4%
12	73.4%
13	68.3%
14	66.4%
15	85.4%
16	85.4%

Performance monitoring period terminated.

HEATING SEASON CHRONOLOGICAL SUMMARY

Feb 1 - March 15, 1976	Collectors manually filled and drained each day to preclude freezing of residual water in the collectors. Collectors dormant on weekends and holidays for this reason. Improperly installed control valves prevented use of solar hot water stored in Tanks 2 and 3. Load being supplied only from Tank 1.
March 15, 1976	Freeze danger past, collectors permitted to fill and drain automatically. Improper installation of two control valves corrected. All three storage tanks enabled to supply the load.
March 19, 1976	Electrically disabled furnace burner control, leaving only the furnace pilot light in operation. Solar storage provides total space heating load through the remainder of the heating season.
April 27, 1976	Space heating load has been nil since 20 April. Terminated solar system space heating in preparation for mechanical corrections to collector fill and drain subsystem, and system changeover to cooling mode.
October 20, 1976	Commenced solar system operation in the heating mode.
December 27, 1976	Collector array supply main pipe section froze and burst.
January 21, 1977	Broken pipe repaired. Solar heat collection commenced.
February 10, 1977	Solar storage reached operating temperature, began to carry space heating load.
February 16, 1977	One-year performance monitoring period terminated.

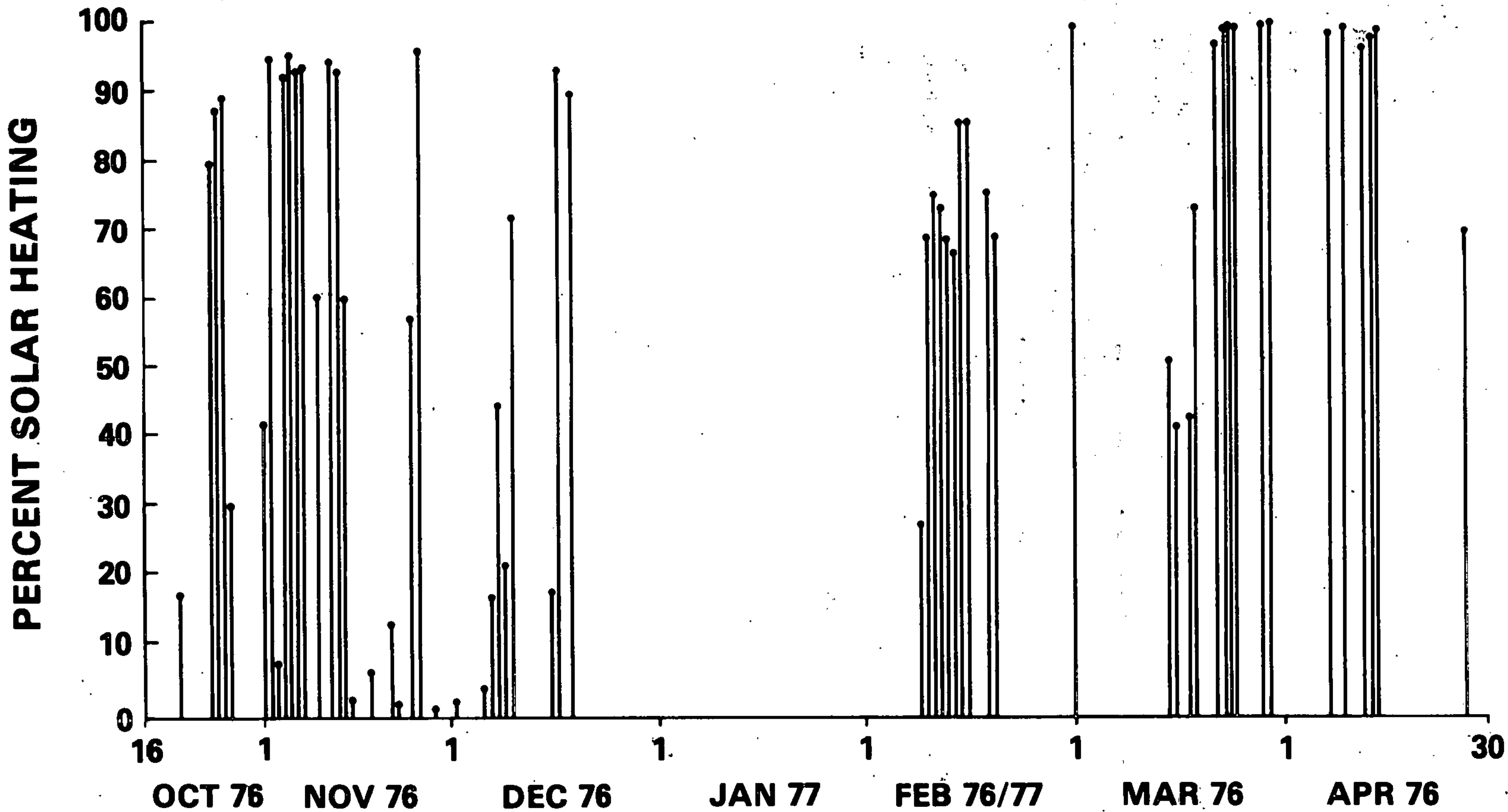


Figure 5. Daily Percentages of Solar Heating

A detailed heat balance analysis of the system operation during the period from October 21, 1976 through February 15, 1976 is presented in Appendix C (with a portion repeated in Table 3, above). In an attempt to represent the actual performance of the system during each month of this period, an analysis was undertaken, based on a selected subset of days for each month. These days represent a portion of the overall performance data collected and were selected for the consistency of their data. They were chosen in sequences of 2 to 10 continuous days and the average performance used to reflect the system performance over that month, and were analyzed as follows. First, the selected periods of data were chosen from the data summaries, the exact period of operating time determined, and the natural gas consumption data were determined from meter readings. Next, the auxiliary energy was computed from the gas consumption using the specific heat reported by the Atlanta Gas Light Company and the boiler efficiency (75%) as measured during the performance evaluation (Appendix C). This figure is the thermal energy used from auxiliary sources during the selected periods.

The solar energy used was considerably more complicated to estimate. Since the collector output is directed first into the storage tanks and then to the load, it is not possible to simply use the collector heat production alone without considering tank energy charges and losses as well. After considerable evaluation of various approaches, the method selected was to essentially perform a heat balance calculation for each tank as follows: For each measurement period (15 min., typical) the heat supplied to the tanks by the collectors, the heat extracted from the tanks by the system, and the thermal losses from the tanks (to the surrounding ground) were equated to the change in internal energy as estimated by the three tank temperature probes in each tank. The tank losses would normally be unknown, but in this case were estimated using the tank loss model derived in Appendix C. Consequently, the heat balance equation can be solved for the heat extracted by the system and it is this figure that is shown as the solar contribution.

The electric energy used during the selected period is also recorded. This number was taken from the electric power meter readings and converted from KW-h to BTU. (It should be noted that the meter readings must be multiplied by 40 to obtain actual kilowatt-hours.) The total energy used is then the sum of auxiliary, solar and electric energy, as calculated above.

The monthly performance was estimated from the selected data by a linear extrapolation based on the auxiliary energy usage as measured by the entire month. In this process, the actual gas/electric usage for the month, compared to that used for the selected test periods, was used to estimate the solar energy used over the month from that used for the test periods. The estimated data are shown in parentheses and the percentage of the total energy supplied by solar is then calculated. The results are shown in Table 4. The low percentages of solar heating estimated in this fashion, reflect not only solar system outages due to malfunctions but also the physical and analytical penalties cited in Section 2.4, above.

3.2 SPACE COOLING

The system was operated in the cooling mode from late June through 2 August, 1976, using the gas furnace while mechanical changes were being made to the solar system. From 28 July to 3 August, the solar system operated to bring the thermal storage tanks up to useful temperatures, and to check out the cascading operation of newly installed valves. From 3 August through 20 October, the system was operated in the automatic cooling mode. Details of system performance during this period are contained in Appendix D.

From Appendix D, the solar component of total energy utilized to meet the cooling load (Q500) is defined as the measured heat input to the chiller generator (Q506), minus the gas input to the boiler corrected for boiler efficiency (0.75 Q 508), or Q 500 = Q 506 – 0.75 (Q 508). The gas input to the boiler is measured from gas meter readings usually recorded twice daily on school days. (The retrospect hazards of

TABLE 4. WINTER MONTHLY ENERGY SUMMARY

MONTH	DAYS	GAS (cf)	AUX (10^6Btu)	SOLAR (10^6Btu)	ELEC. (10^6Btu)	TOTAL (10^6Btu)	% SOLAR
Oct. 76	11	25,370	19.56	13.81	3.37	36.74	38
Nov. 76	21.9	114,400	88.54	34.02	6.40	128.96	
est. (*)	30	155,170	120.09	(46.14)	(9.29)	(175.52)	26
Dec. 76	9.9	83,210	64.03	23.43	3.60	91.06	
est.	31	321,900	247.70	(90.64)	10.11	(348.45)	26
Jan. 77	16.5	298,000	229.54	0	11.20	240.74	
est.	31	531,500	409.40	(0)	(21.66)	(431.06)	0
Feb. 76/77**	20.9	242,170	187.10	37.69	16.40	241.19	
est.	28	(246,000)	(190.06)	(38.29)	(16.67)	(245.02)	16
Mar. 76	7.4	24,180	18.59	23.75	4.00	46.34	
est.	31	93,480	71.86	(91.80)	(9.25)	(172.91)	53
Apr. 76	14.5	20,740	15.94	29.55	(4.80)	50.29	
est.	30	37,430	28.77	(53.33)	(8.80)	(90.90)	59
Winter Season			1087.44	(334.00)	(79.15)	(1500.60)	22

Total Energy Savings as a result of using solar energy $\frac{334.00}{.75} - 79.15 = 336.18 \times 10^6$ Btu

* Estimated performance based on actual auxiliary energy usage; estimates are shown in ( ); see text.

** Figures are an average of 1976 and 1977 data.

this approach, which always penalizes the degree of solar participation, are discussed in Section 2.4, above.) The solar fraction of total energy utilized for cooling (N 500) then becomes: N 500 = Q 500/Q 506. For an indication of the degree of confidence placed on measurements of Q 506 (QGENerator), see Item 26, page D-23, Appendix D. The percentage of solar cooling achieved is listed in Table 5 and shown graphically in Figure 6 for each day on which adequate data was recorded.

As was done for the heating season, an analysis of all available data was performed to determine monthly heat balance estimates and energy summaries. Again, the method of analysis was patterned after the procedures in NBS Report NBSIR-76-1137. However, in that report there was no provision made to accommodate a chilled water storage tank and evaluate its impact on load and performance characteristics. Improvisations have been made and additional performance ratios have been introduced. They are indicated by 700 series numbers in Appendix D.

The monthly energy summary covers the August-September 1976 period and is based on from 12 to 16 selected days for each month. Selected days had to be used because of the unusually low building loads and, as a result, wide fluctuations in chiller performance at reduced loads. These problems are more fully discussed in Appendix D.

The basic approach used to estimate the monthly performance was, for the selected days, to integrate the chiller output (either to the building or to the chilled water storage tank) and the chiller input (generator)

TABLE 5. SUMMER 1976 SOLAR COOLING PERFORMANCE

Month/Date	Solar Fraction of Total Energy to Cooling Load (N500)	Month/Date	Solar Fraction of Total Energy to Cooling Load (N500)
August		September	
5	35.6%	1	4.8%
6	28.4%	2	14.9%
10	97.5%	3	22.8%
13	14.4%	7	2.0%
		8	15.8%
17	34.4%	9	30.8%
19	72.4%	10	25.1%
23	40.4%	13	49.2%
24	18.8%		
27	61.9%	15	24.2%
30	33.8%	17	27.8%
31	8.0%	20	27.1%
		24	41.1%
		28	35.0%
		29	18.2%
		30	21.7%

over the period of time the unit operated. This process yielded the total daily energy supplied to the chiller and the total cooling produced. From this, a daily average *Actual* COP can be defined as the ratio of chiller output to generator input. Next, the gas meter readings for the boiler can be used to determine the amount of energy supplied from auxiliary sources, and using the experimentally determined boiler efficiency of 0.75, this can be transformed to a net energy delivered to the chiller by the boiler. The difference between the daily energy supplied to the chiller and that from the boiler is then the amount of energy supplied by the solar system. Finally an *Effective* COP can be defined as the ratio of the chiller output to the generator input energy supplied by the boiler only. This figure will be larger than the Actual COP and the difference is a direct measure of the solar system contribution; the larger the effective COP as compared to the Actual COP, the greater the contribution of solar energy is to the system operation.

This approach determines the solar contribution as simply the difference between the energy used by the chiller and that supplied from auxiliary sources. Other methods of calculating the solar contribution were attempted, such as using a heat balance analysis on the storage tanks as was done for the winter data, but these yielded erratic results. In the latter case it became impossible to accurately estimate the tank losses at the relatively high temperatures required for chiller operation.

The daily average COP's were defined in terms of the chiller evaporator output and generator input, rather than using the condenser output and either of the other two figures, for two reasons. First, the COP as defined here readily allows the distinction between an Actual COP and an Effective COP which reflects the solar input. Second, it can be shown by uncertainty analysis, that assuming the generator, evaporator and condenser energy measurements all have equal uncertainties, the COP defined as the evaporator-to-generator ratio has the lowest uncertainty, especially under reduced load conditions.

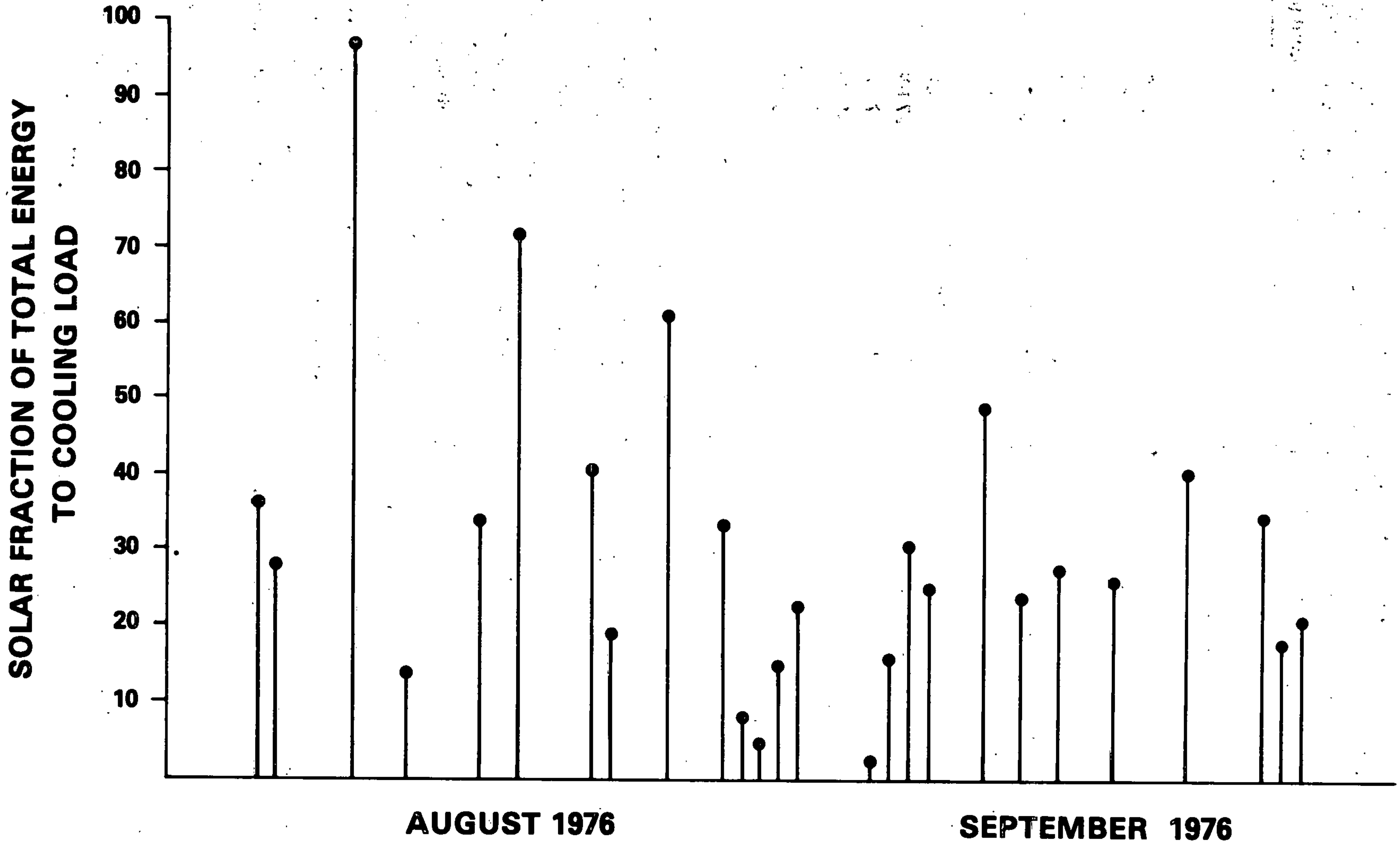


Figure 6. Daily Percentages of Solar Cooling

TABLE 6. SUMMER MONTHLY ENERGY SUMMARY

MONTH	DAYS	ELEC (10^6Btu)	AUX (10^6Btu)	SOLAR (10^6Btu)	GENERATOR (10^6Btu)	BLDG LOAD (10^6Btu)	ACTUAL COP	EFFEC COP	% SOLAR
Aug. 1976	12	11.79	45.90	19.45	65.35	24.99			
est. (*)	31	17.73	61.07	(24.72)	(85.79)	(32.80)	.38	.54	24
Sept. 1976	16	17.87	86.96	23.59	110.55	38.92			
est.	30	22.61	107.16	(28.48)	(135.64)	(47.96)	0.35	0.45	18
Summer Season		40.34	167.41	(54.01)	(221.43)	(80.76)	0.36	0.48	21

Total Energy Savings as a result of using solar energy

$$\frac{54.01}{.75} - 40.34 = 31.67 \times 10^6 \text{ Btu}$$

*Estimated performance based on actual gas and electric usage; estimates are shown in ( ).

Table 6 shows the results of applying this analysis to the August-September 1976 data for the selected days indicated. The net auxiliary energy (boiler) and the chiller generator input are shown in columns 4 and 6. The solar contribution is calculated as the difference and is listed in Column 4. The building load (or more properly the chiller output) totals are shown in column 7. Finally, the Actual COP is calculated as the ratio of the Building Load to the Generator input, and the Effective COP is calculated as the ratio of the Building Load to the Auxiliary input. The percent solar figure is calculated as the fraction of the total energy used (columns 3 and 6) that is supplied by the solar system. It should be noted that while these calculations include operation of the chilled water storage tank, its effect was relatively minor since it was only infrequently used. Details of this aspect of the operation and the unexpectedly high tank heat gains are discussed in Appendix D.

The solar cooling performance is disappointing. The major problem is most clearly evident in the low chiller Actual COP compared to the design values of 0.6 to 0.7. As discussed in Appendix D, the chiller generally operated under a severely reduced load with wide fluctuations in the generator and evaporator temperatures and under these conditions exhibited very low instantaneous as well as average COP's. The part-load characteristics of the WF1200 chiller have not been thoroughly explored, but it is clear that in this application there is a substantial penalty for such operation. It is felt that with a larger building load, and more efficient performance from the pre-existing classroom unit ventilators, the solar contribution would have improved in absolute terms, although the fraction of solar cooling might have been less.

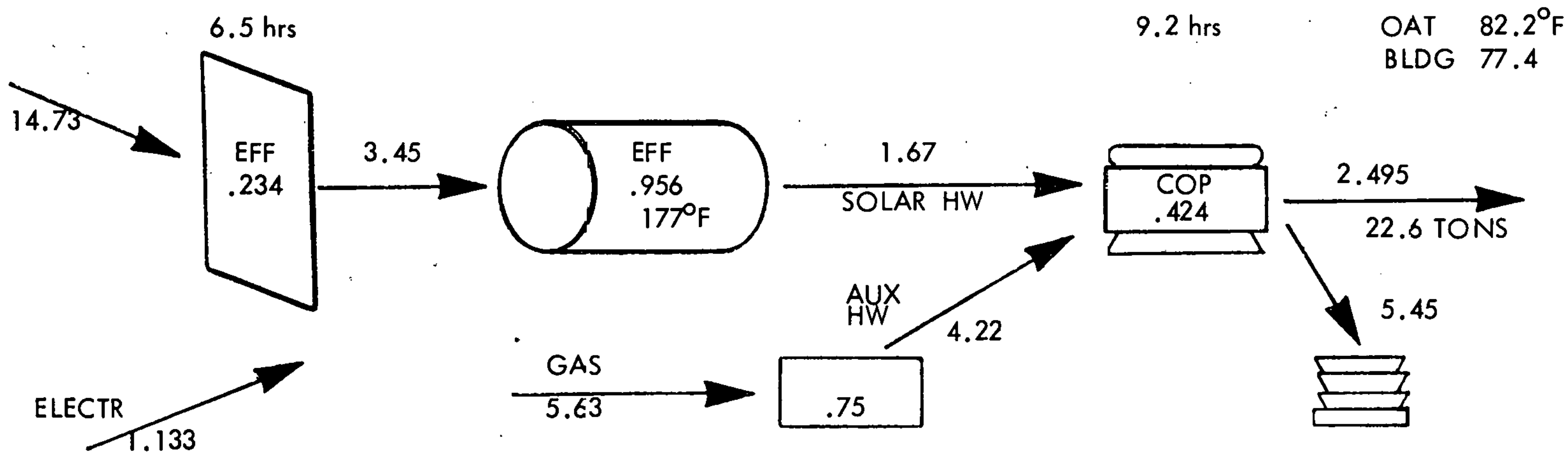
Figure 7, shows the system heat flows, efficiencies, chiller COP and building load on Friday 6 August. This date was selected from the data in Appendix D as a nearly typical day of system operation. Note that the amount of solar heat collected into storage was twice the amount of solar heat provided to the chiller generator. This indicates that the storage tank temperature was being raised to, and above, 177°F. The 9.2 hours of chiller operation was commenced, using the gas boiler as a heat source. As the storage tank temperature raised above about 175°F, the system switched to solar storage as the generator heat source for the remaining 28% of the cooling day.

Figure 8, is a similar display for the following Tuesday 10 August. This date was selected because of the high percentage of solar cooling. This date was more overcast than 6 August and, with a higher storage tank temperature, collection efficiency averaged only 7.5% over a 6.5 hour period. More than twice as much heat is extracted from storage than is put into storage from the collectors. The storage tank temperature dropped through an average temperature of 179°F while operating the chiller for 3.0 hours. At the end of this period, the decreasing outside air temperature and the cooling provided to the school reduced the cooling load to zero.

3.3 COLLECTOR/REFLECTOR ARRAY

A principal purpose of this experiment was to attempt to validate the performance of a large collector/reflector array which would be suitable for commercial size buildings and to compare actual and predicted performance. The array is described in detail in our previous DESIGN REPORT, and consists of first-generation, double-glazed, PPG Baseline collectors, provided with an experimental selective coating (α = .94, ϵ = .34) by ALCOA, with solar augmentation by an experimental fixed planar array of reflective Mylar (r = .76). Collector edge losses were to be minimized by mounting each collector in a neoprene glazing gasket. (This mounting method could not be incorporated because of funds limitations.) It was calculated that the heat production efficiency (Q/I) of each collector in this design configuration would be about 21% during the winter months, and about 44% during the summer months. The detrimental effects on efficiency of ganging over 10,000 square feet of such collectors into a single array and served by a single circulating pump could

TYPICAL DAY
FRIDAY, AUGUST 6, 1976
Data are BTU X 10^6, Total per Day



SOLAR FRACTION OF TOTAL COOLING:

THERMAL	28.4%
THERMAL + ELEC⁻R	19.8%

Figure 7. Typical Cooling Day—Friday, 6 August

SOLAR DAY
TUESDAY, AUGUST 10, 1976
Data are BTU X 10^6, Total per Day

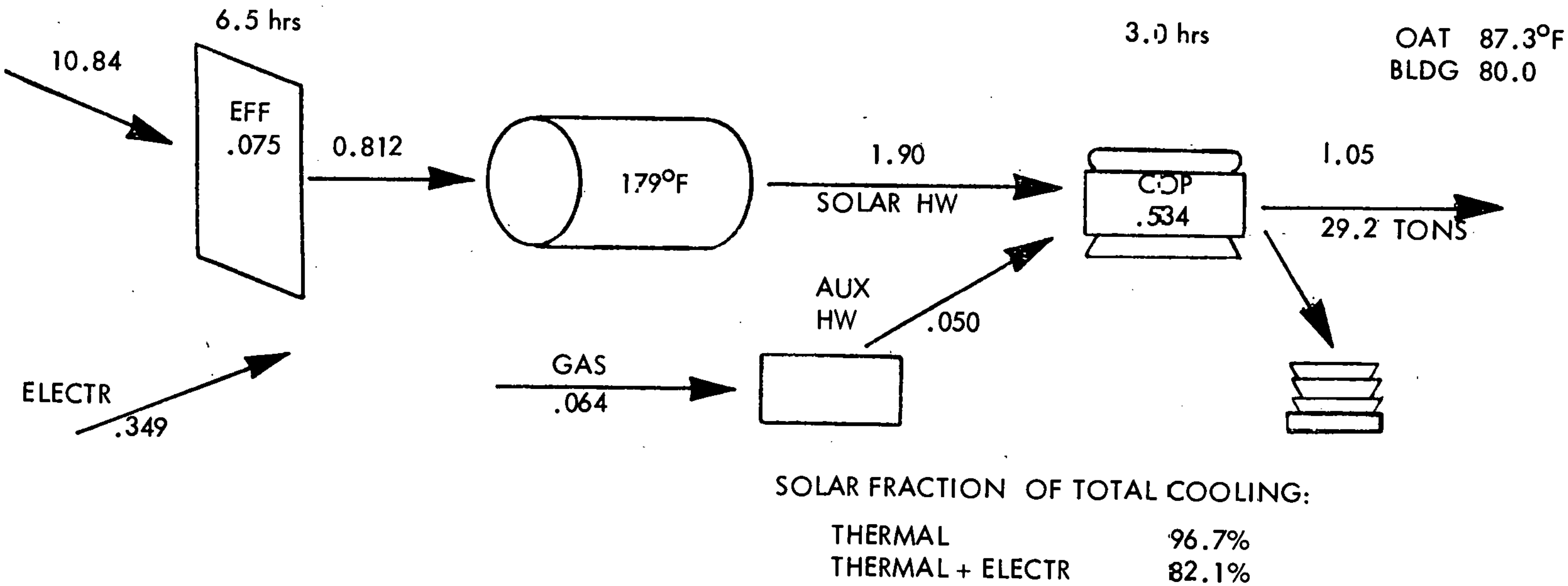


Figure 8. Solar Cooling Day—Tuesday, 10 August

not be estimated, since this was by far the largest liquid solar collector array ever constructed.

The physical performance of the collectors, and their selective coating, is detailed in the previous CONSTRUCTION REPORT. Briefly, the Roll-Bond aluminum absorber plates show promise of a service life in excess of 20 years when operated with tap water with specified concentrations of NUTEK corrosion inhibitor. After about 18 months of solar exposure, the selective coating characteristics have apparently deterioriated to: $a = .81$, $\epsilon = .41$, for a decrease of 14% in absorptivity and an increase of 21% in emissivity. The reflective Mylar appears to be performing as predicted. Incident to a pyronometer test of the array reflectivity on 1 October 1976, a clear day, it was discovered that insolation reflected onto the collectors was improved by 12% by merely wiping the Mylar with a soft cloth. It is apparent that the same dust which covered the Mylar also covered the collector glazing. There is no record of the last rainfall prior to the October test, and it is assumed that periodic rainfall adequately cleans the collectors and reflectors. (Future builders and owners of large-scale collector/reflector arrays, particularly in dry regions, should examine closely the possible economic benefits of occassional wash downs, just as for window walls.)

A daily analysis of the collector/reflector array heat production and performance is contained in Appendixes C and D for the heating and cooling seasons, respectively. This daily information has been summed to obtain monthly performance for the days on which the collectors operated, and the monthly data has been summed, in turn, to generate the seasonal performance results presented in Table 7.

As can be seen, collection efficiency during the winter months (20%) approximated our design estimate (21%). However, the high-temperature collection efficiency of only 11% based on dawn-to-dusk insolation, or 20% based on insolation received during the hours of collector operation, fall far below the design estimates. Some of the reasons for this inefficient performance can be determined by analysis of a poor-performance day of solar heat collection. Figure 9 displays the insolation and collector/reflector array performance for such a day, September 20, 1976.

Addressing the two upper curves of Figure 9: the solid line is the insolation measured in the plane of the front row of collectors; the dotted line is the average insolation on the entire collector array including reflector agumentation. Both curves are measured against the left ordinate in Btu/hr/sq ft.

Of the two lower curves: the solid line is the achievable collection efficiency curve assuming a precise 10° temperature rise through the collector array, and is measured against the right ordinate; the dotted line is the actual collector array heat production efficiency, also measured against the right ordinate.

Instantaneous insolation, flow rates and differential temperature values are sampled at 30 second intervals, summed and averaged every 15 minutes, and the 15 minute averages plotted throughout the day. The asterisks along the abcissa mark each 15 minutes from 6:00 am to 6:00 pm, Eastern Standard Time.

This was a mild day with an average outside air temperature of 78.9°F. Insolation peaks at or above 200 Btu/hr/sq ft indicate that the collectors were exposed at times to clear skies with frequent interruptions by a broken-to-scattered cloud layer. (Remember that these plots are 15-minute averages. Actual peaks and valleys were probably more extreme in magnitude, and occurred more trequently than the intervals shown.)

At point 1 on the abcissa (11:30 am), the collector absorber plate temperature had warmed to 178°F, 10°F above the temperature of the coldest storage tank. The collectors were filled with 120°F water from the holding tank, and the circulating pump began circulating this 600 gallons of water in a closed loop through the collectors, through the circulating pump and back through the collectors at 50 gpm, bypassing the storage tanks. From point 1 to point 2 (12:45 pm), this 600 gallons of water warmed to 176°F, the temperature of Tank 2. At this time, the controls operated to include Tank 2 in the collector loop. From point 2 to point 3, the circulating pump operated at varying flow rates (50 - 260 gpm) attempting to maintain a 10°F temperature rise through the collector array. At point 3 (3:45 pm), with decreasing insolation, the circulating pump was again operating at its lowest speed. At point 4 (5:15 pm), the collector array out-

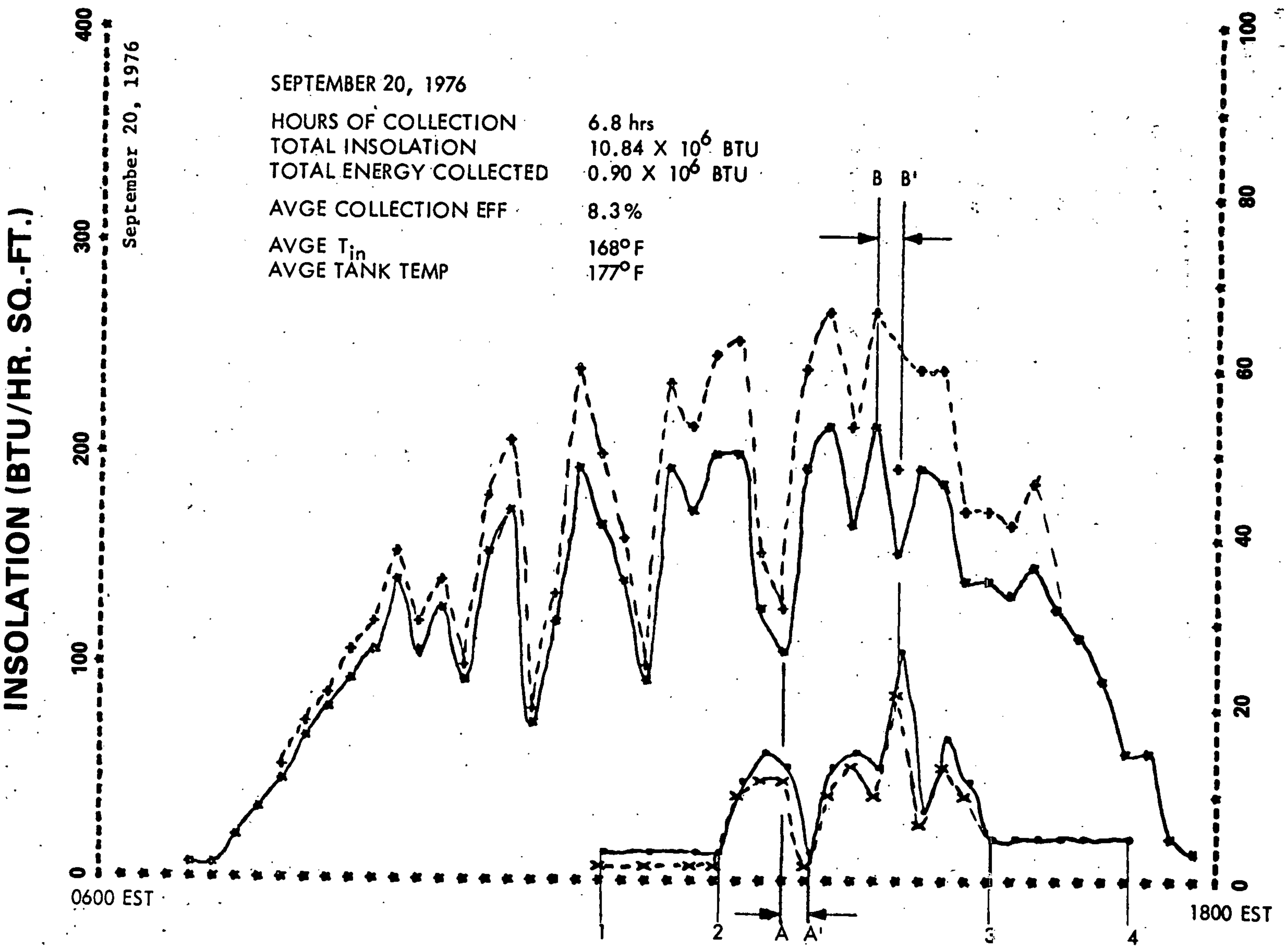


Figure 9. Insolation and Collector Efficiency—20 September

TABLE 7. SEASONAL ENERGY ANALYSIS OF SOLAR COLLECTORS

	Heating Season (Feb. 76-Apr. 76 Oct. 76-Feb. 15, 77)	Cooling Season (May 76, Aug. 76, & Sept. 76)
Insolation on collectors (Dawn to Dusk), 10^6 Btu	1470	889
Insolation on collectors during hours collector pump P2 operated, 10^6 Btu	932	500
Heat energy collected by flowing water, 10^6 Btu	293	101
Collector efficiency based on the insolation received during operating hours of pump P2, %	31%	20%
Number of days collector operated	75	39
Collector efficiency based on the insolation received during days (dawn to dusk) when P2 operated, %	20%	11%

put temperature was down to 170°F, 5°F colder than Tank 2. All solar heat collection stopped, and the system switched to drain down. The 600 gallons of 170°F water drained into the holding tank, to be used to refill the collectors on the next day. (On this day of erratic, inefficient solar heat collection, the chiller operated for 10.5 hours. During this time, 27.1% of the hot water used to drive the chiller was taken from Tank 2, concurrently with solar heat collection.)

Although the total available insolation for the day exceeded 10 x 10^6 Btu, it's apparent that about one-half of this insolation (to point 2) was expended in heating this collector array to the point where the first Btu of energy could be added to a storage tank which is already at 170°F. In this instance, 10,840,000 Btu of insolation fell on 10,360 sq ft of solar collectors over an 11 hour period, for a daily average of only 95 Btu/hr/sq ft. $T_{in} - T_a = 168° - 79° = 89°$. According to the PPG collector performance curves for absorber plates *without* a selective coating, these conditions should yield a collector efficiency of about 8%. However, these collectors have a selective absorber plate coating and a collection efficiency greater than the 8.3% achieved should be expected.

The lower curves of Figure 9 record the efficiency of the total collector array, and the adequacy of circulation control is important to this performance. Note that insolation fell to a minimum at point A on the abcissa, but that the corresponding collection valley appears at A', some 15 minutes later. Similarly, the insolation peak at B is reflected in a collection peak at B', 15 minutes later. The variable-speed pump, which governs flow through the collector array, is controlled by collector array T_{in} and T_{out} sensors, attempting to maintain a 10°F delta-T rise. An increment of water passing the T_{in} sensor, passes the T_{out} sensor some 3 - 12 minutes later. This time lag delays the change of flow rates in response to changes in insolation, and decreases the performance efficiency of the entire array. It's apparent that such control sensors should be mounted at the inlet and outlet of one collector (or paralleled among several collectors for redundancy) rather than at the inlet and outlet of the entire 576 - collector array. Note that the two high insolation peaks on either side of B do not result in correspondingly high peaks in collection. We believe that heat collection is attenuated by the control time lag and the observed inability of the control system to maintain the design temperature rise through the collectors.

In sum, this collector array cannot take advantage of low-order insolation when storage is already charged to a moderately high temperature, which is to be expected. However, collection performance is decreased by the absence of edge insulation around each collector, by deterioration of the selective coating, and by the inability of the pump/control system to adequately control the flow rate through this large array.

3.4 STORAGE SYSTEM

Detailed analyses of the thermal performance of the three storage tanks during the heating and cooling seasons are contained in Appendixes C and D respectively. The method of insulating the three storage tanks is detailed in the CONSTRUCTION REPORT.

An innovative and technically complex method of cascading three storage tanks was explored in this experiment. This method is summarized in Section 1.2, preceding, and is detailed in our CONSTRUCTION REPORT. Briefly, the control system selects the use of 15, 30 or 45 thousand gallons of thermal storage, depending upon the existing combination of tank temperatures, solar collector outlet temperature and water temperature needed at the load. Because hotter storage temperatures are required to drive the absorption chiller in the summer, only 15 or 30 thousand gallons of hot water storage are available in the cooling mode, and the remaining 15 thousand gallon tank may be used for chilled water storage.

In retrospect, the value of such flexibility may not be worth the cost in dollars to install and control the system, or in maintenance effort to keep the system functioning properly without loss of valuable operating time. Had the storage tanks and collectors been insulated as originally designed, and the chiller/distribution system loads been as anticipated as, say, in a new construction project, such concepts could prove their merit. However, with an average chiller COP of 0.36, the practice of depleting solar hot water at the end of each day, and on UNOCCUPIED school days, to generate chilled water for storage appears uneconomic for several reasons. The expenditure of 2.8 Btu of solar heat for each Btu of cooling delivered to the school distribution system is an inflexible function of the chiller/distribution system characteristics. But the premature generation of chilled water (at 36% conversion efficiency) for storage imposes an additional, double penalty on this existing system. The proximity of the chilled water tank to the hottest storage tank provides an attractive heat sink which both depletes hot water temperatures and warms "chilled" water above a useful cooling temperature over a relatively short period of UNOCCUPIED time.

The double penalty of depleting "excess" solar hot water in storage at the end of the day to generate chilled water storage, followed by the further cooling of hot water storage by heat exchange to the earth and to the adjacent cool tank during the balance of the UNOCCUPIED period, defeats the purpose of solar energy storage. The collector system (at about 20% efficiency) must start anew each day to heat the hot water storage tank to a temperature at which it can take over the cooling load.

For these reasons, chilled water storage operations were terminated in early September, 1976. It was recommended that, from the commencement of the 1977 cooling season, the chilled water storage tank (Tank 1) not be deliberately cooled down or utilized, but allowed to remain dormant as a buffer between the hottest storage tank (Tank 2) and the adjacent earth. Improved effectiveness resulting from this method of operation should become apparent during the 1977 cooling season.

The holding tank, used in the collector fill and drain process, also warrants discussion in this section. This tank is buried underground near, but not adjacent to the three large thermal storage tanks. From December 27, 1976, to January 21, 1977, the collector system was inoperable due to a frozen collector main supply line. During this period, the water in this half-empty 1,600-gallon holding tank cooled to near ground ambient temperature. The rooftop piping, much of which was shaded by the collector array, was cooled to the extremely low ambient air temperatures of this unusually cold winter. On the first attempt to fill the collectors after this down period the control system did not report the collectors filled after twice the usual time of fill pump operation. On investigation, the lower connecting hoses to the collectors were found to contain ice slush. The system was switched to the drain mode, and no attempt was made to refill the collectors until two days later, after ambient air temperatures had first increased above freezing for four hours. The collectors were then filled without incident and normal system operation was resumed. This incident raises a potential hazard to a drain-down system of this type in cold, northern climates. Collector fill and drain should be accomplished from and to a main thermal storage tank. If this is not feasible, then the fill and drain holding tank should be located within a heated building space, or the collector fill system should provide the ability to pre-heat collector fill water through the auxiliary furnace, if required. Provision must be made to prevent the freezing of cool collector fill water in rooftop piping which has been subjected to a prolonged "soak" at sub-freezing ambient temperatures, or an anti-freeze system with its thermal and cost penalties should be utilized.

4.0 PRINCIPAL FINDINGS

The objectives of this project were to:

- o Make a significant contribution to solar design, technology and acceptability.
- o Conduct an advanced experiment on an integrated large-scale solar heating and cooling system, determine its performance, reliability and maintainability, and compare these actual results with predicted performance.
- o Identify subsystem interface problems that cannot adequately be predicted by theoretical analysis.
- o Operationally test major components and identify improvements required.
- o Identify cost reducing materials and techniques which may improve the economic viability of solar heating and cooling systems.

A solar heating and cooling project of this magnitude and complexity had never before been undertaken. The final design configuration was established in September 1974, based upon existing state-of-the-art technology and available off-the-shelf components. In this section, the principal findings of this experimental project are summarized. Some findings included here were addressed in greater detail in our previous CONSTRUCTION REPORT. Most of the findings were published or disclosed on an as-occurring basis through technical papers, journal and magazine articles, and professional seminars, and many of the lessons learned have long since been applied to other second and third generation solar heating and cooling projects.

4.1 COLLECTOR/REFLECTOR ARRAY

Based upon our experience in procuring and installing 594 flat-plate collectors, the following collector attrition might be expected during the first 12 months:

Packing/Shipping/Unloading Faults	0.3%
Glass Covers Broken During Installation	0.5%
Vandalism/Foreign Objects Breaks	0.0%

During the first year of operation of these double-glazed collectors, fourteen (2.4%) incidents of crystalized shattering of the inner or outer glazing due to thermal effects on the tempered Herculite were experienced. In no case did both inner and outer covers fail on the same collector. The PPG Corporation reportedly identified the cause of such breaks and corrected the fault in subsequent collector production.

During the first six weeks of collector operation, a pinhole leak was detected in each of three aluminum absorber plates. Two of these pinholes were re-sealed within the next two weeks by particulate in suspension in the collector fluid. In about the fourteenth week of collector operation, two other absorber plates were observed to have a pinhole leak, one of which had re-sealed itself before detection. None of these leaks were large enough to require that the affected collectors be isolated or replaced immediately. The Olin Corporation reportedly identified the cause of such leaks and corrected the absorber plate manufacturing process.

After 13 months of operation, five of the 576 collectors in operation were removed for inspection of the absorber plates. A low-frequency of pitting, 1 to 3 mils deep, was observed in the water tube passages of the aluminum Roll Bond. One pit, penetrating one-third of the 30-mil water tube wall was detected. It is not known whether this pitting existed prior to installation, or occurred during the initial start-up period before the NUTEK corrosion inhibitor was evenly distributed in proper concentration throughout the water system, or during the three-month construction period while the collectors remained empty, or over the thirteen-month operating period.

After 24 months of collector operation, three absorber plates have developed a total of six pinhole leaks within a one-week period, in spite of attentive use of corrosion inhibitors, a getter-column (sacrificial anode system), and nitrogen purging of the collectors when drained. These leaks, all on the back of the absorber plate, were of a size to warrant caulking with an aluminum cement. The seriousness of these few pinholes in a collector array of this size is not known. However, the uncertainties of adequate corrosion control in an aluminum absorber plate array are presently such that the future use of aluminum absorbers of this type in a large-scale array cannot be recommended.

The measured deterioration in performance of the ALCOA selective absorber coating used in this project is such that its future use cannot be recommended.

The use of neoprene glazing gaskets for collector mounting, as designed for this project, would have decreased significantly the thermal edge losses from the collectors.

The use of silicon hose connections between collector nipples and header pipes have proven to be effective and practical.

The use of a reflector array, as designed for this system, is very cost-effective. Newly developed reflective materials may now be more cost-effective than the reflective mylar used in this project. The cost-effectiveness of periodic cleaning of the collector/reflector array should be explored further.

The wood trusses on which the collector and reflector arrays are mounted are practical and inexpensive, and show promise of a useful service life of 20 years or more in this application.

The steel grid which raises the collector/reflector array some two feet above the flat roof membrane is practical and necessary. In retrospect, the array might have been raised an additional two feet in order to permit a steeper slope to all piping above the roof, improving drain-down anti-freeze protection.

4.2 SOLAR HEAT COLLECTION

Heat production by this large-scale collector array is essentially as predicted during the heating season, with 125° - 145°F collector array inlet temperatures. During the cooling season, with 165° - 185°F array inlet temperatures, measured heat production was consistently less than predicted under given conditions, varying up to 50% less than predicted. The most notable effect during the cooling season is the inability to achieve a positive delta-T through the collector array until some two hours later in the morning than predicted. The deterioration of the selective coating and the edge losses of the collectors contribute to this performance.

Compromises in collector/reflector configuration necessary to "optimize" year-round heat collection most adversely affect solar heat collection cost-effectiveness in both the heating and cooling seasons.

4.3 COLLECTOR FILL AND DRAIN SUBSYSTEM

The collector fill and drain subsystem is effective, but complex. The proper functioning of this subsystem is critical to the performance of the solar collection and storage subsystems. If feasible, collectors should be filled from and drained into the main thermal storage tank.

If collector fill and drain is accomplised from a separate holding tank, a capability should be provided to heat the fill water against the possibility that water in the holding tank may sometime cool to near ambient temperatures. In extremely cold weather, cool fill water may freeze before reaching the hot collector plates. The holding tank should be provided with obvious fluid level and temperature indicators.

Valves which must isolate the fill and drain subsystem from the collectors and from the storage tank(s) should be bubble-tight, positively preventing the passage of either gas or fluid through the closed valves under worst-case pressure differentials.

4.4 THERMAL STORAGE

Underground thermal storage is practical and expedient, where the water table permits. The rock/air insulation, employed in this project as a financial expedient, is not considered to be cost-effective at storage temperatures in excess of about 80°F above ground ambient temperatures.

Insulation of the storage subsystem against thermal "short circuit" contact with surface or ground water is mandatory.

There is very little (2° - 3°F) vertical thermal stratification in each 10 ft diameter, 27 ft long cylindrical tank, even when dormant for two or three days. There is no significant stratification when either the collectors or the load are circulating through a tank.

Adequate lateral thermal stratification can be achieved and maintained among several laterally-separated tanks, as in this experimental project. The sequential "cascading" of storage tanks very effectively hastened the thermal recovery of depleted storage tanks on many occasions.

In this project, premature generation and storage of chilled water is not practical, principally because of inadequate tank insulation and the poor COP of the absorption chiller, particularly at derated generator temperatures.

4.5 SOLAR HEAT UTILIZATION

The direct utilization of hot water from storage to the heating load is most practical and shows promise of economic viability, particularly in a system whose collector array and modes of operation are optimized for winter heat collection.

The technical feasibility of utilizing a large-scale collector array to drive an absorption chiller for space cooling has been demonstrated. The economic viability of the use of solar heat through an absorption chiller has not been demonstrated, particularly if the solar heat used (at a COP of 0.6 or less) is collected by a fixed planar array whose configuration must be compromised (and thereby de-rated) for both summer and winter operation.

5.0 EXPERIMENTAL DATA SOURCES

Performance data and analytic text are contained in Appendixes A through D herein. Additional experiment data have been compiled, indexed and bound separately, but have not been included herein because of the sheer bulk of the material.

These data and their Appendix titles are:

		No. Pages
E.	EXPERIMENTAL DATA	
E1	Environmental Data	239
E2	Collector Performance	341
E3	Collector-Storage System Performance	237
E4	Collector-Storage-Load System Performance	236
E5	Building DHW Data	227
E6	Generator-Evaporator Data	52
E7	Condenser-Building Data	60

Title pages and sample pages from each of these appendixes are included in the following for the information of the reader. These appendixes may be studied at the Price Gilbert Memorial Library, Georgia Institute of Technology. Copies of the appendixes can be loaned through the requestor's business library or local library. Personal copies of the appendixes can be procured by payment of reproduction and mailing costs prevailing at the time of reproduction. For library-to-library loans, or for personal copies, write to:

Librarian
Price Gilbert Memorial Library
Georgia Institute of Technology
Atlanta, Georgia 30332

6.0 REFERENCES

This is the third and final report in a series on this project. The two preceding reports in this series, referenced throughout the text, are:

1. "Solar Heating and Cooling Experiment for a School in Atlanta: Design Report," December 1974, COO/2628-1
(NTIS Ref: PB 240 611)

2. "Solar Heating and Cooling Experiment for a School in Atlanta: Construction Report," December 1976, COO/2628-2

Also referenced in the text is:

NBSIR 76-1137, "Thermal Data Requirements and Performance Evaluations Procedure for the National Solar Heating and Cooling Demonstrations Program," by E. Streed, et al, August, 1976

A related report on this project, prepared in International System (S.I.) measurement terminology for the NATO Committee on the Challenges of Modern Society (CCMS) is:

"Report of the George A. Towns Elementary School Solar Heating and Cooling Project, Atlanta, Georgia," July 1976, COO/2628-76/1

All of the above reports may be obtained from:

National Technical Information Service
U.S. Dept. of Commerce
5285 Port Royal Road
Springfield, Va. 22151
Telephone: (703) 557-4650

APPENDIX A

Final Report

Design of Instrumentation and Monitoring System

G.A. Towns Elementary School

(This Final Report was prepared for Section 3.0 of Reference 1.)

FINAL REPORT

ON

DESIGN OF INSTRUMENTATION

AND MONITORING SYSTEM

FOR

SOLAR HEATED AND COOLED

P. O. C. E. AT THE

TOWNS ELEMENTARY SCHOOL

ATLANTA, GEORGIA

NOVEMBER 74

SUBMITTED TO

WESTINGHOUSE ELECTRIC CORPORATION

DEFENSE AND SPACE CENTER

BALTIMORE, MARYLAND 21203

BY

THE GEORGIA INSTITUTE OF TECHNOLOGY

ATLANTA, GEORGIA 30332

OUTLINE

FOR

SECTION 3.0 OF FINAL REPORT OF THE DESIGN OF A SOLAR HEATED AND COOLED SCHOOL IN ATLANTA

3.0 Instrumentation and Monitoring Systems

3.1 System Analysis

- 3.1.1 Solar Collectors
- 3.1.2 Thermal Storage
- 3.1.3 Boiler
- 3.1.4 Absorption Refrigeration Unit
- 3.1.5 Building

3.2 Data Needed for Systems Analysis

3.3 External Environmental Data Sources

3.4 System Instrumentation

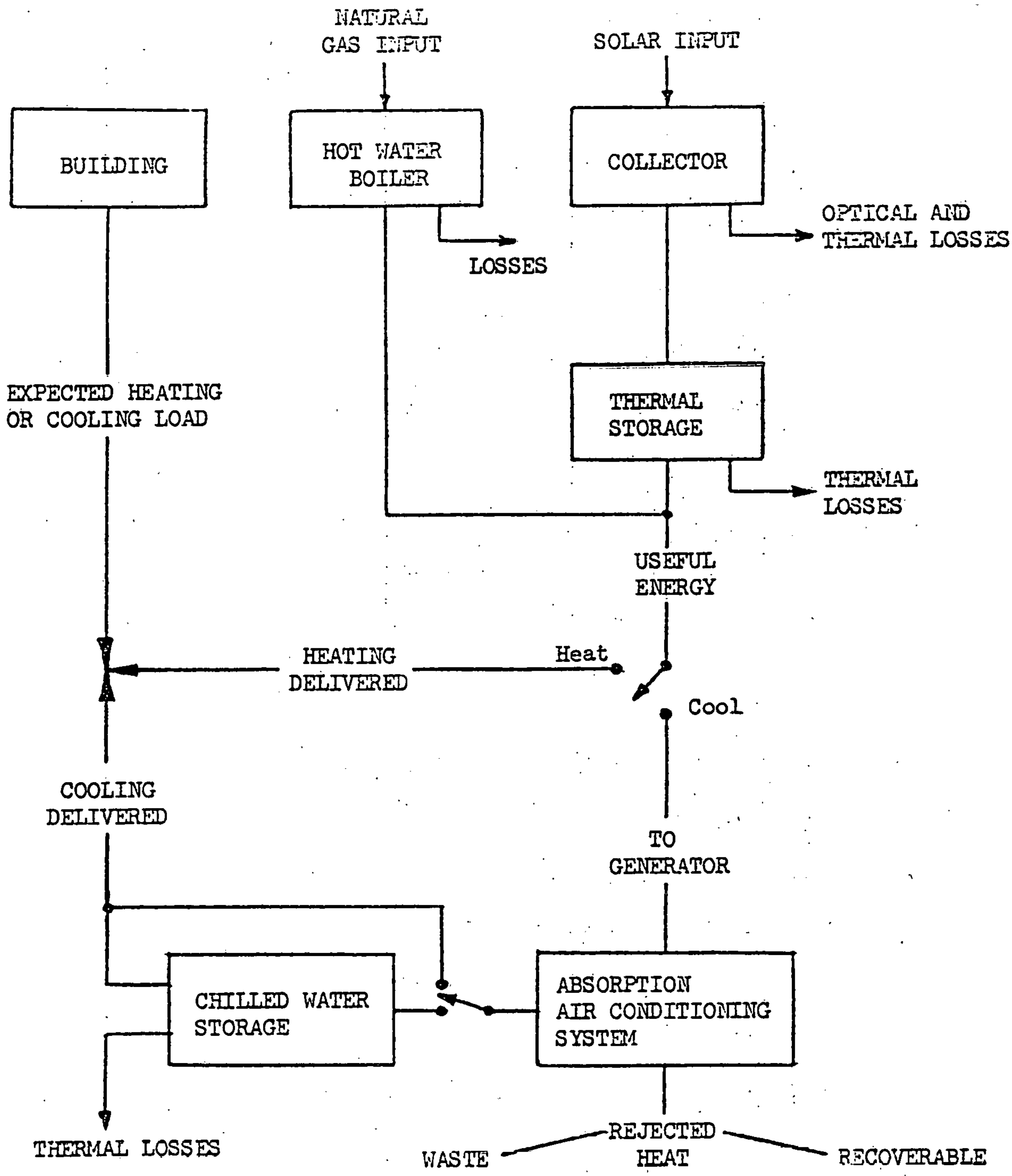
3.0 INSTRUMENTATION AND MONITORING SYSTEM

3.1 SYSTEM ANALYSIS

The solar heating and cooling system at the Towns Elementary School in Atlanta can be divided for analysis into five main areas. These are: the solar collectors, thermal energy storage, an absorption cooler, gas fired hot water boiler to supply auxiliary energy and the building. Energy balance models will provide the basis for detailed performance analysis. Using sensor data from the actual operating conditions of the solar system, these models will be used to calculate component and overall efficiencies for the various control modes. In addition, using thermodynamic concepts, the effectiveness of each component will be determined on the basis of the changes in an availability function. Those components which have low effectiveness (although perhaps a high energy efficiency) when compared to the maximum possible will be re-examined as a basis for an improved design. The instrumentation system designed by the Georgia Institute of Technology will provide sensor data in a computer compatible format (cartridge disc files) for direct use in performance calculations. The computations are to be done on the Georgia Tech on-campus minicomputer using the "background" area of the RTE. A schematic of the performance analysis is shown in Figure 3.1.1 and a brief discussion of each primary area of analysis follows.

3.1.1 Solar Collectors:

During the test period the incoming solar energy will be monitored continuously. Thermophysical properties including coolant mass flow rate and temperature rise will be used to calculate the output of the collectors.



Note: Storage effects in components are not shown but will be a part of the performance analysis.

Figure 3.1.1 Principal Areas in the Performance Analysis of the Atlanta POCE.

This data will be integrated over time and will be used directly to estimate the operating efficiencies of the solar panels. Since losses in excess of 50% of input energy may be expected these calculations require accurately measured data.

The losses from a solar collector include both optical and thermal effects. In addition there may be continuous deterioration in performance due to degradation of materials from scale formulation or fouling. If the system were always in a steady state these components could be analyzed using the measured data and the thermophysical properties of the materials in the collector. In reality the varying angle of incidence of the solar radiation and the local cloud cover together with the varying inlet and outlet temperatures will make any loss analysis very complex. Every effort will be made to consider these conditions in the analysis as well as storage mechanisms such as the heat capacity in the fluid or that in the solid material in the collector.

3.1.2 Thermal Storage:

The variability of insolation necessitates a rather large tank volume for heat storage. The inflow and outflow characteristics and temperature variations within each tank will be used to estimate the amount of thermal storage and the thermal losses from the insulated tanks as a function of time. Mixing losses as well as heat flow to or from the environment will be determined. Here it is not necessary to consider the unsteady effects although this would give a more "realistic" picture.

3.1.3 Boiler:

The existing hot water boiler from the conventional heating system will be used to augment the solar powered heating and cooling equipment. Two basic modes of operation are possible with the boiler either supplying the heating requirement directly or else firing the absorption chiller directly. In neither case is the storage tankage used. Appropriate inlet and outlet parameters will be measured and together with data on the energy input (natural gas) will be used to determine the unit's performance and the amount of auxiliary energy used by the solar heating and cooling system. A steady state type model will be assumed.

3.1.4 Absorption Refrigeration Unit:

The input energy to the absorption system, the chilled water output and the waste energy from the system will be carefully monitored as a function of time. The performance of the unit at full or partial load conditions will be estimated using an energy balance model and will be compared with the manufacturer's data when possible. It should be pointed out, however, that such data is probably not available, especially at off-load conditions, and consequently the present installed and instrumented system will provide an excellent test facility to develop part-load characteristics.

Normally a cooling system operates when the thermostat calls for cooling and shuts off when the demand is satisfied. In a large multizone building the diversity of demand usually requires operation of the air conditioning system at various fractions of design capacity. When the system capacity is large it is possible to decouple the operation of the air conditioning unit and the building demand by the introduction of a chilled water storage tank. The reason for this flexibility is very much the same as that discussed for the collector-storage systems. Such an arrangement will permit the operation of the refrigeration unit at near optimum conditions and at that time of day when the input energy is most available while at the same time providing adequate chilled water to meet building demands. In this application the peak solar energy collection and the peak cooling demand are separated by only a few hours. This coincident characteristic will have a tendancy to reduce the capacity of thermal storage required for this mode of operation. A careful analysis of this type of operation will be made and its implication for future designs evaluated.

3.1.5 Building Analysis:

The building is served by unit ventilator type heat exchangers in each room to provide either heating or cooling. The system circulates either hot or chilled water to these heat exchangers until the zonal thermostats are satisfied. The mass flow rate and temperature change of the water entering and leaving the main supply lines to these heat exchangers will be continuously monitored and recorded at frequent intervals. Accurate measurements from the flow meter and temperature sensors over the full operating range are essential for proper analysis of the data. The product of massflow rate times specific heat and temperature change obtained for each time interval is summed continuously over a prescribed period. This sum corrected for piping looses in unconditioned space represents the thermal energy delivered to or removed from the building by the heating and cooling system. It is essential to obtain as much accuracy in these calculations as practical. The cumulative sum will be used to determine the adequecy and performance factor of the solar heating and cooling system on a weekly, monthly or seasonal basis. In addition to these calculations, the thermal energy supplied to or removed from the building will be compared with the building load profiles. Load estimates will be made with the National Bureau of Standards Heating and Cooling Load Determinations Program (NBSLD). Input for the NBSLD program will include the actual indoor conditions maintained and local environmental data provided by on-site instrumentation and the Georgia Institute of Technology insolation and meteorological station. A favorable comparison between estimated loads and the measured thermal data will validate the computer model for projected systems analysis.

3.2 DATA NEEDED FOR SYSTEM ANALYSIS

The measurements to be monitored and recorded in real time for the analytical studies are:

- Environmental

  Insolation, total on a surface parallel to the collectors.

  Temperature, outside ambient.

  Relative humidity.

  Wind, velocity and direction.

- Collector System

  Temperature, Inlet.

  Temperature, Outlet.

  Mass Flow Rate.

- Storage System

  Temperature, Storage Inlet.

  Temperature, Storage Outlet.

  Mass Flow Rate, In and Out.

  Temperature Gradients in Tanks

- Absorption Air Conditioner, Solar

  Generator, Inlet and Outlet Water Temperature, and Mass Flow Rate.

  Chilled Water, Inlet and Outlet Water Temperature, and Mass Flow Rate.

  Condenser Cooling Water, Inlet and Outlet Temperature, and Mass Flow Rate.

- Heating System, Solar

  Heat Exchanger, Inlet and Outlet Water Temperature and Mass Flow Rate.

- Auxiliary Energy Supply (Boiler)

  Heating, Input and Outlet Energy.

  Cooling, Input and Outlet Energy.

- Domestic Hot Water

  Heat Exchanger, Inlet and Outlet Water Temperature and Mass Flow Rate.

  Auxiliary Energy Used.

- Building

  Zone Temperatures and Relative Humidities.

  Load Profiles.

Miscellaneous

pH, Collector Fluid

Equipment Maintenance Records.

Building Occupancy, Electrical Load, and Any Other Parameters Which May Affect Overall Energy Requirements.

3.3 EXTERNAL ENVIRONMENTAL DATA SOURCES

In addition to the insolation and meteorological data monitored and recorded on site, environmental data will be used from the Department of Commerce and the solar insolation and metorological station at Georgia Institute of Technology. The Georgia Tech facility is located only about 5 miles from the Towns school and will provide much more extensive environmental data then will be collected on site. Figure 3.3.1 shows the existing solar insolation and meteorological data system that has already been installed at Georgia Tech. The first pyranometer is used to measure the unfiltered, indirect, vertical solar energy. The second pyranometer is equipped with four additional optical filters to measure vertical solar energy in particular spectral bands. The third pyranometer is mounted to measure the horizontal solar energy from the southerly direction. A pyroheliometer on a equatorial mount is also used to measure the direct solar energy.

Meteorological data are obtained by two thermistors, a wind velocity meter, and a wind direction meter. The two thermistors are used to measure the differential temperature as a function of height by mounting the two thermistors on a fifty-foot tower. The wind velocity and wind direction are measured by wind sensors mounted on the tower.

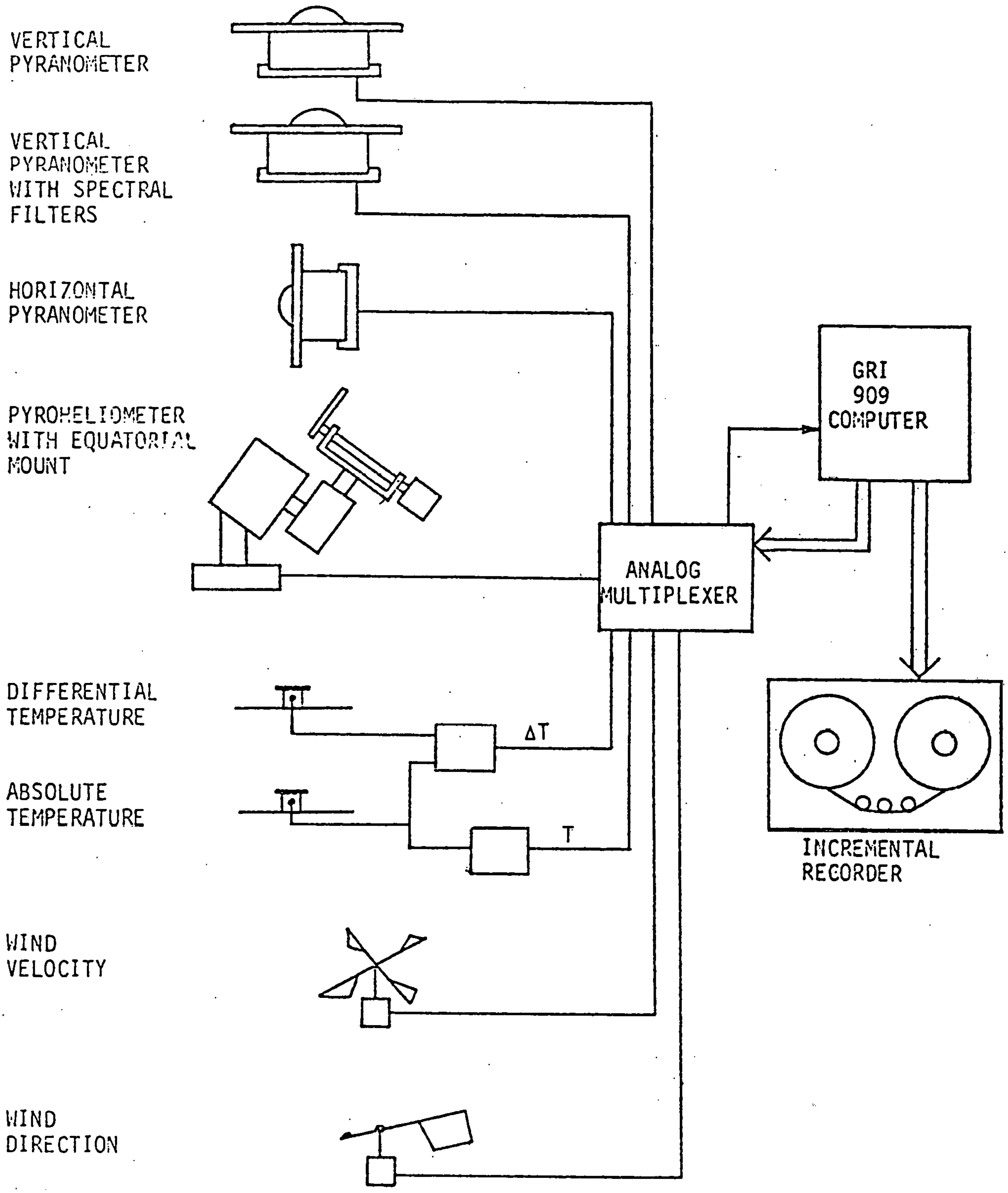


Figure 3.3.1 Solar Insolation and Meteorological Instrumentation System

The solar insolation and wind sensor outputs are amplified and sent to a 16 channel analog multiplexer. The multiplexer is controlled by a GRI 909 computer which can select the particular sensor that is to be fed through the multiplexer and sampled by an analog to digital converter in the computer. The digital computer stores this data on a digital incremental tape recorder for processing on a central digital computer. Eight of the 16 channels are used by the existing data collection system, the remaining 8 channels are free to sample additional channels of data.

3.4 SYSTEM INSTRUMENTATION

3.4.1 Data Acquisition System

A powerful digital computer based data acquisition system has been designed for the Atlanta P. O. C. E. The system employs a small minicomputer at the school site for direct control of the measurement process and makes use of a larger, more powerful minicomputer on the Georgia Tech campus for mass data storage and performance analysis. These two machines will be connected together by means of a leased telephone line so that not only may data be returned to the campus for logging but also changes in the mode of system operation can be initiated from the campus computer. The arrangement is shown schematically in Figure 3.4.1.1.

The communications and control programs will be run as "foreground" real-time programs in the RTE (Real Time Executive) used in the campus machine. Received data will be stored in files on a cartridge disc using a powerful File Manager utility package. The RTE provides multiprogramming capability so that concurrently with data acquisition, programs may be run

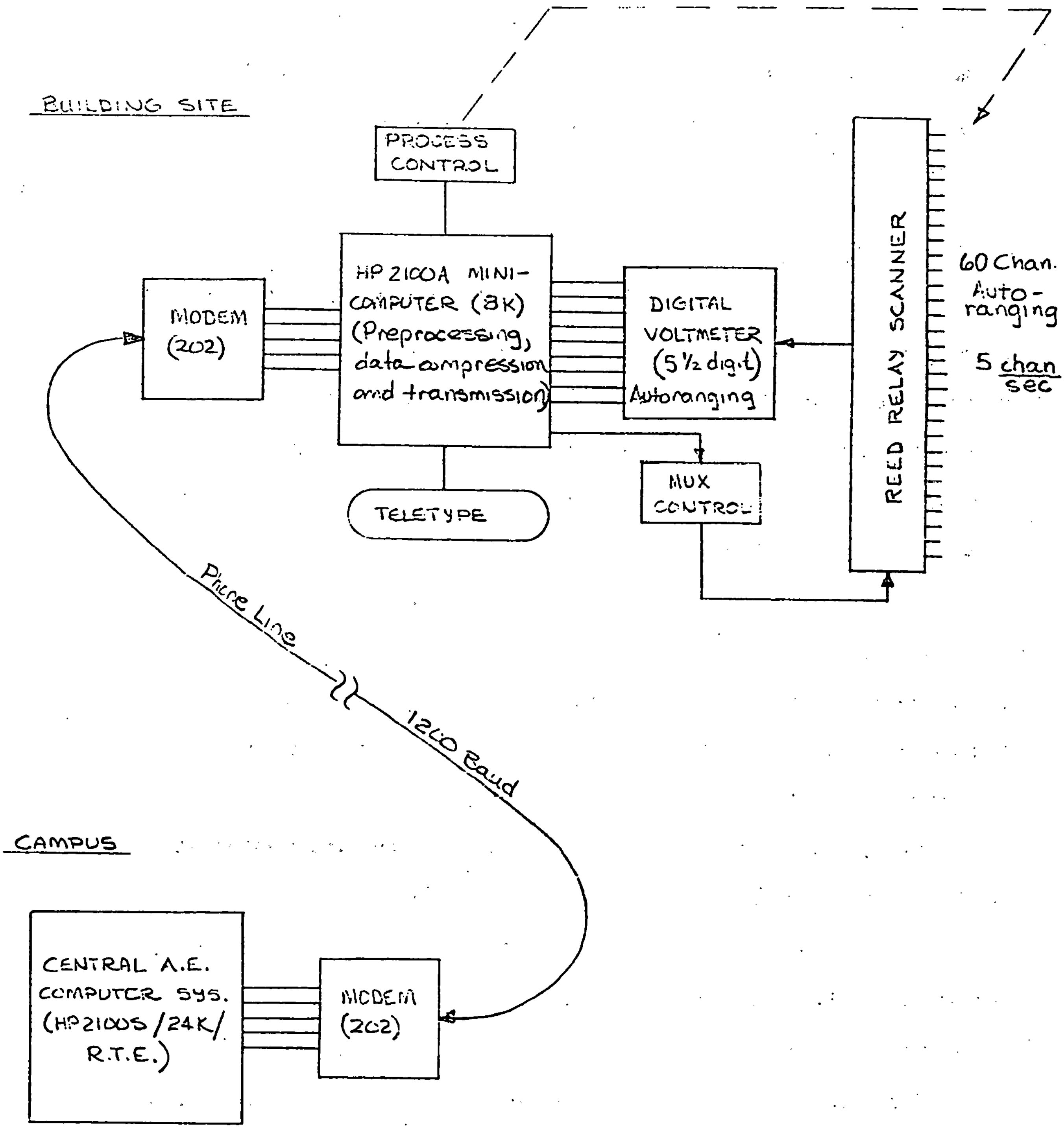


Figure 3.4.1.1 Data Acquisition System Schematic, Atlanta POCE.

in the "background" memory area to examine old or currently open data files. In this way performance analysis programs may be run concurrently with communications programs. Both paper tape and card input can be handled at the central machine and a high speed 80 column line printer is available for output listing.

3.4.2 On-Site Data Gathering:

The site data acquisition system will handle up to 60 three-wire, guarded channels of d.c. voltage at up to 100 volts with as low as 10 microvolt resolution. Appropriate conditioning electronics are provided to accommodate signals from temperature, flow, environmental and meteorological sensors. The system with its interface to the minicomputer is shown in Figure 3.4.1.2.

Several features deserve further explanation. The Teletype is used to enter program directives as well as to provide detailed reports of system operation. For rapid display of operating parameters, four digital display units are also provided. Under program control up to four parameters of interest can be displayed and periodically updated. For example, this might include certain temperatures and flow rates or solar heat conversion rate or building cooling load.

The 60 channel reed relay scanner (Vidar Autodata 616) and digital voltmeter (Fluke 8800A) operate under direct computer control. The scanner is basically a random access unit and a channel address must be supplied for each measurement to be made. The voltmeter is triggered shortly after scanner switch closure and the resultant reading transferred to the computer. This configuration provides the capability to selectively

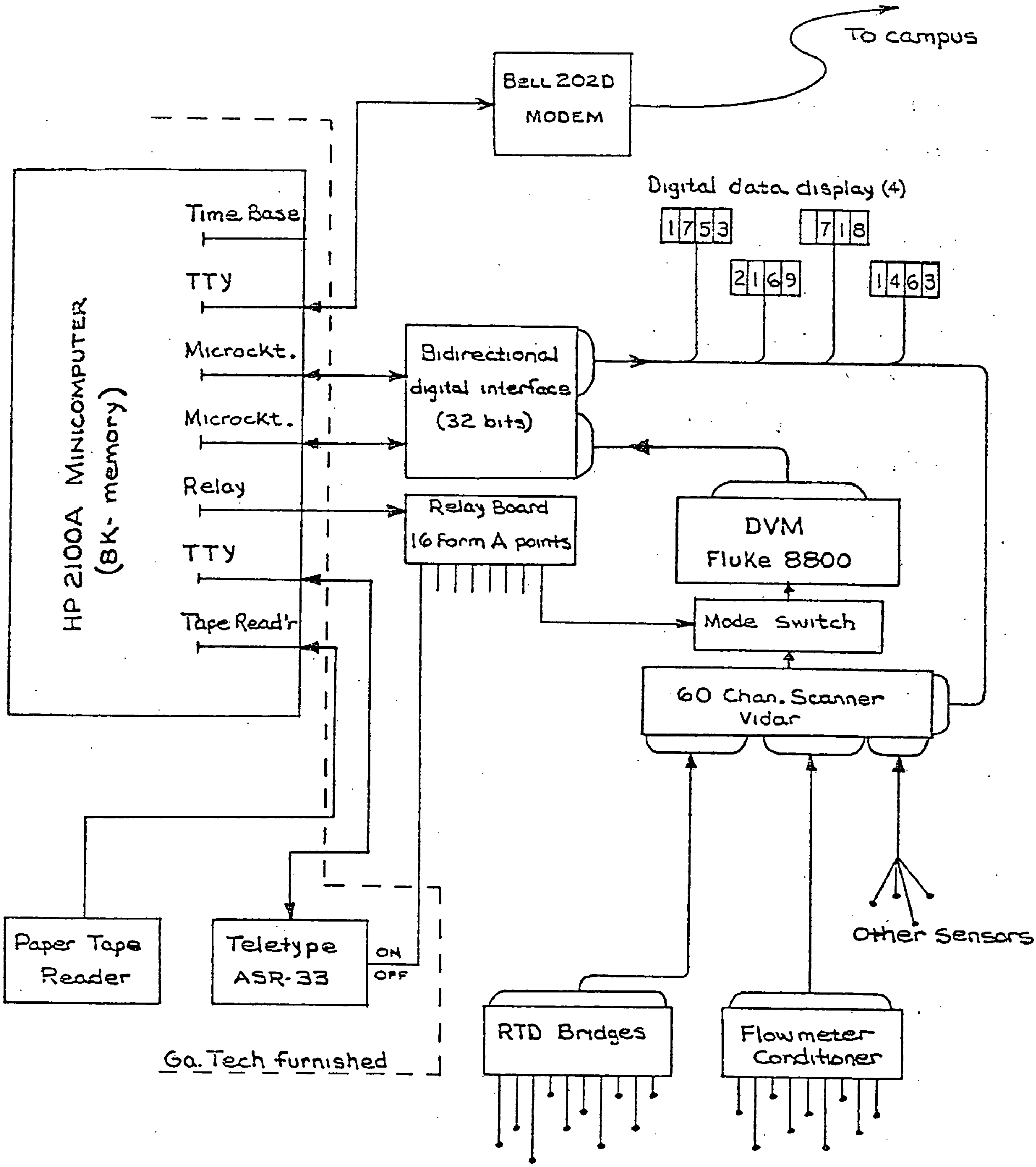


Figure 3.4.1.2 Site Data Acquisition Schematic.

adjust sampling rates on individual channels to suit the measurement requirements. The basic sampling cycle will be on the order of 5 minutes although cycles of a few seconds may be used for rapidly changing variables such as solar radiation.

A relay interface that provides 16 Form A contact closures is also included. Several of these relays are used in the data system and the balance are available for control functions. It is not explicitly proposed to control the solar system from the computer but during the course of the experiment it may be desirable to evaluate different control algorithms by implementing them in the computer. In this case the relay interface could be used for control purposes, i.e., set point or mode control.

The connection to the campus computer is made via a standard bit-serial terminal interface connected to a Bell 202 series MODEM. In this way the communication interface appears identical to a conventional terminal (Teletype for example) and programming is correspondingly simplified. A 1200 baud service has been selected for rapid yet accurate and relative economical data transfer.

Finally, a crystal controlled time base (clock) is included as an interface circuit in the computer. This circuit provides periodic hardware interrupts to the computer at program selectable intervals of from 100 microseconds to 1000 milliseconds. The time base is used to clock all measurement tasks at selected intervals and for convenience is set initially to local time.

In a substantial cost sharing effort, Georgia Tech is making available the site minicomputer teletype, tape reader, equipment rack and several of the interface components. In addition, use of the central campus minicomputer is being provided at no direct cost to the sponsor. The operating budget includes only a modest contingency amount for maintenance to the site computer. The above equipment along with associated data acquisition instruments will be returned to Georgia Tech at the conclusion of the subcontractor's participation in the proposed study.

3.4.2 Sensors and Sensor Placement:

Evaluation of the performance of a heating and cooling system requires that measurements be made of various thermodynamic and meteorological variables. For a solar powered system, the most critical parameters include the solar radiation incident on the collector surfaces, the heat contained in storage, and the heat flow between various system components. Consequently, a majority of the critical measurements involve accurately sensing temperature, temperature differentials and mass flows. An arrangement of sensors has been designed that will provide the highest accuracy consistent with the variables being measured. A thermodynamic schematic of the heating and cooling system is presented in Figure 3.4.2.1 and on it are shown the principal variables that will be measured. Not shown are the atmospheric wind and temperature sensors and the electric power transducers which complete the measurement system. The precise locations for all thermodynamic sensors are shown on the system schematic, Figure 3.4.2.2, and their individual specifications are summarized in Table 3.1. A discussion of each category follows.

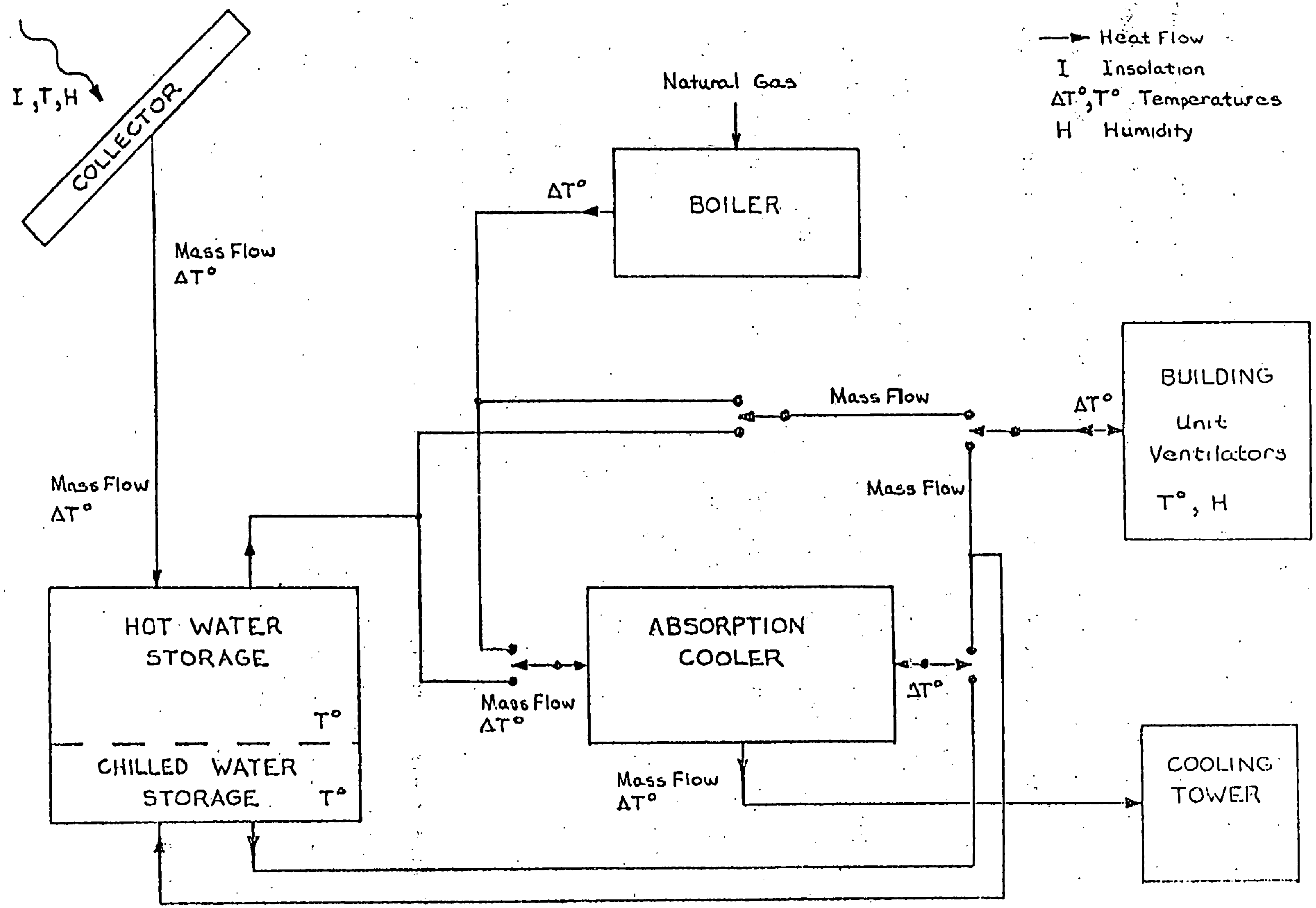


Figure 3.4.2.1 Heating and Cooling Schematic with Performance Instrumentation.

Platinum resistance thermometers (Rosemount, Inc. Series 78 sensors) have been selected for all temperature measurements and individual bridge circuits (Rosemount Model 401R) are provided for maximum flexibility. Critical differential temperature measurements such as those associated with intercomponent heat flow will be made by using a direct differential bridge circuit that avoids the errors associated with differencing readings from separate bridges. Three and four-wire sensor connections will be used for maximum accuracy. Pipe mounted sensors will be housed in conventional thermowells while the 9 tank mounted units will be located in specially fabricated wells accessible through the tank plumbing and valving covers. Building zone temperatures will be measured using the same Series 78 resistance sensors but the units will be housed in a protective shield.

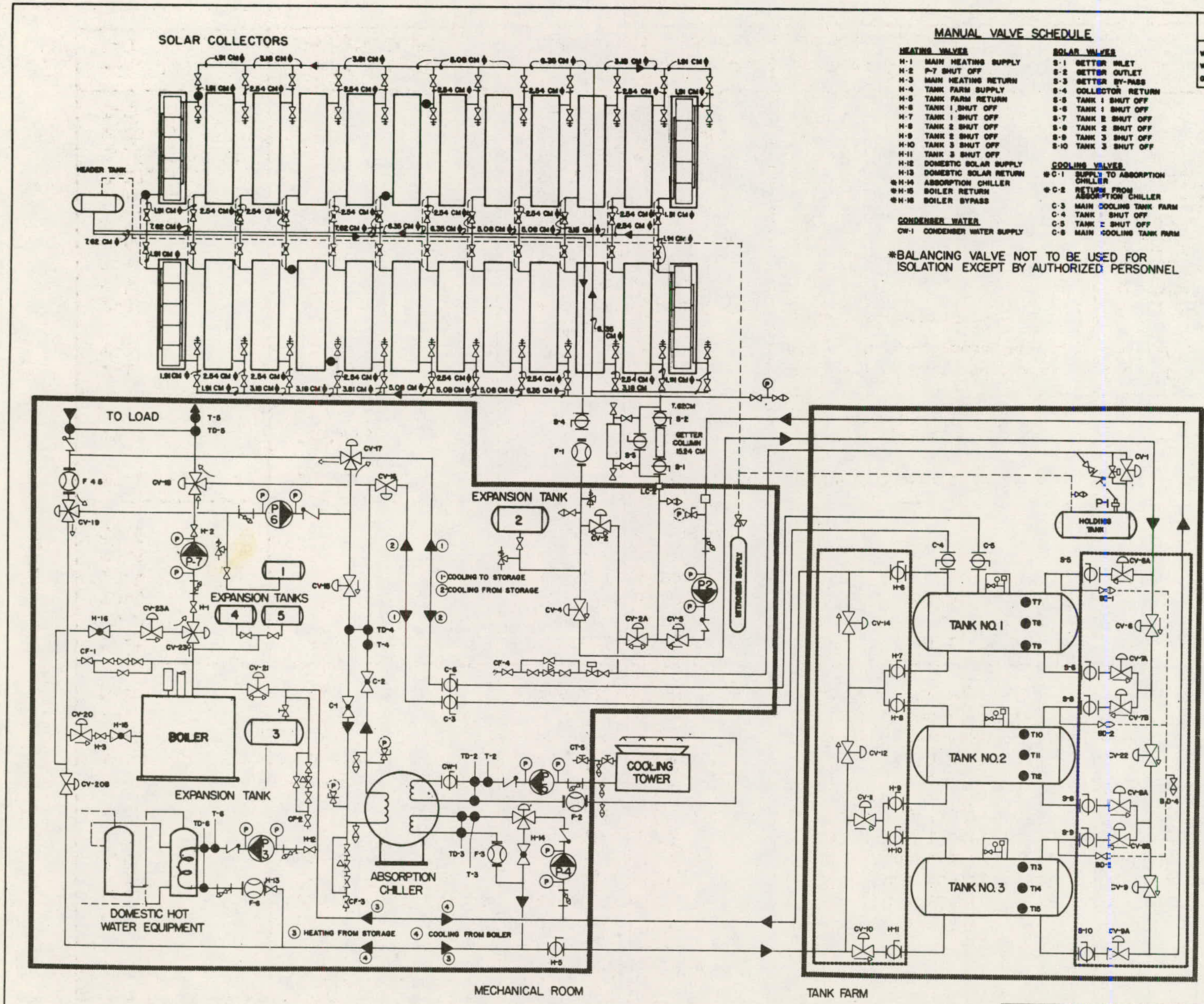
Mass flow measurements will be made using several different types of sensors as are appropriate for the particular circuits. In all cases accuracies to at least 2% have been specified. For example, in the primary collector loop where large turn downs are expected (to optimize collector outlet temperature) a precision Vortex shedding type flowmeter has been specified. On the other hand, in the absorption chiller condenser loop where flow rates are relatively constant an insert flow tube type sensor with d/p cell has been selected. A total of six flow sensors will be used in the system. Their location is shown in Figure 3.4.2.2 and the individual specifications are given in Table 3.1.

Solar radiation measurements are to be made at the collector site using a conventional "improved" Epply pyranometer supplyed by Georgia Tech.

This instrument is recognized to have serious shortcomings especially for long term observations but appears to be the best available at the present time. The insolation data will be supplemented by other measurements from the Georgia Tech Solar Data Station which began operation during the summer of 1974. The station records at one minute intervals both the direct and diffuse radiation, the latter on a horizontal surface, as well as atmospheric temperature and stability. A major purpose for the station is to provide an environment for research and development on improved techniques for solar radiation measurement. The station supports several sponsored research programs on solar energy utilization and is one of the indirect items of cost sharing provided by Georgia Tech.

TABLE 3.1 Transducer Specifications

Transducer	Manufacturer	Location	Description	Range	Accuracy
F-1	Hagan	Collector loop	3" Vortex shedding	40-400gpm	1% F.S.
F-2	Badger/Rosemount	Absorption cond.	4" Flow tube and D/P cell	70-350gpm	2% F.S.
F-3	Badger/Rosemount	Absorption gen.	4" Flow tube and D/P cell	50-250gpm	2% F.S.
F-4	Badger/Rosemount	Absorption evap.	4" Flow tube and D/P cell	40-200gpm	2% F.S.
F-5	Taylor	Building load	3" Magnetic flowmeter	20-200gpm	1% of Rdg.
F-6	Brooks	Domestic hot water	1/2" Turbine flowmeter	0.5-5gpm	0.1% F.S.
I-1	Eppley	Solar pyranometer	Eppley 8-48 thermopile		
TM-1	MRI	Outside temp.	Aspirated thermistor (815-1)	-30 + 50°C	.75% of Rdg.
M-1	MRI	Wind speed	Cup type amemometer (1022S)	0.5-100mph	1% of Rdg.
M-2	MRI	Wind direction	Wind vane (1022D)	0-540°	.5% of F.S.
TD-1	Rosemount	Collector loop	Series 78 dual platimum resistance sensors connected in a differential bridge.	100°F	0.5°F
TD-2		Absorption cond.		20°F	0.5°F
TD-3		Absorption gen.		20°F	0.5°F
TD-4		Absorption evap.		20°F	0.5°F
TD-5		Building load		20°F	0.5°F
TD-6		Domestic hot water		20°F	0.5°F
TH-1, 2, 3, 4	Foxboro	Building zones	"Dewcel" humidity sensor (dew point)	-50 + 142°F	3% of F.S.
TH-5	Foxboro	Outside humidity	"Dewcel" humidity sensor (dew point)	-50 + 142°F	3% of F.S.
T-1	Rosemount	Collector output	Series 78 single element platinum resistance sensors connected to individual bridges.	100-220°F	1°F
T-2		Absorption cond. output		60-120°F	0.5°F
T-3		Absorption gen.input		160-220°F	1°F
T-4		Absorption evap.		30-70°F	0.5°F
T-5		Building supply		30-150°F	0.5°F
T-6		Domestic H.W.output		100-200°F	1°F
T-7,8,9		Tank 1		30-200°F	
T-10,11,12		Tank 2		100°-200°F	0.5°F
T-13,14,15		Tank 3		100°-200°F	0.5°F
T-16,17,18,19		Building zones		50°-100°F	0.5°F
T-20-25		Collector panels		100°-220°F	1°F
T-26-30		Unassigned			
W-1, 2	Leeds & Northrup	Pump electric supply	3ø wattmeter		0.5% F.S.
W-3	Georgia Tech	Domestic H.W. heater	Voltmeter circuit		2% F.S.



MANUAL VALVE SCHEDULE

HEATING VALVES

H-1	MAIN HEATING SUPPLY
H-2	P-7 SHUT OFF
H-3	MAIN HEATING RETURN
H-4	TANK FARM SUPPLY
H-5	TANK FARM RETURN
H-6	TANK 1 SHUT OFF
H-7	TANK 1 SHUT OFF
H-8	TANK 2 SHUT OFF
H-9	TANK 2 SHUT OFF
H-10	TANK 3 SHUT OFF
H-11	TANK 3 SHUT OFF
H-12	DOMESTIC SOLAR SUPPLY
H-13	DOMESTIC SOLAR RETURN
*H-14	ABSORPTION CHILLER
*H-15	BOILER RETURN
*H-16	BOILER BYPASS

CONDENSER WATER

CW-1	CONDENSER WATER SUPPLY

SOLAR VALVES

S-1	GETTER INLET
S-2	GETTER OUTLET
S-3	GETTER BY-PASS
S-4	COLLECTOR RETURN
S-5	TANK 1 SHUT OFF
S-6	TANK 1 SHUT OFF
S-7	TANK 2 SHUT OFF
S-8	TANK 2 SHUT OFF
S-9	TANK 3 SHUT OFF
S-10	TANK 3 SHUT OFF

COOLING VALVES

*C-1	SUPPLY TO ABSORPTION CHILLER
*C-2	RETURN FROM ABSORPTION CHILLER
C-3	MAIN COOLING TANK FARM
C-4	TANK 1 SHUT OFF
C-5	TANK 2 SHUT OFF
C-6	MAIN COOLING TANK FARM

*BALANCING VALVE NOT TO BE USED FOR ISOLATION EXCEPT BY AUTHORIZED PERSONNEL

STORAGE TANKS PRESSURIZATIONS

WATER TEMP.	4.4	9.9	[illegible]	32.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	°C
WATER LEVEL	76.74	76.74	76.2	76.2	[illegible]	[illegible]	71.12	[illegible]	[illegible]	[illegible]	CM
GAUGE PRESSURE	96	96	90	97	105	110	124	136	152	172	kP

AUTOMATIC VALVE SCHEDULE

CV NO.	POSITION	PRESSURE GAUGE NO.
1	N.O.	1
2	N.O.	2
2A	N.O.	2
22	N.O.	3
7B	N.C.	3
8A	N.C.	3
20A	N.O.	4
20B	N.C.	5
6	N.O.	6
6A	N.C.	6
7A	N.C.	6
21	N.C.	7
18	N.O. B TO AB	8 3 WAY
19	COOLING MODE	8
8B	N.C.	9
9	N.O.	9
10	N.C.	10
11	N.C.	11
12	N.C.	12
14	N.C.	14
15	N.C.	15
16	N.C.	16
17	N.O. B TO AB	17 3 WAY
3	N.C.	18
4	N.C.	18
23A	N.O.	

CV NO. LOCATION OF CONTROL VALVE, REFER TO FLOW DIAGRAM & BARBER COLMAN DRAWING ATLANTA - 86290, SHEET NO. 1 OF 9

POSITION VALVE POSITION WITH ZERO GAUGE PRESSURE

PRESSURE GAUGE NO. AS IDENTIFIED IN BARBER COLMAN CONTROL PANEL NO. 2

SYMBOL LIST

- GATE VALVE
- CHECK VALVE
- TWO PORT AUTOMATIC CONTROL VALVE
- THREE PORT AUTOMATIC CONTROL VALVE
- PUMP
- IN LINE STRAINER
- PRESSURE RELIEF VALVE
- PRESSURE REDUCING VALVE
- DRAIN COCK WITH HOSE UNION CONNECTOR
- VENT PIPING (NITROGEN)
- BUTTERFLY VALVE
- PRESSURE GAUGE
- PRESSURE GAUGE TAPPING
- FLOW TRANSDUCER
- TEMPERATURE SENSOR
- TEMPERATURE DIFFERENTIAL SENSOR
- CONTROL SENSORS
- BALANCING VALVE

REVISIONS		
	ATLANTA SOLAR P.O.C.E.	JOB NO. 7615
	BURT, HILL & ASSOCIATES · ARCHITECTS SIXTH FLOOR, MELLON BANK BUILDING — BUTLER, PA. PITTSBURGH, PA. — FORT MYERS, FLA.	SHEET NO. H-1 OF 4
	SOLAR INTERFACE FLOW DIAGRAM	
	DRAWN BY ____ CHECKED BY ____ · DATE ISSUED ____ · SCALE ____	

APPENDIX B

Comments from Data Log Book

G.A. Towns Elementary School

February 1, 1976 to February 16, 1977

APPENDIX B

TOWNS ELEMENTARY SCHOOL SOLAR PROJECT
SIGNIFICANT COMMENTS FROM DATA ACQUISITION LOG BOOK
Feb. 1, 1976 to Feb. 16, 1977

Date		Comments
Feb. 1	a)	Data acquisition task commenced by Ga. Tech - 12 months duration.
	b)	Data system set to operate for a twelve hour period from 0600 to 1800. This interval was selected since the main circulating pump to the building, P7, operates primarily during this period. During the remaining hours from 1800 to 0600 hours P7 operates only to satisfy the set-back thermostats.
	c)	Data system set to operate on week days only since collectors must be filled and drained manually due to faulty fill pump, P1. Thus, the solar system does not operate on weekends.
	d)	Domestic hot water pump, P3, turned off.
Feb. 2,	a)	Electronic package on building flow meter, F4/5, malfunctioned. Returned to factory for repair.
	b)	Wind speed sensor malfunctioned. Returned to factory for repair.
Feb. 9,	a)	Flow meter F4/5 repaired.
Feb. 16,	a)	Digital volt meter, DVM, malfunctoned.
	b)	DHW pump, P3, turned on and checked out.
Feb. 19,	a)	DVM repaired
	b)	Building zone humidity sensors installed.
Feb. 23,	a)	DVM again malfunctioned. Returned to Ga. Tech for repair.
Feb. 26,	a)	DVM repaired.

March 3-9	a)	Bob Sparks from Dubin-Mindell Bloome Associates here to check out some mechanical difficulties with the solar system. These are: 1. Collector fill pump, P1, proved to be inadequate. 2. The control valves cannot maintain pressure differentials within the systems. This allows water to leak back into the collectors after they have been drained.
March 17	a)	Changed data acquisition system to sample all temperature differential signals and flow rates at 30 sec. intervals. The average of these readings will be printed out every 15 minutes.
March 22	a)	Developed a problem with the paper punch.
March 24	a)	Outside temperature sensor giving bad data. Removed for repair.
March 28	a)	Outside temperature sensor repaired.
March 31	a)	The circulating pump, P7, in the building loop was found to be overpressuring the storage tanks. Bob Sparks found that a control valve had been incorrectly installed.
April 22	a)	Dick Duncan here. Began cool down of Tank #1 for summer operation.
April 23-24	a)	Data system operated all night to check tank losses.
April 26	a)	Dick Duncan here. Cooled tank No. 1 and checked out cooling tower.
April 27	a)	Dick Duncan checked out chiller operation. With Tank #1 at 117°F, switched time clock to UNOCCUPIED MODE (to enable chilled water storage) and CHILLED water STORAGE to AUTO. Solar system in - SUMMER Mode, HEAT source AUTO.
April 28	a)	Data system operated all night to check tank losses.
May 4	a)	Activated pumps P4, P5, and P6 to store chilled water in Tank #1 - UNOCCUPIED MODE.
	b)	Data sysem operated all night.
May 12	a)	Activated pumps P4, P5, and P6 to store chilled water in Tank #1 - UNOCCUPIED MODE.
	b)	Data system operated all night.

May 13 a) Activated pumps P4, P5, and P6 to store water in Tank #1 - UNOCCUPIED MODE.

May 19 a) Activated pumps P4, P5, and P6 to store chilled water in Tank #1 - UNOCCUPIED MODE

b) Data system operated all night.

May 20 a) Checked calibration of temperature sensors in Tank #1 and Tank #2. (see Section 3c.)

Procedure: Used precision DECADE Box to simulate RTD signals. Checked signal conditioning and cable. Data given below:

CAL. Temp. °F	Decade Resist. R	Actual Temperature Recorded (RTD Reading) TA1	TA2	TA3 °F	TB1	TB2	TB3
32	100.00	32.58	32.68	32.72	32.62	32.66	32.72
100	114.68	99.84	100.13	100.16	100.07	100.12	100.15
160	127.50				158.09	158.15	158.13
200	135.97	195.47	196.02	196.10	195.98	196.07	196.02

Conclusion:
Absolute temperature data good up to 100°F.
About 2°F low at 160°F
About 4°F low at 200°F.
These correction will be made during the performance analysis.

May 21 a) Teletype repaired.

May 24 a) DVM used on AUTO Range to record data from thermocouples. AUTO Range would not operate properly. DVM set back on 20 volt range.

May 27 a) Chiller operated with solar energy at 0915 EST.

b) Calibrated temperature sensors in collector loop.

Procedure: Used precision DECADE Box to simulate RTD signals. Checked signal conditioning and cables.

Data from TI Sensor (Absolute)

Cal. Temp. °F	DECADE Box R	TI Reading °F
32	100.00	32.30
100	114.68	99.79
160	135.97	157.86
200	127.50	195.80

Conlcusion - Absolute temperature cards are uniformly off from 100°F to 200°F. This is outside of 0 - 100°F range over which they were calibrated initially.

Data from TD1 (Differential Temp.)

Cal. Temp. °F	DECADE Box R	TD1 Reading °F
0	0	-.00031
20	4.29	-.02077
40	8.56	-.04121
Ref.	115.65	104.72°F

Procedure for ΔT calibration: Temperature absolute = 104°F. Replaced single sensor with decade box; set box for approx. 0°F ΔT at 104°F; then set in ΔR for 20°F, 40°F at 100°F Ref.

Conclusion - TD1 sensor appears to be OK. Will recalibrate later.

c) Collector drained manually in preparation for changes to mechanical system.

June 1 a) Delta mechanical contractors here. Work started on mechanical modifications to the solar system. Work estimated to take 8 weeks.

June 2 to July 25 a) Solar system and data systems down during this period while modifications to the mechanical system are being made.

June 28 a) Calibrated temperature sensors in collector array

b) Procedure - Used precision DECADE box to simulate RTD signals. Checked signal conditioning and cables. Data given below:

Cal. Temp. °F	DECADE Box R	TR1	TR2	TR3	TR4	TR5
				Readings °F		
32	100.00	32.42	32.43	23.97	19.89	22.84
100	114.68	99.84	9 99.81	92.24	87.78	90.83
160	135.97	157.84	157.77	150.73	146.14	149.08
200	127.50	195.71	195.63	188.81	184.30	187.01

Conclusions - Absolute temperatures must be corrected during the performance analysis.

July 25 a) Solar system checked out and operating. Data system checked out and operating.

July 27 a) Chiller operated from boiler.

August 3 a) Turned chiller and pump P6 off to build up temperature in Tank #2.

August 4 a) Power outage during the night - 1 hour. Corrected by John Martin at 1500.

August 5 a) Pump P3 off at 1800

August 10 a) Chiller and P6 turned on at 1205

b) Temperature Tank #2: 190°F (B.C.)
Temperature Tank #3: 181°F (B.C.)

c) Performance data given below:

Chiller Performance Data: (Gen.)

Time EST	Gen. T(IN) °F	Gen. ΔT °F	Gen. FLOW GPM
1200	96.6	9.3	0
1215	179.4	14.9	118.8
1230	177.8	10.1	178.0
1245	184.9	10.4	200.5
1300	183.9	26.1	49.4
1315	180.2	26.8	44.1
1330	182.9	25.6	44.8
1345	183.0	21.3	67.4
1400	182.1	21.5	58.8
1415	182.8	19.9	80.2
1430	181.5	20.9	60.7
1445	180.6	20.8	57.6

Chiller Performance Data: (Condenser)

Time EST	Cond. T(IN) °F	Cond. ΔT °F	Cond. FLOW GPM	CAVAT.* TEMP °F	AMB. TEMP °F
1200	91.1	1.0	0	88.8	86.5
1215	80.1	3.9	210	89.6	86.8
1230	79.9	6.1	282	90.4	88.7
1245	80.7	7.1	282	91.1	87.4
1300	77.7	4.1	281	89.2	86.2
1315	78.3	3.2	284.2	90.3	88.1
1330	78.1	3.4	246.7	90.2	87.5
1345	77.6	3.0	251.3	90.2	89.0
1400	79.4	3.6	228.2	91.3	88.4
1415	77.6	3.6	247.8	89.9	86.2
1430	78.2	4.0	240.7	88.5	86.2
1445	77.9	3.6	216.6	88.6	87.4

*Cavativity temperature in humidity sensor

Chiller Performance Data: (Build. & Evap.)

Time EST	Build. T(IN) °F	Build. ΔT °F	EVAP. ΔT °F	EVAP. FLOW GPM
1200	92.2	-.9	-3.0	0
1215	72.2	.4	-.3	183.8
1230	58.1	1.8	1.4	245.4
1245	46.2	2.6	2.0	241.8
1300	45.7	1.3	.6	239.7
1330	47.4	.7	-.1	239.8
1345	44.1	1.0	.2	239.9
1400	46.6	.7	-.1	239.9
1415	48.5	.4	-.4	239.9
1430	45.1	1.1	.3	239.8
1445	47.9	.4	-.4	239.9

Note: 1) Pressurized control vlaves at 1230 - 1,2,3,4,9,10, 13, 14,15,18 (Tanks #2 & 3 cascaded to generator).

2) Pressurized control valves at 1250 - 1, 2, 3, 4, 9, 11, 13, 14, 15, 18 (Tanks #2 & 3 cascaded to collector), (Return from generator direct to Tank #2).

3) Chiller by pass valves open 2/3 at 1300.

4) Pressurized control valves at 1340, - 1, 2, 3, 4, 11, 13, 14, 15, 18 (Collector supplying tank #2 only)

5) Chiller and P6 off at 1445

August 11	a)	Collectors filled at 1030
	b)	Dick Duncan, Stan Bailey and Jim Craig here to check out system.
August 12	a)	School time clock set for: on - 0600, off - 1500
	b)	OAT = 76.8°F
	c)	CP-9 (Collector fill/drain ΔT) set at 70. At this setting, collectors drained at 1620 yesterday with Tank #3 at 182°F, Coll. In at 179°F and Coll. Out at 180°F. Will not fill this A. M. at CP-9 set at 70.
	d)	Collector filled at 1040 with CP-9 set at 70. Reset CP-9 at 74 for earlier fill.
	e)	Under broken clouds (about 75% overcast) since noon. P-2 now running at minimum speed to maintain about 7° ΔT. Time 1520.
	f)	Turned chiller and P-6 and chilled water storage switch ON at 1600. Chiller is being fired by Tank #2 and 3, cascated. Data system time clock set for all night run.
August 17	a)	R Duncan here to check out system. Turned chiller off so as not to deplete tank heat at 1600. Will try to cascade Tanks 2 and 3 and read performance of P-4 on 8/18/77.
	b)	At 1700, CP-9 set at 74, P-2 still on. Collector Out temp is 1°F colder than Tank 2 temp. and Coll. ΔT = -0.5°F. Reset CP-9 at 60 to observe effect on drain down tonight and collector fill tomorrow.
	c)	Collectors drained at 1708 with CP-9 set at 60. Coll. OUT = 174.2°F, Coll. ΔT = -.7°F, Tank 2 = 182.0°F, Tank 3 = 167.6°F.
August 18	a)	Chiller off at 0800, P-6 running, CV-16 and CV-17 closed. (Bldg. not cooled from storage).
	b)	Reset CP-9 at 74, 1145.
August 19	a)	Duncan here making tests at 0820. Readings taking on P-4, and P-6 until 0930.
	b)	Switched to UNOCUUPIED at 0930. CW storage ON, P-3 ON. Chiller operated from Tanks 2 and 3.
	c)	Automatically shifted chiller to Tank 2 only at 1000 (Tank 3 too cold).
	d)	Collectors filled at 1035. Switched to OCCUPIED, chiller ON, CW storage AUTO, DHW (P-3) ON. Returned to full normal summer mode operation.

e) Switched to UNOCCUPIED at 1135 for CW storage.

f) Switched back to OCCUPIED at 1200. Conditions as in d) above.

August 23 a) School clock 1 hour slow due to power outage. Corrected time.

August 25 a) Collectors did not fill although day was clear and Tanks 2 and 3 were low enough. Reason not clear.

August 26 a) P-2, P-4 and P-7 off; P-5 and P-6 running. Time 1515.

August 27 a) Data system set to run during the weekend.

Sept. 7 a) Teletype tape fround jammed at 0800. Problem corrected.

b) Chilled water switched from AUTO to OFF at 1320 per request of Dick Duncan.

Sept. 9 a) Pumps all OFF 0635.

b) Leak noticed in DHW line.

Sept. 10 a) Pumps P-4, P-5, and P-6 ON at 0725.

b) Pumps P-2, P-4, and P-6 ON at 1545.

c) Set data system to operate 0600 to 1800 over weekend.

Sept. 13 a) Pumps P-2, P-4, and P-6 on at 1520.

b) Tank 3 hotter than Tank 2

Sept.16 a) Tank 3 hotter than Tank 2.

b) Noted data is bad due to bad cable in DVM. Cable repaired at 1630.

Sept. 20 a) Pumps P-4, P-5, and P-6 running.

Sept. 22 a) Computer down for repair.

Sept. 23 a) Pumps P-2, P-4, and P-6 on at 0750.

b) Computer still down for repair.

Sept. 24 a) Computer system repaired at 0830.

Sept. 27 a) Pumps P-4 and P-6 ON.

b) Paper punch jammed at 0800.

Sept. 28 a) Paper punch clear at 0705.

Oct. 1 a) IBM here to install their site-data-acquisition system (SDAS).

b) SDAS installed and turned on at 1300.

c) No indication of any problem with the Ga Tech data acquisition system.

Oct. 2 a) Craig and Bailey here to test reflector operation. (Very clear day). Pryraometer moved up and down reflector surface oriented normal to reflector surface. Data givein below:

Test No 1

Time EST	Position from Bottom of Reflector IN.	Test Pyranometer Channel 33 M. V.	Control Pyranometer Channel 34 M. V.
1435	0	11.48	8.89
1438	6	13.62	8.84
1440	12	10.21	8.81
1441	18	11.62	8.82
1442	24	10.58	8.74
	30	8.96	8.73
	36	"	"
	48	"	"
	60	"	"
	72	"	"

Test No. 2

Time EST	Position From Bottom of Reflector IN.	Test Pyranometer Channel 33 M. V.	Control Pyranometer Channel 34 M. V.
1450	0	11.11	8.64
1450	6	15.08	8.59
1450	12	10.87	8.61
1452	18	10.31	8.63
1452	24	10.16	8.66
1452	30	10.20	8.67
1452	36	9.24	8.68
1452	48	9.00	8.61
1457	60	8.97	8.59
1457	72	8.94	8.58

Test No. 3 Reflector cleaned

Time EST	Position From Bottom of Reflector IN.	Test Pyranometer Channel 33 M. V.	Control Pyranometer Channel 34 M. V.
1500	6	16.76/17.08	8.38
1507(1)	--	8.70	8.38
1510(2)	--	8.74	8.28

(1) Both Pry., side-by-side
(2) Both Pry. Side-by-side, both pry. cleaned.
(3) Noted a response lag in pry. output of about 30 sec. when position changed.

b) Craig and Bailey calibrated temperature sensors in condenser and evaporator loop. Data given below:

Test No. 1 - Check COND. T and ΔT. Removed probes - placed in bucket of water and stirred slowly.

Test RUN	Absolute Temp., T Chan. 3 °F	Differential Temp., ΔT Chan. 9 °F	Tm_1 (1) °F	Tm_2 (2) °F
1	145.3	-2.2		
2	144.8	-2.3	145	
3	71.1	-2.2	70	
4	101.5	-2.2	100	
5	101.3	-2.3	100	101.2

(1) Mercury Thermometer, 0 - 220°F
(2) Mercury Thermometer, 0 - 300 °F
(Tm_1 .5°F lower than Tm_2.)

Test No. 2 - Check COND. T and ΔT - Used two buckets of water at different temperatures.

Test	Absolute Temp., T Chan. 3 °F	Differential Temp., ΔT Chan. 9 °F	Tm_1 °F	Tm_2 °F
6	66.1	34.0 ± .5	64	100.5
7	100.6	-38.9	64	100
8	100.5	-38.9	64	100

Conclusion: ΔT Readings are about 2.2°F low.

Test No. 3 - Check Evaporator T and ΔT. Used two buckets of water at different temperatures.

Test RUN	Absolute Temp., T Chan. (4) °F	Differential Temp., ΔT Chan. (10) °F	Tm_1 °F	Tm_2 °F
1	60.6	-2.6	60	--
2	97.9	-2.7	--	98
3	97.8	-41.3	60.5	98
4	61.8	35.2	61.5	97.5
5	62.0	34.7	62	97
6	96.7	-2.7	96.5	97
7	65.2	-3.7	64	63.5
8	63.4	-3.7	--	63
9	95.9	-2.7	--	96
10	95.7	-35.5	64	96
11	64.8	29.9	65	95.5

(1) Probes not stirred, test 1-4
(2) Probes stirred, test 5-11
(3) Test 7-15 bad data

c) Wind sensor re-installed.
d) Drain and fill controller CP-9 set at 72.

October 4 a) Data system down. Reloaded system tape.

October 5 a) Pumps P-4 and P-6 ON

October 6 a) Pump P-4 and P-6 ON

b) Power outage occured in A.M.

c) Paper punch jammed. Punch repaired.

October 8 a) All pumps off

October 11 a) Chiller ON

October 12 a) All pumps OFF

October 13 a) All pumps OFF

b) Punch tape had runout

October 14 a) John Martin requested solar system be switched to Winter Heating Mode. Duncan will be here on 19th to make change over.

b) Pumps P-4 and P-6 turned OFF electrically.

c) Collector P-2 Off due to tripped relay in Robican Control Panel. This occurs whenever P-2 is switched OFF at the Motor Control Panel. After resetting relay, the pump started immediately.

d) Punch tape had run out.

October 15 a) Pump P-2 off due to power outage.

October 18 a) Punch tape had run out, but data collected over the past weekend.

b) Reset P-2 on Robican and Motor Control Panel to insure that P-2 was on line.

October 20 a) Duncan switched to UNOCCUPIED Mode, chilled water storage - Auto and turned on pumps to use HW from Tank 2 to generate chilled water into storage at 0810. However, Tank 2 is down to 178°F and control system (quite properly) refused to operate chiller from Tank 2. Chiller will operate in OCCUPIED Mode from the boiler. Secured from further operation of the chiller by boiler. Intend to change over to Winter Heating mode on Oct. 21. Turned P-3 ON.

b) Switched to Winter Mode at 0845. Switched P-7 ON, Winter Heat source override to boiler, and fill pump P-1 to OFF in order to provide boiler heating to classrooms as a temporary expedient.

c) Collector loop not operated to allow replacement of several broken collector panels: 5L9, 6L18, 10L10, 4R10, 5R4 and 7R7. (i.e., 5L9 means 5th row from front of building, 9 colls. to left of center.)

d) Added 245 gallons of NUTEK to Tanks 1 and 2. All storage tanks are completely filled. Level gauge on Tank 1 reads and operates accurately. Believe level gauges on tanks 2 and 3 also operate OK but are out of zero adjustment. Since all three tanks are interconnected by open piping in valve pit #1, and all are completely filled, the level gauge on Tank 1 will show the common water level of all tanks.

e) Duncan completed changeover to Winter Heating Mode and entire system is set up for normal automatic operation, including the DHW pre-heater.

October 22 a) Solar system in Winter Mode.

b) With CP-9 set at 74, collectors did not fill until 1015. Moved setting upward and fill started at a setting of 120. After

20 minutes of circulation through collectors and Tanks 1 and 2, Collector IN temperature steadied at the Tank 2 temp. of 122°F with a 16°F rise across the collectors. Duncan believes proper setting for CP-9 is about 90-100 for proper fill. CP-P set at 90. Will check relative temperatures of Fill and Drain over the next few days to refine CP-9 setting.

c) Switched Winter Heat Source Overrride to boiler at 1045 to hasten temp. rise in Tank 1 and 2 in order to cascade Tank 3 into solar loop.

d) Inspected collectors at 1000 and found no leaks. However, discovered a small leak in 4L5 upper hose and 9R27 upper hose.

e) Request Winter Heat Source override switch be moved to AUTO on October 25.

f) Bailey and Craig shut off computer system at 1725 to calibrate differential temperature sensors in evaporation and condenser loop.

October 25 a) Switched Winter Heat Source Override switch to AUTO position.

October 29 a) Boiler is being used to heat building even though solar energy is available in storage (140°F). Janitor claims that something is wrong with the solar system and that someone from the school board switched to the boiler mode. Actually, the solar system is being switched to Boiler Operation in the morning to heat up the building as fast as possible even though solar energy is available at 140°F.

Nov. 2 a) Pump P-2 was found shut off at 1200 although day was clear. Turned on P-2 and observed that Collector Out temperature steadied at about 150°F after 15 minutes with a 20°F rise across the collectors.

Nov. 4 a) Noted leak in collector piping near roof hole in mechanical room.

b) Collectors still filled at 1840. OAT = 48.6°F.

c) Switched to Drain to empty collectors in anticipation of freeze tonight.

Nov. 5 a) Noted leak in small copper line in valve pit on West side. Called John Martin.

b) Shut down data system for recalibration of evaporator and condensor temperature sensors. Data given below:

PROBE	TC(1) T(IN) °F	TC(1) T(OUT) °F	RTD T °F	ΔT °F
EVAP.	52.8	32.9	33.58	18.92
	32.9	32.9	33.58	-2.47
	43.6	32.8	33.55	9.18
COND.	32.6	32.6	34.25	-2.12
	32.6	32.6	34.12	-2.14
	32.5	43.7	34.12	9.84
	43.8	43.8	45.94	-2.84
	86.7	86.7	87.85	-2.25
	69.1	85.4	70.96	14.56

(1) TC = Precision Thermometer

c) Leaks in air vent tubing and control tubing in valve pit on West side repaired by John Martin.

Nov. 8 a) At 1800 Stan Bailey found drain light was not on even though CV2 and CV2A were not pressurized and collectors were in the DRAIN mode. Since freezing temperatures were predicted during the night, opened both valves near ceiling of mechanical room in collector loop to allow any water remaining in the collectors to be drained out. Water flowed from both valves for about 12 minutes before flow stopped and green DRAIN light on Barber-Column panel indicated a good drain down.

b) This condition is caused by too much water in the drain down tank. Must run P1 with both of these valves open to remove some water from the drain down tank. Why the drain down tank is filling with excess water is not clear.

c) Suggest, if freezing expected, that building custodian check to be sure the green Drain light is on. Otherwise, excess water must be drained from the collectors as indicated above.

Nov. 9 a) Pump P7 on, clear and cold, collector Drain light on.

Nov. 10 a) No pumps on, warm and clear all day.

Nov. 11 a) All pumps and compressor off. Raining.

Nov. 12 a) Collector not drained at 1945. Did so manually. Drain light now on.

b) Tape did not run all day.

Nov. 13 a) Had to manually drain collectors again at 2000. With valves in collector loop open, turned on P1 and pumped some water out of drain down tank. However, white light did not go off.

Nov. 14 a) Raining, pump P7 on, all others off, collectors drained with green light on at 0745.

b) Cloudy at 1620. Collectors drained with green light on.

Nov. 16 a) At 1930 collector drain light on. Heat source override - on Boiler, collector drain and fill on Auto, all pumps off.

b) School mechanic change heat source override to Boiler at 1100 to provide heat to building.

Nov. 17 a) Cloudy at 0745. Only P7 on.

Nov. 18 a) Clear, bright sun, P2, P4, and P7 running.

b) Dick Duncan found that the solenoid valve on makeup water to the collector loop was sticking causing water to run over in the holding tank. This is causing the white light to come on which indicates a holding tank over one-half full of water. This is, no doubt, the reason that the collectors cannot drain completely. Such a condition is indicated when the green Drain light is not on after the drain cycle has been completed.

Nov. 19	a)	Cloudy most of the day.
Nov. 22	a)	Collectors drained, heat source override on Boiler. All pumps off at 1830.
Nov. 24	a)	Checked system at 1845. Will not have access to school over Thanksgiving Holiday.
Nov. 29	a)	At 1630 found collectors drained. Heat source override on Boiler.
Nov. 30	a)	Tanks not cascaded. Heat source override on Boiler.
	b)	Shut down data system at 1675 to calibrate probes on building, evaporator and condensor.
Dec. 2	a)	Collectors drained at 1630. Heat source override on Boiler. P7 On.
Dec. 3	a)	Collectors filled during the day. Drained at 1950.
Dec. 6	a)	Raining at 1610. Collectors drained, P7 running.
Dec. 7	a)	Raining at 0945. Collectors drained.
	b)	Changed over from Boiler to solar heat at 1500.
Dec. 8	a)	Power outage occurred at 0915.
Dec. 13	a)	At 1640 found collector drained, P7 On.
Dec. 15	a)	Bad data due to problem with DVM cable. Cable repaired at 1530.
Dec. 19	a)	Air line to CV2 leaking. Collectors drained and air line replaced at 1500. Checked drain and fill cycle.
Dec. 27	a)	Collector fill pump P1 started at 1045. Marshal Washington checked collector array and found that a T fitting in the main supply main to collector had split and water was being dumped onto roof. Collectors drained immediately.
Jan. 5	a)	Repairs made on supply main. Fill and drain cycles checked out.

Jan. 7	a)	Another T fitting in main supply line broke due to freeze-up
Jan. 18	a)	School being shut down until Monday to conserve fuel during this extremely cold period. Action taken by school board on all Atlanta City Schools.
	b)	Set-back thermostats set to 45°F.
	c)	Heat source override set on AUTO. Solar system down due to broken supply main.
Jan. 21	a)	Broken T fitting in main supply line replaced.
	b)	Solar systems placed on line.
Jan. 26	a)	Solar collectors filled at 1150.
Jan. 27	a)	System operating. Collectors will be drained this evening but placed on AUTO fill for Friday morning.
Feb. 2	a)	At 1130 collector filled. Found 2 more collector hoses loose at bottom of collector. Also found that another elbow pipe fitting near header tank had split due to freeze-up.
Feb. 16	a)	Georgia Tech data acquisition contract over as of 1 February, 1977. Data system shut down.

APPENDIX C

DAILY HEAT BALANCE ANALYSIS AND PERFORMANCE - HEATING

G. A. Towns Elementary School

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APPENDIX C

DAILY HEAT BALANCE ANALYSIS AND PERFORMANCE - HEATING

1. General Information

This appendix contains the data analysis for the 1976-1977 heating season of G. A. Towns Elementary School. It is based on the experimental data presented in Appendix E (Volume 2). The changeover to heating mode was completed on October 20, 1976 and the data acquisition was terminated on February 16, 1977. Hence, the analysis and discussion covers this period. Between December 20, 1976 and January 25, 1977 the solar collector storage system was not operational. The reason for this lapse of data was due to Christmas holidays, unusual cold spell that followed and the inability of the school to fix promptly an elbow at the roof top that was split due to freezing.

The method of analysis is similar to the cooling mode presented in Appendix D. The automated data acquisition system samples various temperature sensors and flowmeters and prints our the average values every fifteen minutes, generally between 0600 to 1800 hours. In addition the two gas meters and the kwhr meter are read manually twice a day on the weekdays. Using this data base it is possible to study the heat balance characteristics and evaluate the performance of the system for those days the data is complete. For other days partial analysis can be made. Since the school is occupied only during the daytime period and is provided with nighttime setback thermostats the analysis is restricted to this period. Moreover, the type of analysis performed here required integration of time varying data which is only possible for the daytime period. Since the data acquisition system was shut down during nighttime period the same type of analysis cannot be carried out on a 24-hour basis. It is possible to perform partial analysis for the daytime period on weekends and holidays since the data acquisition system was normally operational during these periods. The spirt expressed in a recently published National Bureau of Standars report (NBS 76-1137) has been carried out in order to keep uniformity in data analysis among various institutions and agencies. The thoughts expressed therein suggeste some improvements*. They have been incorporated and used in this analysis. Since the data acquisition system at the Towns School was designed and built prior to publication of this NBS report and the system does not contain enough sensors to perform the ultimate analysis as portrayed in this report some limitations should be expected. However, certain assumptions have permitted extending the current analysis to include an understanding of the effect of variation of several quanitities on the system performance that would not have been possible otherwise.

Figure C-1 represents an energy flow diagram for George A. Towns School using the format and symbols suggested in the NBS report. These symbols as well as the corresponding Georgia Tech-Westinghouse symbols used in various computer programs are described in Nomenclature for Figure C-1 following the figure. They should aid in the inderstanding of the tabulated results, the discussion and the figures.

Careful review of Figure C-1 and the associated nomenclature lends itself to the following conclusions.

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*For example, see cooling mode analysis and additional symbols suggested in the nomenclature of this report.

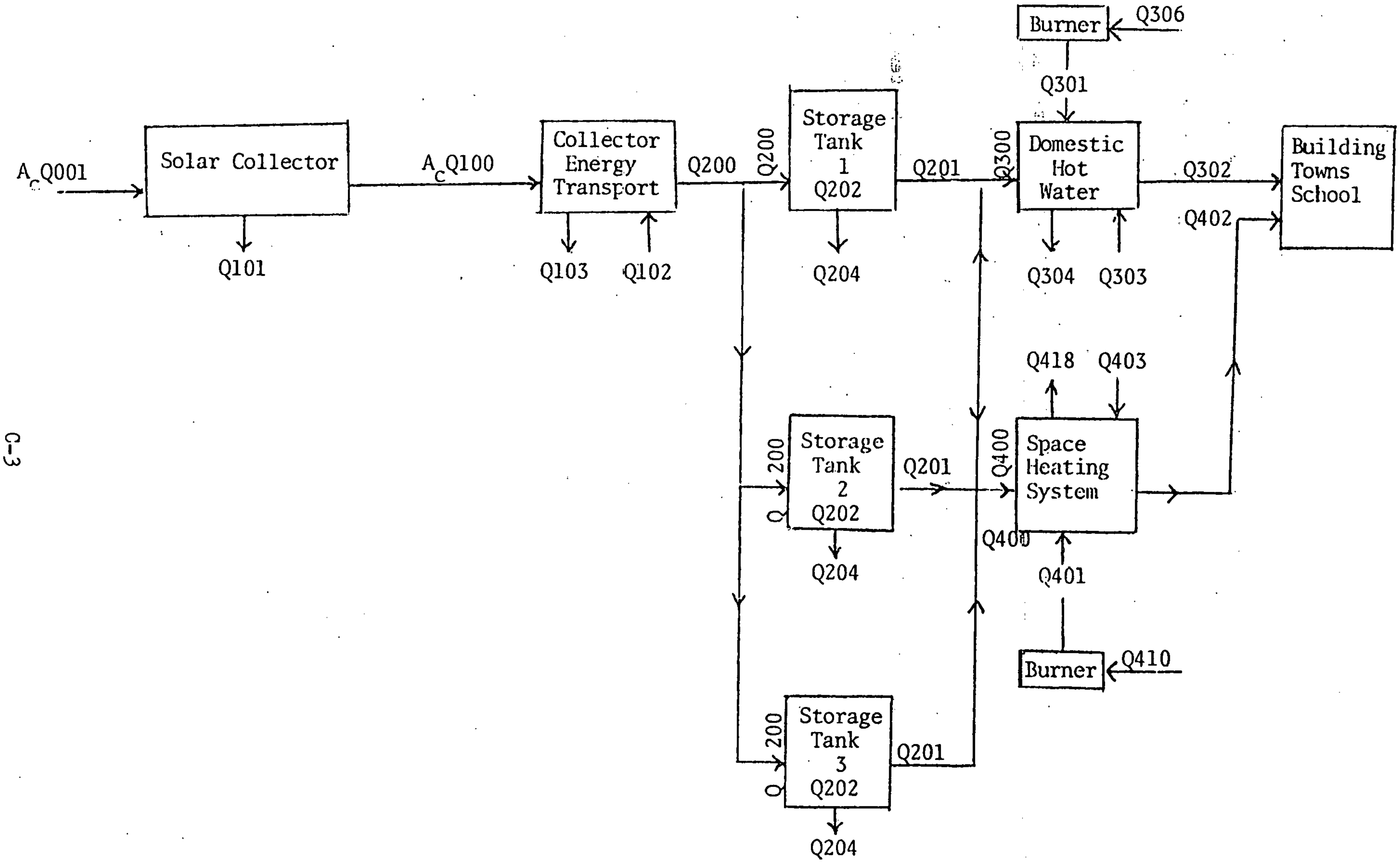

Figure C-1 Energy Flow Diagram - G. A. Towns Elementary School Solar Heating and Domestic Hot Water System

Nomenclature for Figure C-1.

NBSIR[1] Symbol	G.T.- W Symbol	
	HTTWR-T	Average incident solar energy[2] per unit area of collector on a tilted collector including the effect of reflector during the daytime period
Q 001	HTTWR-O	Same as above except for the period the collector was operational
	Δτ COLL	Period the collector was operational
A_cQ100		Solar energy collected from the collector
Q 101	Q LOSS	Collector heat loss
Q 102	Q ESC	Electrical energy added to collector fluid
Q 103		Collector transportation heat loss, not measured
Q 200	Q COLL	Solar energy collected = Solar energy transfered to storage
Q 201	Q UTL	Energy from storage tanks to DHW and space heating, Q 300 & Q 400
Q 202	Q STS	Net storage of solar energy, Q 200 - Q 201 - Q 204
Q 203		Solar energy utilized = Q 201 (Piping losses are assumed zero)
Q 204	Q STL-S	Storage tank heat losses, estimation based on derived empirical equation. See "Tank Losses" section.
	Δτ DHW	Period the domestic hot water preheater was operational

[1]NBSIR 76-1137- "Thermal Data Requirement and Performance Evaluation Procedure for the National Solar Heating and Cooling Demonstration Program" by E. Streed et. al.

[2]Units of Q are Btu for the period except when indicated Δτ are in hours T are in °F and N are dimensionless.

NBSIR Symbol	G.T.- W Symbol	
Q 300	Q DHW	Solar energy utilized in domestic hot water preheater
Q 301		η_b x Q 306; η_b = 0.75, efficiency of the burner
Q 302	Q DHWS	Hot water load delivered to building
Q 303	Q EHW	Electrical energy added to domestic hot water system.
Q 304		Domestic hot water subsystem loss
Q 306	Q DHWAX	Auxiliary gas energy used in domestic hot water system
Q 307		Total energy including solar energy consumed by the domestic hot water system
Q 400	Q BLS	Solar energy used for space heating
Q 401		η_b x Q 410 ; η_b = 0.75, efficiency of the gas burner
Q 402	Q BLD	Space heating load delivered to the building
	$\Delta\tau$BLD	Period the space heating load circuit was operational
Q 403	Q EBL	Electrical energy utilized in delivering space heating load
Q 410	Q BLAX	Auxiliary gas energy used in the boiler of the space heating system
Q 411		Total energy including solar energy consumed by the space heating system
Q 412		Solar heating system fraction of electrical energy
Q 413		Electrical energy consumed by the space heating system
Q 416		Prorated natural gas consumption if the solar energy was not available

NBSIR Symbol	G.T. - W Symbol	
Q 417		Natural gas saved due to solar space heating system.
Q 418		Space heating subsystem loss.
Q 600		Q 301 + Q 401
Q 601	Q ELEC	Total electrical energy consumed
	Q ESUM	QESC + Q EHW + QEBL
	Q ELOSS	Lost electrical energy in motor and speed control windings Q ELEC - Q ESUM
Q 602		Total energy delivered to the building, Q 302 + Q 402
	Q EAX	Electrical energy used by auxiliaries other than pump motors
Q 603		Total gas and electrical energy consumed
N 001		Daily collector efficiency, ratio of energy collected to energy incident on the collector bank during the entire day.
N 100	η_{COLL}	Daily collector efficiency for the period collector was operational Q 100/Q 001 = Q 200/A_c Q 001
N 101		Instantancous collector efficiency, see graphical plots and tabular data
	NTHBL	Storage tank heat balance factor
N 108		Storage tank efficiency
N 110		Coefficient of performance of solar collector - storage system
N 111		Energy collection and storage system conversion efficiency
N 112		Utilization efficiency of storage tank
N 113	TMI	Average ambient outdoor temperature
N 300		Solar fraction of hot water load

NBSIR Symbol	G.T.- W Symbol	
N 301		Solar fraction of energy consumed
N 302		Performance factor of the hot water system
N 400		Solar fraction of space heating load
N 401		Solar fraction of energy consumed
N 406	$\overline{TZ}$	Average building dry bulb temperature during collection period
N 408		Performance factor of the space heating system
N 601		Solar augmentation factor
N 602		System performance factor
	HT ϕ	Insolation measured on horizontal surface
	HTT	Insolation measured on tilted surface without reflectors for the tilt angle of the Towns School
TD 100	TD1	Collector temperature rise
T 100 + TD 100	T1	Collector outlet temperature
T 200	TA, TB, TC	Average tank temperatures of the three storage tanks
TD 301	TD 6	Temperature drop of hot water flowing in the storage tank - DHW preheater loop
T 300 + TD 301	T 6	Temperature of the water flowing from the storage tank and leaving DHW preheater.
TD 302		Temperature rise of hot water in the main domestic hot water system
TD 400		Temperature drop of hot water in the storage tank - building loop when the heat is supplied from solar energy
TD 401		Temperature drop of hot water in the boiler - building loop when natural gas is utilized
T 400 +TD 400 or T 400 + TD 401	T3	Temperature of hot water entering the building loop
TD 402	TD 3	Temperature drop of hot water flowing in building loop

A. Electrical input to the entire solar system is measured by a single watt-hour meter. They are recorded manually twice a day not necessarily at the same time or at the time the computer data logging system started or terminated during each day. Because of this reason, prorating of the data for the entire daytime period is necessary. Moreover, the design features of such meters are meant to measure monthly energy consumption. Hence, they do not provide required accuracy for the daily energy analysis. Occasional errors in recording the data, particularly in the last digit, have been noticed. The decimal points shown in the compliation of meter readings is an estimate based on the position of the needle between two digits. An error of a tenth of a unit reading corresponds to about 10,000 Btu equivalent of electrical energy. Same is true of the two gas meter readings. Since the gas consumption in domestic hot water is rather low these errors should be seriously considered before drawing fine conclusions. This is also true with gas meter readings of the space heater on those days when the building is augmented by solar energy to a large extent.

B. Since the temperatures both at the collector array and storage tanks are not monitored it is not possible to evaluate transportation losses.

C. Assumption has been made that the pumps will draw full load current during the duration of their operation. This is particularly true for pumps in the hot water and the building loop which always pumps against a fixed resistance. The difference in electrical energy consumed minus that due to the pumps has been attributed to auxiliaries (Q EAX) and they are charged to the solar loop. Thus it should be expected that this quantity will exhibit greatest statistical scatter. Such an assumption has made it possible to evaluate the electrical energy consumptions Q 102, Q 303 and Q403 shown in Figure C-1.

D. There are three precision RTD's in the central region of the 15000 gallon storage tank. When the water from the tanks are not used the temperature history reveals a great degree of stratification. However, when the water is being used or circulated in the solar loop the agitation tends to keep their value at uniform conditions. Since there is no firm basis to develop weighted average, a simple arithmetic average is used for tank loss analysis and tank storage characteristics.

E. Gas meter readings and the corresponding heat energy supplied to the building between December 20, 1976 and January 25, 1977 have been used to evaluate daily efficiency of the boiler and their average is 0.75. This is the same value reported during summer mode with very limited data. The burner for the building hot water is also assumed to be 75 percent efficient. No attempt has been made to estimate the pilot gas consumption. Best guess is that it consumes about 1 ft^3/hr per pilot flame and there are at a total of 6 pilot flames.

2. Tank Losses

2(a). Analysis Approach

During winter mode all the three tanks store hot water and supply building heating needs. Since the adjoining ground is at a lower temperature heat losses occur from these tanks. The design specifications call for cascading of these tanks for heat storage purposes. Initially the solar energy is stored in Tank A. When it reaches about 140°F the solar energy is stored in Tank B. If the solar energy is utilized from Tank A for heating of the school its temperature will drop steadily. When the two tanks experience about the same temperatures they are connected in series for storage of excess solar energy. When both of these tanks reach about 140°F Tank C is used for storing of solar energy. With such a priority for storing and usage the water in Tank A when it is being used will experience large hourly fluctuations in its temperature while the Tank C will stay dormant for extended periods of time.

The heat flow from the tank to the adjoining ground can be viewed as heat flow into a semiinfinite medium. The true heat losses from the tanks to the ground can be estimated if one considers the analytical solution to the differential equation governing unsteady state heat conduction with varying boundary conditions which in this case is the water temperature in the tanks. A conceptual view of this solution will reveal the following thoughts. When there is a rapid increase of temperature in the tank due to storing of excess solar energy the heat loss into immediate crust of the ground increases. On the otherhand, if there is utilization of solar energy causing rapid decrease of the tank temperature some of the heat stored in the ground is returned back to the tank, thus, altering the heat loss pattern. The nature of heat losses from these tanks can be viewed as quasi steady state solution with short time fluctuating components superposed on it. Analytical solution describing this view point is rather complex. This descriptive comment together with the cascading of tanks will indicate that Tank A will experience the most fluctuations over the mean tank losses when compared to the other two tanks.

The empirical equations developed for tank losses using the data from the summer months represent the quasi steady component of the heat losses. Moreover, they are based on heat losses to a pseudo fixed temperature at some distance from the tank surface. The same method will be followed to develop a set of empirical equations applicable for the winter months which will then be used in heat balance model of the solar heating system. (See Appendix D).

On October 21, 1976, change over to heating mode was initiated. Prior to this date Tank A was being used to store chilled water while the other two tanks had hot water. The typical temperatures in the three tanks were 90, 170 and 145°F. The data for October 21-22, 1976 shows that there was considerable mixing of water among these tanks in addition to the solar energy collected on October 22nd and stored in these tanks. Towards the end of this day the three tank temperatures were 148, 142 and 131°F respectively. For purposes of developing the empirical equations for tank losses the data between November 1, 1976 to February 10, 1977 was selected. During this period the examination of the data acquired revealed that during several nighttime periods there was no utilization of heat from the storage tanks. This situation was possible because of the nighttime setback of the school thermostat and the logging of data between 0600 and 1800 hours every 15 minute period. For these selected days, the examination of the data revealed that none of the flow meters were active at o0600 hours or at 1800 hours. Several daytime data that satisfied the above test was also included. Furthermore, Atlanta and the rest of the Eastern United States experienced the coldest spell of the century during January, 1977.

From December 27, 1976 to January 26, 1977, the collectors could not be operated because of a broken pipe fitting in the main supply line to the collector array. On December 27th, the temperatures in the three storage tanks were 112°, 112° and 110°, respectively. By January 6th, the storage tank temperatures were at 95°, 98° and 92°F, and on the morning of January 26th, the three storage tanks were down to 81°, 84° and 78°F.

The computer printouts contain averages of the three temperatures measured inside each of the tanks as a function of time. The tanks are assumed to be full with 15,000 gallons of water. Using the overnight temperature drops or when applicable the temperature drops for 24 hour periods the heat loss rates from these tanks for the selected days have been calculated. For the same period the arithmetic mean of the two temperatures for each of the three tanks have been evaluated. They have been utilized to develop equations representing the straight line fits using least square methods. The final results are summarized in Table C-I. The table contains empirical equations for winter and summer modes of operation. The operating range of temperatures and the range of heat loss rates using these equations for the two modes are shown in the table. It should be remembered that during summer months Tank A stores chilled water and generally heat flows into the tank. Since it destroys the cooling ability of the stored chilled water it is termed as heat loss. Typical heat loss rates for the design temperature ranges during winter and summer months are also included in this table.

2(b). Discussion

Fig. C-2 represents the plot of mean tank temperatures and heat losses from the three tanks. They are plot of the empirical equations contained in

Table C-I Empirical Equations to Determine Tank Heat Losses and Typical Heat Loss Rates at Operative Temperature Range

WINTER MODE

	Tank A	Tank B	Tank C
Data Base Nov. 1, '76 to Feb. 10, '77 Selected Days	QSTL1 = 210 [STT1 - 68.9]	QSTL2 = 100 [STT2 - 51.5]	QSTL3 = 110 [STT3 - 53.5]
Operative Temperature Range, °F	105 - 140	105 - 140	105 - 140
Tank Heat Loss, B/hr	7580 - 14930	5350 - 8850	5670 - 9520
Total Tank Heat Loss, B/hr	18600 - 33300		
Data Base Jan. 6, '77 to Jan. 26, '77 Consecutive Days	QSTL1 = 130 [STT1 - 55.5]	QSTL2 = 120 [STT2 - 59.8]	QSTL3 = 120 [STT3 - 53.4]
Operative Temperature Range, °F	105 - 140	105 - 140	105 - 140
Tank Heat Loss, B/hr	6430 - 10990	5420 - 9620	6190 - 10390
Total Tank Heat Loss, B/hr	18040 - 31000		

SUMMER MODE

	Tank A Chilled Water	Tank B Hot Water	Tank C Hot Water
Data Base Aug. 1, '76 to Sept. 30, '76 Selected Days	QSTL1 = 156 [102.6 - STT1]	QSTL2 = 258 [STT2 - 114.8]	QSTL3 = 244 [STT3 - 107.3]
Operative Temperature Range, °F	60 - 50	180 - 195	180 - 195
Tank Heat Loss, B/hr	6650 - 8210	16820 - 20690	17740 - 21400
Total Tank Heat Loss, B/hr	6650 - 8210	34560 - 42090	

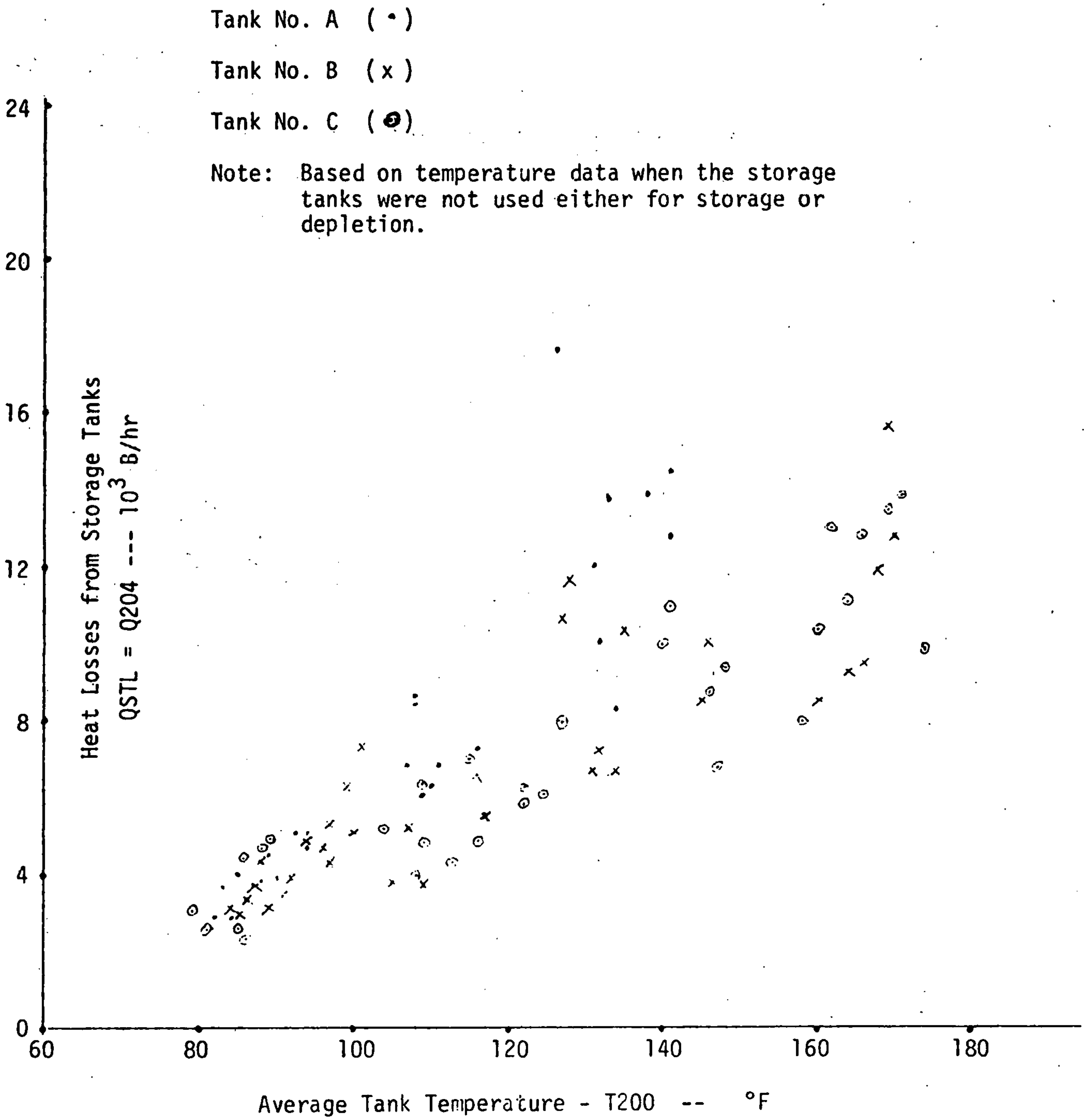

Fig. C-2-a Estimated Heat Losses for the Storage Tanks

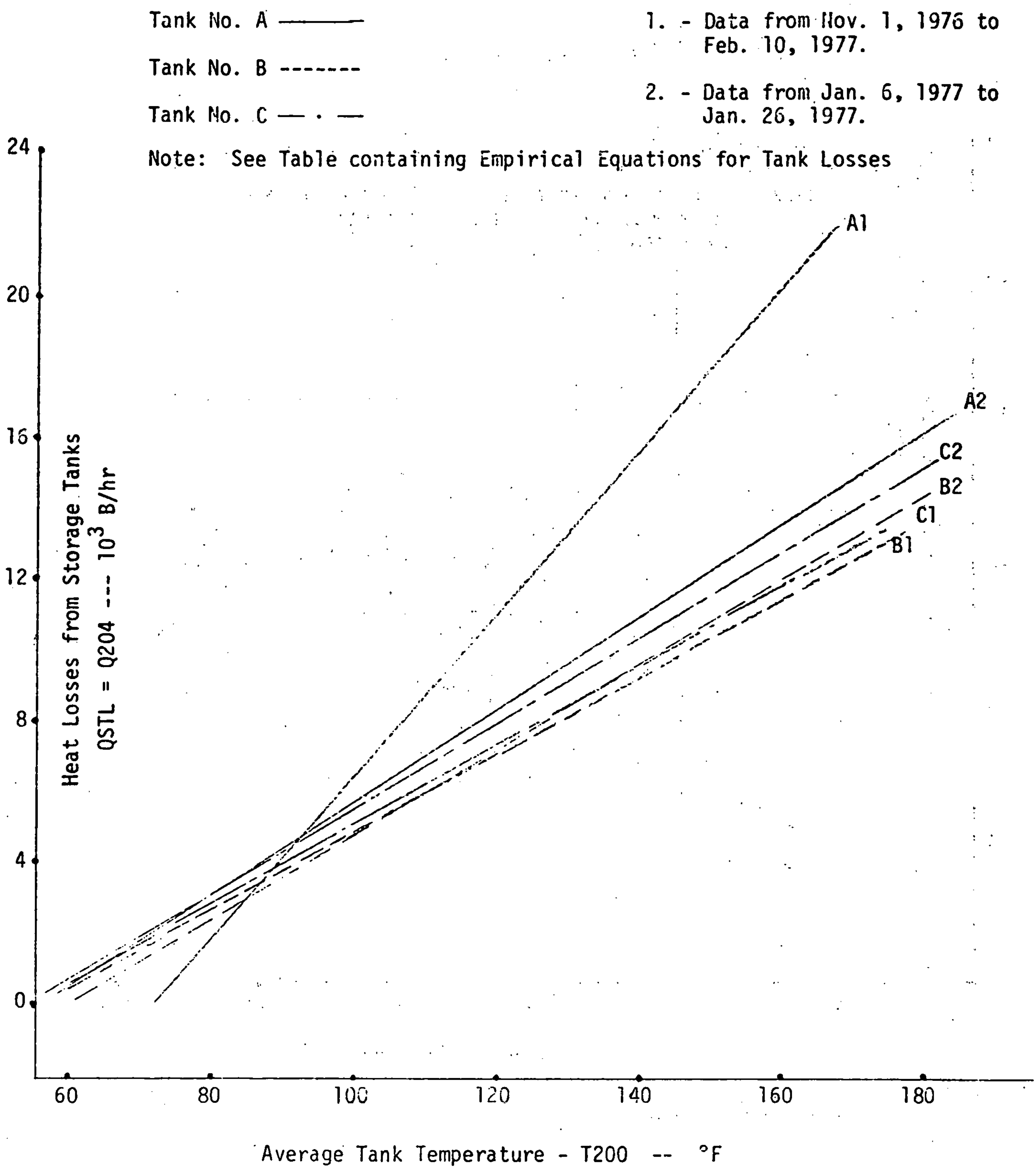

Fig. C-2-b Heat Loss Correlation for the Storage Tanks - Data Collected During Winter Mode the table. The data for the period of January 6-26, 1977 when the tanks were not utilized show that the slopes are about the same and the temperatures at which tank heat losses are zero are within ± 3°F. When large amount of data representative of the entire cooling period is considered the equation for Tank A is different from the other two tanks, the latter being similar to that obtained with limited data. As pointed out earlier, the control strategy adopted in the Towns School system calls for predominant use of Tank A and, hence, the tank is subjected to short duration temperature fluctuations. Meanwhile, Tank C hardly cascades and hence, it is used very little.

The table and the figure representing heat losses from the tanks for winter months show that when the water temperature in the tank is equal to pseudo ground temperature of about 55°F the tank losses are essentially zero. For the summer months during which period the mean tank temperatures are in the vicinity of 170°F the pseudo ground temperature is 108°F. The typical temperature difference between the tanks and their surroundings is about 75°F at the mid design range of operating temperatures selected for the tanks during summer and winter modes. It should also be pointed out that the ground around each of the tanks have been prepared with special care by providing the drain fields in order to keep moisture out of the immediate vicinity of the tanks. This may further justify the concept of a simple equation using pseudo temperatures when compared to seeking solution to complex mathematical problem associated with the heat losses.

The equations contained in Table C-I have been used for estimating the heat loss rates from the tanks and also the daily total heat losses. They are used in estimating heat balance of the storage tanks and to arrive at a value for the utilization of the solar energy.

3. Data Analysis

The Towns School Solar System was converted from the summer mode to the winter mode on October 20, 1976. The data acquired for the entire heating season, up to the termination of the project, have been processed and presented in tabular form in Tables C-II-(a, b, and c). To the extent possible the method outlined in NBSIR 76-1137 report has been used as a guide. Because of the limitation of the data acquisition system all the calculations suggested in that report could not be performed. In some instances, certain quantities not considered in the above report have been introduced and new symbols have been suggested. Wherever possible original Georgia-Westinghouse symbols and NBSIR symbols have been shown for purposes of clear identification. All of these symbols have been described in Section I under Nomenclature for Figure C-1.

Table C-II contains the calculated results for the daytime period when the computer logging system operated. The school is unoccupied during nighttime. The indoor thermostat setback during nighttimes, weekends and holidays alters the load pattern and utilization of solar or auxiliary energy. Some of these results are generated by using several small computer programs and the raw data. Others are hand calculated by using block loads. The units on heat quantities (identified by the letter Q) are generally in million Btu except where indicated. The time is in hours and the temperature is in ^{o}F. Quantities such as efficiency, performance factor, heat balance factor, coefficient of performance and solar fraction of the total load are identified by the letter n and they are dimensionless. The energy flow diagram, Figure C-1, will aid in the understanding of the entries in the table and their interrelationships.

The heating values for natural gas and pump qualifications which are used in the calculations are presented in Tables C-IV and C-V. Further clarification is provided by the sample calculations which follow the table. They are done for November 4, 1976, but in some instances it is felt that the data is not complete and hence, calculations they are shown either for November 3 or November 5, 1976.

The solar component of the hot water load, i.e. the heat exchanger in the preheater and the load supplied to the building, are listed as negative numbers. The reason for this negative sign is due to the way temperature difference in the flow circuit is transduced. One should use the flow diagram as a guide and care should be excerised in the interpretation of the tabular results. Quantities such as efficiency performance factor and heat balance check should be positive. If there are occasional negative signs they should be ignored. Perhaps they may be due to statistical scatter, or taking difference of two large numbers in arriving at the results. In some isolated cases satisfactory explanation is not possible except for those indicated here. Since the storage tanks act as heat receivers a negative sign indicates usage in excess of energy collection.

From December 18, 1976 to January 25, 1977 the solar collector did not operate because of holidays, a broken pipe in the solar collector array, and unusually cold weather experienced in most of the Eastern United States. The auxiliary energy used during this period formed the basis to make a firm estimate of the boiler efficiency which in this case is 0.75. The value is used for the burner of the hot water system. The total electrical energy consumed by the solar system as well as the natural gas consumption is measured manually.

Table C-II-a Heat Load and Performance Analysis Winter Mode - Daytime
October 21, 1976 to November 21, 1976

	1	2	3	4	5	6	7	8	9	10	11	12	13
	HTϕ	HTT	A_cHTTWR-T	Δτ coll	A_cHTTWR-O	Q coll	η_{coll-T}	η_{coll-O}	Q Loss	Q ESC	Δτ DHW	Q DHW	Q EHW
			A_cQ001-T		A_cQ001-O	A_cQ100	N001	N100	Q101	Q102		Q300	Q303
Date	B/ft²-Day	B/ft²-Day	10^6 B	hour	10^6 B	10^6 B	—	—	10^6 B	10^6 B	hour	10^3 B	10^3 B
10/21	1522	1907	20.36								4.5+	- 44.44	2.863
10/22	1366	1702	18.17	5.2	14.01	4.845	0.267	0.346	9.165	0.225	2.2+	- 59.39	1.400
10/23	1213	1425	15.08	4.8	8.766	2.355	0.156	0.269	6.411	0.208			
10/24	431	388	3.512										
10/25	158	440	4.520		0.3723	0.03075	-0.0068	-0.083	0.403		11.5+	-245.7	7.317
10/26	1312	1629	17.09	5.5	12.43	4.978	0.291	0.400	7.452	0.239		- 41.44	
10/27	803	772	8.048		1.506	0.2186	0.027	0.145	1.287		7.0+	-212.2	4.454
10/28	1236	1595	16.63	7.0	14.62	4.101	0.247	0.281	10.519	0.303	8.0	-140.1	5.090
10/29	1314	1591	16.56	5.0	10.63	3.476	0.210	0.327	7.154	0.216	5.2+	-134.7	3.308
10/30	141	115	1.187								12.2+	- 55.92	9.762
10/31	445	374	3.856									3.48	
11/1	1362	1801											
11/2	1371	1835	18.94	3.0	6.709	2.712	0.143	0.404	3.997	0.130			
11/3	1276	1693	17.44	6.0	12.66	4.211	0.241	0.333	8.449	0.260	7.0+	-165.0	4.454
11/4	1215	1560	16.06	5.8	10.69	2.835	0.177	0.265	7.855	0.251	3.0	-115.5	1.909
11/5	984	1354	13.92	4.2	10.08	2.826	0.203	0.280	7.254	0.182		- 73.73	
11/6	1374	1885	19.37	6.0	14.14	4.412	0.228	0.312	9.728	0.260	12.0	- 37.79	7.635
11/7	1190	1605	16.49	4.5	10.64	3.851	0.234	0.362	6.789	0.195	10.0+	- 23.61	6.362
11/8	1348	1911	19.64	3.5	8.213	2.357	0.120	0.287	5.856	0.151	4.0+	- 84.68	2.545
11/9	1226	1759	18.08	7.8+	13.06	4.421	0.245	0.339	8.639	0.337	3.0	- 78.83	1.909
11/10	626	856	8.800	9.2+	8.201	1.739	0.198	0.212	6.462	0.398		- 20.62	
11/11	998	1425	14.64	3.5	7.821	2.871	0.196	0.367	4.95	0.151	4.0+	-154.2	2.545
11/13	1069	1410	14.50	4.2	8.356	2.060	0.142	0.247	6.296	0.182	12.2+	- 53.46	7.762
11/14	140	115									8.0	- 38.54	5.090
11/15	290	224										- 4.49	
11/16	279	215										- 0.91	
11/17	113	87											
11/19	617	600										- 22.87	
11/20	296	229											
11/21	1152	1782	18.32	5.5	12.62	4.924	0.269	0.390	7.696	0.238			

Table C-II-a Continued
October 21, 1976 to November 21, 1976

Date	14 QDHWAX Q306 10^6 B	15 Q301 10^6 B	16 Q302 10^6 B	17 Q307 10^6 B	18 N300	19 N301	20 N302	21 TA T200-A °F	22 QSTL-A Q204-A 10^3 B	23 TB T200-B °F	24 QSTL-B Q204-A 10^3 B	25 TC T200-C °F	26 QSTL-C Q204-C 10^3 B
10/21													
10/22	1.386	1.040	1.108	1.447	0.054	0.041	0.766						
10/23								147	57.096	146	49.651	141	50.458
10/24								145		145		140	
10/25			0.253	0.253	0.971	0.971	1.0						
10/26	1.317	0.988	1.029	1.358	0.040	0.031	.758						
10/27	1.259	0.944	1.161	1.475	0.133	0.149	0.787						
10/28			0.145	0.145	0.966	0.966	1.0	141	77.805	134	62.328	125	60.144
10/29	0.756	0.567	0.705	0.891	0.191	0.151	0.791						
10/30													
10/31													
11/1	1.324	0.993	0.993	1.324			0.75	132		123		123	
11/2	0.588	0.441	0.441	0.588			0.75	141	33.345	135	27.092	122	24.696
11/3	0.640	0.480	0.649	0.809	0.254	0.204	0.802						
11/4	1.164	0.873	0.99	1.28	0.117	0.090	0.773	141	64.467	132	50.251	127	51.226
11/5													
11/6													
11/7													
11/8	1.298	0.974	1.385	1.061	0.080	0.061	0.766						
11/9	0.574	0.431	0.511	0.654	0.154	0.121	0.781						
11/10	1.056	0.792	0.813	1.077	0.025	0.019	0.755						
11/11	1.365	1.024	1.181	1.522	0.131	0.101	0.776						
11/13													
11/14													
11/15	2.681	2.011	2.015	2.685	0.002	0.002	0.750						
11/16	1.148	0.861	0.862	1.149	0.001	0.001	0.750						
11/17	0.948	0.711	0.711	0.948			0.750						
11/19	8.786	6.590	6.613	8.809	0.003	0.003	0.751	117		117		116	
11/20								116		116		115	
11/21								133	55.413	128	45.012	114	39.996

Table C-II-a Continued
October 21, 1976 to November 21, 1976

Date	40 QESUM 10^6 B	41 QELEC Q601 10^6 B	42 QEAX 10^6 B	43 QBLAX Q410 10^6 B	44 Q401 10^6 B	45 Q411 10^6 B	46 N400	47 N401	48 N408	49 Q412 10^6 B	50 Q413 10^6 B	51 Q416 10^6 B	52 Q417 10^6 B	53 Q418 10^6 B
10/21	0.175	0.164	0.088	4.764	3.573	5.946	0.383	0.170	0.443		0.161	3.513	-1.251	2.109
10/22	0.398	0.379	0.204			-0.768		1.224			0.378	2.46	2.46	-2.407
10/23	0.208					0.149								-0.149
10/24						0.041								0.041
10/25	0.007					2.431	5.086		0.197		-0.007	-0.637	-0.637	2.902
10/26	0.396	0.486	0.090	0.095	0.071	1.239	0.608	0.797	1.331	0.235	0.486	2.165	2.070	-0.144
10/27	0.157	0.290	0.133	0.103	0.077	2.071	1.121	0.876	0.782		0.286	2.159	2.056	0.559
10/28	0.470					1.434	0.798	0.887	1.111	0.273	-0.005	2.125	2.125	1.273
10/29	0.387	0.252	-0.135	1.522	1.142	2.404	0.392	0.297	0.758	0.182	0.249	2.429	0.907	0.283
10/30	0.010					0.729					-0.010			0.719
10/31						0.219	2.882		0.347			0.101	0.101	0.143
11/1	0.162	0.294	0.132	3.089	2.317	2.978			0.644		0.294	2.557	-0.532	0.582
11/2	0.287	0.096	-0.191	1.653	1.240	0.951			1.870		0.096	2.372	0.719	-1.307
11/3	0.417	0.195	-0.222	0.933	0.700	1.862	0.346	0.415	1.198	0.214	0.191	2.974	2.041	-0.568
11/4	0.406	0.437	0.027			2.785	0.797	0.945	1.186	0.241	0.435	4.404	4.404	-0.235
11/5	0.182	0.253	0.017	4.715	3.536	5.290	0.204	0.074	0.386	0.155	0.253	2.725	-1.99	2.163
11/6	0.373					1.412	1.417	0.920	0.654	0.253	-0.008	1.232	1.232	0.377
11/7	0.287					1.725	2.302	0.950	0.413	0.192	-0.006	0.949	0.949	0.921
11/8	0.316	0.328	0.012	0.123	0.092	4.082	0.948	0.938	0.989	0.148	0.325	5.384	5.261	0.207
11/9	0.501	0.171	-0.330	0.092	0.069	3.997	1.058	0.936	0.885	0.330	0.169	4.719	4.627	0.442
11/10	0.436	0.287	-0.149	3.096	2.322	5.413			0.148		0.287	1.069	-2.027	-0.472
11/11	0.284	0.165	-0.119	1.158	0.869	3.202	2.067	0.598	0.289	0.140	0.162	1.235	0.077	2.019
11/13	0.209					0.311	0.427	0.939	2.199		-0.007	0.912	0.912	-0.399
11/14	0.120					1.545	1.559	0.926	0.593		-0.005	1.223	1.223	0.508
11/15	0.229	0.325	0.096	1.835	1.376	5.148	0.879	0.599	0.681		0.325	4.676	2.841	1.278
11/16	0.214	0.281	0.067	8.376	6.282	8.793	0.034	0.023	0.661		0.281	7.817	-0.559	0.903
11/17	0.095	0.267	0.172	5.512	4.134	5.242			0.430		0.267	3.005	-2.507	1.782
11/19	0.229	0.363	0.134	5.684	4.263	6.297	0.087	0.061	0.703		0.363	5.90	0.216	0.585
11/20						0.008								0.003
11/21	0.238					0.777				0.238				0.777

Table C-II-a Continued
October 21, 1976 to November 21, 1976

Date	27 QSTS Q202 10^6 B	28 QSTL-S Q204 10^6 B	29 QUTL Q201 10^6 B	30 QTHB 10^6 B	31 NTHBL	32 N108	33 N 110	34 N111	35 N112	36 ΔτBLD hr	37 QBLS Q400 10^6 B	38 QBLD Q402 10^6 B	39 QEBL Q403 10^6 B
10/21	-1.387	0.333	+1.054	-1.387	1.0					9.0+	1.010	-2.635	0.172
10/22	+5.479	0.247	-0.881	5.704	1.041	0.995				9.0+	-0.940	-1.845	0.172
10/23	+2.104	0.401	-0.149	2.312	1.099	0.918					-0.149		
10/24	-0.438	0.397	+0.041	-0.437	1.0						0.041		
10/25	-3.029	0.352	+2.677	-3.060	1.010			7.196			2.431	-0.478	
10/26	+2.308	0.344	+1.028	3.846	1.666	0.979	4.196	0.083	0.206	8.2+	0.987	-1.624	0.157
10/27	-2.158	0.350	+2.027	-2.158	1.000			1.346	9.272	8.0+	1.815	-1.619	0.153
10/28	+2.400	0.328	+1.412	2.664	1.11	0.994	4.660	0.097	0.344	8.5+	1.272	-1.594	0.162
10/29	+2.262	0.365	+0.849	2.479	1.10	0.957	3.930	0.080	0.244	8.8+	0.714	-1.822	0.168
10/30	-1.150	0.366	+0.784	-1.15	1.0						0.729		
10/31	-0.546	0.330	+0.216	-0.546	1.0						0.219	-0.076	
11/1	-0.196	0.307	-0.111	-0.196	1.0						-0.111	-1.918	
11/2	+2.804	0.328	-0.864	3.379	1.205	0.926				8.5+	-0.864	-1.779	0.162
11/3	+2.896	0.379	+0.937	3.156	1.090	0.972	3.60	0.074	0.223	8.2+	0.772	-2.231	0.157
11/4	-0.254	0.342	+2.747	-0.003		0.955	10.94	0.257	0.969	8.0+	2.632	-3.303	0.153
11/5	+2.087	0.248	+0.491	2.269	1.087	0.977	2.697	0.049	0.174	8.2+	0.418	-2.044	0.157
11/6	+2.683	0.381	+1.347	2.944	1.097	0.973	5.181	0.095	0.305	5.5+	1.309	-0.924	0.105
11/7	+1.817	0.372	+1.663	2.012	1.107	0.954	8.528	0.156	0.432	4.5+	1.639	-0.712	0.086
11/8	-1.883	0.328	+3.913	-1.732	0.920	0.95	25.91	0.476	1.660	8.5+	3.828	-4.038	0.162
11/9	+0.288	0.312	+3.822	0.625	2.17	1.006	11.34	0.293	0.865	8.5+	3.743	-3.539	0.162
11/10	+3.725	0.272	-2.258	4.123	1.107	1.072				2.0+	-2.279	-0.802	0.038
11/11	+0.488	0.316	+2.068	0.638	1.307	0.942	13.70	0.264	0.720	6.8+	1.914	-0.926	0.130
11/13	+1.367	0.348	+0.346	1.549	1.133	0.920	1.901	0.041	0.168	1.0+	0.292	-0.684	0.019
11/14	-1.787	0.318	+1.469	-1.787	1.0					6.0+	1.430	-0.917	0.115
11/15	-3.337	0.250	+3.088	-3.337	1.0					12.0+	3.084	-3.507	0.229
11/16	-0.404	0.197	+0.207	-0.404	1.0					11.2+	0.203	-5.863	0.214
11/17	+0.275	0.090	-0.365	0.275	1.0					5.0+	-0.365	-2.254	0.095
11/19	-0.688	0.280	+0.407	-0.687	1.0					12.0+	0.384	-4.425	0.229
11/20	-0.271	0.278	-0.008	-0.271	1.0						-0.008		
11/21	+3.854	0.293	+0.777	4.093	1.062	0.989	3.265	0.062	0.044		0.777		

Table C-II-a
October 21, 1976 to November 21, 1976

	54	55	56	57	58	59	60	61	62	63	64	65
						TZ1	TZ2	TZ3	$\overline{TZ}$	$\overline{TZ}$-CAV	TM1	TCAV
Date	Q600	Q602	Q603	N601	N602							
	10^6 B	10^6 B	10^6 B			°F	°F	°F	°F	°F	°F	°F
10/21	3.573	2.635	5.946	0.400	0.417	78.3	77.1	74.5	75.6	109.7	51.6	54.3
10/22	1.040	2.946	0.914	-0.299	1.669	79.1	78.2	75.5	76.7	111.1	55.2	56.6
10/23			0.357			67.9	68.3	68.3	68.2	104.6	60.1	61.1
10/24			0.041			67.2	67.7	67.8	67.6	105.2	61.3	63.0
10/25		-0.225	2.684			77.8	76.0	79.1	76.9	119.8	61.3	63.3
10/26	1.059	2.653	2.836	0.387		79.4	79.3	81.4	79.1	116.6	54.6	58.1
10/27	1.021	2.78	3.546	0.724		77.5	79.2	78.6	77.2	114.4	51.9	55.0
10/28		1.739	1.882	0.812		75.0	76.2	76.9	74.5	109.7	48.2	51.9
10/29	1.709	2.527	3.511	0.336		76.8	76.2	76.3	75.8	107.6	49.6	52.3
10/30			0.729			66.0	67.9	67.5	67.2	102.2	53.2	54.8
10/31		0.076	0.219	2.842		65.0	66.9	66.5	66.2	101.7	48.7	51.6
11/1	3.31	2.911	4.302	0.038	0.618	75.6	74.0	76.3	74.0	108.6	52.4	54.5
11/2	1.681	2.22	1.669	-0.389	0.953	76.2	76.3	78.6	76.1	110.2	51.7	53.9
11/3	1.180	2.88	2.931	0.325	0.044	76.9	76.2	78.9	76.3	111.6	54.3	55.5
11/4	0.873	4.293	4.316	0.640	2.681	81.6	77.5	82.6	79.4	105.6	52.1	54.7
11/5	3.536	2.044	5.472	0.240	0.411	79.3	78.0	81.5	78.2	102.8	44.6	47.7
11/6		0.924	1.672	1.458		65.3	66.9	67.1	66.4	95.7	48.6	50.2
11/7		0.712	1.920	2.336		64.2	65.8	66.0	65.3	95.6	57.1	57.4
11/8	1.066	5.099	5.618	0.697	2.915	79.0	77.7	82.1	78.3	101.5	40.5	44.2
11/9	0.50	4.05	4.988	0.944	4.839	77.6	75.7	80.1	76.4	100.1	49.6	50.2
11/10	3.114	1.615	6.808	-1.398	0.364	73.5	75.4	75.6	72.4	106.2	60.1	60.3
11/11	1.993	2.107	4.875	0.981	0.784	79.6	77.9	81.3	80.2	110.4	57.5	59.5
11/13		0.684	0.493	0.506		65.2	67.0	67.8	66.7	97.1	44.4	47.8
11/14		0.917	1.545	1.602		63.0	65.3	65.4	64.6	95.3	37.6	42.3
11/15	3.387	5.522	7.833	0.559	1.141	76.8	75.8	80.8	77.0	108.4	43.5	46.8
11/16	7.143	6.725	9.942	0.030	0.686	76.2	81.8	85.7	80.8	110.2	47.7	50.5
11/17	4.845	2.965	6.190	-0.123	0.441	77.0	78.2	84.3	80.3	109.5	47.2	50.5
11/19	10.853	11.038	15.106	0.037	0.744	74.9	83.3	85.1	80.8	109.5	57.6	59.1
11/20			0.008			67.0	70.5	70.3	69.3	101.3	52.4	56.6
11/21			1.015			66.7	69.1	69.1	67.9	99.3	49.8	53.4

Table C-II-b Heat Load and Performance Analysis: Winter Mode - Daytime November 22, 1976 to January 11, 1977

	1	2	3	4	5	6	7	8	9	10	11	12	13
	HTΦ	HTT	A_cHTTWR-T	Δτ coll	A_cHTTWR-O	Q coll	η_{coll-T}	η_{coll-O}	Q Loss	Q ESC	Δτ DHW	Q DHW	Q EHW
			A_cQ001-T		A_cQ001-O	A_cQ100	N001	N100	Q101	Q102		Q300	Q303
Date	B/ft²-Day	B/ft²-Day	10^6 B	hour	10^6 B	10^6 B	—	—	10^6 B	10^6 B	hour	10^3 B	10^5 B
11/22	1214	1803	18.53	3.5+	7.618	2.293	0.124	0.301	5.325	0.151		- 7.67	
11/23	1090	1606	16.51	3.0+	7.437	2.515	0.152	0.338	4.922	0.130			
11/25	1045	1548	15.91	5.5	11.32	4.149	0.261	0.367	7.171	0.238			
11/26	54	49											
11/27	155	127											
11/28	141	116											
11/29	615	859											
11/30	1138	1769											
12/1	738	1631	16.77	5.5+	15.04	7.164	0.427	0.476	7.40	0.238		- 24.85	
12/2	1068	1524	15.66	4.2	8.904	2.855	0.182	0.321	6.049	0.182			
12/3	858	1375	14.13	5.0	11.57	4.359	0.308	0.377	7.211	0.216	2.2	-105.6	1.400
12/4	1048	1639	16.85	5.5	11.78	4.467	0.265	0.379	7.313	0.238			
12/6	1	3											
12/7	177	142										- 5.95	
12/8	717	943										- 42.02	
12/9	1091	1661	17.07	5.0	11.25	4.332	0.254	0.385	6.918	0.216			
12/10	375	311										0.42	
12/11	132	110											
12/12	97	85											
12/13	593	561											
12/16	1024	1695	17.42	6.0	14.03	5.257	0.302	0.375	8.773	0.260			
12/17	1054	1752	18.01	5.8	13.97	5.168	0.287	0.370	8.802	0.251	2.0	- 40.22	1.272
12/18	959	1469									12.5+	- 44.67	7.953
12/19	860	1286									12.0+	- 33.78	7.635
1/6	151	125										- 6.36	
1/7	637	868											
1/8	950	1323											
1/9	35	35											
1/10	981	1454											
1/11	1118	1754											

Table C-II-b Continued
November 22, 1976 to January 11, 1977

	14	15	16	17	18	19	20	21	22	23	24	25	26
	QDHWAX							TA	QSTL-A	TB	QSTL-B	TC	QSTL-C
	Q306	Q301	Q302	Q307	N300	N301	N302	T200-A	Q204-A	T200-B	Q204-A	T200-C	Q204-C
Date	10^6 B	10^6 B	10^6 B	10^6 B				°F	10^3 B	°F	10^3 B	°F	10^3 B
11/22	1.223	0.917	0.925	1.231	0.008	0.006	0.751	134	35.718	131	30.324	113	25.032
11/23	0.642	0.482	0.482	0.642			0.750						
11/25	0.698	0.524	0.524	0.698			0.750						
11/26								109		109		109	
11/27													
11/28								108		107		108	
11/29	1.023	0.767	0.767	1.023			0.75	107		105		107	
11/30	0.730	0.548	0.548	0.730			0.75						
12/1	1.058	0.794	0.815	1.083	0.030	0.023	0.753						
12/2	1.697	1.273	1.273	1.697			0.75	131	41.223	127	33.869	104	25.502
12/3	1.446	1.085	1.191	1.552	0.089	0.068	0.767	138	53.625	132	43.32	104	30.360
12/4													
12/6	0.114	0.086	0.086	0.114			0.75						
12/7	1.669	1.252	1.258	1.675	0.005	0.004	0.751						
12/8	1.310	0.983	1.352	1.025	0.041	0.031	0.758						
12/9	-6.765	-5.073	-6.765	-5.073			0.75	115	38.675	113	31.920	115	
12/10								111		109		113	
12/11								110		109		113	
12/12								109		109		112	
12/13	1.432	1.074	1.432	1.074			0.75						
12/16	0.678	0.509	0.678	0.509			0.75	126	54.99	121	44.064	108	39.312
12/17								130	56.173	127	46.771	109	38.698
12/18								126		122		108	
12/19													
1/6								95		97		92	
1/7								94		97		91	
1/8								94		96		90	
1/9								93		85		89	
1/10								92		94		88	
1/11								91		93		88	

Table C-II-b Continued
November 22, 1976 to January 11, 1977

Date	27 QSTS Q202 10^6 B	28 QSTL-S Q204 10^6 B	29 QUTL Q201 10^6 B	30 QTHB 10^6 B	31 NTHBL	32 N108	33 N110	34 N111	35 N112	36 $\Delta\tau$BLD hr	37 QBLS Q400 10^6 B	38 QBLD Q402 10^6 B	39 QEBL Q403 10^6 B
11/22	+0.600	0.306	+1.386	0.751	1.252	0.932	9.176	0.182	0.604	11.8+	1.378	-6.927	0.225
11/23	+2.079	0.228	+0.208	2.209	1.063	0.961	1.600	0.028	0.082	8.5+	0.208	-6.632	0.162
11/25	-1.854	0.301	+5.703	-1.346	0.726	1.050	23.96	0.504	1.375	11.8+	5.703	-5.328	0.225
11/26	-3.971	0.217	+3.754	-3.97	1.0					9.5+	3.754	-3.463	0.181
11/27	-0.092	0.245	-0.154	-0.091	1.0								
11/28	-0.088	0.238	-0.151	-0.087	1.0								
11/29	-0.275	0.223	+0.052	-0.275	1.0					11.8+	0.052	-9.024	0.225
11/30	+0.050	0.197	-0.247	0.50	1.0					10.5+	-0.247	-7.715	0.200
12/1	-15.78	0.187		-15.538	0.985					7.8+		-1.689	0.148
12/2	+2.379	0.275	+0.201	2.561	1.077	0.967	1.104	0.022	0.070	11.8+	0.201	-7.983	0.225
12/3	+1.712	0.266	+2.381	1.919	1.127	0.986	11.02	0.206	0.546	10.8+	2.275	-5.960	0.206
12/4	+3.929	0.336	+0.202	4.168	1.061	0.978	0.849	0.017	0.045		0.202		
12/6	-0.608	0.122	+0.487	-0.608	1.0					4.0+	0.487	-2.329	0.076
12/7	-2.212	0.372	+1.841	-2.212	1.0					12.5+	1.835	-7.342	0.239
12/8	-3.742	0.307	+3.435	-3.741	1.0					11.5	3.393	-5.805	0.220
12/9	+2.258	0.239	+1.835	2.474	1.096	0.995	8.495	0.163	0.424	11.2+	1.835	-6.743	0.214
12/10	-0.867	0.258	+0.609	-0.866	1.0					12.5+	0.609	-6.765	0.239
12/11	-0.188	0.253	+0.066	-0.187	1.0						0.066		
12/12	-0.221	0.238	-0.017	-0.221	1.0						-0.017		
12/13	-0.221	0.234	-0.013	-0.221	1.0					11.8+	-0.013	-7.470	0.225
12/16	+4.421	0.258	+0.578	4.681	1.059	1.000	2.223	0.041	0.110	11.2+	0.578	-5.720	0.214
12/17	+1.962	0.297	+2.908	2.214	1.128	0.991	11.58	0.208	0.563	12.0+	2.868	-5.545	0.229
12/18	-0.508	0.297	+0.211	-0.508	1.0						0.166		
12/19	-0.479	0.279	+0.191	-0.470	0.981					1.0	0.157	-0.601	0.019
1/6	-0.196	0.176	+0.019	-0.196	1.0					12.0+	0.013	-6.577	0.229
1/7	-0.150	0.176	-0.026	-0.150	1.0					12.2+	-0.026	-6.810	0.233
1/8	-0.150	0.172	-0.022	-0.150	1.0					12.2+	-0.022	-5.342	0.233
1/9	-0.142	0.165	-0.024	-0.141	0.993					12.0+	-0.024	-4.796	0.229
1/10	-0.162	0.158	+0.005	-0.162	1.0					12.0+	0.005	-8.634	0.229
1/11	-0.196	0.163	+0.003	-0.196	1.0					12.8+	0.003	-7.105	0.244

Table C-II-b Continued
November 22, 1976 to January 11, 1977

	40	41	42	43	44	45	46	47	48	49	50	51	52	53
	QESUM	QELEC	QEAX	QBLAX										
		Q601		Q410	Q401	Q411	N400	N401	N408	Q412	Q413	Q416	Q417	Q418
Date	10^6 B	10^6 B	10^6 B	10^6 B	10^6 B	10^6 B				10^6 B	10^6 B	10^6 B	10^6 B	10^6 B
11/22	0.376	0.231	-0.145	9.427	7.070	11.030	0.199	0.125	0.628	0.150	0.231	9.236	-0.191	1.752
11/23	0.292	0.214	-0.078	10.919	8.189	11.289	0.031	0.018	0.587	0.130	0.214	8.843	-2.076	1.979
11/25	0.463			4.055	4.041	9.983	1.070	0.571	0.534	0.238		7.104	3.049	4.416
11/26	0.181					3.935	1.084	0.954	0.880			4.617	4.617	0.291
11/27														
11/28														
11/29	0.225	0.378	0.153	13.422	10.067	13.699	0.006	0.003	0.659		0.378	12.032	+1.39	1.473
11/30	0.200	0.316	0.166	12.690	9.518	12.583			0.613		0.316	10.287	+2.403	1.872
12/1	0.387	0.388	0.001	9.543	7.157						0.388	2.252	-7.291	
12/2	0.407	0.452	0.045	10.010	7.508	10.435	0.025	0.019	0.765	0.182	0.452	10.664	0.634	0.178
12/3	0.423	0.486	0.063	4.675	3.506	7.156	-0.382	-0.318	0.833	0.207	0.485	7.947	3.272	
12/4	0.238									0.237				0.306
12/6	0.076	0.473	0.397	11.576	8.682	12.139	0.209	0.040	0.192		0.473	3.105	3.105	7.313
12/7	0.239	0.513	0.274	9.113	6.845	11.187	0.250	0.164	0.656		0.513	9.789	-1.787	0.825
12/8	0.220	0.308	0.088	4.070	3.053	7.683	0.584	0.442	0.756		0.308	7.74	3.67	0.949
12/9	0.430	0.655	0.225	6.56	4.92	8.609	0.272	0.213	0.783	0.216	0.655	8.990	2.43	0.667
12/10	0.239					0.848	0.090	0.718				9.02	9.02	
12/11														0.066
12/12														-0.017
12/13	0.225	0.452	0.227	10.602	7.952	10.840	0.002		0.689		0.452	9.96	0.642	0.945
12/16	0.474	-0.977	-1.451	2.493	1.870	3.285	0.101	0.176		0.260	-0.977	7.627	5.134	3.733
12/17	0.481					3.097	0.517	0.926		0.248	-0.001	7.393	7.393	
12/18	0.008										-0.008			0.174
12/19	0.027					0.176	0.261	0.892			-0.007	0.801	0.801	-0.451
1/6	0.229	0.415	0.186			0.242	0.002	0.054			0.415	8.769	8.769	
1/7	0.233	0.415	0.182			0.207					0.415	9.08	8.08	
1/8	0.233					0.211						7.123	7.123	
1/9	0.229					0.205						6.395	6.395	
1/10	0.229	0.389	0.160			0.234		0.021			0.389	11.512	11.512	
1/11	0.244	0.455	0.211			0.247		0.012			0.455	9.473	9.473	

Table C-II-b Continued
November 22, 1976 to January 11, 1977

	54	55	56	57	58	59	60	61	62	63	64	65
						TZ1	TZ2	TZ3	$\overline{TZ}$	$\overline{TZ}$-CAV	TM1	TCAV
Date	Q600	Q602	Q603	N601	N602							
	10^6 B	10^6 B	10^6 B			°F	°F	°F	°F	°F	°F	°F
11/22	7.987	7.852	12.412	0.177	0.722	77.9	76.8	85.4	79.1	100.7	39.4	43.9
11/23	8.671	7.114	12.061	0.029	0.604	77.6	78.9	87.0	80.6	95.7	37.4	41.3
11/25	4.565	5.852	10.919	0.975	1.231	78.1	68.8	85.5	76.7	99.6	52.9	54.5
11/26		3.463	3.935	1.084		78.2	68.3	83.5	76.2	103.2	49.3	53.1
11/27						67.5	67.1	69.7	68.2	101.3	59.9	61.5
11/28						68.0	67.7	69.3	68.3	106.0	62.3	65.1
11/29	10.834	9.791	14.722	0.005	0.661	77.8	78.2	86.6	79.5	103.9	30.6	37.0
11/30	10.066	8.263	13.313	-0.030	0.602	78.7	79.7	87.6	80.8	98.5	29.2	34.5
12/1	7.951	2.504			0.228	81.1	72.2	86.9	76.8	100.1	43.9	50.0
12/2	8.781	9.256	12.314	0.022	0.761	78.9	76.6	86.4	79.2	99.2	43.8	46.1
12/3	4.591	7.151	8.924	0.333	1.082	77.5	75.3	85.5	77.9	98.6	43.8	47.1
12/4						64.7	66.0	69.0	66.6	90.6	44.9	47.6
12/6	8.768	2.415	12.253	0.202	0.199	76.7	78.5	86.8	76.5	99.5	40.0	43.6
12/7	8.097	8.60	12.862	0.214	0.761	78.7	77.2	85.2	79.3	107.8	45.5	48.8
12/8	4.036	6.83	9.035	0.503	1.201	78.9	77.4	84.3	78.7	103.6	32.6	37.4
12/9	-0.153	11.816	8.825	0.155	26.258	78.3	75.9	85.6	79.0	100.0	40.0	42.8
12/10		6.765	0.848	0.090		77.4	78.7	85.4	79.0	102.9	46.8	48.4
12/11						65.4	66.4	67.5	66.5	95.8	50.3	52.6
12/12						64.4	65.5	65.9	65.3	97.5	54.4	56.6
12/13	9.026	8.544	12.272	0.002	0.684	78.2	78.5	86.1	79.7	106.6	43.9	48.6
12/16	2.379	6.229	4.223	0.093	2.839	79.9	78.1	85.4	79.5	108.3	49.8	52.9
12/17		5.545	3.348	0.866		79.0	74.7	85.4	78.1	101.9	51.2	52.8
12/18						66.2	66.9	69.0	67.4	95.3	55.6	56.6
12/19		0.601	0.176	0.318		64.0	64.8	66.7	65.5	94.1	53.6	54.6
1/6		6.577	0.242	0.003	15.848	82.2	77.2	84.7	80.8	104.9	38.8	44.3
1/7		6.810	0.207	-0.004	16.410	83.3	78.0	84.5	81.6	104.6	38.0	42.3
1/8		5.342	0.211	-0.004		71.7	68.7	85.2	75.1	91.6	37.5	42.3
1/9		4.796	0.205	-0.005		69.4	67.5	84.2	73.7	93.1	36.3	40.7
1/10		8.634	0.234	0.001	22.195	82.8	77.5	84.8	80.7	96.6	26.3	31.4
1/11		7.105	0.247	0.000	15.616	82.7	76.9	88.1	81.1	93.2	21.5	27.4

Table C-II-c Heat Load and Performance Analysis: Winter Mode - Daytime
January 12, 1977 to Fe-ruary 16, 1977

	1	2	3	4	5	6	7	8	9	10	11	12	13
	HTϕ	HTT	A_cHTTWR-T	Δτ coll	A_cHTTWR-O	Q coll	η_{coll-T}	η_{coll-O}	Q Loss	Q ESC	Δτ DHW	Q DHW	Q EHW
			A_cQ001-T		A_cQ001-O	A_cQ100	N001	N100	Q101	Q102		Q300	Q303
Date	B/ft^2-Day	B/ft^2-Day	10^6 B	hour	10^6 B	10^6 B	—	—	10^6 B	10^6 B	hour	10^3 B	10^5 B
1/12	1092	1656											
1/13	1000	1403											
1/14	77	69											
1/17	1151	1661											
1/18	574	609											
1/19	1176	1708											
1/20	596	629											
1/21	1212	1827											
1/22	1202	1781											
1/23	671	696											
1/24	99	86											
1/25	826	1020											
1/26	1279	1821	18.72	4.8	11.57	5.706	0.305	0.493	5.864	0.208			
2/1	1323	1870	19.22		0.2842	0.0012		0.0042	0.283				
2/2	1336	1973										- 7.84	
2/3	372	301	3.092										
2/4	1216	1629											
2/5	1242	1670	17.17										
2/6	1427	1977											
2/7	1410	1949	20.03										
2/8	1319	1781											
2/10	1344	1786	18.35	7.0	13.56	4.464	0.243	0.329	9.096	0.303			
2/11	785	754		5.2						0.225			
2/12	229	203	2.088										
2/13	1455	1933											
2/14	1475	1912	19.65	8.5*	17.69	8.575	0.436	0.485	9.115	0.368			
2/15	1224	1394		7.0						0.303			
2/16	1555	2012		9.0						0.389			

Table C-II-c Continued
January 12, 1977 to February 16, 1977

Date	14 QDHWAX Q306 10^6 B	15 Q301 10^6 B	16 Q302 10^6 B	17 Q307 10^6B	18 N300	19 N301	20 N302	21 TA T200-A °F	22 QSTL-A Q204-A 10^3 B	23 TB T200-B °F	24 QSTL-B Q204-A 10^3 B	25 TC T200-C °F	26 QSTL-C Q204-C 10^3 B
1/12								90		93		87	
1/13								89		92		86	
1/14								88		91		85	
1/17	1.64	1.23	1.23	1.64			0.75	86		89		83	
1/18	-0.177	-0.133	0.133	0.177			0.75	85		88		82	
1/19	1.553	1.165	1.165	1.553			0.75	85		88		82	
1/20								84		87		81	
1/21								83		87		80	
1/22								83		86		80	
1/23								82		85		79	
1/24								82		85		79	
1/25	1.435	1.076	1.076	1.435			0.75	81		84		78	
1/26	1.148	0.861	0.861	1.148			0.75						
2/1	0.867	0.650	0.65	0.867									
2/2	1.658	1.244	1.252	1.666	0.006	0.005	0.752	100		101		86	
2/3	2.214	1.661	1.661	2.214			0.75	99		100		86	
2/4	1.757	1.318	1.318	1.757			0.75	98		99		85	
2/5								97		98		85	
2/6								96		97		84	
2/7								95		96		83	
2/8								94		95		82	
2/10	0.530	0.398	0.398	0.530			0.75						
2/11	1.444	1.083	1.083	1.444			0.75						
2/12													
2/13													
2/14	1.172	0.879	0.879	1.172			0.75						
2/15	1.693	1.270	1.270	1.693			0.75						
2/16	0.323	0.242	0.242	0.323			0.75						

Table C-II-c Continued
January 12, 1977 to February 16, 1977

Date	27 QSTS Q202 10^6 B	28 QSTL-S Q204 10^6 B	29 QUTL Q201 10^6 B	30 QTHB 10^6 B	31 NTHBL	32 N108	33 N110	34 N111	35 N112	36 ΔTBLD hr	37 QBLS Q400 10^6 B	38 QBLD Q402 10^6 B	39 QEBL Q403 10^6 B
1/12	-0.167	0.159	+0.000	-0.166	0.994					12.8+	0.007	-6.550	0.244
1/13	-0.138	0.150	-0.012	-0.137	0.993					12.0+	-0.012	-5.987	0.229
1/14	-0.083	0.149	-0.066	-0.083	1.0					12.5+	-0.066	-6.929	0.239
1/17	-0.200	0.134	+0.066	-0.200	1.0					12.0+	0.066	-8.562	0.229
1/18	-0.133	0.139	-0.006	-0.133	1.0					12.8+	-0.006	-8.257	0.244
1/19	-0.158	0.135	+0.022	-0.158	1.0					12.8+	0.022	-9.623	0.244
1/20	-0.158	0.127	+0.031	-0.158	1.0					12.0+	0.031	-7.815	0.229
1/21	-0.142	0.127	+0.015	-0.142	1.0					12.5+	0.015	-8.213	0.239
1/22	-0.150	0.124	+0.026	-0.150	1.0					9.8+	0.026	-2.327	0.187
1/23	-0.125	0.119	+0.006	-0.125	1.0					10.5+	0.006	-5.367	0.200
1/24	-0.125	0.112	+0.013	-0.125	1.0					11.5+	0.013	-7.181	0.220
1/25	-0.125	0.118	+0.007	-0.125	1.0					12.8+	0.007	-7.956	0.244
1/26	+4.946	0.151	+0.610	5.153	1.042	1.009	2.933	0.053	0.107	12.8+	0.610	-6.540	0.244
2/1	-0.325	0.188	+0.138	-0.325	1.0					12.2+	0.138	-6.278	0.233
2/2	+0.408	0.186	-0.356	0.171	0.419			0.486		12.5+	-0.364	-5.514	0.239
2/3	-0.196	0.176	+0.020	-0.196	1.0					12.2+	0.020	-5.658	0.233
2/4	-0.233	0.177	+0.056	-0.233	1.0					12.5+	0.056	-4.453	0.239
2/5	-0.167	0.173	-0.006	-0.166	0.993					12.5+	-0.006	-4.750	0.239
2/6	-0.179	0.165	+0.014	-0.179	1.0					12.2+	0.014	-5.090	0.233
2/7	-0.192	0.155	+0.037	-0.192	1.0					11.8+	0.037	-5.671	0.225
2/8	-0.150	0.151	-0.001	-0.150	1.0					11.8+	-0.001	-4.917	0.225
2/10	+5.662	0.172	+0.631	3.965	0.70	1.030	2.082	0.046	0.141	11.5+	0.631	-4.050	0.220
2/11	-0.433	0.216	+1.558	-1.549	3.577		6.924			12.5+	1.558	-4.259	0.239
2/12	-0.858	0.199	+0.659	-0.858	1.0					12.5+	0.659	-0.511	0.239
2/13	-0.679	0.177	+0.502	-0.679	1.0					12.2+	0.502	-0.439	0.233
2/14	+7.262	0.195	+1.117	7.631	1.051	1.020	3.035	0.063	0.130	11.8+	1.117	-4.955	0.225
2/15	+0.912	0.258	+1.975	-1.93			6.518			12.8+	1.975	-5.347	0.244
2/16	+2.317	0.280	+3.068	-2.979			7.886			12.8+	3.068	-6.760	0.244

Table C-II-c Continued
January 12, 1977 to February 16, 1977

Date	40 QESUM 10^6 B	41 QELEC Q601 10^6 B	42 QEAX 10^6 B	43 QBLAX Q410 10^6 B	44 Q4C1 10^6 B	45 Q411	46 N400	47 N401	48 N408	49 Q412 10^6 B	50 Q413 10^6 B	51 Q416 10^6 B	52 Q417 10^6 B	53 Q418 10^6 B
1/12	0.244	2.201	1.957			0.251	0.001	0.028			2.201	8.733	8.733	
1/13	0.229	0.406	0.177			0.217					0.406	7.983	7.983	
1/14	0.239					0.173						9.239	9.239	
1/17	0.229	0.273	0.044	9.43	7.073	9.725	0.008	0.007	0.880		0.273	11.416	1.986	-1.150
1/18	0.244	0.406	0.162	13.440	10.08	13.678	0.002		0.604		0.406	11.009	-2.431	2.223
1/19	0.244	0.430	0.186	0.630	0.473	0.896	0.004	0.024			0.430	12.831	12.201	-8.698
1/20	0.229					0.260	0.004	0.119				10.42	10.42	
1/21	0.239					0.254	0.002	0.059				10.951	10.951	
1/22	0.187					0.213	0.011	0.122				3.103	3.103	
1/23	0.200					0.206	0.001	0.029				7.156	7.156	
1/24	0.220					0.233	0.002	0.056				9.575	9.575	
1/25	0.244	-0.396	-0.640	6.616	4.962	6.867	0.001	0.001			-0.396	10.608	3.992	-3.383
1/26	0.452	0.415	-0.037	14.120	10.59	14.974	0.093	0.041	0.436	0.208	0.415	8.72	-5.4	5.075
2/1	0.233	0.357	0.124	0.268	0.201	0.639	0.022	0.216			0.357	8.371	8.103	5.206
2/2	0.239	0.596	0.357	0.448	0.336	0.323	0.004				0.596	7.352	6.904	-4.946
2/3	0.233	0.923	0.690	0.693	5.200	0.946	0.004	0.021			0.923	7.544	6.851	0.485
2/4	0.239	0.378	0.159	0.299	0.224	0.594	0.013	0.094			0.378	5.937	5.638	-3.795
2/5	0.239					0.233						6.333	6.333	
2/6	0.233					0.247	0.003	0.057				6.787	6.787	
2/7	0.225					0.262	0.007	0.141				7.561	7.561	
2/8	0.225					0.224						6.556	6.556	
2/10	0.523	0.430	-0.093	0.292	0.219	1.143	0.156	0.552		0.303	0.430	5.40	5.108	-2.770
2/11	0.464	0.218	-0.245	0.270	0.233	2.067	0.366	0.754		0.225	0.218	5.679	5.409	-2.780
2/12	0.239					0.898	1.290	0.734	0.569			0.681	0.681	0.148
2/13	0.233					0.735	1.143	0.683	0.597			0.585	0.585	0.063
2/14	0.593	0.559	-0.034	0.341	0.256	1.683	0.225	0.664		0.368	0.559	6.607	6.268	-3.023
2/15	0.547	0.124	-0.423	0.093	0.070	2.312	0.369	0.854		0.303	0.124	7.129	7.036	-3.178
2/16	0.633	0.375	-0.258	0.282	0.212	3.594	0.454	0.854		0.389	0.375	9.013	8.731	-3.105

Table C-II-c Continued
January 12, 1977 to February 16, 1977

	54	55	56	57	58	59	60	61	62	63	64	65
						TZ1	TZ2	TZ3	$\overline{TZ}$	$\overline{TZ}$-CAV	TM1	TCAV
Date	Q600	Q602	Q603	N601	N602							
	10^6 B	10^6 B	10^6 B			°F	°F	°F	°F	°F	°F	°F
1/12		6.550	0.251	0.001	2.976	82.7	76.9	85.0	80.1	92.4	32.2	37.0
1/13		5.987	0.207	-0.002	14.746	80.9	78.8	84.3	80.6	92.1	40.1	44.0
1/14		6.929	0.173	0.009		69.7	82.5	85.2	79.2	95.1	37.2	43.2
1/17	8.303	9.792	10.365	0.007	0.863	83.7	79.1	86.2	82.8	89.6	15.2	22.0
1/18	9.947	8.39	13.855	-0.001	0.614	85.3	78.2	84.6	81.9	90.0	20.5	26.3
1/19	1.638	10.788	2.449	0.002	4.129	82.7	81.7	85.7	82.4	89.8	17.9	22.4
1/20		7.815	0.260	0.004		67.9	81.3	88.8	78.8	85.9	31.5	35.8
1/21		8.213	0.254	0.002		66.2	80.5	89.0	78.2	84.6	24.2	36.3
1/22		2.327	0.213	0.011		61.8	65.9	66.9	64.9	75.6	20.8	36.1
1/23		5.367	0.206	0.001		62.1	71.6	75.7	69.5	78.0	37.2	41.5
1/24		7.181	0.233	0.002		66.8	81.4	88.6	78.9	89.9	35.4	42.9
1/25	6.038	9.032	8.302	0.001	1.180	81.1	77.5	83.6	79.4	94.8	37.2	42.6
1/26	11.451	7.410	16.330	0.082	0.472	79.1	74.9	78.0	76.6	93.1	42.2	45.0
2/1	0.851	6.928	1.506	0.020	4.643	75.3	73.2	80.7	75.8	85.4	32.4	37.2
2/2	1.58	6.766	1.989	-0.052	2.504	76.4	74.2	79.7	76.5	85.6	29.2	43.8
2/3	6.861	7.319	3.160	0.003	1.911	78.1	77.3	81.0	78.3	93.6	35.5	45.1
2/4	1.542	5.771	2.351	0.010	2.371	79.1	78.0	82.1	79.2	98.7		52.1
2/5		4.75	0.233	-0.001		76.3	80.2	82.0	79.5	92.6	37.1	44.0
2/6		5.09	0.247	0.003		76.7	82.7	81.1	80.2	84.8	24.3	37.7
2/7		5.67	0.262	0.007		78.9	79.8	83.6	80.4	88.1	32.9	37.4
2/8		4.917	0.224	0.000		79.3	80.2	80.6	79.9	88.0	37.1	42.1
2/10	0.617	4.448	1.976	0.142	3.553	77.7	79.3	80.0	78.6	95.3	51.8	53.7
2/11	1.286	5.342	3.736	0.292	2.765	76.5	77.7	78.7	76.5	96.6	51.2	53.8
2/12		0.511	0.898	1.290		66.2	68.7	68.0	67.7	90.9	52.5	55.2
2/13		0.439	0.735	1.143		65.7	67.3	67.4	66.7	92.2	50.3	53.5
2/14	1.135	5.834	3.223	0.191	2.816	77.1	76.5	76.2	74.9	98.2	52.6	53.8
2/15	1.34	6.617	4.308	0.298	3.464	77.8	76.4	81.5	78.3	99.9	40.5	45.4
2/16	0.454	7.002	4.306	0.438	7.145	78.1	78.8	79.2	78.4	94.7	32.7	37.9

It is reasonable to assume that the pump motor will draw full load current anytime it is running. Hence, it is possible to divide the total electrical energy consumption into its components. This assumption formed the basis for several entries in the table and a more complete representation of the calculations supporting the analysis.

Sample Calculations

1. HTϕ. Intensity of solar radiation on the horizontal surface as measured by the pyranometer. Nov. 4; 1215 B/ft^2 - Day. (Output of computer program)

2. HTT. Intensity of solar radiation on the tilted surface without reflector augmentation as measured by the pyranometer. Angle of tilt same as the tilt of the solar collectors. Nov. 4; 1560 B/ft^2 - Day. (Output of computer program)

3. A_cHTTWR - T = A_cQ001 - T. Total insolation falling on the collector banks during the entire day even if the solar collector pump is not operational. Nov. 4; 16.06 x 10^6 Btu (Output of computer program) In G.A. Towns School major portion of the collector banks are reflector augmented. The splitting of the total insolation into direct and diffuse components in order to estimate the extent of solar energy augmented by the reflectors is according to Liu and Jordan. Rest of the values are based on measured data. Hence only the augmentation factor is estimated.

4. Δτ COLL Duration the flow meter F1 operated continuously enabling the collection of solar energy. Nov. 4; 5.8 hours. (Based on the output of the computer program). When the pump worked intermittently the duration the pump did not operate has been subtracted.

5. A_cHTTWR-0 = A_cQ001-0. Total insolation falling on the collector banks during the period collector pump was operational. Nov. 4; 10.69 x 10^6 Btu (Output of computer program). See note contained in Col. 3.

6. QCOLL = A_cQ100 = Q200. Energy collected by the flowing water in the collector. Nov. 4; 2.835 x 10^6 Btu (Output of computer program). Here the temperature across the collector bank is measured at the roof top above the equipment room. The actual temperature rise at the collector banks and the temperature drop between the sensors and the storage tanks have not been measured. Hence, the piping losses (Q103) and the transportation efficiency cannot be estimated.

7. η_{COLL-T} = N001 = A_cQ100/A_cQ001-T. Efficiency of the collector system based on the total insolation falling on the collector banks.
Nov. 4; N001 $(2.835 \times 10^6)/(16.06 \times 10^6) = 0.177$.

8. η_{COLL-0} = N100 = A_cQ100/A_cQ011-T. Efficiency of the collector system based on the insolation falling on the collector during the time the collector pump operated.
Nov. 4; N100 = $(2.835 \times 10^6)/(10.69 \times 10^6) = 0.265$.
On December 3, 1976 and January 14, 1977 the corresponding efficiencies were 0.385 and 0.485, respectively.

9. QLOSS = Q101 = (A_cQ001-0) - A_cQ100. Heat loss during the collection period.
Nov. 4; Q101 = $(10.69 \times 10^6 - 2.835 \times 10^6) = 7.855 \times 10^6$ Btu.
Data show large amount of solar energy is lost even on clear day.

10. QESC = Q102 = 17 x 2545 x ΔτCOLL. Electrical energy used in the collector storage loop for pumping water. An estimate based on the pump rating (17 h.p.) and duration of the collector pump operation. Does not include energy used in the variable speed control device of the Solar collector pump. See also QEAX.
Nov. 4; Q102 = 17 x 2545 x 5.8 = 0.251×10^6 Btu.

11. ΔτDHW. Duration the domestic hot water preheater was operational as determined by the flowmeter F-6 and the pump P-3.
Nov. 4; 3.0 hours. (Based on the output of the computer program). See comment in item 4.

12. QDHW = Q300. Heat energy added to the domestic hot water in the preheater prior to its flow in the main hot water heater which uses natural gas as the energy source.
Nov. 4; -115.5×10^3 Btu. (Output of the computer program). Negative sign is due to recording of the temperature difference as (in-out). Here, the amount shown is actually supplied from the solar storage tanks.

13. QEHW = Q303 = 0.25 x 2545 x ΔτDHW. Electrical energy used in the domestic hot water loop circulating the water between the solar storage tanks and the preheater. An estimate based on the pump rating (0.25 hp) and its duration of operation.
Nov. 4; Q303 = 0.25 x 2545 x 3.0 = 1.909×10^3 Btu.

14. QDHWAX = Q306. Heat equivalent of gas energy expended in the domestic hot water heater.

$$Q306 = \Delta\ (\text{Gas Reading})\ 100 \times \text{CVF} \left(\frac{\Delta\tau\ \text{Comp}}{\Delta\tau\ \text{Reading}}\right):$$

Gas readings are recorded twice a day.

Here, assumption is made that if the gas meter reading were taken at the same instants as the start and the stop of the computer printout the gas consumption would be larger. Such a prorating is necessary since the readings were logged manually at irregular times.

Nov. 4; $Q306 = 7.1 \times 100 \times 1025 \times (\frac{12.0}{7.5}) = 1.164 \times 10^6$ Btu

Here, CVF = 1025 B/ft^3

The duration between readings = 7.5 hours and the duration between data logging = 12.0 hours

15. Q301 = η_b x Q306. Heat energy added to the hot water used in the School. η_b - burner efficiency is estimated to be 0.75. See also item 44.
Nov. 4; $Q301 = 0.75 (1.164 \times 10^6) = 0.873 \times 10^6$ Btu

16. Q302 = Q300 + Q301. Hot water load delivered to the School.
Nov. 4; $Q302 = 0.115 \times 10^6 + 0.873 \times 10^6 = 0.99 \times 10^5$ Btu

17. Q307 = Q300 + Q303 + Q306. Total energy including solar augmentation and electrical energy used in the school hot water system.
Nov. 4; $Q307 = (0.115 + 0.0019 + 1.164) \times 10^6 = 1.28 \times 10^6$ Btu

18. N300 = Q300/Q302. Solar fraction of hot water load. Range of values from 0 to 1.0
Nov. 4; $N300 = (0.115 \times 10^6/0.99 \times 10^6) = 0.117$

19. N301 = Q300/Q307. Solar fraction of total energy consumed.
Nov. 4; $N301 = (0.115 \times 10^6/1.28 \times 10^6) = 0.090$

20. N302 = Q302/Q307. Performance factor of the hot water system used in the school. Ranges from 0.75 when there is no solar input to a value close to 1.0 when all the heat is supplied from the solar energy.
Nov. 4; $N302 = (0.99 \times 10^6/1.28 \times 10^6) = 0.773$

21. TA = T200 - A Average temperature of the storage tank A (i.e., Tank 1)
Nov. 4; T200 - A = 141^{o}F. This value is the arithmetic average of the temperatures measured at the three locations near the central region of 15000 gallon tanks for the daytime period. (Output of the computer program)

22. QSTL - A = Q204 - A. An estimate of heat loss from the storage tank A to the ground during the period collector operated. See section on "Tank Losses" for the basis of this computation

$Q204 - A = 130 [TA - 55.5] \Delta\tau$ COLL; TA = S TT1

Nov. 4; $Q204 - A = Q204 - A = 130 [141 - 55.5]\ 5.8 = 64.467 \times 10^3$ Btu

23. TB = T200 - B. Average temperature of the storage tank B (i.e., Tank 2). See item 21.
Nov. 4; T200 _ B = 132°F. (Output of the computer program)

24. QSTL - B = Q204 - B. Same as item 22 for the storage tank B.

Q 204 - B = 120 [TB - 59.8]Δτ COLL; TB = STT2

Nov 4; Q204 - B = 120 [132 - 59.8]5.8 = 50.251×10^3 Btu

25. TC = T200 - C. Average temperature of the storage tank C (i.e., tank 3). See item 21.
Nov. 4; T200 - C = 127°F. (Output of the computer program)

26. QSTL - C = Q204 - C. Same as item 22 for the storage tank C.

Q204 - C = 120 [TC - 53.4]Δτ COLL; TC = STT3

Nov. 4; Q204 - C = 120 [127 - 53.4]5.8 = 51.226×10^3 Btu

27. QSTS = Q202. Net heat energy stored in the three storage tanks. Positive values mean excess solar energy above the usage. Negative values mean excess usage over and above the useful energy collected. Solar energy collected (Q200) will be a positive number or zero. Heat losses from the tank to the ground is taken as positive. Depending on relative rate of temperature fall in the tanks it is possible to have heat gain into the tank from the ground. On a cloudy day this value will be negative, the magnitude depending on the extent the tank temperatures is above the minimum useful temperature.
Nov. 4; Q202 = -0.254×10^6 Btu (Output of the computer program)

28. QSTL - S = Q204. Sum of the estimated heat losses for the three tanks based on the derived empirical equations. See the section on "Tank Losses".
Nov. 4; Q204 = 0.342 x 10 Btu. (Output of the computer program). This value will differ from sum of items 22, 24 & 26 which was hand calculated. Here this heat loss rate for each 15 minute period was calculated for each of the three tanks and were added up using a specially written program.

29. QUTL = Q201 = Q300 + Q400. Solar energy utilized for space heating and in the preheater of the hot water system. This value should be always positive or zero. The values in this column are subjected to the accuracy of the monitored data, the inaccuracies introduced in the averaging and the lack of complete information to evaluate time dependent fluctuations imposed on the storage system and their surroundings. Several

of these factors have contributed to the negative values.
Nov. 4; Q201 = 2.747 x 10^6 Btu (output of the computer program).

30. QTHB = Q200 + Q102 - Q201 - Q204. Storage tank balance. For a perfect check this should be equal to Q202 described in item 27. Since the quantities are time dependent functions with large thermal capacities large deviations should be expected.
Nov. 4: QTHB = (2.835 + 0.251 - 2.747 - 0.342) x 10^6 = -.0003 x 10^6 Btu

31. NTHBL = QTHB/QSTS. Heat balance check for the three storage tanks. For a perfect check this should be 1.0 since differences of large numbers and their ratios involved these values will vary widely. See also item 27 and 30.
Nov. 4; NTHBL = (-.003 x 10^6)/(-0.254 x 10^6) = 0.002
Nov. 5; NTHBL = (2.269 x 10^6)/(2.087 x 10^6) = 1.087

32. N108 = (QUTL + QTHB)/QCOLL = (Q200 + Q102 - Q204)/Q200. Storage tank efficiency.
Nov. 4: N108 = (2.747 x 10^6 + (-.003 x 10^6))/2.835 x 10^6 = 0.955
Values greater than 1.0 means depletion of energy in the storage tanks.

33. N110 = Q201/Q102. Coefficient of performance of the solar energy storage system, i.e., the ratio of utilization of solar energy is to the electrical pump work. Here, since the solar energy is recognized as free energy it is expected that this number can be anywhere between zero and very large value.
Nov. 4; N110 = +2.747 x 10^6/0.251 x 10^6 = 10.94
Highest value is 96 on December 1. Typical value is about 10. Negative values are attributable to the comment made in item 29.

34. N111 = Q201/A_cQ001 - O. Conversion efficiency of the solar collector storage system, i.e., the ratio of the energy utilized to the energy incident on the collector banks during operational hours of the collector pump. Here, depending on the temperature history of the storage tanks it is possible for the building to be supplied from the storage tanks for a maximum of twelve hours of data acquisition period irrespective of the kind of day, i.e., sunny or cloudy. If the denominator is zero the value is not computed since it means that the collector pump did not operate. See also item 29.
Nov. 4; N111 = ÷2.747 x 10^6/10.69 x 10^6 = 0.257
In the Towns School Q203 = Q201.

35. N112 = Q201/Q200. Utilization efficiency of the solar collector system, i.e. the ratio of the solar energy utilized to the net solar energy collected.
Nov. 4; N112 - +2.747 x 10^6/2.835 x 10^6 = 0.969

In the Towns School Q203 = Q201 and Q200 = A_cQ100 since sufficient data is not available to estimate piping losses.

36. $\Delta\tau$BLD. Duration the building load was supplied as determined by the flowmeter F4-5 output and the operation of pump P-7. Nov. 4; $\Delta\tau$BLD = 8.0^{+} hours. (Based on the output of the computer program). Here (+) sign signifies that the building loop was already active supplying the heating load when the computer data logging system came on. Occasionally same situation existed when the data logging system was shut down during the evening hours.

37. QBLS = Q400 = Q201 - Q300. Extent of the building load supplied from the solar collector storage system. See design specifications. Here, Q300 is measured. Q201 is an estimate based on the heat balance around the storage tanks. This value is the difference between the total solar energy utilized minus that used in the preheater of the hot water system.
Nov. 4; Q400 = $(2.747 - 0.115)\ 10^6 = 2.632 \times 10^6$ Btu
See item 29 for the significance of negative value.

38. QBLD = Q402. Space heating load as seen by the pump circulating hot water either from solar storage tanks when the temperatures are favorable or from the auxiliary boiler using the natural gas.
Nov. 4; Q402 = -3.303×10^6 Btu. (Output of the computer program). See item 12 for the meaning of negative sign. Here, since the temperature difference is defined as (in-out) it is always negative. The amount shown was delivered to the building to overcome the daytime building heat losses.
Note that during weekends because of the setback on the thermostat the building load is considerably less.

39. QEBL = Q403 = 7.5 x 2545 x $\Delta\tau$BLD. Electrical energy used by the pump P-7 to supply building load during the data acquisition period. An estimate based on the pump rating (7.5 h.p.) and its duration of operation.
Nov. 4; Q403 = $7.5 \times 2545 \times 8.0 = 0.153 \times 10^6$ Btu

40. QE SUM = Q102 + Q303 + Q403. Total electrical energy consumed by the pumps operating the solar loop, the hot water loop and the building loop.
Nov. 4; QE SUM = $(0.251 + 0.0019 + 0.153) \times 10^6 = 0.406 \times 10^6$ Btu

41. QELEC = Q601. Total electrical energy consumed by various pumps, controls and auxiliaries used in the solar system.

$$\Delta(\text{kwhr. Reading}) \times 40 \times 3414 \left(\frac{\Delta\tau \text{ Comp}}{\Delta\tau \text{ Reading}} \right)$$

Gas and electric readings are recorded twice a day on weekdays not necessarily at the beginning and end of the data logging period. See also item 14 about prorating.

Nov. 4; $Q601 = 2.0 \times 40 \times 3413 \left(\frac{12}{7.5}\right) = 0.437 \times 10^6$ Btu

See item 14 for $\Delta\tau$ reading and $\Delta\tau$ computer.

42. QEAX = QELEC - QESUM. Electrical energy used by the fill pump, variable speed winding, controls and unaccounted losses.
Nov. 4; $QEAUX = (0.437 - 0.406) \times 10^6 = 0.027 \times 10^6$ Btu
Possible reasons for negative values are manual logging of kwhr readings and taking differences of two large numbers. Statistical analysis of the data will provide average energy consumption from the auxiliaries mentioned here and the standard deviation.

43. QBLAX = Q410. Auxiliary gas used to supply building heating load when solar energy stored in the storage tanks was not sufficient.

$$410 = \Delta(\text{Gas Reading})\ 100 \times CVF \left(\frac{\Delta\tau\ \text{Comp}}{\Delta\tau\ \text{Reading}}\right)$$

See item 14 about the nature of this data which is similar to auxiliary energy used with hot water heating. Here the building heat is either supplied by the storage tanks or by the auxiliary boiler. In the case of hot water heating the auxiliary heater makes up the difference.
Nov. 4; No gas meter reading
Nov. 5; $Q410 = 44.7 \times 100 \times 1025 \left(\frac{12.0}{11.60}\right) = 4.715 \times 10^6$ Btu

Here $CVF = 1025\ B/ft^3$

The duration between reading = 11.66 hours and the duration between data logging is = 12.0 hurs.

44. $Q401 = \eta_b\ Q401$. Heat energy added to the water which is circulated through the building supplying the heating load. Here η_b, boiler efficiency is estimated to be 0.75 based on the gas consumption during 20 days in January 1977.
Nov. 4; No gas meter reading
Nov. 5; $Q401 = 0.75 \times 4.715 \times 10^6 = 3.536 \times 10^6$ Btu

45. Q411 = Q400 + Q403 + Q410. Total energy consumed in order to heat the school which includes solar component, electrical energy for the pumps and the natural gas used in the boiler.
Nov. 5; $Q411 = (0.418 + 0.157 + 4.715) \times 10^6 = 5.290 \times 10^6$ Btu

46. N400 - Q400/Q402. Solar fraction of the total building heating load supplied. Range of values between 0 and 1.0. Zero implying total use of auxiliary boiler and 1.0 indicating total use of solar energy.

Nov. 4; N400 = $2.632 \times 10^6/3.303 \times 10^6 = 0.797$
See comment included in item 38 about the meaning of the negative sign for Q402.

47. N401 = Q400/Q411. Solar fraction of the total energy consumed.
Nov. 4; N401 = $2.632 \times 10^6/(2.632 + .157 + 0)\ 10^6 = 0.950$
Nov. 5; N401 = $0.418 \times 10^6/5.290 \times 10^6 = 0.079$

48. N408 = Q402/Q411. Performance factor of the space heating system should vary from about 0.75 when there is no solar energy to a value close to 1.0 when the building heat is supplied entirely by the solar energy. See also item 20.
Nov. 4; N408 = $3.303 \times 10^6/2.785 \times 10^6 = 0.797$
Nov. 5; N408 = $2.044 \times 10^6/5.290 \times 10^6 = 0.386$
Both of these examples represent departures from expected values.

49. Q412 = Q400/N110. Solar heating system fraction of the electrical energy consumed.
Nov. 4; Q412 = $2.632 \times 10^6/10.94 = 0.241 \times 10^6$ Btu
See item 10 compares favorably.

50. Q413 = Q601 - Q303. Electrical energy consumed in the space heating system only.
Nov. 4; Q413 = $(0.437 - 0.0019) \times 10^6 = 0.435 \times 10^6$ Btu
See item 39. Here auxiliaries are charged to the space heating system.

51. Q416 = Q402/η_b. Natural gas energy that would be required if the solar system was absent.
Nov. 4; Q416 = $3.303 \times 10^6/0.75 = 4.404 \times 10^6$ Btu

52. Q417 = Q416 - Q410. Fossil energy saved due to use of the solar heating system.
Nov. 4; No gas meter data
Nov. 3; Q417 = $(2.974 - 0.933)\ 10^6 = 2.041 \times 10^6$ Btu
Negative values indicate statistical scatter in the data.

53. Q418 = Q400 + Q401 + Q413 - Q402. Space heating system loss.
Nov. 5; Q418 = $(0.418 + 3.536 + 0.253 - 2.044) \times 10^6 = 2.163 \times 10^6$ Btu
Negative values indicate statistical scatter.

54. Q600 = Q301 + Q401. Total auxiliary energy delivered to the building.
Nov. 4; Q600 = $(0.873 + 0)\ 10^6 = 0.873 \times 10^6$ Btu
Nov. 3; Q600 = $(0.480 + 0.700)\ 10^6 = 1.180 \times 10^6$ Btu

55. Q602 = Q302 + Q402. Total energy delivered to the building including the solar component.
Nov. 4; Q602 = $(0.99 + 3.303) \times 10^6 = 4.293 \times 10^6$ Btu
Nov. 3; Q602 = $(.649 + 2.231) \times 10^6 = 2.88 \times 10^6$ Btu

56. Q603 = Q102 + Q307 + Q411. Sum of all the electrical energy and natural gas utilized in the building.
Nov. 4; Q603 = $(0.251 + 1.280 + 2.785)\ 10^6 = 4.316 \times 10^6$ Btu

57. N601 = Q201/Q602. Solar fraction of the total load supplied to the building.
Nov. 4; N601 = $2.747 \times 10^6 / 4.293 \times 10^6 = 0.640$

58. N602 = Q602/(Q306 + Q410 + Q601). System performance factor i.e., ratio of the energy supplied to the building to the natural gas and electrical energy used in the building.
Nov. 4; N602 = $4.293 \times 10^6/(1.164 + 0 + 0.437)\ 10^6 = 2.681$
Nov. 3; N602 = $2.88 \times 10^6/(0.640 + 0.933 + 0.195)\ 10^6 = 1.629$
Whenever there is a significant amount of solar energy utilization this value will be very much greater than unity.

59. TZ1 = N406 - 1. Average temperature of zone i.e., south zone classrooms of the Towns School between 8 AM and 5PM.
Nov. 4; N406 - 1 = 81.6°F (Output of the computer program)

60. TZ2 = N406 - 2. Average temperature of zone 2 i.e., center zone classrooms of the Towns School between 8 AM and 5 PM.
Nov. 4; N406 - 2 = 77.5°F (Output of the computer program)

61. TZ3 = N406 - 3. Average temperature of zone 3 i.e., north zone classrooms of the Towns School between 8 AM and 5 Pm.
Nov. 4; N406 - 3 = 82.6°F (Output of the computer program)

62. $\overline{TZ}$ = N406. Average temperature of all the three zones for the entire period data was logged which is approximately 12 hours.
Nov. 4; N406 = 79.4°F (Output of the computer program).

63. $\overline{TZ}$ - Cav. Average cavity temperature for all the three zones used in the determination of the moist air properties. Measured at the same location as the dry bulb temperature.
Nov. 4; $\overline{TZ}$ - Cav. = 105.6°F

64. $\overline{TMI}$ = N113. Average ambient outdoor dry bulb temperature measured at the north face of the building under the shade.
Nov. 4; N113 - 52.1°F

65. $\overline{T\ Cav.}$ Average outdoor cavity temperature used in the determination of the moist air properties. Measured at the same location as the dry bulb temperature.
Nov. 4; $\overline{T\ Cav}$ = 54.7°F

4. Discussion of Results

During 1976-77 Winter Season computer data acquisition system was operational for a total of 88 days, between October 21, 1976 and February 16, 1977. Several small computer programs have been developed to utilize this data. The time dependent output obtained from these programs have been summed up to obtain daytime average values. These are reported in a tabular form in the Section 3, Table C-II. The sample calculations contained therein gives details of block load heat balance analysis and various performance and utilization factors. Partial analysis of the data has been carried out when the data are not complete. Data from the gas and the electric meters that were manually logged have been used in this analysis.

The discussion of these results are in four parts. They are:

- Solar Collector Storage Systems
- Hot Water Heating System
- Space Heating System
- Overall Evaluation of the System

4a. Solar Collector Storage System

Table C-III contains frequency distribution data for the solar collector system. There were 53 days in which insolation on the tilted collector exceeded 1200 B/ft^2-day. They may be classified as sunny to partially sunny days. Among 120 days span covering the period of this report, they represent 44 percent of the days. The levels in this table are arbitrarily selected. The frequency represents days in which the level exceeded but was not higher than the next chosen level. The cumulative frequency represents the number of days the insolation exceeded the chosen level. The same type of interpretation

Table C-III Frequency Ditribution Data*

(a) Solar Collector Storage System

Insolation on Tilted Collector	Level 100 B/ft^2-Day	20	19	18	17	16	15	14	13	12	Total
	Frequency	1	7	7	11	12	4	6	4	1	(53)
	Cumulative Frequency	1	8	15	26	38	42	48	52	53	
Total Solar Energy Falling on Collector System	Level 10^6 Btu/Day	20	19	18	17	16	15	14	13		Total
	Frequency	2	4	8	5	6	3	3	1		(32)
	Cumulative Frequency	2	6	14	19	25	28	31	32		
Duration of Collector Pump Operation	Level Hours	9	8	7	6	5	4	3			Total
	Frequency	2	1	4	3	12	6	4			(32)
	Cumulative Frequency	2	3	7	10	22	28	32			
Collector Efficiency Operating Hours	Level	0.45	0.40	0.35	0.30	0.25	0.20				Total
	Frequency	3	2	10	8	6	1				(30)
	Cumulative Frequency	3	5	15	23	29	30				
Daily Collector Efficiency	Level	0.40	0.35	0.30	0.25	0.20	0.15				Total
	Frequency	2	0	3	7	9	4				(25)
	Cumulative Frequency	2	2	5	12	21	25				

	Level, °F	145	140	135	130	125	120	115	110	105	Total
Storage Tank A	Frequency	2	3	1	5	2	0	3	2	4	(22)
	Cumulative Frequency	2	5	6	11	13	13	16	18	22	
Storage Tank B	Frequency	2	0	1	4	3	3	2	1	5	(21)
	Cumulative Frequency	2	2	3	7	10	13	15	16	21	
Storage Tank C	Frequency	0	2	0	0	2	2	3	5	6	(20)
	Cumulative Frequency	0	2	2	2	4	6	9	14	20	

(b) Hot Water System (Week Day Data)

Natural Gas Consumption	Level 10^6B/Day	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.0	0.9	Total
	Frequency	4	4	1	4	6	2	5	3	1	(30)
	Cumulative Frequency	4	8	9	13	19	21	26	29	30	
Hot Water Load	Level 10^6B/Day	1.4	1.3	1.2	1.1	1.0	0.9	0.8	0.7	0.6	Total
	Frequency	4	3	5	5	3	3	5	3	2	(33)
	Cumulative Frequency	4	7	12	17	20	23	28	31	33	

(c) Space Heating System (Week Day Data)

Natural Gas Consumption	Level 10^6 B/Day	14	12	10	8	6	4	2			Total
	Frequency	1	3	4	5	3	7	3			(26)
	Cumulative Frequency	1	4	8	13	16	23	26			
Space Heating Load	Level 10^6B/Day	9	8	7	6	5	4	3	3	1	Total
	Frequency	2	5	8	12	9	7	4	5	8	(60)
	Cumulative Frequency	2	7	15	27	36	43	47	52	60	
Solar Augmentation	Level 10^6B/Day	4.0	3.5	3.0	2.5	2.0	1.5	1.0			Total
	Frequency	3	2	4	2	6	2	5			(24)
	Cumulative Frequency	3	5	9	11	17	19	24			

* All energy consumption contained in this table refer to daytime period only. They are not for 24-hour period.

is implied in the other entries.

Next entry in the Table C-II refers to the amount of insolation falling on the entire collector banks including the reflector augmentation. The 36 deg angle from the horizonal selected for the reflectors in the design of this system provides for very little augmentation during winter months because of the low altitude of the sun. The graphical plots of solar radiation shown at the end of Section 6 confirms this fact. The data contained therein are for 15 minutes variation. The plots contain instantaneous collector efficiency. In Table C-II, data for 32 days in which the total insolation between dawn to dusk falling on the collector array exceeded 13 million Btu have been included. They represent 27 percent of the days included in the analysis. The highest possible amount of solar radiation falling on the collector banks of the Towns School reached 20 million Btu only on two days.

The duration that the collector pump was operational is also shown in the table. It ranges from a maximum of 9 hours to a minimum of 3 hours which is the lowest cut off value arbitrarily selected. They represent 32 days i.e. 27 percent of the period selected. Maximum possible sunshine hours during this period is between 10 to 11 hours. There were two days in which the collector pump operated for 9 hours storing energy. It should be noted that the storage tank temperatures on these days were low enough to make long hours of energy collection possible. Typical duration of collector pump operation when the storage tank temperatures are in the vicinity of 140°F and the days are clear is about 5 hours.

Table C-III also contains the average collector efficiency of the solar collector system during operational hours and the daily collector efficiency. The latter includes the total amount of solar energy received by the collector array on the selected day. As stated before, high efficiency of 45 percent during hours of operation of the solar collector array coincides with the days when the storage tank temperatures are below the usable temperature of 105°F. On a daily basis, this corresponds to about 40%. A typical efficiency of 30% is reasonable to expect when the three tanks are cascading. They represent about 75% of the days having appreciable sunshine or about 33% of the calander days during winter season. On a daily basis, the operational collector efficiency of 30% has to be derated to about 22% if the entire sunshine hours are considered. It should be noted that during the month of December 1976 and January 1977, there were 11 days (28% of the days) on which appreciable solar energy could have been collected had the system been operational. They would have increased the number of days included in the table containing frequency distribution.

The frequency distribution data for the temperature levels of the three storage tanks have been divided to 5F steps in the useful range of 105°F to 145°F. The distribution of these frequency numbers show some evidence that the three tanks were cascading in the order called for in the design. For example, the temperature of 130°F has been exceeded on 11 days in tank A, 7 days in tank B and only 2 days in tank C. There were only 18% of the days in the winter season when the temperature exceeded minimum useful temperature of 105°F set forth in this design. Had the system been operational during December 1976 - January 1977, this percentage would have increased to about 28 to 30 percent. Considering that the months of December and January to be the coldest (Atlanta and the rest of the Eastern United States experienced record cold temperatures), it is only natural to expect the solar augmentation from the collector array of the Towns School to be marginal and the usage of natural gas to be appreciable.

Fig. C-3 dipicts the level of total solar radiation falling on the 10,000 sq. ft. of the 36 deg reflector augmented 45 deg inclined collector array Included in this figure are the solar radiation levels for the entire daytime

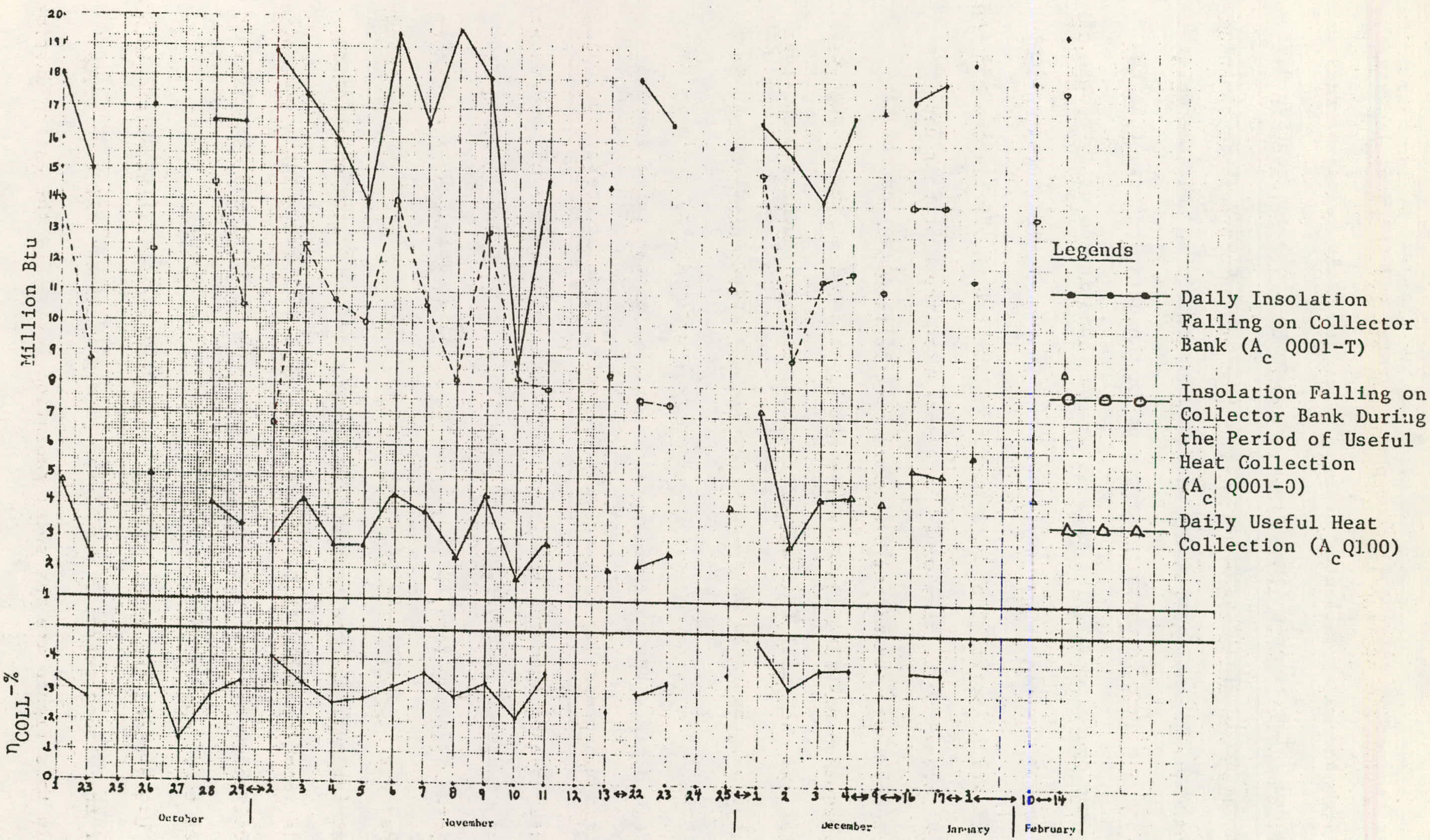

Figure C-3. Insolation Characteristics and Efficiency of the Solar Collector (Towns School) (1976-1977 Winter) period, for the period solar collector pump operated and the useful energy collected from the solar collector system. They are daily values expressed in million Btu. The zig-zag lines are drawn through those consecutive days the system operated. The gaps in the figure represent cloudy or partially cloudy days when the incident energy was not appreciable to heat the water above that of the storage tanks. Large gaps in the data indicate that the system was not operational. The reasons may be found in the daily record of the log, Appendix B. Also shown in Figure C-3 are the average solar collector efficiencies for the period the collector pump operated. The figure clearly demonstrates that even on clear days the daily collector efficiency of 30% should be expected. Thus appreciable amount of solar energy cannot be utilized in such a system. As stated earlier, the level of the storage tank temperatures and the small fraction of maximum possible sunshine hours that the collector pump operated have contributed, to a great extent, to this low efficiency level.

Fig. C-4 dipicts the daily temperature history of the three storage tanks. Minimum temperature for useful utilization of solar energy is 105°F. Fig. C-5 dipicts the inflow energy to the storage tanks (Q200) and the utilization of stored energy (Q201) in the preheater of the hot water system (Q300) and the space heating system (Q400) on a daily basis. Only days when there were significant amounts of collection have been selected for comparison. Table C-II contained in the section on "Data Analysis" may be reviewed for other days. It is possible to expect utilization over the useful energy collection on certain days. In the limited comparison shown in Fig. C-5 there are four such days.

Fig. C-6 dipicts the level of heat balance (N108) exhibited in the storage tanks on a daily basis. They include inflow from the solar collector

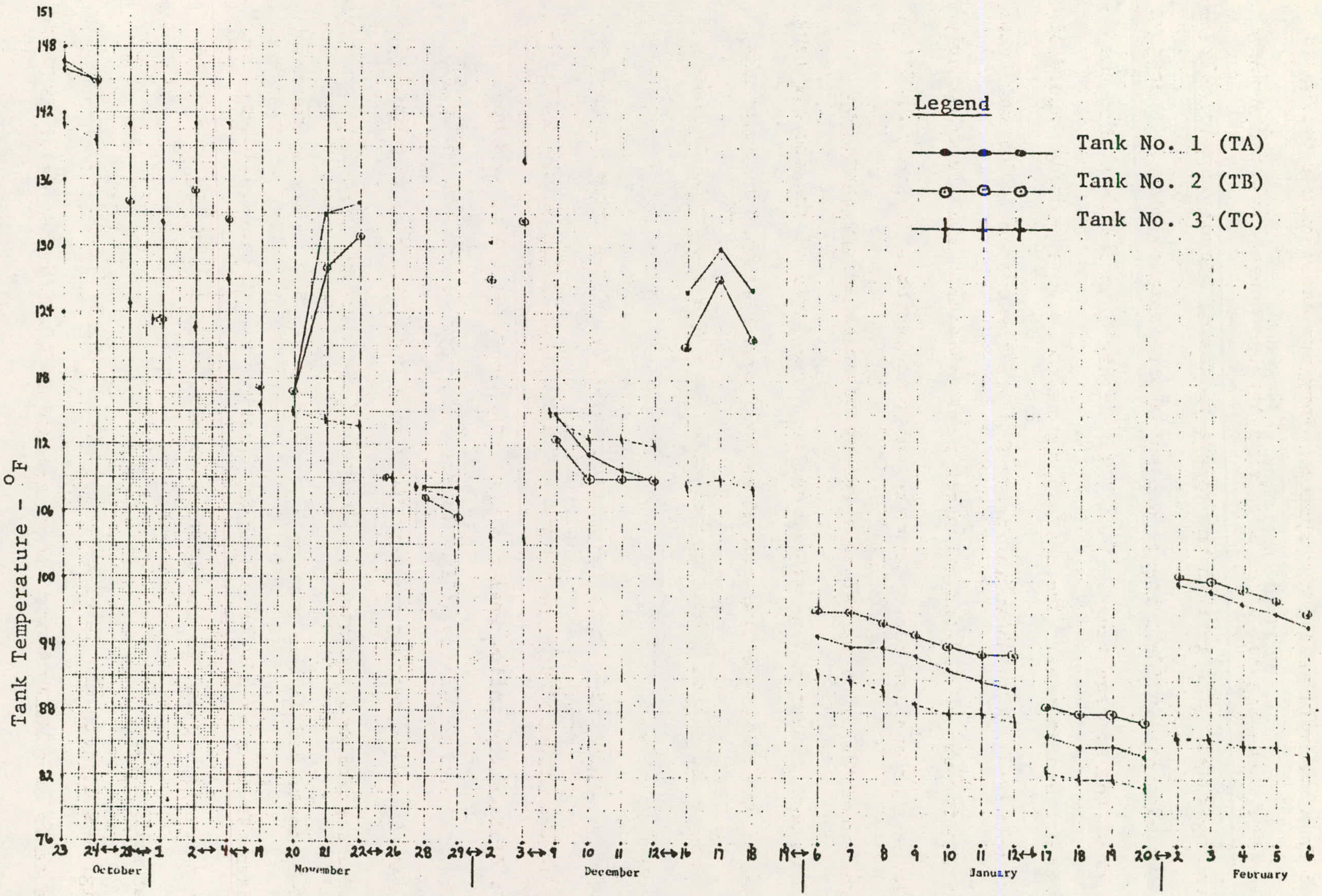

Figure C-4. Hot Water Storage Tank Temperatures (Towns School 76-77 Winter)

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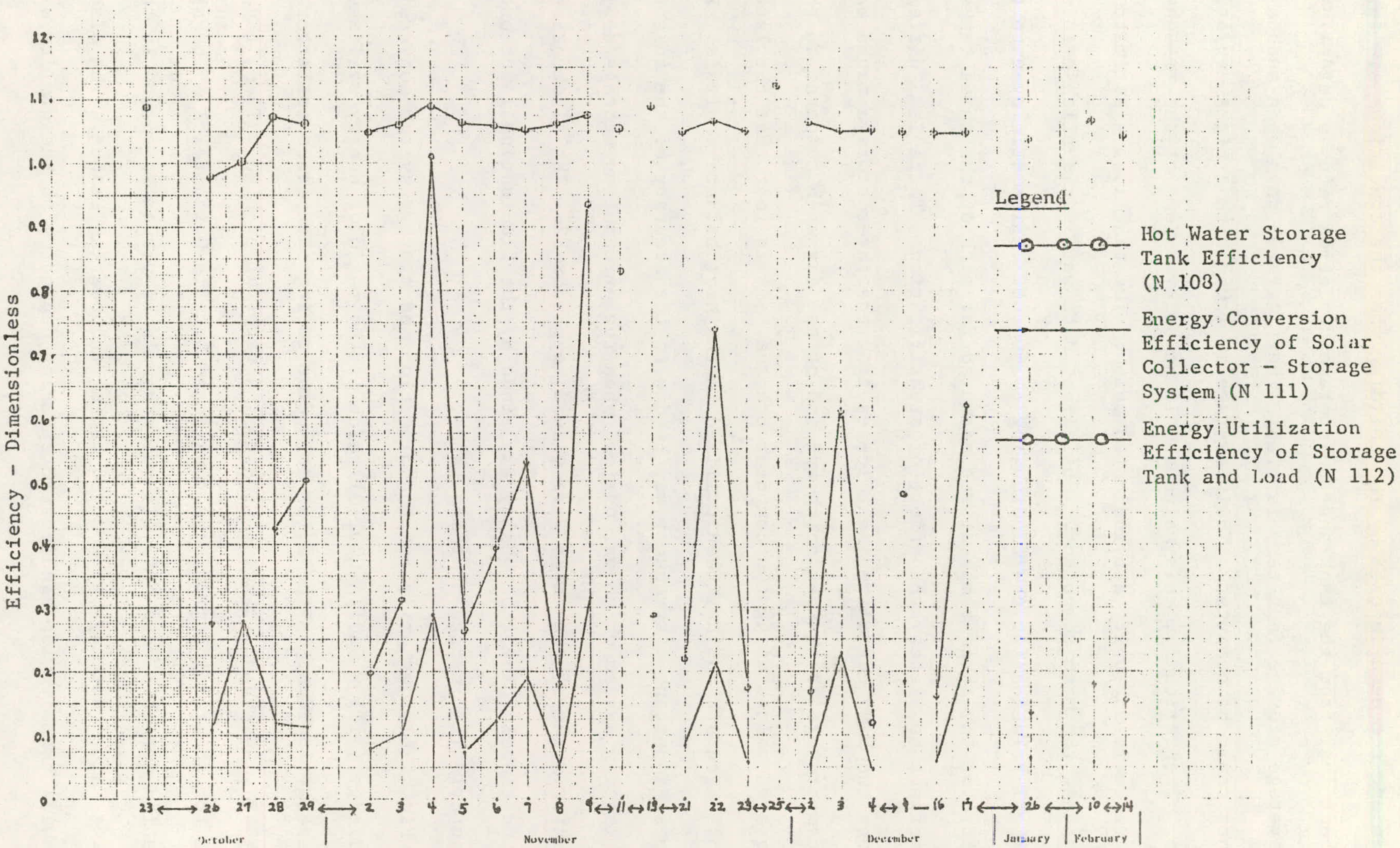

Figure C-6. Characteristics of Conversion Storage and Utilization Efficiency of Solar Collector - Storage System (Towns School 76-77 Winter) system and the need imposed by the building when the conditions are favorable, the heat leak from the tank and the storage/depletion rate as determined by the average storage tank temperatures. There were 33 days when such a heat balance could be computed. Their average is 1.053 with a sigma deviation of 0.056. Theoretically, this value should be unity. Some of the reasons that this value is not unity are indicated below: The tank losses estimate represents the mean component. Sufficient data were not available to establish empirical relation for the fluctuating component. Arithmetic average temperature of the three temperatures measured for each of the three tanks does not reflect completely the effect of stratification. There is a difference between the hand calculated heat losses from the three storage tanks based on the temperature at the beginning and end of the day when compared to the time integrated values using the computer program. It is felt that the latter value is more accurate and has been utilized in the heat balance analysis. Perhaps the most important discrepancy may be due to the accuracy of the snesors and data logging system which was noticed when the printout on storage/depletion characteristics of the tanks were viewed, Appendix E2. The fluctuations noticed therein cannot be wholly explained by the fluctuating input-output characteristics imposed on these tanks.

Fig. C-6 shows daily energy collection and storage system conversion efficiency (N111 = $Q201/A_c Q001$-0) which is the ratio of energy utilized to the energy incident on the solar collector during the period collector operated. Excluding three days which indicate rather high values, the average value for the remaining 30 days considered here is 0.15 or 15%. The sigma deviation for this data is 0.115 which should be viewed as spread in the average value that may be expected during the hearing season. The distribution will exhibit wide band characteristics depending on the quality of sunshine the temperature level in the tanks and the demand imposed by the School. It should be remembered that after accounting for the days when no data was collected, only 30 days out of 80 days had significant data. This value would be essentially zero for the other 50 days.

Also shown in Fig. C-6 is the utilization efficiency of the storage tanks. It is defined as the ratio of the energy utilized to the energy collected in the collector array. Since the energy utilization is a function of demand, the energy collected is primarily a function of the clear days and the storage tank is expected to act as a heat accumulator. It is expected that this ratio will take any value from zero to a very high value. In Fig. C-6 the value is computed only for the daytime period. The tabulated data as well as this plot does not demonstrate the possibility of large values to exist even on cloudy days.

4b. Hot Water Heating System

Since the Towns School is occupied only between 8:00 AM and 5:00 PM on weekdays, it is natural to expect large demands during this period. Since water being used must be potable, an indirect heat exchanger preheats the incoming water as much as possible with solar heat energy contained in the storage tanks. From the preheat tank, the water flows to another small insulated storage tank where a natural gas fired heater brings it up to the required temperature. It is also stored in this small insulated storage tank until it is utilized. Table C-III contains the frequency analysis of natural gas consumption and hot water load. On weekdays, barring any occasional errors in manual recording of the gas meter, the energy consumption varies from a high of 2.6 million Btu per day to 0.11 million Btu per day. There are 44 days of data for freqeuency analysis. The range of level chosen for the frequency analysis is from between 0.9 to 1.7 x 10^6 Btu per day. The range for hot water load is from 0.6 to 1.4 x 10^6 Btu per day which is approximately 70% of the energy consumption. It is surprising that these two quantities do not show the expected central tendencies. On the other hand, they are evenly distributed.

Fig. C-7 shows the graphical plots of the tabulated data on natural gas input and load characteristics of the hot water system contained in Table C-II. It can be seen that the amount of solar augmentation is marginal when compared to the demand or the energy consumption.

4c. <u>Space Heating System</u>

The design specification of the solar system of the Towns School states that when any of the three tanks contain water at a temperature in excess of 105°F, the building will be supplied with only solar energy. At other times, the natural gas fired boilers will be used. The School is also equiped with nighttime and weekend thermostat setback. Hence, the frequency analysis and the graphical plot in Fig. C-8 are restricted to weekdays only. Table C-III contains frequency analysis dipicting the amount of natural gas utilization, the extent of solar augmentation and the demand imposed by the building. The results contained in the table are for 88 days of which there are 60 weekdays. The space heating demands have been divided into increments of million Btu in the range 1 to 9 million Btu. The frequency distribution demonstrates that the majority of the days correspond to moderately severe winter days. Except for the unusual cold spell, there would have been more days representing milder days.

The natural gas consumption data has been divided into increments of 2 million Btu in the range 2 to 14 million Btu. There are 26 days included in this group. They represent days in which the entire space heating load is supplied by the boiler and those days during which the boiler supplied the load during morning hours until the time solar-storage system had

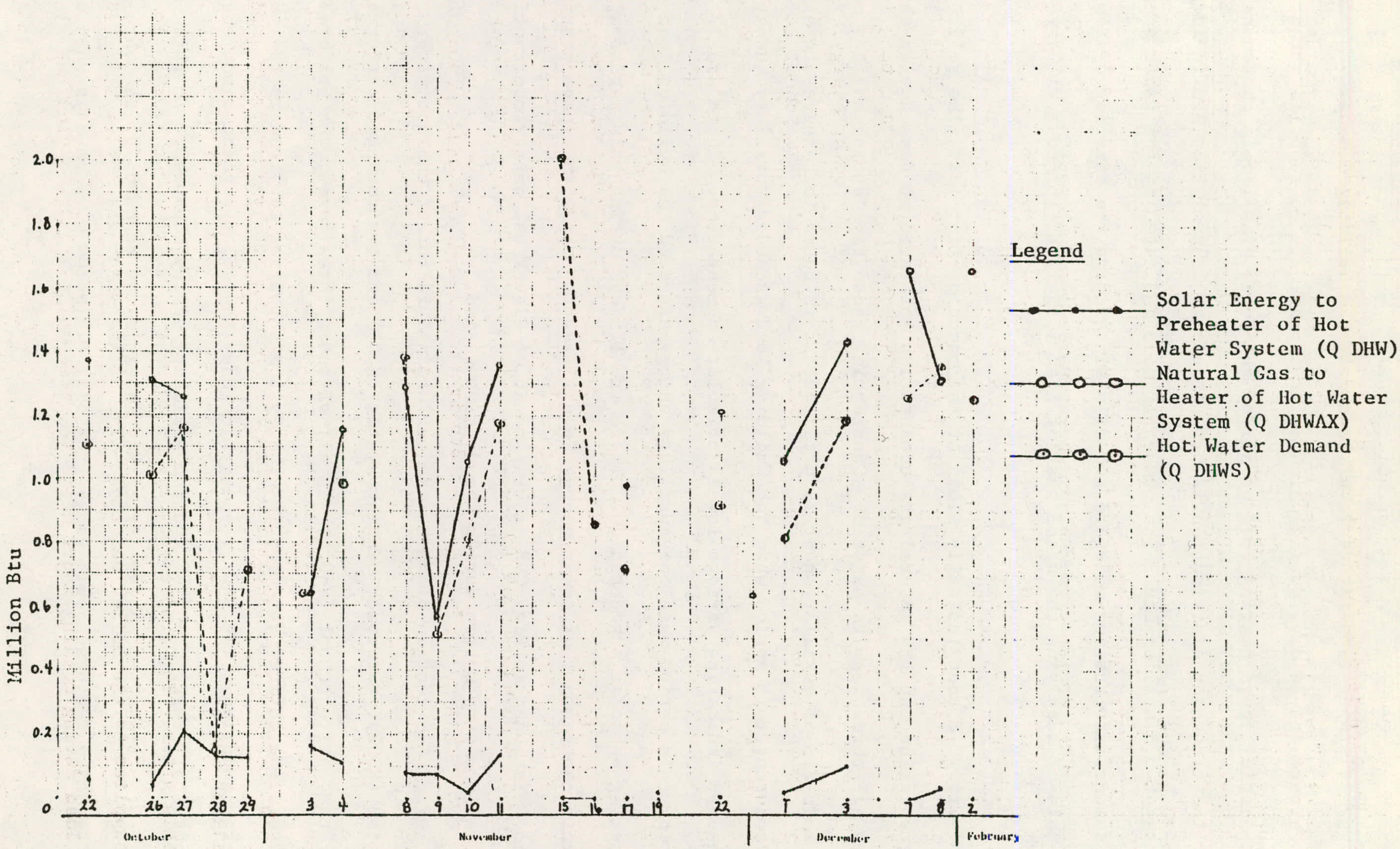

Figure C-7. Solar Augmentation, Natural Gas Input and Load Characteristics of Hot Water System (Towns School) (76-77 Winter) energy at proper temperature level to supply the building demand.

There are 24 days during which solar-storage system supplied either the partial space heating load or all of the load. The levels chosen here for the frequency distribution is between one to four million Btu in increments of 0.5 million Btu. The number of days indicated in the table seem to demonstrate that on moderate and mild winter days the existing system is capable of supplying the space heating load with little or no auxiliary natural gas.

Fig. C-8 contains daily plots of the space heating load, the solar augmentation and the natural gas consumption for selected days during which time all three results existed. Considering those days during which a million or more Btu of auxiliary heat is utilized, it is found that there are six days during this period when the building load exceeded auxiliary energy consumed indicating various levels of solar augmentation. There are 17 days during this period when the auxiliary energy exceeded the building load indicating no solar augmentation. There are 13 days during this period a significant amount of solar energy is utilized to supply the space heating load. Included in Fig. C-8 is the amount of electrical energy consumption in various pump motors during the daytime period.

Fig. C-9 contain plots of the performance factor of the hot water system (N302), the space heating system (N408) and the combined performance for the entire school (N602). In all of these three cases, the performance factors are defined as output of the system supplying the load to the total energy supplied. The supply energy includes the solar augmentation, the electrical energy supplied and the auxiliary energy consumed. In this analysis, since the boiler efficiency is estimated to be 0.75, the three performance factors should range from slightly below 0.75 on days when only

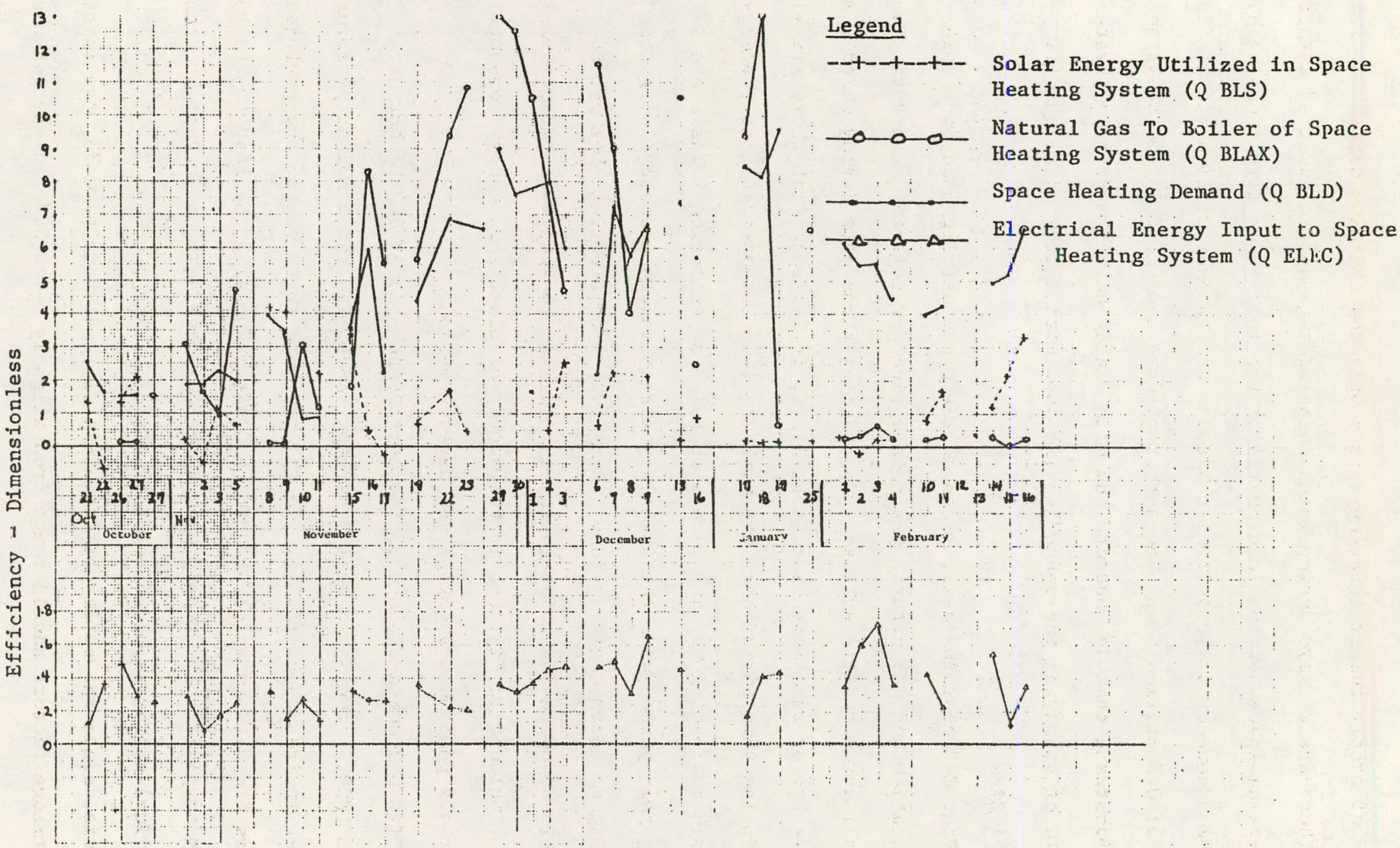

Figure C-8. Solar Augmentation, Natural Gas Input, Electrical Energy Usage and Load Characteristics of Space Heating System (Towns School 76-77 Winter)

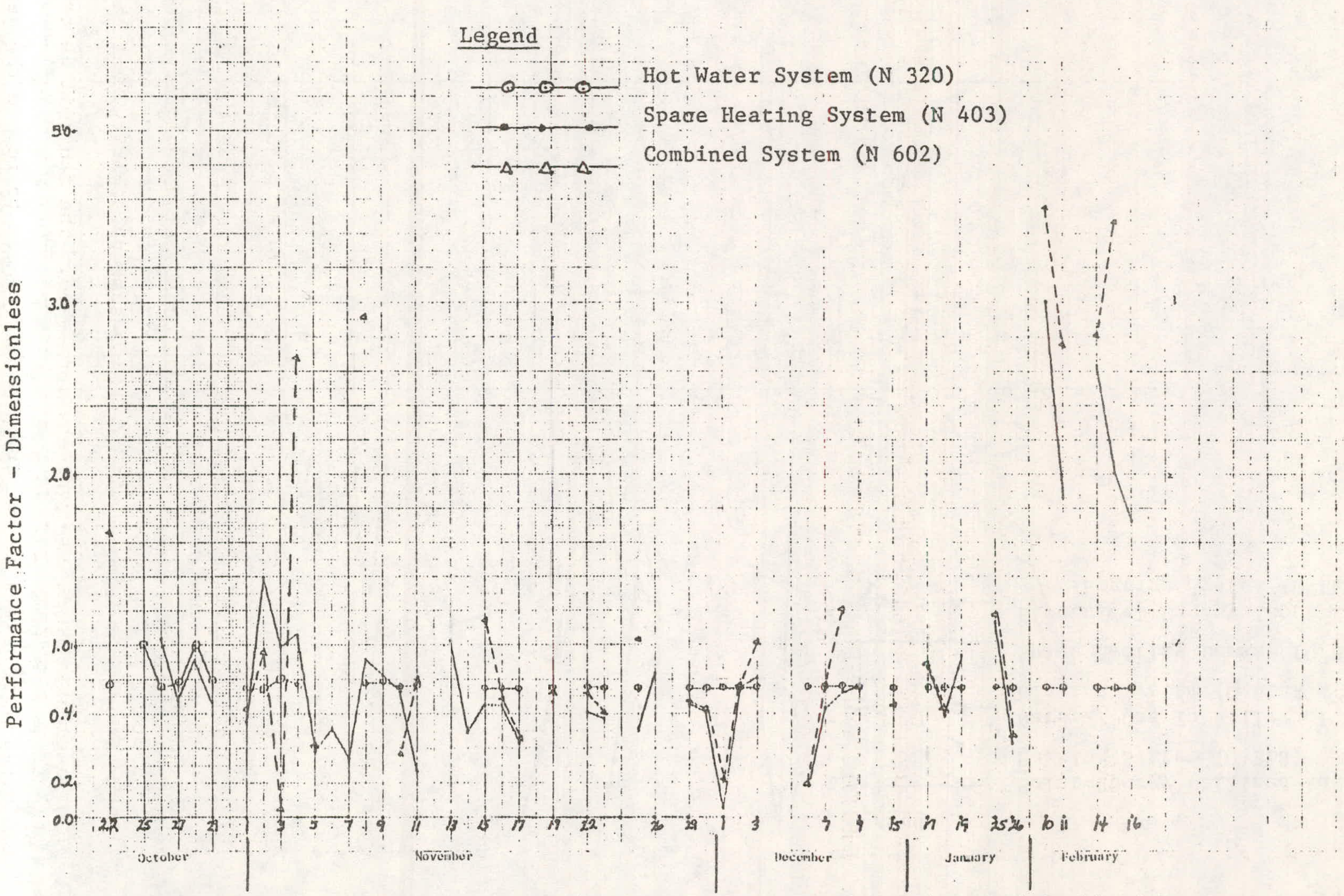

Figure C-9. Performance Factors - Hot Water System, Space Heating System and Combined System the natural gas and the electricity are used to supply the load to a value slightly less than unity when only solar augmentation and the electricity are used. Some of the data points shown in the figure exceed either limit. Possible reasons for this deviation have been given in Section 3.

4d. Overall Evaluation of the System

Fig. C-10 dipicts the daily average value of the three zone temperatures between 8:00 AM and 5:00 PM and the average value for all three zones, generally between 6:00 AM and 6:00 PM. The average of all the three zones ($\overline{TZ}$) is slightly less than one third the sum of the three individual zones indicating the effect of nighttime setback on the value during early morning and late evening hours. The weekend setback of the thermostat to about 65°F is clearly evident in this figure. North zone temperatures (TZ3) are several degrees warmer than the central zone temperatures (TZ2) which is slightly above the south zone temperatures (TZ1). It is possible that the southside being exposed to sun may have contributed to this departure. These temperatures seem to increase as the season advances to coldest part of the winter. During two weeks in January 1977, when Atlanta and the eastern United States experienced the coldest spell, the average school temperatures seem to range from 78°F in the south zone to 84°F in the north zone which is almost 15°F departure from the 65°F recommended by President Carter because of the natural gas shortage. Perhaps the reason for this preferential high temperature may be due to the predominant make of one group of the student body who are traditionally acclimatized to warmer temperatures. Had the school been operated close to 65°F, the natural gas consumption could have been significantly reduced and there would have been some possibility that the hours of solar augmentation could have been increased. The fan coil units would have exhibited more favorable temperature differences to remove the heat from the

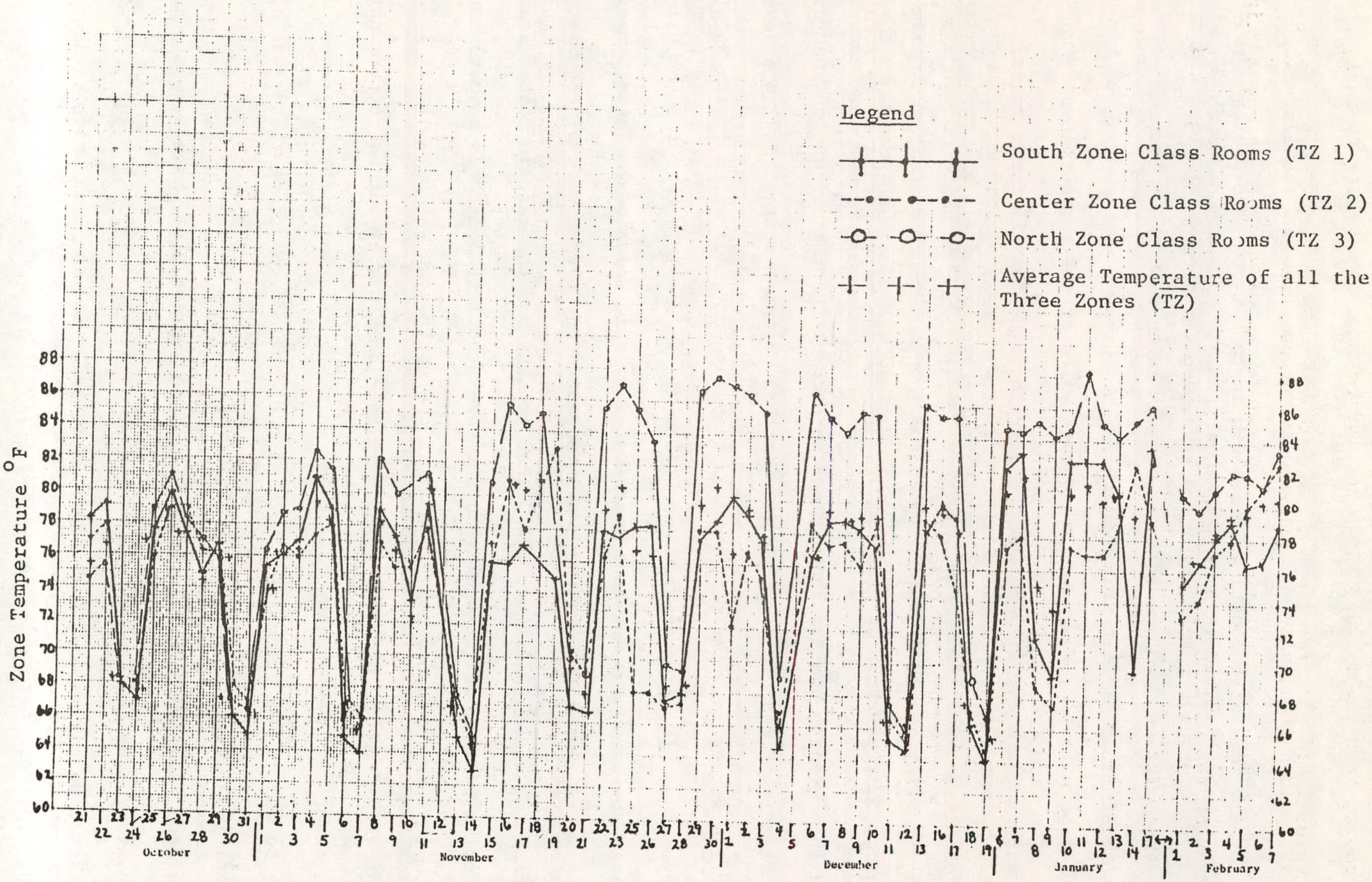

Figure C-10. Average Temperatures of Interior Zones (Towns School 76-77 Winter) water coming from the storage tanks and reduce this temperature to much lower values. If the preference of the student body and its faculty is to have warmer summer temperatures than the customary preference for the cooling period, than the cooling load will be reduced to an extent thus favoring better augmentation from the solar energy operated absorption system.

APPENDIX D

DAILY HEAT BALANCE ANALYSIS AND PERFORMANCE - COOLING

G.A. Towns Elementary School

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APPENDIX D

Daily Heat Balance, Balance Analysis, and Performance - Cooling

1. General Information

George A. Towns Elementary School Solar System was operated in the cooling mode in April 1976 and May 1976. During this period the system was operated to check-out the various options that are available in the system. These tests were made by setting various control modes manually and running the system for short intervals of time until the desired target was reached. They generally referred to checks made on the hydronic and control systems. From May 28, 1976, through July 27, 1976, the solar system was shut down for control valve changes and relocation of the fill pump P-1. After July 28, 1976 the collector system was operated to store solar energy in tanks B and C for the purpose of operating the system under the cooling mode. The solar system was operated automatically in the cooling mode from August 3, 1976, to October 20, 1976. At the end of this period the change over to the heating mode occured. This report contains the daily analysis of data collected during the cooling mode. This experimental data is presented in Appendix E (Volume 2)

The automated data acquisition system samples all temperature sensors and flow meters every and 30 seconds and prints out the average signal every fifteen minutes. The design of the data acquisition system incorporates the capability for gross heat balance analysis and description of adequate performance characteristics. Recently, the National Bureau of Standards report "NBSIR 76-1137-Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program "by E. Streed et. al. describes a consistant method for data reduction and recommends the use of terminology in reporting the results. A review of this N.B.S. report implies the ultimate potential that exists, if all possible data were recorded with laboratory precision. It would permit quasi steady state performances as well as time average performance calculations to be made. Their relative variations describe the dynamic behavior of the system under varying operating conditions. The number of sensors utilized in the George A. Towns School Solar System are minimal, and hence, only limited but still very important results can be avaluated and expressed in functional form.

Figure D1 represents the energy flow diagram for Georgia A. Towns Elementary School Solar System using the format of N.B.S. report. The Nomenclature for Figure D-1 shows the meaning of the suggested N.B.S. symbols and their equivalence as used in the earlier reports of Georgia Tech and Westinghouse Electric Corporation. As per design, during the cooling mode the storage tank A is used to store chilled water. Hence, the quantities related to heat flow, storage and losses are illustrated by 700 series numbers which is not recognized in N.B.S. report. Their significance is similar to the 200 series numbers shown around the storage tanks B and C. It should be noted that the heat gain into the storage tank (Q704) is a thermodynamic loss. In analyzing effectiveness of the storage tanks B and C it is necessary to know exactly when they are cascaded.

A careful review of the Figure D1 and the associate nomenclature lends itself to the following conclusions.

a) Electrical input to the entire solar system is measured by a single watt hour meter. It is recorded mannually twice a day and not necessarily at the same time of the day. The difference between the two successive readings represents the difference of two large numbers. This aspect, together with the occasional errors in the recording themselves does not lend itself to the fine analysis portrayed in the N.B.S. report.

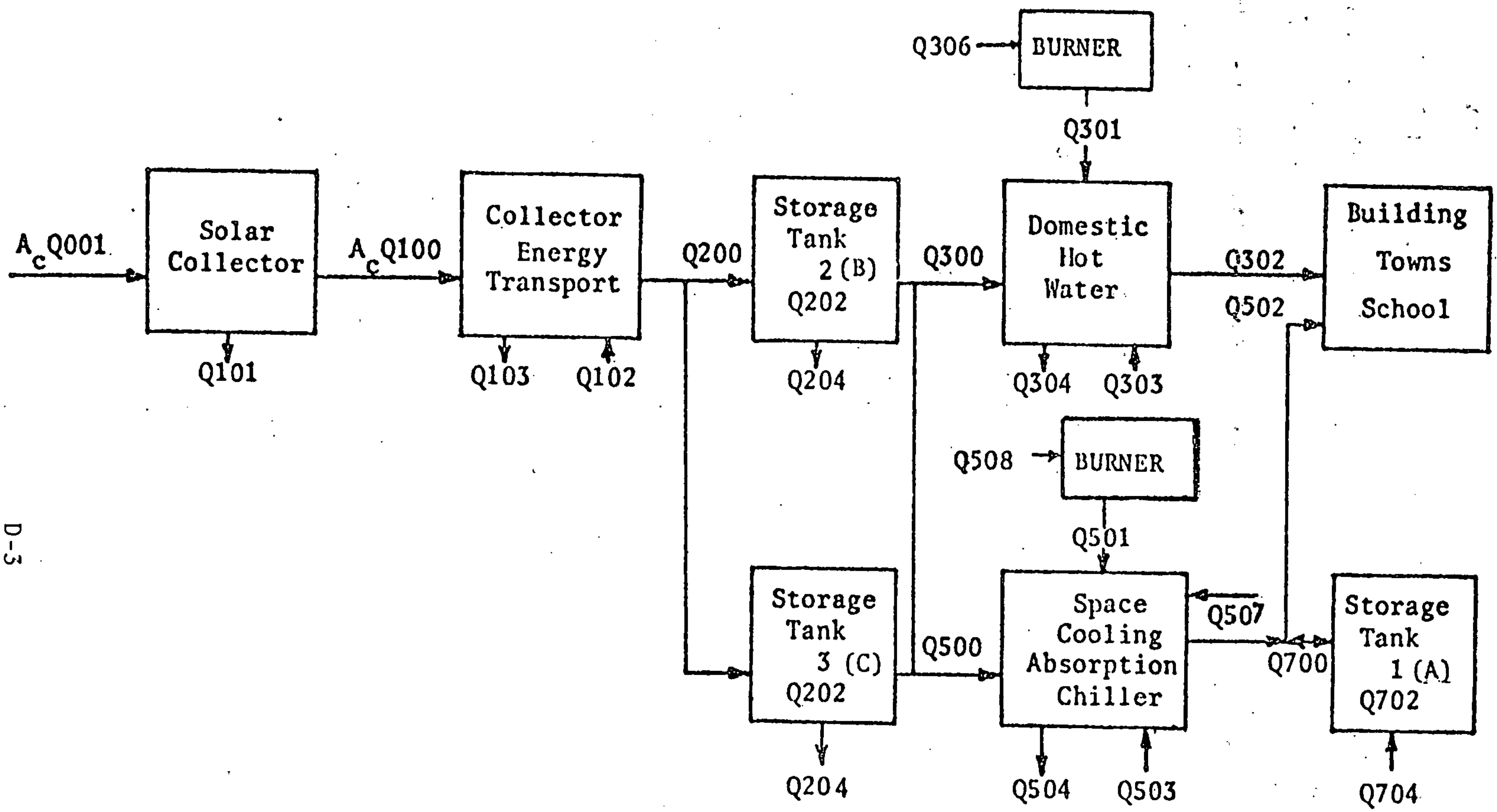

Figure D1 Energy Flow Diagram - G. A. Towns Elementary School Solar Cooling and Domestic Hot Water System

Nomenclature for Figure D1

NBSIR[2] Symbol	G.T. - W Symbol	
Q 001	HTTWR	Average Incident Solar Energy[1] per unit area
Q 100		Solar Energy Collected per unit area
Q 101		Collector Heat Loss
Q 102		Electrical Input into Solar Collector System
Q 200	Q COLL	Solar Energy Collected = Solar Energy to Storage = A_cQ100
Q 201		Q 300 + Q 500, Energy From storage to DHW and Abs. Chiller
Q 202		Q 200 - Q 201 - Q 204, Solar Energy Increase in Hot Tanks
Q 203		Same as Q 201
Q 204		Storage Tank Heat Loss
Q 300	QDHW	Solar Energy Utilized by Domestic Hot Water Preheater
Q 301		η_b x Q 306, η_b - Efficiency of Burner
Q 302		Hot Water Load Delivered to Building
Q 306	Q DHWAX	Auxiliary Gas Energy to DHW
Q 307		Q 300 _ Q 303 + Q 306
Q 500		Solar Energy Utilized by Absorption Chiller
Q 501		η_b x Q 508, η_b - Efficiency of Boiler

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[1]Units of Q are Btu for the period except when indicated T are ^oF and N are dimensionless.

[2]NBSIR 76-1137 - "Thermal Data Requirements and Performance Evaluation Procedure for the National Solar Heating and Cooling Demonstration Program" by E. Streed, M. McCabe, D. Waksman, J. Hebrank, and T. Richtmyer.

[3]Part of the collector bank is augmented by reflector. This has been prorated by using in part Liu and Jordan Method.

NBSIR Symbol	G.T. - W Symbol	
Q 502	QBLDG	Space Cooling Load as seen by the Chiller
Q 503		Electrical Input to Absorption Chiller[4]
Q 504	Q COND	Heat Rejection from Absorption Chiller to Cooling Tower, Condenser Load
Q 506	Q GEN	Thermal Input to Generator of Absorption Chiller,
Q 507	Q EVAP	Absorption Chiller Load
Q 508	Q GENAX	Auxiliary Gas Energy to Absorption Chiller
Q 515		Total Energy Consumed
Q 600		Q 301 + Q 501
Q 601	Q ELEC	Total Electrical Energy Consumed Q 102 + Q 303 + Q 503
Q 602		Total Energy Delivered to the Building Q 302 + Q 502
Q 700		Energy Content of Chilled Water Removed from Storage
Q 702		Space Cooling Load Supplied from Whilled Water Storage
Q 704		Heat Loss from Storage Tank
N 100		Daily Collector Efficiency Q 100/ Q 001 = Q 200/ A_cQ 001
N 101		Instantaneous Collector Efficiency, Graphical Plots
N 108		Storage Tank Efficiency
N 111		Energy Collection and Storage System Conversion Efficiency
N 112		Utilization Efficiency of Storage Tank

[4] See Q 601 Electrical Input into Solar Packaged is Manually Logged.

NBSIR[2] Symbol	G.T. - W Symbol	
N 113	TMI	Average Ambient Out Door Temp
N 114	WS	Average Wind Speed
N 115	WD	Average Wind Direction
N 500		Solar Fraction of Total Energy Utilized for Cooling Load
N 501		Solar Fraction of Total Energy Utilized for Cooling Load
N 503	COP	Absorption Chiller Coefficient of Performance
N 505	TZ	Average Building Dry Bulb Temperature
	TEAV	Average Cavity Temperature
TD 100	TDI	Collector Temperature Rise
TD 101		Not Measured = TD 100
T 100 + TD 100	TI	Collector Outlet Temperature
T 200	TA, TB, TC	Average Tank Temperature of Three Storage Tanks
TD 301	TD 6	Temperature Rise of Hot Water Flowing in DHW - Preheat Exchanger
T 300 + TD 301	T6	Temperature leaving D H W Preheat Exchanger
TD 302		Temperature Rise of Water in Main DHW Heater.
TD 400		T 200 - T 400
TD 402	TD3	Temperature drop of Hot Water Flowing in Generator of Absorption Chiller
T 400 + TD 400 or TD 401	T3	Temperature of Hot Water Entering Generator

[5]Here, the heat leaks from the ground to the tank destroying the heat content of chilled water. Hence, it is termed as loss.

NBSIR Symbol	G.T. - W Symbol	
TD 500	TD5	Temperature drop of Chilled Water Flowing in Evaporator of Absorption Chiller
T 500 + TD 500	T5	Temperature of Chilled Water Leaving Evaporator
TD 501	TD4	Temperature Rise of Cooling Water Through Absorption Chiller
T 501 + TD 501	T4	Temperature of Condenser Water Entering Absorption Chiller
TD 600	TD2	Temperature Rise of Chilled Water Flowing Through Building
T 600 + TD 600	T2	Temperature of Chilled Water Entering Building
		Duration of time evaporator/building pum operated
	TNGC	Average tons of cooling generated during the period chiller operated (tons)
	TNSB	Average tons of cooling supplied during the period building operated (tons)

b) Since the temperature difference across the collector banks is measured near the roof top, the solar energy collected (A_cQ100) is a measured quantity. The piping losses (Q103) to (and from) the storage tanks will be assumed zero. The electrical input (Q102) to the solar collector loop is small compared to the heat energy transported. This is a standard assumption in the analysis of such thermal systems. Thus, within the accuracy of the heat balance analysis, it is appropriate to assume A_cQ100 = Q200.

c) There are three pricision RTD's in each of the storage tanks which are used to estimate the mean temperature of the water in the tanks. During stagnant conditions considerable stratification due to the thermosyphonic currents have been noticed. However, when the tank is used the thermal mixing caused by in flows and out flows at one or both ends will reduce the stratification effects to a varying degree. Based on the observed results it has been difficult to establish a method to weigh the three temperatures to truly reflect the average tank temperature at all times. Hence, the tank losses (Q204) have been estimated. (See section on tank losses) The heat in flow (Q200) and the out flow Q203 which in this case is equal to Q300 + Q500 during Summer and Q300 + Q400 during Winter, are monitored and their difference will be assumed to be equal to the heat losses (Q204).

d) During daytime hours when the system is operating in the cooling mode the domestic hot water is not preheated by the stored solar energy. This is due to lack of proper suction head on DHW pump (P-3) when either the chiller pump (P-4) or the building pump (P-7) are operating. Hence, when the solar energy to the chiller (Q500) or the building load (Q502) exists the preheating of domestic hot water (Q300) is zero (i.e. Q300 = 0 when Q500 or Q502 is positive).

e) The gas meters supplying natural gas to the domestic hot water (Q301) and to the absorption chiller (Q501) are read manually at the same time as the kwhr meter is read. Hence, as explained earlier, even the daily energy analysis of gas and electricity consumption is subject to a large percentage of error.

f) Detailed examination of computer output and the manual logging of the boiler gas meter readings revealed that there were several days during which the chiller operated using only natural gas. For such days the ratio of hot water input to the generator (QGEN, Q501) and the energy input to the boiler (QGENAX, Q508) for the same period represents the thermal efficiency of the boiler. On September 14, these values were 0.77 and 0.74 respectively. An average value of n_B = 0.75 for the thermal efficiency of the boiler has been used. Because of the lack of similar data for DHW heater its thermal efficiency has also been assumed to be 0.75.

2. Tank Losses

2(a) Concept

During summer months Tank A contains chilled water. Since its temperature is lower than the ambient ground temperature heat leaks into the tank raising the temperature of the water contained in this tank. Since such a heat gain destroys the cooling potential of the stored chilled water it has been termed a heat loss. Tanks B and C contain hot water at temperatures above the ambient ground temperature and, hence, the heat lost is from the tanks to the ground. During overnight, if the water from these tanks are not utilized the measured data will indicate rise in the mean temperature of Tank A and drop in the mean temperature of Tanks B and C.

The computer printout shows the water temperature in each 15,000 gallon tank at three locations on a vertical line near the center of the tank. These locations are 36, 60 and 114 inches from the top of the tank. Since the data system is shut down during the night, an examination of the data between the last printout of a given day and the first printout of the following day can be used as guide to determine whether there was overnight usage. A no flow status of the various flow meters communicating with the storage tanks at the end of a day and the start of the following day is a further check on no overnight usage. The temperature trends under such conditions are described below.

2(b) Procedure

The data of August and September were used to determine tank losses. Detailed examination of computer results permitted selection of 14 days in August and 13 days in September for the tank losse study. Since it was difficult to describe the temperature pattern caused by the thermosyphonic action in such huge tanks with just three temperature measurements it was descided to evaluate an arithmetic average. For each of the days selected, the mean tank temperatures and the temperature change were determined. Using these data and 15000 gals of water in each tank the heat loss per hour from each of the three tanks was determined.

2(c) Discussion

Figure D2 represents the plot of mean tank temperatures and heat loss rates. It shows the scatter in evaluated data and the least square straight lines through them. Also shown in the figure are the equations for these three lines. Since the crossover points are close to each other and there is considerable scatter in the evaluated data, the crossover point of 108°F has been assumed but respective slopes have been preserved. This ambient temperature of 108°F represents a pseudo ground temperature to which heat is exchanged. The arrangement of the three tanks is such that the tank A (chilled water tank) experiences undisturbed ground temperature on one side and the proximity of hot water tank B on the other side. Such a proximity effect increases heat leak into the tank A when compared to the the case of the isolated tank. It should be remembered that such a proximity effect also increases the heat loss of the tank B since a portion of this tank sees temperature lower than the mean pseudo ambient temperature on the side of tank A and higher values on the side of tank C. Furthermore, the cost of the heat leak into the chilled water tank A is very much higher than heat leaks from the other two tanks since it represents either the natural gas expended or the solar energy collected to create the chilled water. This heat leak should be divided by the coefficient of performance of the chiller which is applicable for the period for a true comparison.

Monthly Letter Progress Report May-July, 1976, prepared for ERDA contains another method to determine the tank losses. It was made possible since the computer printout for overnight was available. In that analysis the pseudo ground temperature was 94°F. Since overnight data was not normally collected,

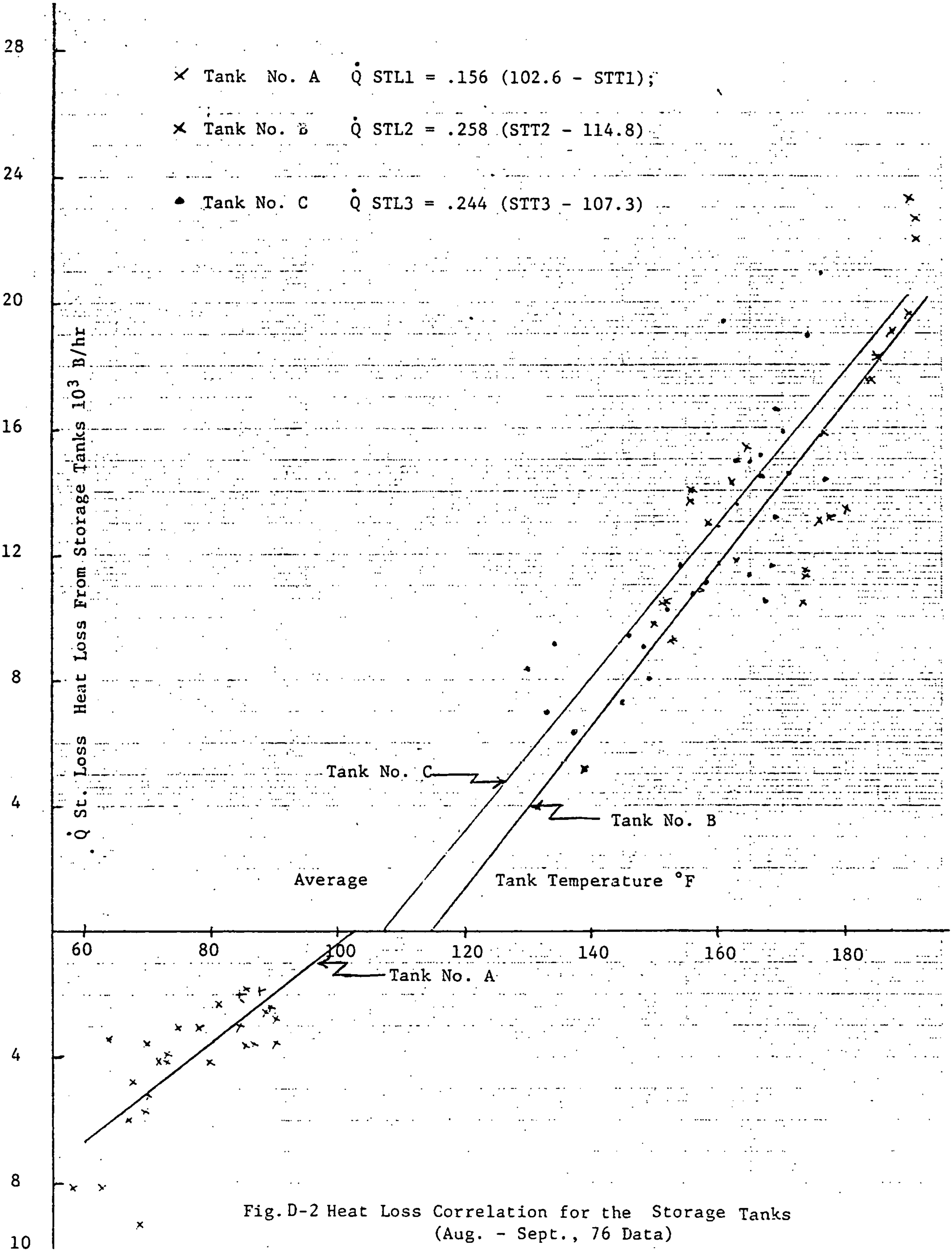


Fig. D-2 Heat Loss Correlation for the Storage Tanks
(Aug. - Sept., 76 Data)

this procedure was abandoned. If this data has been available statistical analysis of tank losses would be possible. It should be noted that the heat flow into the ground is a complex heat conduction problem since it involves the thermal diffusivity effects and heat storage capacity.

3(d) Empirical Tank Loss Equation

Demonstration of the daily heat balance of the storage tanks involves an estimation of the heat losses from the tanks. The limited data tranduced in the G. A. Towns School project does not permit direct evaluation of such losses. However the empirical heat loss equations for the three tanks are given in Table D-I below:

Table D-I Empirical Equations for Determine Tank Heat Losses and Typical Heat Loss Rates at Operative Temperature Range.

Data Base	Tank A Chilled water	Tank B Hot water	Tank C Hot water
Aug. 1,76 to Sept. 20,76 Selected Days	Q STL 1 = 156[102.6-STT1]	Q STL 2 = 258[STT2-114.8]	Q STL 3 = 244[STT3-107.3]
Operative Temp. Range °F	60-50	180-195	180-195
Tank Heat Loss, B/hr	6650-8210	16820-20690	17740-21400
Total Tank Heat Loss, B/hr	6650-8210	34560-42090	

3. Analysis of Data

Table D-II contains calculated results for the month of August and September when the system is operating under cooling mode. The units on heat quantities are in million BTU. There are only 20 days during the two month period for which more complete data is available. The evaluation of data corresponds to the method outlined in NBSIR 76-1137 report. Since the G. A. Towns School installation was already operational when this report was published there are some differences. The energy flow diagram shown in Figure D-1 should be used as a guide to follow the analysis and discussion. Each column in the table has been identified. All of the symbols have been described in Section 1 under Nomenclature for Figure D-1. The analysis, a sample calculations for August 5 and the discussion of results are presented for each of these columns.

Sample Calculation for Table D-II

1. $\Delta\tau$ COLL. Duration the flow meter F1 operated continuously enabling collection of solar energy.
   Aug. 5; pump operated for 6 hours between 12:00 and 18:00 hours (Output of computer program)
   Even on clear sunny days when the number of sunshine hours is nearly 14 hours the maximum period of heat collection is only 7.0 to 7.5 hours. The reason for this is unfavorable angle of incidence during early morning and late evening hours and higher water temperatures in the tank during summer months.

2. HTTWR = A_cQ001 Total insolation falling on the collector banks.
   Aug. 5; 13.2 x 10^6 Btu (output of computer program)
   In G. A. Towns School part of the collections are augmented by reflector. The splitting of total insolation into direct and diffuse components in order to estimate the extent of solar energy augmented by the reflector is according to Liu and Jordan. Rest are measured data.

3. Q COLL = A_c Q100 $\simeq$ Q200 Energy collected by the flowing water in the collector
   Aug. 5; 2.983 x 10^6 Btu. (output of computer program)
   Here temperature rise across the collector bank is measured at the roof top above the equipment room. The temperature drop between outlet of the collector and inlet to the storage tank and from the

TABLE D-II Performance Analysis of Solar Cooling System of G. A. Towns Elementary School - August, September 1976

	1	2	3	4	5	6	7
	$\Delta\tau$COLL	HTTWR	QCOLL	η_{COLL}	QLOSS	QDHW	QDHWAX
		A_cQ001	A_cQ100	N100	Q101	Q300	Q306
Aug. 5	6	13.20	2.983	.225	10.217	.095	.441
Aug. 6	6.5	14.73	3.445	.234	11.285	-	.265
Aug. 10	5.5	10.84	0.812	.075	10.028	-	.200
Aug. 13	4.5	8.70	1.802	.207	6.898	-	.115
Aug. 16	3.0	5.03	0.926	.184	4.104	-	.209
Aug. 17	6.0	13.31	2.400	.179	10.91	-	.336
Aug. 19	6.0	15.47	3.670	.237	11.80	.029	.284
Aug. 23	4.2	9.75	1.950	.200	7.8	.104	.351
Aug. 24	-	-	-	-	-	.286	.212
Aug. 27	-	-	-	-	-	-	.367
Aug. 30	-	-	-	-	-	-	.741
Aug. 31	-	-	-	-	-	-	.967
Sept. 1	-	-	-	-	-	-	.940
Sept. 2	2.5	4.44	1.06	.239	3.380	-	.918
Sept. 3	2.8	5.23	1.51	.289	3.720	-	.973
Sept. 7	-	-	-	-	-	-	.658
Sept. 8	5.8	12.21	3.74	.306	8.47	-	.940
Sept. 9	5.0	10.55	2.81	.267	7.74	-	.940
Sept. 10	7.5	18.13	3.35	.185	14.78	-	1.021
Sept. 13	7.0	12.96	1.41	.108	11.55	-	1.382
Sept. 14	-	-	-	-	-	-	1.088
Sept. 15	4.0	9.83	1.64	.167	8.19	-	.992
Sept. 17	7.0	15.34	2.47	.161	12.87	-	.886
Sept. 20	6.8	10.84	0.90	.083	9.94	-	.974
Sept. 24	7.5	16.10	3.01	.187	13.09	-	.633
Sept. 28	6.2	10.47	0.79	.076	9.68	-	1.509
Sept. 29	4.0	6.96	0.65	.093	6.31	-	.998
Sept. 30	-	-	-	-	-	-	1.342

Table D-II continued:

	8	9	10	11	12	13	14	15	16
	Tank A		Tank B		Tank C				
	TA		TB		TC		TZ	TMI	TCAV
	T200	Q204	T200	Q204	T200	Q204	N505	N113	
Aug. 5	85	.0215	177	.1068	132	.0351	78.9	80.6	84.2
Aug. 6	86	.0221	176	.1140	131	.0365	77.4	82.2	85.2
Aug. 10	88	.0171	179	.1007	176	.0913	80.0	87.3	89.5
Aug. 13	71	.0261	175	.0778	175	.0736	80.8	90.2	92.7
Aug. 16	65	.0201	174	.0511	166	.0425	80.0	83.2	86.0
Aug. 17	67	.0384	175	.1037	163	.0805	79.2	81.1	83.6
Aug. 19	64	.0412	182	.1146	173	.0952	78.0	77.6	80.4
Aug. 23	63	.0295	173	.0704	164	.0574	79.9	84.9	87.3
Aug. 24	-	-	-	-	-	-	81.3	86.2	88.1
Aug. 27	-	-	-	-	-	-	82.6	81.7	84.6
Aug. 30	-	-	-	-	-	-	82.6	79.3	82.3
Aug. 31	-	-	-	-	-	-	81.5	77.4	80.3
Sept. 1	-	-	-	-	-	-	81.2	77.8	81.0
Sept. 2	74	.0133	154	.0297	145	.0226	81.1	76.2	79.5
Sept. 3	75	.0142	158	.0361	144	.0246	80.8	74.6	77.7
Sept. 7	-	-	-	-	-	-	78.0	75.4	77.2
Sept. 8	78	.0271	168	.0898	138	.0425	78.5	79.4	81.4
Sept. 9	79	.0226	172	.0826	137	.0354	79.4	81.7	84.0
Sept. 10	80	.0328	174	.1277	136	.0512	78.1	71.5	75.4
Sept. 13	82	.0284	175	.1210	182	.1264	77.5	76.1	77.5
Sept. 14	-	-	-	-	-	-	77.4	65.0	69.5
Sept. 15	83	.0156	172	.0660	175	.0654	76.6	70.0	72.5
Sept. 17	84	.0262	175	.1210	169	.1042	76.8	75.5	77.3
Sept. 20	85	.0244	177	.1211	168	.0996	76.4	78.9	80.3
Sept. 24	87	.0246	181	.1413	170	.1135	77.8	80.5	81.4
Sept. 28	89	.0184	181	.1168	171	.0953	77.6	76.9	79.3
Sept. 29	90	.0112	177	.0712	168	.0586	79.6	75.7	78.3
Sept. 30	-	-	-	-	-	-	77.2	63.2	67.5

Table D-IIcontinued:

	17	18	19	20	21	22	23
	QGEN	QGENAX					
	Q506	Q508	Q500	Q202	N108	N111	N112
Aug. 5	4.85	4.17	1.73	1.111	.952	.131	0.58
Aug. 6	5.89	5.63	1.67	1.622	.956	.114	0.48
Aug. 10	1.95	.064	1.90	-1.282	.764	.175	2.34
Aug. 13	3.02	3.45	0.43	1.216	.916	.050	.24
Aug. 16	2.63	6.90	?	-	-	-	-
Aug. 17	9.98	8.73	3.44	-1.22	.923	.258	1.43
Aug. 19	4.71	1.74	3.41	.052	.943	.220	0.93
Aug. 23	4.13	3.28	1.67	.152	.934	.171	0.86
Aug. 24	4.73	5.12	0.89	-	-	-	-
Aug. 27	4.41	2.24	2.73	-	-	-	-
Aug. 30	10.19	9.00	3.44	-	-	-	-
Aug. 31	8.86	10.87	0.71	-	-	-	-
Sept. 1	8.27	10.49	0.40	-	-	-	-
Sept. 2	9.06	10.28	1.35	- .342	.951	.304	1.27
Sept. 3	9.99	10.29	2.27	- .824	.950	.435	1.51
Sept. 7	6.05	7.90	0.12	-	-	-	-
Sept. 8	8.37	9.40	1.32	2.288	.965	.108	0.35
Sept. 9	7.82	7.22	2.40	.287	.958	.228	0.86
Sept. 10	6.86	6.85	1.72	1.448	.947	.095	0.51
Sept. 13	3.92	2.65	1.93	-.767	.824	.149	1.37
Sept. 14	5.22	7.05	-.07	-	-	-	-
Sept. 15	3.96	4.00	0.96	.552	.920	.097	0.58
Sept. 17	6.81	6.56	1.89	.353	.909	.123	0.77
Sept. 20	8.05	7.83	2.18	-1.50	.755	.201	2.42
Sept. 24	4.11	3.23	1.69	1.066	.915	.105	0.56
Sept. 28	7.02	6.08	2.46	-1.882	.732	.235	3.11
Sept. 29	8.95	9.76	1.63	-1.110	.800	.234	2.51
Sept. 30	6.09	6.36	1.32	-	-	-	-

Table D-II continued:

	24	25	26	27	28	29	30
	QCOND	QENAP	HBL		QELEC		QBLDG
	Q504	Q507		N500	Q601	N501	Q502
Aug. 5	4.34	2.003	.632	.356	.910	.254	1.93
Aug. 6	5.49	2.500	.654	.284	1.133	.198	2.23
Aug. 10	2.13	1.042	.712	.975	.349	.822	1.05
Aug. 13	3.95	2.170	.761	.144	.624	.097	2.10
Aug. 16	1.29	.637	.395	-	.988	-	0.82
Aug. 17	6.25	3.26	.472	.344	1.208	.257	3.08
Aug. 19	5.80	2.95	.757	.724	1.107	.545	1.46
Aug. 23	4.51	4.46	.525	.404	.848	.288	2.32
Aug. 24	3.83	1.62	.603	.188	1.056	.126	1.65
Aug. 27	4.76	2.02	.740	.619	1.182	.444	2.08
Aug. 30	7.06	3.19	.528	.338	1.086	.255	3.23
Aug. 31	6.80	3.02	.572	.080	1.303	.055	3.04
Sept. 1	6.80	2.79	.615	.048	1.176	.033	2.88
Sept. 2	7.08	3.01	.587	.149	1.178	.105	3.14
Sept. 3	7.10	3.10	.542	.228	1.226	.165	3.14
Sept. 7	4.87	2.07	.600	.020	.972	.014	2.19
Sept. 8	6.71	2.94	.593	.158	1.231	.110	3.01
Sept. 9	7.44	3.28	.670	.308	1.322	.220	3.40
Sept. 10	6.30	2.74	.656	.251	1.258	.175	2.81
Sept. 13	3.46	1.50	.638	.492	1.246	.331	1.68
Sept. 14	4.42	1.88	.622	-	1.107	-	1.99
Sept. 15	3.89	1.64	.695	.242	.824	.165	1.75
Sept. 17	5.24	2.12	.587	.278	.962	.201	2.27
Sept. 20	6.86	2.85	.629	.271	1.167	.195	3.04
Sept. 24	3.25	1.38	.592	.411	.700	.301	1.49
Sept. 28	6.38	2.67	.658	.350	1.291	.250	2.84
Sept. 29	6.23	2.63	.538	.182	1.163	.130	2.87
Sept. 30	4.76	1.92	.594	.217	1.043	.151	2.10

Table D-II continued:

	31	32	33	34	35
	COP	ΔτE/β	TNGC	TNSB	NSG
	N503				
Aug. 5	.412	10.0	16.7	16.1	0.964
Aug. 6	.424	9.2	22.6	20.2	0.893
Aug. 10	.534	3.0	28.9	29.2	1.010
Aug. 13	.719	4.5	40.2	38.9	0.968
Aug. 16	.242	3.2	16.6	21.4	1.289
Aug. 17	.327	9.2	29.5	27.9	0.945
Aug. 19	.626	7.2	34.1	16.9	0.496
Aug. 23	1.080	9.8	37.9	19.7	0.520
Aug. 24	.342	9.8	13.8	14.0	1.014
Aug. 27	.458	9.2	18.3	18.8	1.027
Aug. 30	.313	10.0	26.6	26.9	1.011
Aug. 31	.341	9.2	27.4	27.5	1.004
Sept. 1	.337	5.8	26.4	27.2	1.030
Sept. 2	.332	9.2	27.3	28.4	1.040
Sept. 3	.310	9.2	28.1	28.4	1.011
Sept. 7	.342	6.8	25.4	26.8	1.055
Sept. 8	.351	8.8	27.8	28.5	1.025
Sept. 9	.419	9.2	29.7	30.8	1.037
Sept. 10	.399	9.2	24.8	25.5	1.028
Sept. 13	.383	8.5	14.7	16.5	1.122
Sept. 14	.360	9.2	17.0	18.0	1.059
Sept. 15	.414	8.2	16.7	17.8	1.066
Sept. 17	.311	9.5	18.6	19.9	1.070
Sept. 20	.354	10.5	22.6	24.1	1.066
Sept. 24	.336	6.0	19.2	20.7	1.078
Sept. 28	.380	9.2	24.2	25.7	1.062
Sept. 29	.294	9.0	24.3	26.6	1.095
Sept. 30	.315	9.5	16.8	18.4	1.095

Text continued from p. D-10

storage to inlet to the collector is not measured. The losses represented by these temperature drops are negligible Hence, $A_cQ100 = Q200$

4. $\eta_{COLL} = N\ 100 = A_cQ100/A_cQ001$ Efficiency of collector system
Aug 5; $N100 = 2{\cdot}983 \times 10^6/13{\cdot}2 \times 10^6 = 0{\cdot}225$
There were five days when the heat collection exceeded three million Btu. During those days the efficiency of collection varied from 18 to 30 percent.

5. Q LOSS = Q 101 = A_c (Q001 - Q100) Heat loss during collection period.
Aug 5; $Q101 = 13{\cdot}2 \times 10^6 - 2{\cdot}983 \times 10^6 = 10{\cdot}217 \times 10^6$ Btu
Data complements measured efficiency showing large percentage of heat is lost. This value does not include the amount of incident energy that was needed to heat the material of the collector and the fluid contained in the system.

6. QDHW = Q 300 Heat energy added to domestic hot water in the perheat exchanger prior to its flow in the main hot water heater
Aug 5; $0{\cdot}095 \times 10^6$ Btu (output of computer program)
During daytime due to design difficiency explained earlier the preheater has never worked satisfactorily. The manually recorded data showed that the temperature leaving the preheater during the morning hours was high while it fell to a low value by the time evening reading was taken. This demonstrates that solar preheater works during night time only.

7. Q DHWAX = Q306 Heat Equivalent of gas energy expended in the domestic hot water heater
$Q\ 306 = \Delta(\text{Gas Reading})\ 100 \times CVF \left(\frac{\Delta\tau\ \text{comp}}{\Delta\tau\ \text{Read}}\right)$ gas readings are recorded manually twice a day.
Aug 5; CVF = 1029 B/ft^3. (Ref. Section 8, Appendix C)

$$Q306 = 3{\cdot}6 \times 100 \times 1029 \times \frac{12{\cdot}0}{10{\cdot}08} = 0{\cdot}441 \times 10^6 \text{ Btu}$$

The time between the readings 10·08 hrs. The time between the computer data acquisition 12·0 hrs. These figures need to be multiplied by the efficiency of the burner say $\eta_b = 0{\cdot}75$ to obtain Q301, energy added to the domestic hot water.

$$Q301 = 0{\cdot}75 \times 0{\cdot}441 \times 10^6 = 0{\cdot}331 \times 10^6 \text{ Btu}$$

8. $\overline{TA} = T\ \underline{200}$ Average temperature of the chilled water tank A
Aug 5; $\overline{TA} = T200 = 85$ (output of computer program)
This value is a simple average of the three temperatures measured in the central region of the tank. During six day period between Aug 1 to Aug 16, the data shows considerable production of chilled water since the mean temperature of the tank dropped from 88 to 65°F. The computer data for Aug 11 and 12 was missing while on Aug 14 and 15, being weekend the data was not collected. Hence critical analysis of the system performance was not possible for this period.

9. Q204 Heat loss (heat leak into) tank A for the period collector operated

$Q204 = 0{\cdot}000156\ (108 - \overline{TA})\ \Delta\tau\ coll \times 10^6$ Btu
Aug 5; $Q204 = 0{\cdot}000156\ (108 - 85)\ 6.0 = 0.0215 \times 10^6$ Btu
An estimate, see tank losses section.

10. $\overline{TB}$ = T200 Average temperature of the hot water tank B.
Aug 5; $\overline{TB}$ = T200 = 177°F (output of computer program)
Obtained similar to $\overline{TA}$ in item 8.

11. Q204. see item 9.
$Q204 = 0{\cdot}000258\ (\overline{TB} - 108)\ \Delta\tau\ coll \times 10^6$ Btu
Aug 5; $Q204 = 0{\cdot}000258\ (177 - 108)\ 6{\cdot}0 = 0{\cdot}1068 \times 10^6$ Btu

12. $\overline{TC}$ = T200 Average temperature of the hot water tank C.
Aug 5; $\overline{TC}$ = T200 = 132°F (output of computer program)

13. Q204 see item 9
$Q204 = 0{\cdot}000244\ (1\ \overline{TC} - 108)\ \Delta\tau coll \times 10^6$ Btu
Aug 5; $Q204 = .000244\ (132 - 108)\ 6{\cdot}0 = 0{\cdot}0351 \times 10^6$ Btu

14 $\overline{TZ}$ = N505 Average dry bulb temperature of the building.
Aug 5; $\overline{TZ}$ = N505 = 78·9°F (output of computer program)
This is an average of three temperatures measured in the north, middle and south zone of the building.

15 TMI = N113 Average outdoor dry bulb temperature.
Aug 5; TMI = N113 = 80·6°F (output of computer program)
This temperature is measured near the north face of the building under the shade of the overhang.

16. TCAV The outdoor cavity temperature.
Aug 5; TCAV = 84·2°F (output of computer program)
This is the temperature of the humidity meter which in conjunction with the manufacturers calibration curve permits determination of the wet bulb temperature of the outside air. Figure E1

17. Q GEN = Q 506 Hot water input to the generator of the absorption chiller.
Aug 5; Q GEN = Q 506 = $4{\cdot}86 \times 10^6$ Btu (output of computer program)
This value is determined by the flow meter data and the temperature drop of the generator. In order to determine the exact time during which the chiller operated using solar energy it is necessary to examine the temperatures of the tanks B and C. The rate of temperature fall in these tanks larger than that accountable for losses only is indicative of solar energy utilization. See item 19 for another method utilized in determining solar component of energy used to generate chilled water.

18. Q GENAX = Q 508 Heat equivalent of natural gas used during the daytime period computer operated.
$Q\ 508 = \Delta(\text{Gas Reading})\ 100\ CVF\ \dfrac{\Delta\tau\ comp}{\Delta\tau\ Read}$ Gas readings are recorded manually twice a day.
Aug 5; CVF = 1029 B/ft^3 (Ref, Section 8, Appendix C)
$Q508 = 34 \times 100 \times 1029 \times \dfrac{12{\cdot}0}{10{\cdot}08} = 4{\cdot}17 \times 10^6$ Btu
See also item 7. Note that the lowest value of Q 506/Q508 should be the day when only natural gas was used for cooling. September 14

was such a day for which the ratio is 0·74. Here the boiler efficiency of 0·75 has bee used. Note Q 501 = η_B x Q 508. This is the amount of heat added to hot water flowing into the generator of the absorption chiller due to the use of natural gas.
For selected nights in the month of August when no pumps were running it was assumed that all the natural gas consumption in meter No. 2 connected to the boiler is due to pilot light. This amounts to 7530 Btu/hr. Had the gas consumption corresponding to the pilot gas been subtracted Q 508 would decrease. This will change boiler efficiency from 0·74 to 0·75 which is the assumed value in these calculations.

19. Q500 Solar component of energy utilized to operate the absorption chiller.
$Q500 = Q506 - \eta_B\, Q508 = Q506 - Q501$
Aug 5; $Q500 = 4{\cdot}86 \times 10^6 - (0{\cdot}75 \times 4{\cdot}17 \times 10^6) = 1{\cdot}73 \times 10^6$ Btu
The data of gas meter reading for Aug 17 may be in error. Had the boiler efficiency of 0·74 been used or credit to pilot gas been given the value of Q500 for September 14 would have been zero. There are three days when the solar input to absorption chiller exceeded 3·4 million Btu.

20. Q202 Increased in stored energy of the tanks due to operation of the collector and absorption chiller. Obtained by considering the heat balance for the storage tanks during the period system operated.
$Q202 = Q200 - Q500 - \Sigma\, Q204$
Note $Q200 = A_C Q100$ (assumed)
Aug 5; $Q202 = [2{\cdot}983 - 1{\cdot}73 - (0{\cdot}1068 + 0{\cdot}0351)]\, 10^6 = 1{\cdot}111 \times 10^6$ Btu.
On this day there was net inflow of solar energy for the period system operated. Negative sign in this column represents depletion.

21. N108 Efficiency of the storage tank.
$$N108 = \frac{Q201 + Q202}{Q200} = \frac{Q300 + Q500 + Q202}{Q200} \simeq \frac{Q500 + Q202}{Q200}$$
Also $N108 = 1 - \dfrac{\Sigma_{BC}\, Q204}{Q200}$
Note $Q\,200 = A_C\, Q100$
$$N108 = \frac{1{\cdot}73 \times 10^6 + 1{\cdot}111 \times 10^6}{2{\cdot}983 \times 10^6} = 0{\cdot}952$$
As explained earlier Q300 during the daytime hours of operation was assumed zero. Highest value in this column is 0·965. It represents the day when the heat collection was maximum. The lowest value corresponds to the day when the heat collection was lowest. On days when the heat collection is below the losses from the tank this value will be negative.

22. N111 Energy collection storage system efficiency.
$$N111 = \frac{Q\,203}{A_C Q001} = \frac{Q\,500}{A_C Q001}$$
Since $Q203 = Q201 = Q300 + Q500 \simeq Q500$
Note Q300 = 0 which has been explained earlier
Aug 5; $N111 = \dfrac{1{\cdot}73 \times 10^6}{13{\cdot}2 \times 10^6} = 0{\cdot}131$
Low value is indicative of low thermal efficiency of the collector system. For the days when the tanks are depleted due to chiller operation and if there is no appreciable solar radiation this value can be large.

23. N112 Energy collection storage system utilization efficiency.

$$N112 = \frac{Q203}{A_c Q100} = \frac{Q500}{A_c Q100}$$

See item 22. Same comment applies

$$\text{Aug 5; } N112 = \frac{1\cdot 73 \times 10^6}{2\cdot 983 \times 10^6} = 0\cdot 58$$

Numbers greater than unity in this column indicates depletion of storage tank is greater than net energy collected during the period.

24. Q COND = Q504 Heat rejected to the cooling water flowing through the absorber and condenser of the absorption chiller.
Aug 5; Q COND = Q504 = $4\cdot 34 \times 10^6$ Btu. (output of computer program)

25. Q EVAP = Q507 Heat given up by chilled water flowing through the evaporator of the absorption chiller.
Aug 5; QEVAP = Q507 = $2\cdot 003 \times 10^6$ Btu (output of computer program).

26. HBL Heat balance factor of absorption chiller.

$$HBL = \frac{Q\ COND}{Q\ GEN + Q\ EVAP}$$

$$\text{Aug 5; } HBL = \frac{4\cdot 34}{4\cdot 86 = 2\cdot 003} = 0\cdot 632$$

In theory according to the first law of thermodynamics this value should be always unity. This is possible if all the three pumps pushing water through condenser, generator and evaporator are steady or vary proportionately preserving the heat balance. Here since these values are time integrated values and the method of data collection does not consider the large thermal inertia associated with the flowing fluids this value of heat balance should be expected to vary on either side of unity. With the exception of two days these values vary between 0·52 and 0·76. The typical value seem to be around 0·65. When such an unbalance was first noticed it was expected that the differential temperature probes might be out of calibration. The calibration that was done indicated some errors, which changed these factors towards unity only slightly. These calculations reflects the above mentioned correction. See calibration section for the method and how it was applied in revising the cooling load calculations. More systematic tests that assure near steady state conditions are required to assure integrity of the heat balance and associated calculations. It is possible that calibration of flow meters may aid in obtaining the heat balance to a closer degree.

27. N500 Solar fraction of total energy utilized for cooling load.
N500 = Q500/Q506
Aug 5; N500 = $1\cdot 73 \times 10^6 / 4\cdot 86 \times 10^6 = 0\cdot 356$
This factor will be high on the days when little of no natural gas used in the building

28. Q ELEC = Q601 Heat equivalent of electrical energy utilized in the solar system.
Q ELEC = Q601 = Q102 + Q303 + Q503

$$\Delta(\text{kwhr Reading}) \times 40 \times 3413 \frac{\Delta\tau\ Comp}{\Delta\tau\ Read}$$

kwhr readings are recorded manually twice a day.

$$\text{Aug 5; } Q601 = 5\cdot 6 \times 40 \times 3413 \times \frac{12\cdot 0}{10\cdot 08} = 0\cdot 910 \times 10^6 \text{ Btu}$$

On an average three to four hundred kilowatt hours of electrical energy are consumed during day time hours. Part of this energy is utilized to drive domestic hot water pump and the major portion is utilized to drive solar collector pump. The variable speed pump has a speed control device which uses electricity on a 24-hour basis. An auxiliary energy analysis similar to pilot gas consumption using night time data suggests the energy consumption rate of 0·9 kw. This value has not been subtracted from the electrical energy consumption.

29. N501 Solar fraction of total energy utilized for cooling load.

$$N501 = \frac{Q500}{Q515} = \frac{Q500}{Q500 + Q503 + Q508} = \frac{Q500}{Q500 + Q601 + Q508}$$

Since electrical energy input to absorption chiller (Q503) is not measured total electrical energy to solar system (Q601) has been utilized.

$$\text{Aug 5; } N501 = \frac{1{\cdot}73 \times 10^6}{1{\cdot}73 \times 10^6 + 0{\cdot}91 \times 10^6 + 4{\cdot}17 \times 10^6} = 0{\cdot}254$$

This factor is always less than N500 (item 27) since all energy input to solar system is considered.

30. QBLDG = Q502 Space cooling load as seen by the chiller located in the mechanical equipment room.
Aug 5; QBLDG = Q502 = $1{\cdot}93 \times 10^6$ Btu (output of computer program)
When the Q EVAP (Q507) is in excess of QBLDG (Q502) it should be assumed that chilled water is being stored in tank A.

31. COP = N503 Coefficient of performance of the absorption chiller

$$COP = N503 = \frac{Q507}{Q506} = \frac{Q\ EVAP}{Q\ GEN}$$

$$\text{Aug 5; } N503 = \frac{2{\cdot}003 \times 10^6}{4{\cdot}86 \times 10^6} = 0{\cdot}412$$

The value of COP of 1·08 on August 23 may be due to error in recorded data. An average COP of 0·4 has been reported for most of the days.

32. $\Delta\tau E/B$ Duration of time the evaporator/building pump operated
Aug 5; $\Delta\tau E/B$ = 10·0 hrs. (obtained from computer program).
The water flow through evaporator circuit and building are measured using a common flow meter. The chiller can operate either to supply building load or store chilled water. Detail study of computer print out is necessary to separate these two modes of operation.

33. TNGC Average tons of cooling generated in the chiller during daytime period when the chiller operated

$$TNGC = \frac{Q507}{\Delta\tau E/B \times 12000}$$

$$\text{Aug 5; } TNGC = \frac{2{\cdot}003 \times 10^6}{10{\cdot}00 \times 12000} = 16{\cdot}7 \text{ tons}$$

The examination of results show that on August 13 the average evaporator load is 40 tons. Typical value seems to be 25 tons.

34. TNSB Average tons of cooling supplied to the building.

$$TNSB = \frac{Q502}{\Delta\tau E/B \times 12000}$$

$$\text{Aug 5; } TNSB = \frac{1{\cdot}93 \times 10^6}{10 \times 12000} = 16{\cdot}1 \text{ tons}$$

35. NSG Ratio of cooling supplied to the building to that generated by the chiller.

$$NSG = \frac{Q502}{Q507} = \frac{TNSB}{TNGC}$$

Aug 5; $NSG = \frac{16 \cdot 1}{16 \cdot 7} = 0 \cdot 964$

Since the temperature rise of chilled water flowing in the building and the drop in temperature of returning chilled water flowing through the evaporator is measured in the equipment room. This ratio should be approximatly unity for those days when chilled water is not stored in the tank A. During latter part of September when the chilled water is not stored this ratio is about 1·07 instead of unity. Perhaps this discrapency is due to errors in temperature measurements. On August 16 this ratio is 1·289 suggesting part of the building load is supplied from storage tank A. On August 19 there was storage of chilled water which accounts for the ratio of 0·496. On August 23 even though the ratio is 0·52 the computer data shows no appreciable storage.

4. Discussion of Results

The following comments are based on the detailed review of the calculated results printed for 15 minute periods.

When there is sudden cloud cover for short intervals, the outlet temperature drops below inlet temperature causing negative heat collection. Since the daily heat collection is algebraic sum it affects the average collection efficiency reported in the daily performance table.

In the computer program when the temperature difference in any of the flow circuit exceeds 40°F, it has been suppressed. Such a situation has existed several times during these two months. They have been attributed to spurious signals in transducing data.

On August 23 the generator and the condenser flow circuits operated for fewer hours while the evaporator and the building flow circuits operated for longer hours. On this day evaporator load is larger than building load. There is no cooling of water in tank A. On August 16 a similar situation existed, but the evaporator and building loads were about the same suggesting the possible use of chilled water. This situation may exist when the cooling load is supplied from the storage tank. It was expected that during this period the evaporator load would be the same as the building load, but this was not so. Under normal operation all the heat exchangers should operate for the same length of time. During September such a situation did exist.

On August 19, between 10 and 12 a.m. the stored energy from storage tank B was utilized for chiller operation.

During August 24 to September 1, there was several days during which reasonable amount of solar energy was incident, but the daily insolation falling on the collector (output of computer program) is zero. During this period flowmeter F1 did not work causing no recorded heat collection and stroage

Fluctuating solar intensity causes fluctuating collector flow. However, the temperature rise across the collector is not necessarily constant. This temperature rise even during steady operation is in excess of 20°F.

On September 3 and 7, the chiller was operated by boiler, but the temperature T 3 of the water entering the chiller seems to be around 180°F. Had this temperature been around 200°F, a higher COP could have been realized.

September 11 was a clear sunny day. On this day tank B reached 190°F and then the tank C was cascaded, but the flow in the collector started fluctuating when it was communicating with tank C.

During the night of September 12-13, chiller operated, but there is no evidence of tank 1 being cooled.

On September 14, there was no solar radiation. Hence the chiller operation was by using natural gas. Tank B was at 171°F showing no substantial change. The water leaving the boiler and entering the generator fluctuated between 164 to 204°F. The instantaneous COP varied from 0.19 to 1.0 rather violently. The flow of water through the flometer F 3 also fluctuated.

Even on clear days the period of heat collection is about 7 hours even though the number of sunshine hours is about 14 hours. Typical average collection efficiency is 0.25 which is lower than typical winter efficiency. Part of the reason is higher tank temperatures. The number of hours of useful heat collection even on clear winter days is about the same. Thus the collector operates from a late morning hour and stops long before sunset. The instantaneous collection efficiency for such days reaches a maximum and stays constant for several hours unless cascading takes place.

During most of this period the G.A. Towns Elementary School was closed. Hence the cooling load of the building is low. Typical building load absorbed by the chilled water varied from 14 to 30 tons. On August 10, the maximum average outdoor daytime drybulb temperature is 87.3°F. On this day the average building temperature of 80°F was maintained. Had the thermostat been set to a lower value higher load would have resulted.

During morning hours considerable statification in tanks has been noticed. When the flow in or out of the tank exists this statification is destroyed. In the hot tanks statification causes lower skin temperature when compared to bulk temperature. This should have favorable effect on tank losses. For the cold tank the convective currents due to statification may increase the losses creating unfavorable effect. However, since the mean temperature difference between tank A and the ground is small the overnight heat loss(leak) is small. For true comparision of the losses the leak into chilled water tank should be magnified with the (1/COP) as a factor, typical COP being 0.3 in this system.

When the returning chilled water is in the range 55 to 65°F there is evidence of steady chiller operation with respectable COP. This is not so if the water temperature falls below 50°F. There seems to be considerable instability with fluctuating generator flow and sometimes condenser flow. However, lower temperature may be required if dehumidification is expected. The COP fluctuates rather violently during such an operation. When operating on boiler, intermittent operation will waste the thermal inertia of the system.

It should be possible to lower the temperature of the water leaving the cooling tower. This should aid in improving COP of the system and assist the system towards stable operation. On mild days this will be advantageous.

Because of the heat leak into tank A and the increase in its value with lower temperatures there is little incentive to generate and store chilled water at lower temperatures for a long period unless dehumidification is necessary. There is a possibility to use storage tank A very much like D.H.W. preheater tank and cooling this water to lower temperature as required.

APPENDIX E

EXPERIMENTAL DATA

(Sample pages only. See Section 4.0 of the text)

APPENDIX E1

ENVIROMMENTAL DATA

(Sample pages only. See Section 4.0 of the text)

APPENDIX E 1
ENVIRONMENTAL DATA

LIST OF SYMBOLS

1. Hourly Data: (The following symbols appear as column headings)

Time:	EST
Outside TOUT:	Outside ambient temperature (°F)
Outside TCAV:	Cavity temperature (°F) in outside DewProbe sensor (related to dew-point temperature, ambient temperature and per cent relative humidity by Figure E1, page E1-3.
Solar HTO:	Total insolation on horizontal surface (BTU/Sq. Ft.-Hr)-measured
Solar HTT:	Total insolation on plane of collectors (BTU/Sq. Ft.-HR)-measured.
Zone Temps, TZ1, TZ2, TH3:	Zone temperature (°F) in building zone 1, 2, and 3. (See Design Report for locations of zones)
Zone Temps AVE:	Average Zone temperature (°F) for the building
Zone Cavity Temps, TH1, TH2, TH3:	Zone cavity temperature (°F) in DewProbe sensors located in building zones 1, 2 and 3
Zone Cavity Temps, AVE:	Average zone cavity temperature (°F) for the building
Build load, BTU/Hr:	Rate of heating or cooling delivered to the building, BTU/Hr. A negative number indicates that heat is being supplied to the building. A positive number indicates that heat is being removed from the building.

2. Daily Summary: (The following abbreviations appear at the bottom of each page)

Insolation: Horiz	Total daily horizontal insolations, BTU/Sq. Ft.-Day
Tilted:	Total daily insolation received on plane of collectors, BTU/Sq. Ft.-Day
AVG Zone Temp:	Average daily zone temperatures (°F) during operation of data system
Bldg. Load:	Daily heating or cooling delivered to the building during operation of data system (BTU)

AUG5 ENVIRONMENTAL DATA

TIME	OUTSIDE TOUT	OUTSIDE TCAV	SOLAR HTV	SOLAR HTT	ZONE TEMPS TZ1	ZONE TEMPS TZ2	ZONE TEMPS TZ3	ZONE TEMPS AVE	ZONE CAVITY TEMPS TH1	ZONE CAVITY TEMPS TH2	ZONE CAVITY TEMPS TH3	ZONE CAVITY TEMPS AVE	PLUG LOAD BTU/HR
6.00	63.9	70.7	0	0	79.9	78.9	75.2	78.3	123.	123.	125.	124.	0.000E+00
6.25	63.9	70.6	2	3	80.0	78.9	75.7	78.2	123.	123.	125.	124.	0.000E+00
6.50	65.6	71.3	9	7	80.0	78.9	75.3	78.1	123.	123.	125.	124.	0.000E+00
6.75	67.3	73.3	24	13	80.4	78.9	75.2	78.2	123.	123.	125.	124.	0.000E+00
7.00	67.8	73.6	42	22	80.0	78.9	75.2	78.0	123.	123.	125.	123.	0.000E+00
7.25	69.5	74.2	43	26	80.0	79.1	75.3	78.1	123.	123.	125.	124.	0.000E+00
7.50	69.4	74.4	22	17	80.1	79.0	75.4	78.2	123.	123.	125.	124.	0.000E+00
7.75	69.8	74.4	42	34	79.9	78.9	75.5	78.[illegible]	123.	123.	125.	124.	0.000E+00
8.00	71.0	75.8	103	55	80.4	79.1	75.6	78.2	123.	123.	126.	124.	0.000E+00
8.25	73.6	77.0	131	75	80.1	79.4	75.8	78.4	123.	123.	127.	124.	0.000E+00
8.50	72.2	76.0	111	77	80.2	79.5	76.1	78.6	123.	124.	127.	125.	0.000E+00
8.75	73.0	77.9	121	88	80.1	79.4	75.3	78.6	123.	123.	128.	125.	0.000E+00
9.00	75.6	78.5	127	96	80.3	79.7	76.7	78.9	123.	124.	129.	125.	0.000E+00
9.25	75.4	79.1	136	104	80.4	79.7	77.0	79.0	123.	124.	129.	125.	0.000E+00
9.50	75.6	79.9	168	129	80.4	79.9	77.2	79.2	123.	124.	131.	126.	1.230E+04
9.75	78.5	81.1	198	153	80.5	80.0	77.7	79.4	123.	124.	132.	126.	7.377E+04
10.00	80.6	82.7	189	151	79.5	78.9	77.5	78.7	123.	123.	132.	126.	4.604E+05
10.25	80.1	83.4	176	139	78.6	78.5	77.6	78.2	122.	124.	132.	126.	1.717E+05
10.50	81.0	84.1	192	150	78.3	78.7	77.9	78.3	122.	125.	132.	126.	7.368E+04
10.75	82.6	84.7	270	216	77.7	78.5	78.2	78.1	120.	124.	131.	125.	7.632E+05
11.00	80.9	84.6	154	122	78.3	78.2	77.9	78.1	121.	123.	130.	125.	3.123E+05
11.25	82.7	84.5	145	117	78.6	77.9	77.7	78.1	122.	122.	129.	124.	3.240E+05
11.50	79.6	83.6	89	73	78.9	77.8	77.7	78.1	122.	121.	128.	124.	3.842E+05
11.75	79.7	83.1	81	67	78.9	77.6	77.5	78.0	122.	121.	128.	124.	3.119E+05
12.00	85.0	85.6	308	255	79.3	77.6	77.8	78.2	121.	120.	126.	123.	2.402E+05
12.25	85.4	87.3	312	256	79.6	77.5	78.0	78.4	121.	120.	126.	122.	3.461E+05
12.50	86.3	89.0	320	259	79.9	77.7	78.2	78.6	121.	120.	126.	122.	3.000E+05
12.75	85.2	89.5	311	254	80.1	77.6	78.2	78.6	120.	120.	125.	122.	2.520E+05
13.00	85.8	90.0	315	254	80.3	77.6	78.4	78.8	120.	120.	125.	122.	3.240E+05
13.25	86.0	90.7	310	252	80.5	77.5	78.5	78.9	120.	120.	125.	121.	2.761E+05
13.50	87.6	91.1	311	252	80.4	77.4	78.5	78.8	119.	119.	124.	121.	3.237E+05
13.75	88.1	91.7	311	249	80.9	77.5	78.8	79.1	120.	119.	124.	121.	3.239E+05
14.00	88.9	91.4	262	210	81.2	77.6	78.9	79.2	120.	119.	125.	121.	3.241E+05
14.25	87.8	91.6	269	213	81.3	77.6	79.0	79.3	120.	119.	124.	121.	2.641E+05
14.50	86.8	91.1	205	167	81.5	77.4	79.0	79.3	120.	119.	124.	121.	2.999E+05
14.75	86.3	90.5	229	185	81.6	77.5	79.2	79.4	120.	119.	124.	121.	3.479E+05
15.00	87.3	90.7	215	174	81.9	77.6	79.4	79.6	120.	119.	124.	121.	2.880E+05
15.25	87.5	91.2	240	195	82.4	77.6	79.5	79.9	120.	119.	124.	121.	2.639E+05
15.50	86.7	90.8	168	134	82.3	77.4	79.5	79.7	120.	119.	124.	121.	3.359E+05
15.75	84.7	89.3	83	67	82.0	77.4	79.2	79.5	119.	118.	124.	120.	3.243E+05
16.00	87.2	89.5	151	119	82.1	77.7	79.3	79.7	120.	121.	125.	122.	3.369E+03
16.25	86.7	89.6	195	149	82.4	78.1	79.6	80.2	121.	121.	126.	123.	0.000E+00
16.50	86.1	89.8	159	120	82.6	78.3	79.6	80.2	121.	121.	126.	123.	0.000E+00
16.75	86.4	89.2	119	91	82.6	78.5	80.0	80.4	122.	122.	127.	123.	0.000E+00
17.00	86.9	89.3	139	102	82.7	78.5	80.0	80.4	122.	122.	127.	124.	0.000E+00
17.25	86.0	89.1	84	61	82.9	78.7	80.0	80.5	122.	122.	127.	124.	0.000E+00
17.50	88.4	90.5	114	79	82.9	78.7	80.2	80.6	122.	122.	126.	124.	0.000E+00
17.75	88.6	90.6	100	68	82.7	78.5	80.2	80.4	122.	122.	128.	124.	0.000E+00
18.00	88.9	90.7	83	53	82.6	78.7	80.1	80.5	122.	122.	128.	124.	0.000E+00
18.25	88.6	90.3	64	37	82.4	78.8	80.1	80.4	122.	123.	128.	124.	0.000E+00
18.50	88.4	89.8	50	25	82.1	78.8	80.1	80.3	122.	123.	128.	124.	0.000E+00
18.75	86.9	89.0	24	17	82.0	78.7	79.9	80.2	122.	123.	128.	124.	0.000E+00
19.00	85.1	88.1	15	13	81.9	78.7	79.9	80.2	122.	123.	128.	124.	0.000E+00
19.25	82.2	87.3	6	7	81.7	78.7	79.9	80.1	122.	123.	129.	124.	0.000E+00
19.50	81.1	85.9	3	4	81.5	78.7	79.9	80.0	122.	123.	129.	124.	0.000E+00
19.75	80.6	84.9	0	0	81.3	78.8	80.0	80.0	122.	123.	129.	124.	0.000E+00

20.00	79.6	84.0	0	0	81.2	78.7	80.[illegible]	[illegible]	121.	123.	129.	124.	0.000E+0
20.25	79.0	83.4	0	0	81.1	78.6	79.0	79.0	121.	123.	129.	124.	0.000E+00
20.50	78.4	82.8	0	0	81.2	78.7	80.0	[illegible]	122.	123.	129.	124.	0.000E+00
20.75	78.0	82.3	0	-0	81.0	78.5	80.6	79.9	122.	123.	129.	125.	0.000E+00
AVG:	81.0	84.0						79.2				123.5	

INSOLATION: HORIZ= 2014 TILTED= 1564 BTU/SQFT/DAY
AVG ZONE TEMP (8AM-5PM): 80.5 76.2 78.2
BLDG LOAD: 1.934E+06 BTU

NOV4

ENVIRONMENTAL DATA

TIME	OUTSIDE TOUT	TCAV	SOLAR HT0	HT1	ZONE TEMPS TZ1	TZ2	TZ3	AVE	ZONE CAVITY TEMPS TH1	TH2	TH3	AVE	BLDG LOAD BTU/HR
7.00	36.6	44.1	0	0	80.7	75.2	81.6	79.2	104.	110.	115.	110.	-5.767E+05
7.25	37.4	43.8	1	2	81.3	75.5	82.1	79.6	105.	111.	115.	110.	-5.633E+05
7.50	36.8	43.5	7	9	82.1	75.9	82.4	80.1	106.	111.	115.	111.	-5.131E+05
7.75	40.0	44.1	20	47	82.5	76.0	82.6	80.4	106.	111.	115.	111.	-5.674E+05
8.00	41.2	45.1	34	70	82.7	76.1	82.9	80.6	106.	111.	115.	111.	-5.264E+05
8.25	41.6	46.0	49	91	83.0	76.5	83.2	80.9	107.	111.	116.	111.	-5.295E+05
8.50	42.3	46.6	65	112	82.6	76.8	83.7	81.0	106.	110.	115.	110.	-5.039E+05
8.75	44.1	47.5	81	131	81.2	77.1	83.6	80.9	103.	108.	114.	108.	-4.946E+05
9.00	45.4	48.5	97	149	81.5	75.6	84.4	80.5	102.	104.	115.	107.	-4.808E+05
9.25	46.3	49.4	98	143	81.8	75.5	85.5	80.9	102.	104.	117.	107.	-4.605E+05
9.50	47.5	50.5	128	183	82.4	77.1	85.3	81.6	105.	107.	115.	109.	-4.345E+05
9.75	48.1	51.2	103	142	82.5	77.4	85.1	81.7	106.	108.	114.	109.	-4.081E+05
10.00	49.4	51.9	122	166	82.9	77.1	85.3	81.8	106.	107.	113.	109.	-4.120E+05
10.25	52.3	53.3	165	221	83.1	77.8	85.5	82.1	107.	108.	113.	109.	-3.908E+05
10.50	54.3	54.7	176	234	83.2	78.2	85.1	82.2	105.	108.	113.	109.	-3.751E+05
10.75	54.3	55.4	184	244	83.2	78.8	84.1	82.0	104.	109.	112.	108.	-3.749E+05
11.00	55.7	56.3	194	256	82.6	78.3	83.2	81.4	103.	106.	111.	107.	-3.866E+05
11.25	55.8	56.8	201	264	83.0	78.0	83.8	81.5	104.	105.	108.	106.	-4.461E+05
11.50	56.2	57.2	200	263	83.4	78.0	83.9	81.8	104.	105.	107.	105.	-4.318E+05
11.75	57.2	57.7	213	273	83.7	77.3	83.7	81.6	105.	103.	108.	105.	-3.860E+05
12.00	56.5	58.1	202	256	83.8	78.4	85.1	82.4	105.	105.	109.	106.	-4.052E+05
12.25	56.5	57.9	195	243	83.6	78.4	84.8	82.3	103.	103.	108.	105.	-3.930E+05
12.50	56.4	58.0	198	252	82.6	78.3	84.0	81.6	99.	103.	109.	104.	-3.931E+05
12.75	57.2	58.7	216	271	82.3	78.2	83.4	81.3	98.	101.	107.	102.	-3.805E+05
13.00	58.3	59.2	219	273	82.3	78.2	83.6	81.4	98.	100.	107.	102.	-3.201E+05
13.25	58.2	59.5	209	245	82.4	78.2	83.4	81.3	99.	102.	108.	103.	-2.733E+05
13.50	58.8	59.6	186	218	82.8	78.6	83.6	81.7	99.	103.	109.	104.	-3.703E+05
13.75	57.4	59.3	165	197	83.2	78.7	83.6	81.8	99.	102.	108.	103.	-3.701E+05
14.00	58.0	59.4	153	163	83.7	78.9	83.8	82.1	100.	102.	108.	104.	-3.542E+05
14.25	57.6	59.4	136	136	84.0	79.6	84.3	82.6	100.	104.	108.	104.	-3.378E+05
14.50	57.5	59.3	99	89	84.4	79.9	84.3	82.9	101.	103.	108.	104.	-3.047E+05
14.75	58.0	59.5	109	106	84.2	79.8	83.7	82.6	102.	104.	109.	105.	-1.434E+04
15.00	56.9	59.4	91	86	83.5	79.2	82.4	81.7	103.	104.	109.	105.	-2.570E+04
15.25	56.9	58.9	83	81	80.4	77.9	80.5	79.6	101.	106.	113.	107.	-9.140E+03
15.50	56.1	58.5	60	54	78.9	76.7	79.3	78.3	100.	107.	112.	106.	0.000E+00
15.75	56.2	58.1	67	72	77.3	76.1	78.1	77.2	97.	106.	112.	105.	0.000E+00
16.00	57.0	58.3	99	135	76.8	75.7	77.5	76.7	97.	106.	111.	105.	0.000E+00
16.25	56.5	58.2	84	129	76.0	75.1	76.6	75.9	95.	106.	110.	104.	0.000E+00
16.50	56.2	58.0	59	88	75.6	74.5	75.8	75.3	93.	105.	109.	103.	0.000E+00
16.75	56.2	57.9	43	38	74.9	74.9	75.2	75.0	92.	106.	109.	102.	0.000E+00
17.00	55.3	57.4	21	31	74.6	75.3	74.0	74.8	91.	106.	108.	102.	0.000E+00
17.25	54.3	56.9	12	12	73.9	75.3	74.3	74.5	93.	106.	108.	102.	0.000E+00
17.50	53.4	56.6	9	9	73.4	74.9	74.1	74.1	93.	105.	108.	102.	0.000E+00
17.75	52.4	56.0	1	3	72.7	74.3	73.9	73.6	93.	105.	107.	102.	0.000E+00
18.00	51.6	55.5	0	0	72.1	73.7	73.6	73.1	93.	105.	107.	102.	0.000E+00
18.25	50.4	54.9	0	0	71.8	73.0	73.4	72.7	93.	104.	107.	101.	0.000E+00
18.50	49.5	54.2	0	0	71.6	72.7	73.0	72.4	93.	104.	107.	101.	0.000E+00
18.75	48.6	53.6	0	0	71.3	72.4	72.9	72.2	93.	104.	106.	101.	0.000E+00
AVG:	52.1	54.7						79.4				105.6	

INSOLATION: HORIZ= 1215 TILTED= 1566 BTU/SQFT/DAY
AVG ZONE TEMP (8AM-5PM): 81.6 77.5 82.6
BLDG LOAD: -3.343E+06 BTU

APPENDIX E2

COLLECTOR PERFORMANCE

(Sample pages only. See Section 4.0 of the text)

APPENDIX E2
COLLECTOR PERFORMANCE

1. <u>Hourly Data</u> (The following symbols appear as column headings)

Time:	EST
SOLT:	Solar time (correction to EST to account for difference in longitude between Atlanta and the standard meridian for EST, 75^{o}W and to account for the equation of time).
HTO:	Total insolation on horizontal surface (BTU/Sq. Ft.-Hr.)-measured
HTT:	Total insolation on plane of collectors (BTU/Sq. Ft.-Hr.)-measured
HTTC:	Total insolation on tilted surface (BTU/Sq. Ft.-Hr)-calculated from HTO using Liu and Jordan method
HTTWR:	Total insolation on plane of collector (BTU/Sq. Ft.-Hr.) with reflector augmentation-calculated by increasing HTT by the amount of beam component reflected to the collector by the reflector, estimated by using HTTC
EFFY:	Ratio of energy absorbed by the water to energy incident on the collector. (Instantaneous efficiency)

2. <u>Daily Summary</u> (The following abbreviations appear at the bottom of each page)

Insolation During Operation:	Integrated value of solar energy falling on the collector bank including reflector augmentation during the hours solar collector pump operated
Total Heat Collected:	Integrated value of heat energy collected by the water flowing in the collector circuit. Product of flow rate, specific heat and instantaneous temperature difference between the inlet and the outlet of solar collector banks.

2. Daily Summary (cont'd)

Total Daily Insolation:	Integrated value of solar energy falling on the collector bank including reflector augmentation from sunrise to sunset.
Average Operating Efficiency:	Ratio of total heat collected to insolation during operating hours, expressed as a percentage.

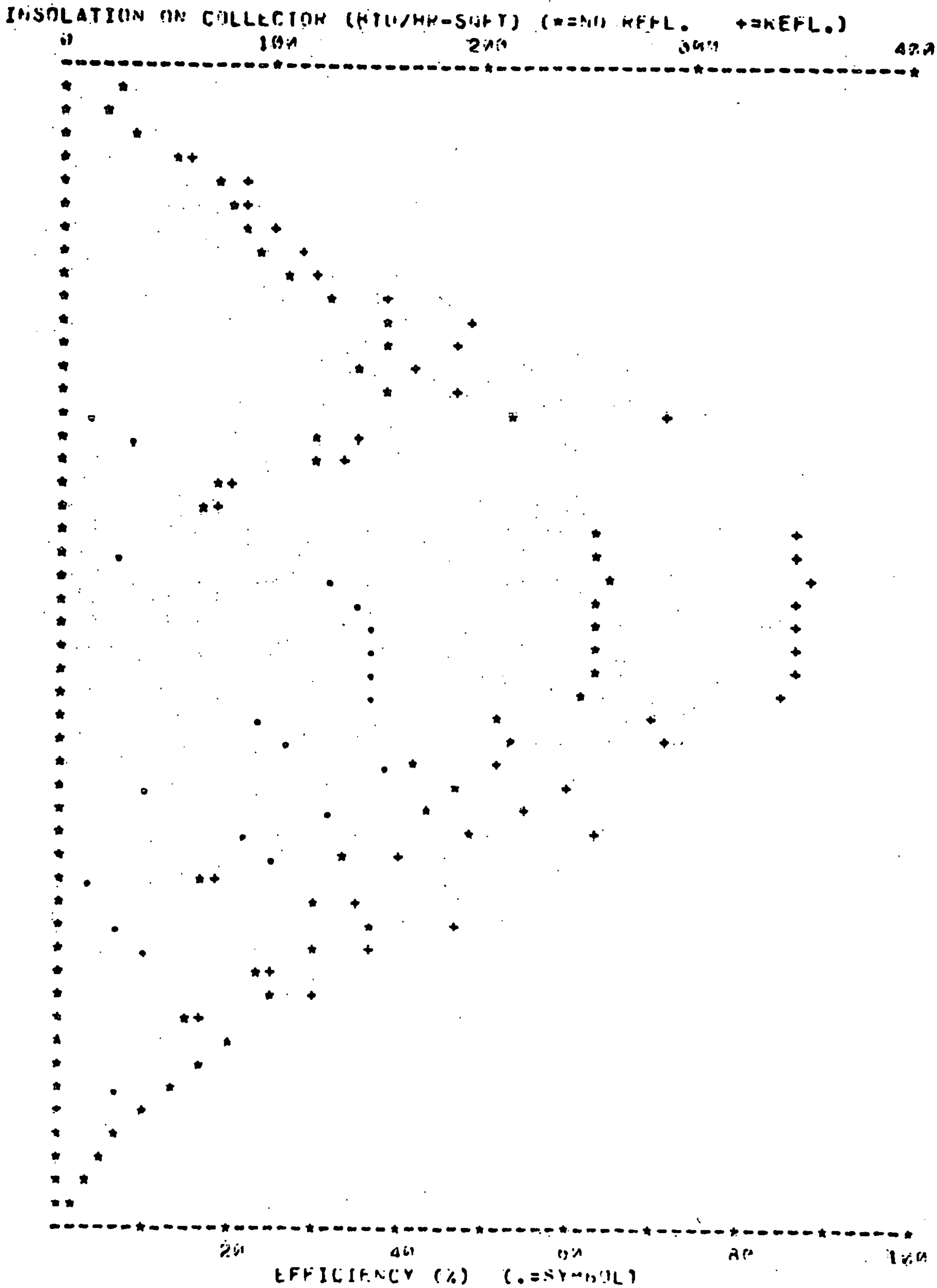
3. Plots:

Ordinates:	1) Insolation on the collector (BTU/Hr.-sq. ft.); * = no reflector augmentation, typical of the value on the front panels, + = reflector augmentation.
	2) Efficiency of the solar collector (percent), (·) = symbol used to represent collector efficiency
Abscissa:	Time of the day, the space between each pair of asterisks represent 15 min. duration

AUG5 COLLECTOR PERFORMANCE

EST	SOLT	HTP	HTI	HTTC	HTIWR	EFFY
7.25	6.55	42.72	25.90	34.77	25.90	.03
7.50	6.80	22.30	17.50	21.63	17.50	.00
7.75	7.05	42.40	30.30	39.83	30.30	.03
8.00	7.30	103.20	54.60	86.08	57.05	.20
8.25	7.55	131.20	74.80	112.00	83.38	.08
8.50	7.80	111.00	77.90	102.30	65.47	.00
8.75	8.05	120.90	68.50	113.62	100.40	.02
9.00	8.30	127.20	96.10	122.03	110.34	.00
9.25	8.55	135.82	103.80	132.07	120.71	.03
9.50	8.80	157.70	128.60	164.31	156.43	.04
9.75	9.05	198.30	153.30	190.30	143.46	.00
10.00	9.30	188.80	150.80	186.97	147.57	.00
10.25	9.55	175.72	130.30	177.10	160.55	.02
10.50	9.80	192.52	150.50	195.42	166.69	.00
10.75	10.05	270.50	215.60	278.32	258.93	.04
11.00	10.30	154.00	122.20	156.58	142.54	.09
11.25	10.55	145.10	117.20	147.54	134.56	.00
11.50	10.80	86.70	72.80	89.35	77.22	.03
11.75	11.05	80.70	67.40	81.22	70.75	.09
12.00	11.30	307.90	254.90	323.74	346.95	.00
12.25	11.55	311.60	256.20	328.19	349.12	.06
12.50	11.80	319.90	259.20	337.25	353.41	.31
12.75	12.05	310.90	254.30	327.03	346.77	.35
13.00	12.30	314.80	254.40	331.78	346.80	.36
13.25	12.55	309.80	252.20	326.10	343.52	.37
13.50	12.80	310.90	252.40	326.51	343.34	.37
13.75	13.05	310.90	249.00	325.69	338.00	.35
14.00	13.30	262.50	209.90	273.04	278.45	.23
14.25	13.55	269.30	213.10	279.35	284.79	.27
14.50	13.80	205.30	166.90	210.25	209.26	.38
14.75	14.05	229.40	165.40	234.57	239.87	.19
15.00	14.30	214.52	173.80	217.77	221.90	.32
15.25	14.55	240.10	195.10	241.94	256.06	.21
15.50	14.80	167.90	133.60	157.48	161.73	.25
15.75	15.05	83.30	67.10	82.95	71.70	.03
16.00	15.30	151.50	119.10	148.04	141.67	-.02
16.25	15.55	195.12	148.80	185.95	186.72	.07
16.50	15.80	159.30	119.90	140.98	143.93	.14
16.75	16.05	119.50	90.70	111.37	102.45	-.02
17.00	16.30	139.50	102.50	122.42	117.16	-.00
17.25	16.55	83.90	50.90	76.14	63.93	-.03
17.50	16.80	113.72	79.30	89.79	81.16	-.01
17.75	17.05	100.10	57.60	72.59	57.60	-.03
18.00	17.30	53.12	53.00	54.29	53.00	.47
18.25	17.55	64.10	36.70	35.59	36.70	.02
18.50	17.80	49.94	25.80	.00	25.80	.01
18.75	18.05	24.22	17.50	.00	17.50	.00
19.00	18.30	14.98	13.10	.00	13.10	.00
19.25	18.55	8.40	6.80	.00	6.80	.00

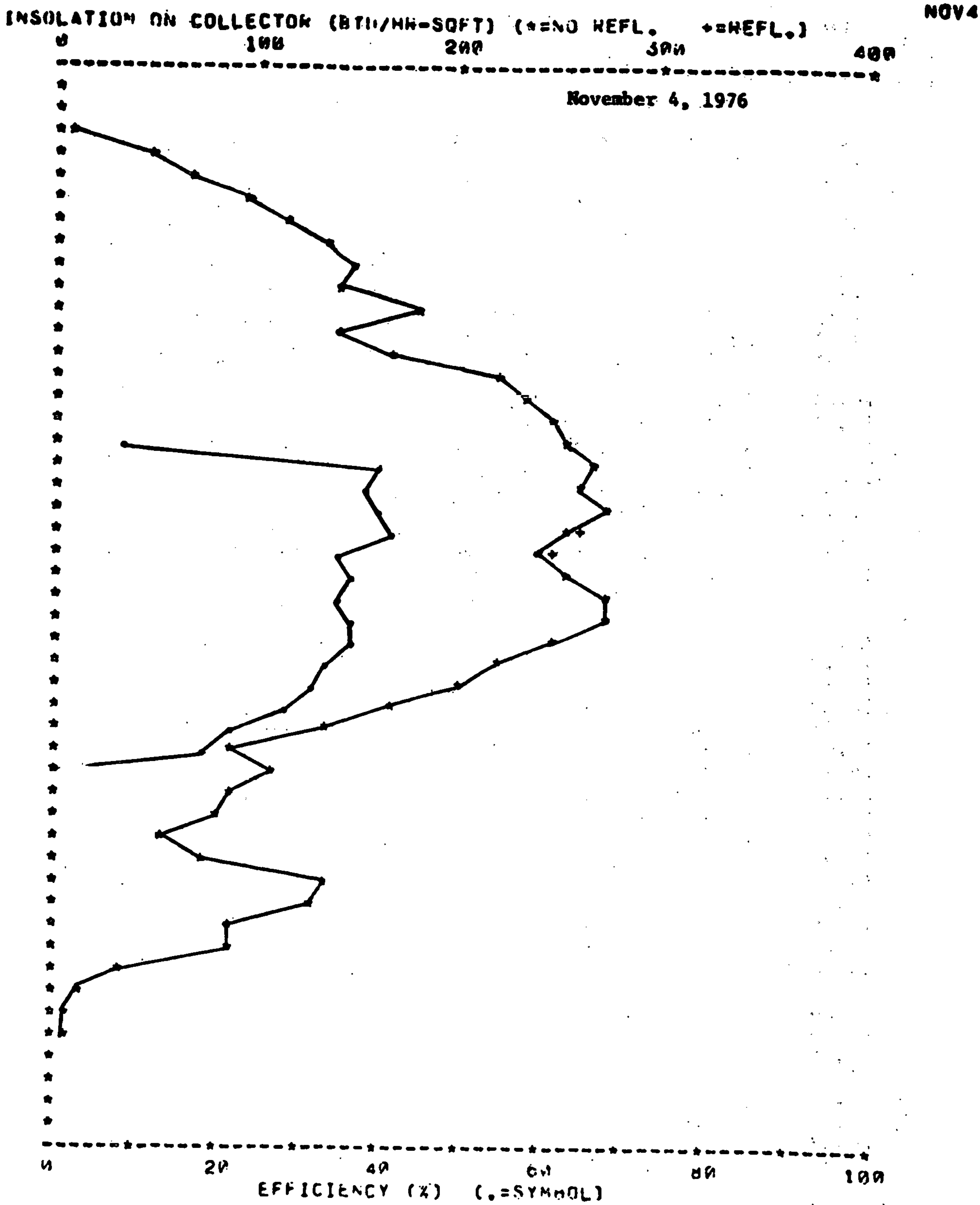
INSOLATION DURING OPERATION= 1.362E+07 TOTAL HEAT COLLECTED= 2.983E+06
TOTAL DAILY INSOLATION= 1.924E+07
AVERAGE OPERATING EFFICIENCY= 21.9%


INSOLATION ON COLLECTOR (BTU/HR-SQFT) (*=NO REFL. +=REFL.)
0
100
200
300
400
20
40
60
80
100
EFFICIENCY (%) (.=SYMBOL)

NOV4 COLLECTOR PERFORMANCE

EST	SOLT	HTO	HTT	HTTC	HTTWR	EFFY
7.00	6.65	.10	.20	.00	.20	.00
7.25	6.90	1.20	1.70	1.18	1.70	.00
7.50	7.15	7.50	8.90	10.15	8.90	.00
7.75	7.40	20.20	47.40	32.58	47.40	.00
8.00	7.65	34.50	69.70	58.16	69.70	.00
8.25	7.90	48.90	91.20	82.39	91.20	.00
8.50	8.15	65.10	111.90	110.24	111.90	.00
8.75	8.40	81.50	131.30	137.72	131.30	.00
9.00	8.65	96.90	148.90	162.18	148.90	.00
9.25	8.90	97.80	143.30	152.46	143.30	.00
9.50	9.15	127.90	182.90	211.33	182.90	.00
9.75	9.40	102.90	142.30	147.18	142.30	.00
10.00	9.65	122.50	165.80	181.40	165.80	.00
10.25	9.90	164.90	220.60	265.61	220.60	.00
10.50	10.15	175.90	234.40	281.94	234.40	.00
10.75	10.40	184.30	244.30	293.46	244.30	.00
11.00	10.65	193.70	255.80	307.78	255.80	.09
11.25	10.90	201.50	263.80	319.52	263.80	.43
11.50	11.15	200.20	262.60	313.56	263.02	.39
11.75	11.40	213.30	272.90	330.94	274.27	.39
12.00	11.65	202.10	256.50	313.39	258.30	.42
12.25	11.90	195.40	242.60	298.98	244.50	.35
12.50	12.15	197.90	252.20	304.16	254.16	.37
12.75	12.40	215.80	271.40	340.31	273.26	.35
13.00	12.65	218.90	273.10	345.97	274.31	.37
13.25	12.90	209.40	245.30	332.06	245.50	.35
13.50	13.15	186.30	217.80	289.04	217.80	.33
13.75	13.40	165.10	197.20	249.11	197.20	.32
14.00	13.65	152.70	163.40	228.05	163.40	.29
14.25	13.90	135.70	136.20	198.41	136.20	.21
14.50	14.15	99.50	89.10	131.71	89.10	.19
14.75	14.40	109.50	106.50	155.72	106.50	-.03
15.00	14.65	91.00	86.50	124.59	86.50	-.03
15.25	14.90	82.60	81.40	113.73	81.40	-.04
15.50	15.15	59.70	54.00	75.99	54.00	-.11
15.75	15.40	66.90	71.80	95.10	71.80	-.08
16.00	15.65	99.40	135.50	188.06	135.50	-.02
16.25	15.90	84.40	129.10	167.80	129.10	-.03
16.50	16.15	59.30	88.20	116.56	88.20	-.08
16.75	16.40	42.60	67.80	67.37	67.80	.00
17.00	16.65	20.80	30.60	37.08	30.60	.00
17.25	16.90	12.40	12.40	27.86	12.40	.00
17.50	17.15	8.80	9.40	2.53	9.40	.00
17.75	17.40	1.40	3.50	.00	3.50	.00
18.00	17.65	.10	.50	.00	.50	.00
18.25	17.90	.00	.10	.00	.10	.00
18.50	18.15	.10	.00	.00	.00	.00
18.75	18.40	.00	.00	.00	.00	.00

INSOLATION DURING OPERATION= 1.069E+07 TOTAL HEAT COLLECTED= 2.835E+06
TOTAL DAILY INSOLATION= 1.606E+07
AVERAGE OPERATING EFFICIENCY= 26.5%


INSOLATION ON COLLECTOR (BTU/HR-SQFT) (*=NO REFL. +=REFL.)
NOV4
0
100
200
300
400
November 4, 1976
0
20
40
60
80
100
EFFICIENCY (%) (.=SYMBOL)

APPENDIX E3

COLLECTOR-STORAGE SYSTEM PERFORMANCE

(Sample pages only. See Section 4.0 of the text)

APPENDIX E3
COLLECTOR-STORAGE SYSTEM PERFORMANCE

LIST OF SYMBOLS

1. Hourly Data: (The following symbols appear as column headings).

Time:	Eastern Standard Time
HTO:	Total insolation on horizontal surface (BTU/Sq. Ft.-Hr.)-measured
HTT:	Total insolation on plane of collectors (BTU/Sq. Ft.-Hr.)-measured
F1:	Water flow rate as measured by flow meter FI (g.p.m.)
T1:	Collector outlet temperature (F^o)
TD1:	Collector temperature difference (F) - positive values indicate temperatures rise due to flow of water in the collector
TT1:	Average of three temperatures measured in tank 1 (tank A)
TT2:	Same as TT1 for tank 2 (tank B)
TT3:	Same as TT1 for tank 3 (tank C)
QCOL:	Solar energy collected by the flowing water (BTU/hr.)

2. Daily Summary: (The following abbreviation appear at the bottom of each page)

Total Heat Collected During the Day:	Integrated value of total solar energy absorbed by the flowing water and delivered to the storage tanks during the entire day. (BTU/day)

COLLECTOR - STORAGE SYSTEM PERFORMANCE
DAY = AUG5

TIME	HTO	HTT	F1	T1	TO1	TT1	TT2	TT3	UCOL
6.00	.20	.40	.00	84.00	14.25	85.37	175.93	132.47	0.000E+00
6.25	2.20	2.50	.00	83.60	13.75	85.37	175.77	132.33	0.000E+00
6.50	9.10	6.90	.00	82.60	13.45	85.33	175.70	132.37	0.000E+00
6.75	23.60	13.20	.00	82.00	13.35	85.33	175.63	132.30	0.000E+00
7.00	41.90	22.30	.00	81.20	12.95	85.33	175.60	132.27	0.000E+00
7.25	42.70	25.90	.00	80.70	12.35	85.43	175.77	132.43	0.000E+00
7.50	22.30	17.50	.00	80.10	11.65	85.40	175.77	132.33	0.000E+00
7.75	42.40	36.30	.00	79.60	11.05	85.33	175.47	132.23	0.000E+00
8.00	103.20	54.60	.00	79.30	10.25	85.37	175.67	132.33	0.000E+00
8.25	131.20	74.50	.00	79.20	9.45	85.33	175.63	132.30	0.000E+00
8.50	111.00	77.00	.00	79.10	8.45	85.37	175.60	132.30	0.000E+00
8.75	120.90	88.50	.00	79.20	7.45	85.33	175.37	132.20	0.000E+00
9.00	127.20	96.10	.00	79.70	6.65	85.40	175.53	132.33	0.000E+00
9.25	135.80	103.80	.00	80.30	5.95	85.40	175.47	132.20	0.000E+00
9.50	167.70	128.60	.00	81.00	5.45	85.40	175.17	132.10	0.000E+00
9.75	198.30	153.30	.00	81.80	4.95	85.37	172.57	132.47	0.000E+00
10.00	188.80	150.80	.00	97.20	3.15	85.43	171.14	132.43	0.000E+00
10.25	175.70	139.30	.00	88.20	-4.15	85.33	170.70	132.30	0.000E+00
10.50	192.50	150.50	.00	98.90	-2.55	85.43	170.80	132.43	0.000E+00
10.75	270.50	215.60	55.90	148.70	3.55	85.43	170.83	132.37	9.922E+04
11.00	154.00	122.20	59.00	162.90	4.35	85.47	170.83	132.27	1.283E+05
11.25	145.10	117.20	.00	151.00	-2.15	85.37	170.64	132.23	0.000E+00
11.50	88.70	72.80	.00	131.50	-.55	85.47	170.77	132.30	0.000E+00
11.75	80.70	67.40	.00	134.50	-5.85	85.47	170.80	132.23	0.000E+00
12.00	307.00	254.90	.00	123.70	-3.35	85.43	170.80	132.23	0.000E+00
12.25	311.60	250.20	76.10	171.20	5.75	85.47	171.33	132.27	2.188E+05
12.50	319.90	259.20	136.90	186.60	15.75	85.43	173.00	132.33	1.078E+06
12.75	313.90	254.30	159.80	190.90	15.25	85.50	175.10	132.27	1.211E+06
13.00	314.80	254.40	159.10	192.60	15.45	85.50	177.13	132.27	1.229E+06
13.25	309.80	252.20	159.20	194.00	15.55	85.53	178.13	132.40	1.238E+06
13.50	310.90	252.40	158.70	194.70	15.45	85.43	179.17	132.27	1.226E+06
13.75	310.90	249.00	157.40	196.20	15.05	85.50	180.60	132.27	1.184E+06
14.00	262.50	209.90	111.80	194.50	11.35	85.53	180.90	132.27	5.345E+05
14.25	269.30	213.10	114.50	200.30	13.25	85.53	181.43	132.20	7.592E+05
14.50	245.30	166.90	122.90	188.90	12.95	85.53	182.17	132.13	7.958E+05
14.75	229.40	185.40	70.40	196.60	6.75	85.53	181.37	132.23	2.376E+05
15.00	214.60	173.80	119.90	189.00	11.85	85.53	181.97	132.17	7.104E+05
15.25	240.10	195.10	100.00	190.00	10.55	85.53	182.07	132.23	5.275E+05
15.50	167.30	133.60	89.60	185.50	9.25	85.47	181.6[illegible]	132.23	4.144E+05
15.75	83.30	67.10	63.50	179.80	.75	85.50	183.60	132.17	2.392E+04
16.00	151.50	118.10	63.50	181.70	-.95	85.47	180.40	132.33	-3.916E+04
16.25	195.10	146.80	63.20	188.50	4.85	85.53	180.70	132.11	1.240E+05
16.50	159.30	119.90	61.30	184.50	4.65	85.50	[illegible]	[illegible]	1.425E+05
16.75	119.50	90.70	59.10	178.00	-.15	85.53	181.87	132.11	-4.433E+03
17.00	139.50	102.50	65.70	176.80	-.05	85.50	18[illegible].57	132.03	-1.643E+03
17.25	93.90	52.90	67.10	17[illegible].70	-.65	85.57	181.73	132.11	-2.181E+04
17.50	113.70	79.30	66.60	166.40	-.35	[illegible]	18[illegible].87	132.10	-1.166E+04
17.75	100.10	67.00	55.60	163.90	-.65	85.50	180.47	131.97	-2.132E+04
18.00	83.10	53.00	14.00	159.80	5.25	85.57	180.63	132.10	3.815E+04
18.25	64.10	40.70	.00	156.50	6.55	85.57	180.87	132.07	0.000E+00
18.50	49.40	25.80	.00	154.40	6.35	85.57	[illegible]	132.03	0.000E+00
18.75	24.20	17.50	.00	151.20	6.85	85.53	[illegible]	132.03	0.000E+00
19.00	14.90	13.10	.00	147.00	6.45	85.60	181.47	132.03	0.000E+00

19.25	8.40	6.00	.00	144.00	5.45	85.63	180.47	132.03	0.000E+00
19.50	2.70	3.60	.00	141.10	6.85	85.60	180.43	132.00	0.000E+00
19.75	.00	.30	.00	138.10	7.05	85.60	180.44	131.93	0.000E+00
20.00	.10	.30	.00	135.10	7.25	85.63	180.43	131.93	0.000E+00
20.25	.10	.90	.00	132.40	7.45	85.57	180.17	131.93	0.000E+00
20.50	.00	.20	.00	124.80	6.65	85.60	160.27	131.93	0.000E+00
20.75	.00	-.10	.00	127.20	6.55	85.00	150.27	131.93	0.000E+00

TOTAL HEAT COLLECTED DURING THE DAY=2.0834E+06

COLLECTOR - STORAGE SYSTEM PERFORMANCE
DAY = NOV4

TIME	HTO	HTT	F1	T1	TO1	TT1	TT2	TT3	QCOL
7.00	.10	.20	.00	90.70	10.15	139.30	133.70	131.60	0.000E+00
7.25	1.20	1.70	.00	89.90	10.25	138.03	133.50	131.63	0.000E+00
7.50	7.50	8.90	.00	89.50	10.35	137.17	133.40	131.73	0.000E+00
7.75	20.20	47.40	.00	88.90	10.35	136.47	133.20	131.53	0.000E+00
8.00	34.50	69.70	.00	88.30	10.45	136.00	132.90	131.23	0.000E+00
8.25	48.90	91.20	.00	87.80	8.95	135.43	132.67	130.90	0.000E+00
8.50	65.10	111.90	.00	87.40	8.65	135.03	132.47	130.43	0.000E+00
8.75	81.50	131.30	.00	87.10	9.15	134.63	132.10	130.23	0.000E+00
9.00	95.90	148.50	.00	86.80	8.75	134.27	131.87	129.97	0.000E+00
9.25	97.80	143.30	.00	86.70	8.15	133.87	131.53	129.57	0.000E+00
9.50	127.90	182.90	.00	86.70	7.55	133.73	131.47	129.53	0.000E+00
9.75	102.90	142.30	.00	86.20	7.85	133.10	130.90	129.00	0.000E+00
10.00	122.50	165.60	.00	86.10	8.05	132.80	130.53	128.63	0.000E+00
10.25	164.90	220.60	.00	86.10	9.05	132.57	130.27	128.30	0.000E+00
10.50	175.90	234.40	.00	86.00	10.25	132.30	129.90	127.90	0.000E+00
10.75	184.30	244.30	.00	91.10	6.35	132.30	129.70	127.83	0.000E+00
11.00	193.70	255.60	96.30	144.70	4.85	132.80	129.13	127.87	2.335E+05
11.25	201.50	263.80	157.40	146.40	13.85	134.77	129.23	127.87	1.090E+06
11.50	200.20	262.60	157.10	146.30	13.35	136.10	129.10	127.67	1.049E+06
11.75	213.30	272.90	157.50	147.50	14.05	137.60	129.53	127.80	1.106E+06
12.00	202.10	250.50	157.70	145.70	14.05	138.50	129.63	127.67	1.108E+06
12.25	195.40	242.60	142.50	145.50	12.25	139.37	129.97	127.73	8.728E+05
12.50	197.90	252.20	151.00	146.20	12.65	139.93	130.30	127.60	9.551E+05
12.75	215.80	271.40	154.80	149.10	12.55	140.67	130.83	127.67	9.714E+05
13.00	218.90	273.10	155.40	150.40	13.35	141.83	131.63	127.77	1.037E+06
13.25	209.40	245.30	145.20	146.10	12.55	142.53	132.33	127.70	9.111E+05
13.50	186.30	217.60	129.50	146.20	11.55	143.00	132.53	127.67	7.479E+05
13.75	165.10	197.20	117.40	146.00	11.05	143.17	132.80	127.63	6.486E+05
14.00	152.70	163.40	98.80	143.50	9.85	143.20	133.10	127.63	4.866E+05
14.25	135.70	136.20	69.20	141.70	8.45	143.00	133.13	127.63	2.924E+05
14.50	99.50	89.10	69.30	135.40	5.05	142.63	133.07	127.60	1.750E+05
14.75	109.50	106.50	72.60	135.20	-1.05	142.63	133.17	127.57	-3.812E+04
15.00	91.00	86.50	72.40	134.70	-.65	142.60	133.10	127.53	-2.353E+04
15.25	82.60	81.40	71.70	133.30	-.95	142.60	133.13	127.50	-3.406E+04
15.50	59.70	54.00	72.20	128.60	-1.65	142.57	133.03	127.53	-5.956E+04
15.75	66.90	71.60	72.30	125.80	-1.55	142.50	133.10	127.57	-5.603E+04
16.00	99.40	135.50	72.20	129.90	-.65	142.47	133.10	127.60	-2.347E+04
16.25	84.40	129.10	72.30	132.50	-1.15	142.47	133.10	127.50	-4.157E+04
16.50	59.30	48.20	61.30	127.80	-2.25	142.40	133.07	127.47	-6.895E+04
16.75	42.60	67.80	.00	127.10	.45	142.40	133.00	127.50	0.000E+00
17.00	20.80	30.60	.00	125.30	.45	142.40	133.03	127.50	0.000E+00
17.25	12.40	12.40	.00	125.40	-.05	142.37	133.03	127.50	0.000E+00
17.50	8.80	9.40	.00	124.60	.25	142.30	133.00	127.43	0.000E+00
17.75	1.40	3.50	.00	123.60	.45	142.33	132.97	127.47	0.000E+00
18.00	.10	.52	.00	122.80	.35	142.30	132.97	127.43	0.000E+00
18.25	.00	.10	.00	122.00	3.75	142.33	132.97	127.43	0.000E+00
18.50	.10	.00	.00	121.20	4.05	142.23	132.97	127.43	0.000E+00
18.75	.00	.00	.00	120.30	3.85	142.27	132.93	127.37	0.000E+00

TOTAL HEAT COLLECTED DURING THE DAY=2.8348E+06

APPENDIX E4

COLLECTOR-STORAGE-LOAD SYSTEM PERFORMANCE

(Sample pages only. See Section 4.0 of the text)

APPENDIX E4

COLLECTOR-STORAGE-LOAD SYSTEM PERFORMANCE

1. Hourly Data (The following symbols appear as column headings)

Time:	Eastern Standard Time
QCOL:	Solar energy collected by the flowing water (BTU/hr)
Tank QDOT:	Rate of net heat stored in the storage tanks (BTU/hr): Positive values indicate storage and negative values indicate heat depletion: During winter mode all three tanks are lumped and during summer mode the value refers to tanks 2 and 3
Tank Loss:	Estimated heat loss from the hot water storage tanks using the developed empirical equations. (BTU/hr)
QUTIL:	Solar energy utilized from the storage tanks to domestic hot water, and space heating or space cooling
Q BLDG:	Space load delivered to the building: Negative value, represent heat supplied to the building by the circulating hot water during winter mode; and positive values represent cooling supplied to the building by the circulating chilled water during summer mode (BTU/hr)

2. Daily Summary (The following abbreviation appear at the bottom of each page)

SUM:	Integrated value of the numbers appearing in each column described above; (+) positive value is the sum of all the positive entries in the column and (-) negative values is the sum of all the negative entries in the column; these two values are algebraically added to provide integrated sum. (BTU/daytime period i.e. for the hours shown in each page)

NOVA

COLLECTOR - STORAGE - LOAD SYSTE1 PERFORMANCE

TIME	QCOL	TANK QDOT	TANK LOSS	QUTIL	QLOAD
7.00	0.000E+00	0.000E+00	2.915E+04	-2.915E+04	-5.757E+05
7.25	0.000E+00	-7.166E+05	2.896E+04	[illegible]	[illegible]
7.50	0.000E+00	-4.333E+05	2.885E+04	[illegible]	[illegible]
7.75	0.000E+00	-5.500E+05	2.871E+04	[illegible]	[illegible]
8.00	0.000E+00	-5.333E+05	[illegible]	[illegible]	[illegible]
8.25	0.000E+00	-5.567E+05	2.844E+04	[illegible]	[illegible]
8.50	0.000E+00	-5.333E+05	[illegible]	[illegible]	[illegible]
8.75	0.000E+00	-4.833E+05	2.816E+04	4.522E+05	[illegible]
9.00	0.000E+00	-4.333E+05	[illegible]	[illegible]	[illegible]
9.25	0.000E+00	-5.666E+05	[illegible]	5.347E+05	[illegible]
9.50	0.000E+00	-1.167E+05	2.791E+04	[illegible]	[illegible]
9.75	0.000E+00	-8.666E+05	2.769E+04	[illegible]	[illegible]
10.00	0.000E+00	-5.166E+05	2.757E+04	4.491E+05	[illegible]
10.25	0.000E+00	-4.166E+05	2.746E+04	3.442E+05	[illegible]
10.50	0.000E+00	-5.167E+05	2.734E+04	[illegible]	[illegible]
10.75	0.000E+00	-1.333E+05	[illegible]	[illegible]	-3.749E+05
11.00	2.335E+05	-1.666E+04	2.731E+04	2.224E+05	[illegible]
11.25	1.090E+06	1.033E+06	2.757E+04	2.912E+04	-4.451E+05
11.50	1.049E+06	5.000E+05	2.771E+04	5.214E+05	-4.318E+05
11.75	1.106E+06	1.033E+06	2.797E+04	4.517E+04	[illegible]
12.00	1.108E+06	4.333E+05	[illegible]	6.455E+05	[illegible]
12.25	8.728E+05	6.333E+05	2.824E+04	2.113E+05	[illegible]
12.50	9.551E+05	3.833E+05	2.834E+04	5.434E+05	[illegible]
12.75	9.714E+05	6.666E+05	2.851E+04	2.762E+05	[illegible]
13.00	1.037E+06	1.033E+06	2.877E+04	-2.475E+04	[illegible]
13.25	9.111E+05	6.667E+05	2.893E+04	2.155E+05	[illegible]
13.50	7.479E+05	3.166E+05	2.902E+04	[illegible]	[illegible]
13.75	6.486E+05	2.000E+05	2.906E+04	[illegible]	[illegible]
14.00	4.866E+05	1.667E+05	2.911E+04	[illegible]	-3.542E+05
14.25	2.924E+05	-8.334E+04	[illegible]	[illegible]	[illegible]
14.50	1.750E+05	-2.333E+05	[illegible]	[illegible]	[illegible]
14.75	-3.812E+04	3.332E+04	[illegible]	[illegible]	[illegible]
15.00	-2.353E+04	-6.656E+04	[illegible]	[illegible]	[illegible]
15.25	-3.406E+04	-7.629E+00	2.901E+04	[illegible]	[illegible]
15.50	-5.956E+04	-4.998E+04	[illegible]	-3.359E+04	[illegible]
15.75	-5.603E+04	1.665E+04	[illegible]	[illegible]	[illegible]
16.00	-2.347E+04	1.526E+01	2.901E+04	-5.249E+04	[illegible]
16.25	-4.157E+04	-5.001E+04	[illegible]	[illegible]	[illegible]
16.50	-6.896E+04	-6.665E+04	2.893E+04	[illegible]	[illegible]
16.75	[illegible]	-1.668E+04	[illegible]	[illegible]	[illegible]
17.00	[illegible]	1.668E+04	[illegible]	[illegible]	[illegible]
17.25	[illegible]	-1.668E+04	[illegible]	[illegible]	[illegible]
17.50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17.75	[illegible]	1.667E+04	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
18.25	[illegible]	1.666E+04	[illegible]	[illegible]	[illegible]
18.50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
18.75	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
+SUM:		[illegible]		[illegible]	[illegible]
-SUM:		[illegible]		[illegible]	[illegible]
SUM:	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

NOV5

COLLECTOR - STORAGE - LOAD SYSTEM PERFORMANCE

TIME	QCOL	TANK GAIN	TANK LOSS	[illegible]	[illegible]
9.25	0.000E+00	0.000E+00	2.849E+04	-2.849E+04	[illegible]
9.50	0.000E+00	-1.065E+04	2.849E+04	[illegible]	[illegible]
9.75	0.000E+00	-1.833E+05	2.845E+04	[illegible]	[illegible]
10.00	0.000E+00	4.033E+05	[illegible]	[illegible]	[illegible]
11.75	0.000E+00	[illegible]	2.857E+04	[illegible]	[illegible]
12.00	0.000E+00	-3.332E+04	2.837E+04	[illegible]	[illegible]
12.25	1.225E+05	-3.335E+04	2.835E+04	1.278E+05	[illegible]
12.50	7.922E+05	1.333E+05	2.858E+04	[illegible]	[illegible]
12.75	1.017E+06	1.100E+05	2.895E+04	-1.121E+05	[illegible]
13.00	1.003E+06	8.666E+05	2.917E+04	[illegible]	[illegible]
13.25	9.619E+05	9.500E+05	2.941E+04	[illegible]	[illegible]
13.50	9.133E+05	1.300E+06	2.973E+04	-4.104E+05	[illegible]
13.75	8.766E+05	7.633E+05	2.993E+04	[illegible]	[illegible]
14.00	1.383E+06	1.283E+06	3.024E+04	7.497E+04	[illegible]
14.25	8.335E+05	8.333E+05	3.044E+04	[illegible]	[illegible]
14.50	7.596E+05	9.833E+05	3.067E+04	[illegible]	[illegible]
14.75	6.780E+05	4.500E+05	3.078E+04	[illegible]	[illegible]
15.00	5.653E+05	5.166E+05	3.090E+04	1.775E+04	[illegible]
15.25	4.585E+05	3.833E+05	3.099E+04	4.418E+04	[illegible]
15.50	3.710E+05	2.000E+05	3.104E+04	[illegible]	[illegible]
15.75	3.059E+05	4.633E+05	3.116E+04	[illegible]	[illegible]
16.00	2.017E+05	1.833E+06	3.122E+04	[illegible]	[illegible]
16.25	5.789E+04	3.050E+01	3.120E+04	[illegible]	[illegible]
16.50	0.000E+00	3.000E+05	3.127E+04	-3.313E+05	[illegible]
15.75	0.000E+00	-6.671E+04	3.126E+04	[illegible]	[illegible]
17.00	0.000E+00	-4.000E+05	3.119E+04	[illegible]	[illegible]
17.25	0.000E+00	-1.597E+05	3.112E+04	[illegible]	[illegible]
17.50	0.000E+00	-2.000E+05	3.107E+04	[illegible]	[illegible]
17.75	0.000E+00	1.333E+05	3.111E+04	[illegible]	[illegible]
18.00	0.000E+00	-5.667E+05	3.097E+04	[illegible]	[illegible]
18.25	0.000E+00	-9.999E+05	3.072E+04	[illegible]	[illegible]
18.50	0.000E+00	-5.634E+05	[illegible]	5.527E+05	[illegible]
18.75	0.000E+00	-2.167E+05	3.052E+04	[illegible]	[illegible]
+SUM:		3.142E+06		[illegible]	[illegible]
-SUM:		-1.054E+06		[illegible]	[illegible]
SUM:	2.826E+06	2.087E+05	2.443E+05	[illegible]	[illegible]

AUG5

COLLECTOR - STORAGE - LOAD SYSTEM PERFORMANCE

TIME	QCOL	TANK QDOT	TANK LOSS	QUTIL	QBLOG
6.00	0.000E+00	0.000E+00	2.731E+04	-2.731E+04	0.000E+00
6.25	0.000E+00	-1.500E+05	2.727E+04	1.227E+05	0.000E+00
6.50	0.000E+00	-3.334E+04	2.726E+04	6.477E+03	0.000E+00
6.75	0.000E+00	-6.668E+04	2.725E+04	3.943E+04	0.000E+00
7.00	0.000E+00	-3.332E+04	2.724E+04	6.085E+03	0.000E+00
7.25	0.000E+00	2.000E+05	2.729E+04	-2.273E+05	0.000E+00
7.50	0.000E+00	-5.001E+04	2.728E+04	2.273E+04	0.000E+00
7.75	0.000E+00	-2.333E+05	2.722E+04	2.061E+05	0.000E+00
8.00	0.000E+00	1.667E+05	2.726E+04	-1.940E+05	0.000E+00
8.25	0.000E+00	-5.003E+04	2.725E+04	2.279E+04	0.000E+00
8.50	0.000E+00	1.526E+01	2.725E+04	-2.726E+04	0.000E+00
8.75	0.000E+00	-1.833E+05	2.720E+04	1.561E+05	0.000E+00
9.00	0.000E+00	1.833E+05	2.725E+04	-2.106E+05	0.000E+00
9.25	0.000E+00	-1.000E+05	2.722E+04	7.278E+04	0.000E+00
9.50	0.000E+00	-2.000E+05	2.718E+04	1.728E+05	1.230E+04
9.75	0.000E+00	-1.133E+06	2.690E+04	1.106E+06	7.377E+04
10.00	0.000E+00	-7.166E+05	2.673E+04	6.899E+05	4.684E+05
10.25	0.000E+00	-3.167E+05	2.665E+04	2.900E+05	1.717E+05
10.50	0.000E+00	1.667E+05	2.670E+04	-1.934E+05	7.358E+04
10.75	9.922E+04	-1.666E+04	2.669E+04	8.919E+04	7.632E+05
11.00	1.283E+05	-4.999E+04	2.668E+04	1.515E+05	3.123E+05
11.25	0.000E+00	-1.667E+05	2.664E+04	1.400E+05	3.240E+05
11.50	0.000E+00	1.667E+05	2.668E+04	-1.933E+05	3.842E+05
11.75	0.000E+00	-1.666E+04	2.668E+04	-1.001E+04	3.119E+05
12.00	0.000E+00	-1.668E+04	2.667E+04	-9.994E+03	2.402E+05
12.25	2.188E+05	3.000E+05	2.674E+04	-1.079E+05	3.481E+05
12.50	1.078E+06	8.500E+05	2.695E+04	2.012E+05	3.000E+05
12.75	1.211E+06	1.050E+06	2.720E+04	1.337E+05	2.520E+05
13.00	1.229E+06	1.017E+06	2.744E+04	1.850E+05	3.240E+05
13.25	1.238E+06	5.833E+05	2.758E+04	6.269E+05	2.761E+05
13.50	1.226E+06	4.000E+05	2.768E+04	7.963E+05	3.237E+05
13.75	1.184E+06	7.500E+05	2.786E+04	4.066E+05	3.239E+05
14.00	6.345E+05	1.666E+05	2.799E+04	4.399E+05	3.241E+05
14.25	7.592E+05	2.333E+05	2.796E+04	4.979E+05	2.641E+05
14.50	7.958E+05	3.333E+05	2.804E+04	4.344E+05	2.999E+05
14.75	2.376E+05	-3.500E+05	2.795E+04	5.596E+05	3.479E+05
15.00	7.104E+05	2.167E+05	2.800E+04	4.638E+05	2.860E+05
15.25	5.275E+05	1.333E+05	2.804E+04	3.661E+05	2.639E+05
15.50	4.144E+05	-3.666E+05	2.795E+04	7.531E+05	3.359E+05
15.75	2.392E+04	-4.167E+05	2.785E+04	4.127E+05	3.243E+05
16.00	-3.016E+04	-1.833E+05	2.780E+04	1.253E+05	8.390E+03
16.25	1.280E+05	2.167E+05	2.785E+04	-1.165E+05	0.000E+00
16.50	1.425E+05	-1.000E+05	2.783E+04	2.147E+05	0.000E+00
16.75	-4.433E+03	1.533E+05	2.788E+04	-2.150E+05	0.000E+00
17.00	-1.643E+03	-2.000E+05	2.783E+04	1.705E+05	0.000E+00
17.25	-2.181E+04	1.500E+05	2.786E+04	-1.997E+05	0.000E+00
17.50	-1.166E+04	-1.668E+04	2.786E+04	-2.284E+04	0.000E+00
17.75	-2.132E+04	-2.167E+05	2.781E+04	1.675E+05	0.000E+00
18.00	3.815E+04	1.833E+05	2.785E+04	-1.730E+05	0.000E+00
18.25	0.000E+00	0.000E+00	2.785E+04	-2.785E+04	0.000E+00
18.50	0.000E+00	-5.000E+04	2.784E+04	2.216E+04	0.000E+00
18.75	0.000E+00	-1.666E+04	2.784E+04	-1.118E+04	0.000E+00
19.00	0.000E+00	-3.332E+04	2.783E+04	5.495E+03	0.000E+00
19.25	0.000E+00	0.000E+00	2.783E+04	-2.783E+04	0.000E+00
19.50	0.000E+00	-3.332E+04	2.782E+04	5.503E+03	0.000E+00
19.75	0.000E+00	-4.990E+04	2.781E+04	2.213E+04	0.000E+00

20.00	0.000E+00	1.666E+04	2.781E+04	-4.440E+04	0.000E+00
20.25	0.000E+00	-2.000E+05	2.776E+04	1.723E+05	0.000E+00
20.50	0.000E+00	1.167E+05	2.779E+04	-1.445E+05	0.000E+00
20.75	0.000E+00	0.000E+00	2.779E+04	-2.779E+04	0.000E+00
+SUM:		1.946E+06		2.62[illegible]E+06	1.934E+06
-SUM:		-1.442E+06		-5.531E+05	0.000E+00
SUM:	2.983E+06	5.041E+05	4.119E+05	2.[illegible]07E+06	1.934E+06

APPENDIX E5

BUILDING-DHW DATA

(Sample pages only. See Section 4.0 of the text)

APPENDIX E5

BUILDING AND DOMESTIC HOT WATER DATA

1. Hourly Data (The following smybols appear as column headings)

Time:	Eastern Standard Time
DHW:	Domestic Hot Water
Building:	Space being heated or cooled
F6:	Water flow rate flowing through the preheater as measured by flow meter F6 (g.p.m.)
T6:	Temperature of the water leaving the preheater exchanger and returning to the solar storage tanks (°F)
TD6:	Temperature drop of the hot water flowing through the preheater exchanger of DHW. (F)
QDHW:	Component of solar heat utilized in DHW preheater prior to the main gas-fired heater
F4-5:	Water flow rate flowing through the building as measured by flow meter F 4-5 (gpm); winter mode: hot water from storage tanks or auxiliary boiler. Summer mode: chilled water from absorption chiller or chilled water storage tank 1 (tank A)
T2:	Building inlet water temperature (°F)
TD2:	Temperature difference (out-in) of the water flowing in the building loop (F) - positive values represent summer mode when chilled water picks up building cooling load: Negative values represent winter mode when hot water delivers building heating load.
QBLD:	Space heating load delivered, (-) negative values, during winter mode and space cooling load absorbed (+) positive values, during summer mode.

APPENDIX E5 (Cont'd)

BUILDING AND DOMESTIC HOT WATER DATA

2. Daily Summary (The following abbreviations appear at the bottom of each page)

Total QDHW:	Integrated value of the solar energy utilized in the preheater exchanger of DHW
Total QBLD:	Integrated value of the heating load supplied to the building during winter mode or the cooling load absorbed from the building during summer mode. (BTU/daytime period i.e., for the hours shown in each page).

AJG5

BUILDING-DHW DATA

TIME	F6	DHW TS	TUA	QDHW	FA-S	TR	BUILDING TUB	QCLF
6.00	.00	105.90	7.00	[illegible]E+00	246.[illegible]	45.1[illegible]	[illegible]	[illegible]E+00
6.25	.00	10[illegible].[illegible]	6.20	[illegible]E+00	246.[illegible]	44.[illegible]	[illegible]	[illegible]E+00
6.50	.00	106.00	5.80	[illegible]E+00	246.[illegible]	44.[illegible]	[illegible]	[illegible]E+00
6.75	.00	106.20	4.80	[illegible]E+00	246.5[illegible]	44.[illegible]	[illegible]	[illegible]E+00
7.00	.00	106.20	4.30	.0000E+00	246.3[illegible]	44.3[illegible]	[illegible]	[illegible]E+00
7.25	.00	105.40	3.20	[illegible]E+00	246.2[illegible]	44.[illegible]	[illegible]	[illegible]E+00
7.50	.00	104.60	1.90	.0000E+00	246.4[illegible]	44.2[illegible]	[illegible]	[illegible]E+00
7.75	.00	103.40	.40	.0000E+00	246.1[illegible]	44.1[illegible]	[illegible]	[illegible]E+00
8.00	.00	103.20	-.50	[illegible]E+00	246.2[illegible]	44.1[illegible]	[illegible]	[illegible]E+00
8.25	.00	102.50	-1.40	.0000E+00	246.1[illegible]	44.2[illegible]	[illegible]	[illegible]E+00
8.50	.00	102.10	-2.10	.0000E+00	246.1[illegible]	44.[illegible]	[illegible]	[illegible]E+00
8.75	.00	100.00	-3.40	.0000E+00	246.2[illegible]	44.[illegible]	[illegible]	[illegible]E+00
9.00	.00	97.90	-5.90	.0000E+00	246.[illegible]	44.0[illegible]	[illegible]	[illegible]E+00
9.25	.00	96.40	-7.90	.0000E+00	246.1[illegible]	44.7[illegible]	[illegible]	[illegible]E+00
9.50	.00	96.10	-8.60	.0000E+00	246.[illegible]	45.[illegible]	.1[illegible]	.12[illegible]E+05
9.75	.00	103.50	-22.[illegible]0	[illegible]E+00	245.9[illegible]	79.[illegible]	.6[illegible]	.7377E+05
10.00	.00	102.00	-41.30	.0000E+00	245.5[illegible]	55.5[illegible]	5.8[illegible]	.46[illegible]E+05
10.25	3.10	152.30	-26.70	-.4138E+05	245.3[illegible]	54.4[illegible]	1.40	.1717E+05
10.50	1.60	165.60	-57.50	-.46[illegible]E+05	245.5[illegible]	5[illegible]	.5[illegible]	.7358E+05
10.75	2.70	168.40	-31.90	-.4305E+05	242.30	45.4[illegible]	5.30	.7632E+05
11.00	1.70	159.90	-41.20	-.3502E+05	240.20	46.30	2.6[illegible]	.3123E+05
11.25	1.90	160.00	-34.40	-.3268E+05	240.[illegible]	47.5[illegible]	2.70	.324[illegible]E+05
11.50	1.30	163.20	-39.80	-.2567E+05	240.1[illegible]	43.3[illegible]	3.20	.3442E+05
11.75	1.70	170.50	-31.80	-.2713E+05	239.9[illegible]	45.0[illegible]	2.6[illegible]	.3119E+05
12.00	1.30	157.00	-49.80	-.3237E+05	240.2[illegible]	44.[illegible]	2.[illegible]	.2442E+05
12.25	1.40	169.30	-40.20	-.2814E+05	240.1[illegible]	45.7[illegible]	2.9[illegible]	.3481E+05
12.50	1.60	164.80	-29.30	-.2344E+05	240.[illegible]	45.[illegible]	2.5[illegible]	.3[illegible]E+05
12.75	1.30	168.50	-37.30	-.2424E+05	240.[illegible]	46.1[illegible]	2.1[illegible]	.252[illegible]E+05
13.00	1.30	167.90	-29.90	-.1943E+05	240.[illegible]	4[illegible]	2.7[illegible]	.32[illegible]E+05
13.25	.00	164.00	-22.70	.0000E+00	2[illegible].1[illegible]	47.5[illegible]	2.[illegible]	.27[illegible]1E+05
13.50	.00	159.70	-20.00	.0000E+00	239.5[illegible]	47.1[illegible]	2.7[illegible]	.3237E+05
13.75	.00	155.90	-8.90	.0000E+00	239.90	46.2[illegible]	2.7[illegible]	.3239E+05
14.00	.00	152.70	1.60	.0000E+00	240.10	45.2[illegible]	2.7[illegible]	.3241E+05
14.25	.00	149.90	8.20	.0000E+00	240.10	47.1[illegible]	2.2[illegible]	.2541E+05
14.50	.00	147.30	11.70	.0000E+00	239.9[illegible]	47.4[illegible]	2.5[illegible]	.2949E+05
14.75	.00	144.60	13.70	[illegible]E+00	239.[illegible]	45.[illegible]	2.9[illegible]	.3479E+05
15.00	.00	142.40	14.70	.0000E+00	240.1[illegible]	43.3[illegible]	2.4[illegible]	.2[illegible]E+05
15.25	.00	140.20	15.30	.0000E+00	239.[illegible]	47.1[illegible]	2.2[illegible]	.25[illegible]E+05
15.50	.00	137.80	15.40	[illegible]E+00	239.[illegible]	4[illegible]	2.[illegible]	.3[illegible]E+05
15.75	.00	135.70	15.30	[illegible]E+00	240.2[illegible]	45.[illegible]	2.7[illegible]	.32[illegible]E+05
16.[illegible]	.00	145.60	-28.5[illegible]	[illegible]	2[illegible]	4[illegible]	[illegible]	[illegible]
16.25	.00	143.70	-29.6[illegible]	[illegible]	[illegible]	47.[illegible]	.5[illegible]	[illegible]
16.[illegible]	.00	141.10	-27.7[illegible]	[illegible]	[illegible]	45.[illegible]	.[illegible]	[illegible]
16.75	.00	137.[illegible]	-27.1[illegible]	[illegible]	[illegible]	44.[illegible]	.[illegible]	[illegible]
17.[illegible]	.[illegible]	132.[illegible]	-28.7[illegible]	[illegible]	[illegible]	5[illegible]	-.1[illegible]	[illegible]
17.25	.[illegible]	128.10	-31.4[illegible]	[illegible]	[illegible]	51.[illegible]	-.[illegible]	[illegible]
17.[illegible]	.[illegible]	12[illegible].50	-32.2[illegible]	[illegible]	[illegible]	52.[illegible]	-.4[illegible]	[illegible]
17.75	.[illegible]	124.30	-29.[illegible]	[illegible]	[illegible]	5[illegible]	-.4	[illegible]
1[illegible]	.[illegible]	12[illegible].70	-2[illegible]	[illegible]	[illegible]	5[illegible]	-.[illegible]	[illegible]
1[illegible].25	.[illegible]	121.10	-26.[illegible]	[illegible]	[illegible]	5[illegible]	-.2[illegible]	[illegible]
1[illegible]	.[illegible]	11[illegible].70	-25.[illegible]	[illegible]	[illegible]	5[illegible]	.[illegible]	[illegible]
1[illegible].75	.[illegible]	11[illegible].50	-24.7[illegible]	[illegible]	[illegible]	5[illegible]	.[illegible]	[illegible]
1[illegible]	.[illegible]	117.[illegible]	-23.[illegible]	[illegible]	[illegible]	5[illegible]	.[illegible]	[illegible]
1[illegible].25	.[illegible]	115.[illegible]	-22.4[illegible]	[illegible]	[illegible]	57.[illegible]	.7[illegible]	[illegible]

19.50	.00	114.70	-21.40	.[illegible]E+[illegible]	.[illegible]	57.7[illegible]	.9[illegible]	.[illegible]E+[illegible]
19.75	.96	113.70	-20.34	.[illegible]	.[illegible]	58.4[illegible]	1.1[illegible]	.[illegible]E+[illegible]
20.00	.00	112.70	-19.3[illegible]	.[illegible]E+[illegible]	.[illegible]	56.7[illegible]	1.4[illegible]	.[illegible]E+[illegible]
20.25	.00	111.60	-18.2[illegible]	.[illegible]E+1[illegible]	.[illegible]	54.5[illegible]	1.7[illegible]	.[illegible]E+1[illegible]
20.50	.00	110.60	-17.2[illegible]	.[illegible]E+[illegible]	.[illegible]	5[illegible].1[illegible]	2.[illegible]	.[illegible]E+[illegible]
20.75	.00	110.00	-16.20	.[illegible]+1[illegible]	.[illegible]	[illegible]	2.2[illegible]	.[illegible]E+[illegible]

TOTAL QDNw =-9.467E+04 TOTAL [illegible]= 1.[illegible]

NOV4

BUILDING-DHW DATA

TIME	F6	DHW TP	TDS	QDHW	F4-5	T2	BUILDING TD2	QBLD
7.00	.00	117.40	-.90	.0000E+00	256.30	137.80	-4.50	-.5767E+06
7.25	.00	115.10	-.90	.0000E+00	234.70	137.90	-4.80	-.5633E+06
7.50	.00	113.20	-.60	.0000E+00	238.30	135.40	-4.10	-.5131E+06
7.75	.00	111.10	-.60	.0000E+00	236.40	136.00	-4.80	-.5674E+06
8.00	.00	109.50	-.40	.0000E+00	256.80	134.30	-4.10	-.5264E+06
8.25	.00	107.70	-.40	.0000E+00	258.30	133.90	-4.10	-.5295E+06
8.50	.00	106.10	-.60	.0000E+00	258.40	133.60	-3.90	-.5039E+06
8.75	.00	104.50	-.90	.0000E+00	260.30	132.90	-3.80	-.4946E+06
9.00	.00	103.10	-.90	.0000E+00	267.10	132.50	-3.60	-.4808E+06
9.25	.00	101.00	-1.10	.0000E+00	270.90	132.20	-3.40	-.4605E+06
9.50	.00	100.40	-1.20	.0000E+00	280.30	131.20	-3.10	-.4345E+06
9.75	.00	99.10	-1.20	.0000E+00	291.50	130.40	-2.80	-.4081E+06
10.00	.00	93.60	-22.80	.0000E+00	294.30	129.40	-2.80	-.4120E+06
10.25	.00	96.30	-40.10	.0000E+00	300.60	129.00	-2.60	-.3908E+06
10.50	.00	94.00	-39.80	.0000E+00	300.10	128.80	-2.50	-.3751E+06
10.75	.00	89.40	-41.50	.0000E+00	299.90	128.40	-2.50	-.3749E+06
11.00	.00	86.40	-46.30	.0000E+00	297.40	128.90	-2.60	-.3866E+06
11.25	.00	79.90	-54.40	.0000E+00	297.40	130.70	-3.00	-.4461E+06
11.50	.00	80.80	-52.40	.0000E+00	297.80	132.00	-2.90	-.4318E+06
11.75	4.50	123.40	-26.30	-.5917E+05	308.80	131.70	-2.50	-.3860E+06
12.00	4.60	124.60	-16.50	-.3795E+05	311.70	132.30	-2.60	-.4052E+06
12.25	5.00	126.00	-15.00	-.3750E+05	314.40	132.50	-2.50	-.3930E+06
12.50	4.60	126.40	-15.20	-.3496E+05	314.50	133.20	-2.50	-.3931E+06
12.75	5.00	129.30	-14.60	-.3650E+05	317.10	132.90	-2.40	-.3805E+06
13.00	6.10	132.10	-12.70	-.3873E+05	320.10	133.30	-2.00	-.3201E+06
13.25	6.50	130.00	-12.50	-.4062E+05	321.50	128.00	-1.70	-.2733E+06
13.50	5.70	131.40	-13.40	-.3819E+05	322.90	130.00	-2.30	-.3703E+06
13.75	4.80	129.90	-13.30	-.3192E+05	321.80	131.30	-2.30	-.3701E+06
14.00	4.50	130.40	-15.50	-.3487E+05	322.30	131.70	-2.20	-.3542E+06
14.25	4.40	128.60	-14.90	-.3278E+05	321.70	131.50	-2.10	-.3378E+06
14.50	4.00	123.90	-19.30	-.3860E+05	322.70	127.50	-1.90	-.3047E+06
14.75	.00	110.80	-21.80	.0000E+00	286.80	115.20	-.10	-.1434E+05
15.00	.00	109.60	-21.00	.0000E+00	171.30	106.70	-.30	-.2570E+05
15.25	.00	83.60	-36.70	.0000E+00	45.70	103.90	-.40	-.9140E+04
15.50	.00	82.90	-34.60	.0000E+00	.00	103.70	-.20	.0000E+00
15.75	.00	83.20	-27.00	.0000E+00	.04	103.70	-.10	.0000E+00
16.00	.00	82.30	-21.00	.0000E+00	.00	103.30	.00	.0000E+00
16.25	.00	81.60	-15.10	.0000E+00	.00	102.90	.20	.0000E+00
16.50	.00	81.50	-12.50	.0000E+00	.00	102.70	.10	.0000E+00
16.75	.[illegible]	81.50	-10.[illegible]	.0000E+00	.00	102.4[illegible]	.20	.0000E+00
17.00	.00	81.50	-7.80	.0000E+00	.00	1[illegible]2.[illegible]	.30	.0000E+00
17.25	.00	81.40	-5.30	.0000E+00	.00	101.80	.40	.0000E+00
17.50	.00	81.50	-4.90	.0000E+00	.00	101.30	.40	.0000E+00
17.75	.00	81.70	-3.50	.0000E+00	.00	101.10	.50	.0000E+00
18.00	.00	82.[illegible]	-2.50	.0000E+00	.00	10[illegible].70	.50	.0000E+00
18.25	.00	81.1[illegible]	-1.80	.0000E+00	.00	10[illegible].40	.60	.0000E+00
18.50	.00	79.50	-3.[illegible]	.0000E+00	.00	10[illegible].[illegible]	.50	.0000E+00
18.75	.[illegible]	8[illegible].[illegible]	-3.1[illegible]	.0000E+00	.[illegible]	[illegible]	.70	.0000E+00

TOTAL QDHW =-1.1[illegible]E+05   TOTAL QBLD =-3.3[illegible]E+06

APPENDIX E6

GENERATOR-EVAPORATOR DATA

(Summer Mode-Cooling Season)

(Sample pages only. See Section 4.0 of the text)

APPENDIX E6

GENERATOR-EVAPORATOR DATA

(Applies to Summer Mode Only)

Hourly Data (The following symbols appear as column headings)

Time:	Eastern Standard Time
Generator:	Heat exchanger of the absorption chiller used to vaporize refrigerant
Evaporator:	Heat exchanger of the absorption chiller used to chill the returning water from the building or storage tank 1.
F3:	Water flow rate in the generator of the absorption chiller as measured by flow meter F3 (g.p.m.)
T3:	Inlet temperature of the water flowing into the generator either from the storage tanks 2 and 3 or the auxiliary boiler (^oF)
TD3:	Temperature drop of the hot water flowing in the generator heat exchanger of the absorption chillers (F)
QGEN:	Rate of heat delivered to the generator (BTU/hr)
F 4-5:	Water flow rate flowing through the building-evaporator loop as measured by flow meter F 4-5 (g.p.m.)
T5:	Evaporator water outlet temperature (^oF)
TD5:	Temperature difference (in-out) of the water flowing in the evaporator (water chiller) (F).
QEVAP:	Rate of heat aborbed from the returning chilled water (BTU/hr).
C.O.P.	Instantaneous coefficient of performance of the absorption chiller (QEVAP/QGEN). (Dimensionless).

APPENDIX E6 (Cont'd)

GENERATOR-EVAPORATOR DATA

2. <u>Daily Summary</u> (The following abbreviations appear at the bottom of each page)

Total QGEN:	Integrated value of the energy supplied to the generator of the absorption chiller (BTU/daytime period i.e., for the hours shown in each page)
Total QEVAP:	Integrated value of the energy absorbed in the water chiller from the returning building water (BTU/daytime period, i.e., for the hours shown in each page)

AUG5
GENERATOR-EVAPORATOR DATA AND RATIO (QEVAP/QGEN)

	GENERATOR				EVAPORATOR				
TIME	F3	T3	TD3	QGEN	F4-5	T5	TD5	QEVAP	C.O.P
6.00	.00	97.70	.25	.0000E+00	246.90	85.30	-.01	-.1235E+04	99.00
6.25	.00	97.60	.55	.0000E+00	246.60	85.10	.09	.1110E+05	99.00
6.50	.00	97.50	.75	.0000E+00	246.60	84.90	.09	.1110E+05	99.00
6.75	.00	97.40	1.05	.0000E+00	246.50	84.60	.09	.1109E+05	99.00
7.00	.00	97.40	1.25	.0000E+00	246.30	84.60	.09	.1108E+05	99.00
7.25	.00	97.40	1.45	.0000E+00	246.20	84.40	.09	.1108E+05	99.00
7.50	.00	97.30	1.65	.0000E+00	246.40	84.40	.09	.1109E+05	99.00
7.75	.00	97.20	1.75	.0000E+00	246.10	84.40	.09	.1107E+05	99.00
8.00	.00	97.20	1.95	.0000E+00	246.20	84.40	.09	.1108E+05	99.00
8.25	.00	97.20	2.05	.0000E+00	246.10	84.40	.09	.1107E+05	99.00
8.50	.00	97.10	2.25	.0000E+00	246.10	84.50	.09	.1107E+05	99.00
8.75	.00	97.00	2.35	.0000E+00	246.20	84.70	.09	.1108E+05	99.00
9.00	.00	97.10	2.45	.0000E+00	246.00	84.80	.09	.1107E+05	99.00
9.25	.00	97.00	2.55	.0000E+00	246.10	85.00	.09	.1107E+05	99.00
9.50	.00	96.90	2.65	.0000E+00	246.00	85.30	.09	.1107E+05	99.00
9.75	57.80	175.70	34.45	.9956E+06	245.90	79.10	.69	.8484E+05	.09
10.00	191.80	173.60	7.95	.7624E+06	245.50	63.60	4.09	.5020E+06	.66
10.25	141.30	194.50	12.85	.9079E+06	245.30	64.70	1.49	.1827E+06	.20
10.50	74.40	194.20	.00	.0000E+00	245.60	66.20	.69	.8473E+05	99.00
10.75	233.00	223.70	14.75	.1718E+07	242.30	45.80	6.69	.8105E+06	.47
11.00	115.00	205.70	28.25	.1624E+07	240.20	47.10	2.59	.3111E+06	.19
11.25	111.30	211.60	27.55	.1533E+07	240.00	47.80	2.69	.3228E+06	.21
11.50	50.90	189.50	29.55	.7546E+06	240.10	43.80	3.19	.3830E+06	.51
11.75	82.70	225.40	28.15	.1164E+07	239.90	45.90	2.49	.2987E+06	.26
12.00	78.30	156.40	27.65	.1090E+07	242.20	48.30	1.99	.2390E+06	.22
12.25	83.50	199.90	33.85	.1413E+07	240.10	45.10	2.99	.3589E+06	.25
12.50	64.50	213.40	25.65	.8272E+06	240.00	45.30	2.49	.2988E+06	.36
12.75	56.50	185.50	.00	.0000E+00	240.00	47.30	2.09	.2508E+06	99.00
13.00	57.80	168.00	32.65	.1107E+07	240.00	48.10	3.19	.3828E+06	.35
13.25	87.70	180.20	14.75	.6468E+06	240.10	47.80	2.29	.2749E+06	.43
13.50	39.70	161.20	20.15	.4000E+06	239.80	47.40	2.79	.3345E+06	.84
13.75	38.40	182.60	22.35	.4291E+06	239.90	46.40	2.69	.3227E+06	.75
14.00	48.80	183.40	22.15	.5405E+06	240.10	45.60	2.69	.3229E+06	.60
14.25	44.90	183.50	23.45	.5265E+06	240.10	46.30	2.09	.2509E+06	.48
14.50	32.30	184.00	25.95	.4191E+06	239.90	47.50	2.39	.2867E+06	.68
14.75	41.60	183.90	24.15	.5023E+06	239.90	45.70	2.89	.3467E+06	.69
15.00	45.50	184.00	23.55	.5358E+06	240.00	43.60	2.39	.2868E+06	.54
15.25	36.80	183.80	26.35	.4848E+06	239.90	47.30	2.09	.2507E+06	.52
15.50	33.80	183.90	25.15	.4250E+06	239.90	46.10	2.79	.3347E+06	.79
15.75	30.40	183.50	24.55	.5187E+06	240.20	44.40	2.69	.3231E+06	.52
16.00	.00	182.90	25.95	.0000E+00	20.90	46.40	1.39	.1453E+05	99.00
16.25	.00	182.40	23.35	.0000E+00	.00	47.30	1.49	.0000E+00	99.00
16.50	.00	181.50	24.35	.0000E+00	.00	48.20	1.09	.0000E+00	99.00
16.75	.00	180.90	25.35	.0000E+00	.00	49.10	.79	.0000E+00	99.00
17.00	.00	180.00	26.25	.0000E+00	.00	49.70	.69	.0000E+00	99.00
17.25	.00	179.60	27.15	.0000E+00	.00	50.60	.49	.0000E+00	99.00
17.50	.00	178.70	28.15	.0000E+00	.00	51.20	.49	.0000E+00	99.00
17.75	.00	177.80	29.75	.0000E+00	.00	51.90	.39	.0000E+00	99.00
18.00	.00	177.20	29.95	.0000E+00	.00	52.40	.29	.0000E+00	99.00

TOTAL QGEN= 4.557E+06 TOTAL QEVAP= 2.003E+06

APPENDIX E7

CONDENSER-BUILDING DATA

(Summer Mode–Cooling Season)

(Sample pages only. See Section 4.0 of the text)

APPENDIX E7

CONDENSER-BUILDING DATA
(Applies to Summer Mode Only)

1. Hourly Data (The following symbols appear as column headings)

Time:	Eastern Standard Time
Condenser:	Heat exchangers (absorber/condenser) of the absorption chiller used to remove the heat of solution and the heat of condensation of the refrigerant
Building:	Building-evaporator loop containing fan coil units through which chilled water is being circulated
F2:	Water flow rate in the absorber and the condenser of the absorption chiller as measured by flow meter F2 (g.p.m.)
T4:	Inlet temperature of the water flowing into the absorber/condenser from the cooling tower (^oF)
TD4:	Temperature rise of the cooling water flowing through the absorption chiller (^oF)
QCOND:	Rate of heat absorbed by the cooling water flowing through the absorber/condenser of the absorption chiller (BTU/hr)
F4-5:	Water flow rate flowing through the building-evaporator loop as measured by flow meter F4-5 (g.p.m.)
T2:	Water inlet temperature entering building loop (^oF)
TD2:	Temperature rise (out-in) of the chilled water flowing in the building loop (F)
QBLD:	Rate of cooling delivered to the building (cooling load of the building) (BTU/hr)

APPENDIX E7 (Cont'd)

CONDENSER-BUILDING DATA

1. Hourly Data (cont'd)

HTBL: Instantaneous heat balance factor of the absorption chiller, i.e., ratio of the sum of evaporator load and generator load to condenser load. For perfect heat balance this ratio is 1.0. When the computer generates a large number or the denominator is zero the number (99.00) is entered in the column. Ignore negative numbers. (Dimensionless)

2. Daily Summary (The following abbreviations appear at the bottom of each page)

Total QCOND: Integrated value of the heat removed from the absorption chiller by the cooling water flowing through the cooling tower (BTU/day time period i.e., for the hours shown in each page).

Total QBLD: Integrated value of the cooling load delivered to the building by the chilled water. (BTU/day time period, i.e., for the hours shown in each page)

AUG5
CONDENSER-BUILDING DATA AND RATIO (QCOND/(QEVAP+QGEN))

	CONDENSER					BUILDING			
TIME	F2	TA	TD4	QCOND	F4-5	T2	TD2	QBLD	HTBAL
6.00	.00	92.60	-.12	.0000E+00	246.90	85.10	.00	.0000E+00	.00
6.25	.00	92.40	-.12	.0000E+00	246.80	84.80	.00	.0000E+00	.00
6.50	.00	92.30	-.12	.0000E+00	246.60	84.60	.00	.0000E+00	.00
6.75	.00	92.20	-.02	.0000E+00	246.50	84.40	.00	.0000E+00	.00
7.00	.00	92.10	-.02	.0000E+00	246.30	84.30	.00	.0000E+00	.00
7.25	.00	92.10	-.02	.0000E+00	246.20	84.20	.00	.0000E+00	.00
7.50	.00	92.00	.08	.0000E+00	246.40	84.20	.00	.0000E+00	.00
7.75	.00	91.90	.08	.0000E+00	246.10	84.10	.00	.0000E+00	.00
8.00	.00	91.90	.08	.0000E+00	246.20	84.10	.00	.0000E+00	.00
8.25	.00	91.80	.18	.0000E+00	246.10	84.20	.00	.0000E+00	.00
8.50	.00	91.80	.28	.0000E+00	246.10	84.30	.00	.0000E+00	.00
8.75	.00	91.80	.28	.0000E+00	246.20	84.40	.00	.0000E+00	.00
9.00	.00	91.70	.38	.0000E+00	246.00	84.60	.00	.0000E+00	.00
9.25	.00	91.60	.38	.0000E+00	246.10	84.70	.00	.0000E+00	.00
9.50	.00	91.50	.48	.0000E+00	246.00	85.00	.10	.1230E+05	.00
9.75	101.30	76.30	2.08	.1054E+06	245.90	79.00	.60	.7377E+05	.10
10.00	286.20	76.60	8.18	.1171E+07	245.50	63.60	3.80	.4664E+06	.93
10.25	132.90	77.50	3.68	.2445E+06	245.30	64.40	1.40	.1717E+06	.22
10.50	84.60	79.30	4.28	.1810E+06	245.60	66.00	.60	.7358E+05	2.14
10.75	275.50	81.60	12.18	.1678E+07	242.30	45.40	5.30	.7632E+06	.66
11.00	192.00	79.00	7.38	.7085E+06	240.20	46.90	2.60	.3123E+06	.37
11.25	253.40	77.00	8.08	.1024E+07	240.00	47.60	2.70	.3240E+06	.55
11.50	199.30	77.50	7.58	.7553E+06	240.10	43.30	3.20	.3842E+06	.66
11.75	169.10	78.10	6.98	.5902E+06	239.90	45.50	2.60	.3119E+06	.40
12.00	161.70	77.30	7.38	.6705E+06	240.20	48.50	2.00	.2402E+06	.50
12.25	239.90	77.00	7.38	.6852E+06	240.10	45.70	2.90	.3481E+06	.50
12.50	190.80	78.10	6.48	.6182E+06	240.00	45.00	2.50	.3000E+06	.55
12.75	247.90	77.20	7.28	.7568E+06	240.00	48.10	2.10	.2520E+06	3.02
13.00	203.50	77.40	7.18	.7306E+06	240.00	48.80	2.70	.3240E+06	.49
13.25	224.70	76.10	6.18	.5943E+06	240.10	47.60	2.30	.2761E+06	.75
13.50	223.40	75.90	6.08	.6791E+05	239.80	47.10	2.70	.3237E+06	.92
13.75	214.40	76.30	5.78	.6196E+06	239.90	46.20	2.70	.3239E+06	.8?
14.00	249.20	75.40	5.58	.6953E+05	240.10	45.20	2.70	.3241E+06	.8?
14.25	226.30	75.30	5.58	.5305E+06	240.10	47.10	2.20	.2641E+06	.8?
14.50	269.00	75.50	5.78	.6?40E+06	239.90	47.40	2.50	.2999E+06	.86
14.75	227.90	75.40	5.98	.6928E+06	239.90	45.60	2.90	.3479E+06	.82
15.00	251.60	75.40	5.58	.7220E+05	240.00	43.60	2.40	.2880E+06	.85
15.25	213.10	75.30	5.48	.5839E+05	239.90	47.10	2.20	.2639E+06	.79
15.50	213.30	75.50	5.18	.5653E+06	239.90	45.50	2.80	.3359E+06	.88
15.75	202.10	75.40	5.78	.6708E+06	240.20	45.70	2.70	.3243E+06	.71
16.00	.00	77.50	5.28	.0000E+00	20.90	46.50	.80	.8360E+04	.00
16.25	.00	79.50	4.98	.0000E+00	.00	47.70	.60	.0000E+00	99.00
16.50	.00	81.10	4.68	.0000E+00	.00	48.50	.40	.0000E+00	99.00
16.75	.00	82.30	4.38	.0000E+00	.00	49.60	.10	.0000E+00	99.00
17.00	.00	[illegible]	4.08	.0000E+00	.00	52.60	-.10	.0000E+00	99.00
17.25	.00	85.20	3.78	.0000E+00	.00	51.30	-.30	.0000E+00	99.00
17.50	.00	85.40	3.48	.0000E+00	.00	52.30	-.40	.0000E+00	99.00
17.75	.00	87.40	3.18	.0000E+00	.00	53.60	-.40	.0000E+00	99.00
18.00	.00	[illegible]	2.98	.0000E+00	.00	53.70	-.30	.0000E+00	99.00
18.25	.00	[illegible]	2.88	.0000E+00	.00	54.50	-.20	.0000E+00	99.00
18.50	.00	[illegible]	2.68	.0000E+00	.00	55.00	.00	.0000E+00	99.00
18.75	.00	[illegible]	2.48	.0000E+00	.00	55.90	.40	.0000E+00	99.00
19.00	.00	91.20	2.38	.0000E+00	.00	56.50	.60	.0000E+00	99.00

19.25	.00	91.51	2.18	.0000E+00	.00	57.10	.70	.0000E+00	99.00
19.50	.00	92.30	2.10	.0000E+00	.00	57.70	.90	.0000E+00	99.00
19.75	.00	92.80	2.08	.0000E+00	.00	58.40	1.10	.0000E+00	99.00
20.00	.00	93.30	1.98	.0000E+00	.00	58.70	1.40	.0000E+00	99.00
20.25	.00	93.50	1.88	.0000E+00	.00	59.50	1.70	.0000E+00	99.00
20.50	.00	94.10	1.78	.0000E+00	.00	60.10	2.00	.0000E+00	99.00
20.75	.00	94.30	1.55	.0000E+00	.00	60.50	2.20	.0000E+00	99.00

TOTAL QCONV= 4.334E+06   TOTAL QSLO= 1.934E+06

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