PERFORMANCE ANALYSIS AND OPTIMIZATION
OF THE UNIVERSITY OF PENNSYLVANIA RETROFITTED
SOLAR HEATED PHILADELPHIA ROW HOME

Progress Report
for Period October 15, 1976 - August 15, 1977

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Abstract

The design, specification and purchasing phase of the instrumentation and data acquisition system needed for the performance analysis and optimization of the solar heating system, and for the acquisition of Philadelphia weather and insolation data is complete, and is described briefly. A subroutine for the analysis of the effects of the control logic and limits on the performance of the solar system has been written and implemented into the University of Pennsylvania general program SOLSYS. The installation of the instruments is ongoing. A contract renewal proposal was written to conduct the data acquisition, and system analysis and optimization beginning from the heating season 1977/8.

1. INTRODUCTION

This project can be seen to consist of two major parts:

- A. Design and construction of the instrumentation and data acquisition system.
- B. Performance testing, analysis and optimization of the solar heating system, as well as acquisition of weather and solar data for Philadelphia.

The official starting date of the contract is October 15, 1976; however, the actual contract papers were sent to the University of Pennsylvania and signed only at the end of December 1976. We could not therefore start the work (i.e. incur expenses) before that later date. The major consequence of this delay was that we could not complete the needed instrumentation system in time for the 1976/7 heating season, but we would be ready for the 1977/8 heating season. A contract renewal proposal to allow this is being sent to ERDA alongside this report.

2. ACCOMPLISHMENTS

The major accomplishments under this contract so far are:

2.1 Design of the Instrumentation and Data Acquisition System

The design of the instrumentation system is complete. This included:

- (1) Definition of the solar system performance criteria, for the calculation of which the measurements are made.
- (2) Selection of appropriate types of instruments for the measurement of temperature, flow, pressure, insolation, wind velocity and direction, humidity, and electric power.

- (3) Design of appropriate instrument installation techniques, in consultation with available pertinent standards and recommended practices issued by the ASHRAE, ASME, ISA, ASTM, BS and DIN. The experience accumulated at the University of Pennsylvania in the area of solar component testing was fully utilized.
- (4) Design of appropriate sensor signal conditioning methods, and selection of an effective and economical method for data acquisition.

In particular, the transient nature of many of the measured parameters requires a measurement frequency of the order of one measurement per minute or better. Since our system has approximately 80 channels, this would result in the acquisition of a very large quantity of data over the year. To alleviate this problem, two major steps were taken: large capacity magnetic digital tape recording (1/2" x 1200' reel) of the data is used, and a technique of digital data averaging, available in the chosen data acquisition system was employed. In this technique, the most transient channels are scanned continuously (i.e., at a frequency of 1 channel per 8 seconds in our system), the results are digitally averaged by the DAS, and then the averages are recorded at a slower frequency, say once per 80 seconds.

2.2 Specification and Purchasing

All the instrumentation to be purchased was fully specified, and in most cases requests for quotations (RFQ-S) were issued to vendors. A careful

comparison of technical specifications, costs, delivery periods, and service arrangements was made before the actual purchase order was issued. All the instrumentation is now either on order or has already been received by us.

The selection of performance criteria and the specification of instruments was aided by publications of The Solar Heating and Cooling Performance Evaluation Committee¹ and of NBS/ERDA².

A detailed topical report describing the design, specification, selection, purchase, calibration and installation of the instrumentation system is now under preparation. The highlights are presented in Appendix A to this progress report.

2.3 Control Logic Analysis Program

A subroutine for the analysis of the effects of the control logic and limits on the performance of the solar heating system was added to the University of Pennsylvania general computer program SOLSYS. SOLSYS has the capability of analyzing the performance of solar heating systems and components and has been used to design the system on the subject row home.

The subroutine will allow the planning of effective optimization experiments, which are part of the ongoing project, and would be tested by the actual experimental results.

2.4 Publications

The following publications related to the project appeared during this period:

¹Hale, M. J., et al., "Instrumentation Installation Guidelines for the National Solar Heating and Cooling Program", USERDA Publication SHC-1006, August 4, 1976.

²Streed, E., et al., "Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program", Publication NBSIR 76-1137, National Bureau of Standards (Prepared for USERDA, Division of Solar Energy and for U.S.H.U.D., Division of Energy, August 1976).

1. N. Lior, J. A. Lepore and S. Shore, "Residential Solar Heating Retrofit in the Urban Environment", Proceedings of the Joint Conference of the American Section of the International Solar Energy Society and the Solar Energy Society of Canada, August 15-20, 1976, Winnipeg, Manitoba, Canada. Also published in edited form as MEAM Report No. 76-10 in December 1976.
2. N. Lior, J. O'Leary and D. Edelman, "Optimized Spacing between Rows of Solar Collectors", Proc. International Solar Energy Society Conference (U.S. Section), June 6-10, 1977, Orlando, FL.
3. S. Shore, J. A. Lepore and N. Lior, "Solar System Retrofit of Row Houses - A Proven Energy Conservation Method?", Proc. National Conference and Exhibition on Technology for Energy Conservation, June 8-10, 1977, Washington, DC.

A presentation on the project was made, and its typed contents submitted, at the USERDA Solar Heating and Cooling R&D Branch Contractors Meeting at Reston, VA during August 8-10, 1977. This presentation is enclosed as Appendix A to this report.

Reprints of all above publications were submitted to ERDA during the above-mentioned Contractors Meeting at Reston, VA.

2.4 Time Spent by Principal Investigator

91.1% of the time formally allocated in the proposal was devoted by the Principal Investigator to this project til August 15, 1977. Although only 8.9% remain til the end of the present contract period, the Principal Investigator shall devote to this project significantly more, as part of a cost-sharing process.

3. PLANNED WORK

During the remaining period, til October 15, 1977, it is planned to complete the calibration and installation of the instrumentation system. If the contract renewal proposal is approved by ERDA, solar heating performance analysis and optimization shall be conducted starting from the heating season 1977/8.

APPENDIX

Design and Specification Highlights of the Instrumentation and Data Acquisition System

PERFORMANCE ANALYSIS AND OPTIMIZATION OF
THE UNIVERSITY OF PENNSYLVANIA RETROFITTED
SOLAR HEATED PHILADELPHIA ROW HOME

U.S.E.R.D.A. CONTRACT NO. EG-77-S-02-4142.*000

PRINCIPAL INVESTIGATOR: DR. NOAM LIOR
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PROJECT MONITORS: MR. MICHAEL MAYBAUM, PROGRAM MANAGER
MR. WALTER ADAMS

ERDA SOLAR HEATING AND COOLING R&D BRANCH CONTRACTOR'S MEETING
RESTON, VA; AUGUST 8-10

PROJECT OBJECTIVES

- A. TO MONITOR AND ANALYZE THE PERFORMANCE OF THE PHILADELPHIA ROW HOME WHICH WAS RETRO-FITTED TO SOLAR HEATING BY THE UNIVERSITY OF PENNSYLVANIA, AND TO EXAMINE ITS ACCEPTANCE IN THE URBAN ENVIRONMENT.
- B. TO OPTIMIZE THE PERFORMANCE OF THE SYSTEM RELATIVE TO ENERGY-EFFICIENCY AND COST.
- C. TO PROVIDE HOURLY WEATHER AND INSOLATION DATA FOR PHILADELPHIA FOR A PERIOD OF TWO YEARS.

PERFORMANCE EVALUATION CRITERIA

- 1. SAVINGS IN FOSSIL FUEL
- 2. TOTAL THERMAL ENERGY LOADS
- 3. FRACTION OF THERMAL LOADS SUPPLIED BY SOLAR ENERGY
- 4. SOLAR SYSTEM ENERGY CONVERSION EFFICIENCY
- 5. THERMAL PERFORMANCE OF MAJOR COMPONENTS
 - *COLLECTORS, WITH & WITHOUT PARTIAL SHADING
 - *STORAGE
 - *FREEZE PROTECTION DRAIN-DOWN SYSTEM
 - *HEAT EXCHANGERS
- 6. OCCUPANTS SYSTEM USE (DEMAND, TEMPERATURE, ETC.)
- 7. OPERATIONAL CHARACTERISTICS, CONTROLS, DEGRADATION
- 8. OPTIMIZATION: QUANTITY OF STORAGE, FLOW RATE, CONTROLS
- 9. ACCEPTANCE BY RESIDENTS, NEIGHBORHOOD, CITY GOVERNMENT
- 10. HOURLY SOLAR AND WEATHER-DATA FOR PHILADELPHIA.

CLIMATOLOGICAL MEASUREMENTS

INSOLATION

TOTAL: EPPLEY PSP PYRANOMETER (\$990)

DIFFUSE: EPPLEY PSP PYRANOMETER WITH SHADOWBAND
(\$1690)

WIND

R.M. YOUNG CO. UVW PROPELLER ANEMOMETER (\$1487)

HUMIDITY

WEATHERMEASURE HM111 SOLID STATE RELATIVE
HUMIDITY SENSOR (\$772)

TEMPERATURE

ARI 100 Ω PLATINUM RTD (\$41)

TEMPERATURE MEASUREMENT

EXCEPT FOR AIR TEMPERATURE DIFFERENCES IN DUCTS,
USE 100 Ω MATCHED PLATINUM RESISTANCE TEMPERA-
TURE DETECTORS (ARI, INC.) DUE TO HIGH STABILITY
AND LEVEL OF OUTPUT SIGNAL.

COST (INCLUDING TERMINAL HEAD): \$41 EACH

PRESENT DAY DVM-S AND STABLE CURRENT
SOURCES ALLOW SUFFICIENTLY PRECISE
TEMPERATURE MEASUREMENT BY THE CON-
STANT CURRENT, 4-WIRE METHOD

ADVANTAGES OF 4-WIRE CONSTANT CURRENT METHOD:

- *ELIMINATE LEAD RESISTANCE ERRORS
- *SIMPLE INEXPENSIVE CIRCUIT
- *INCREASED (AT LEAST DOUBLE) SENSITIVITY
- *LINEAR OUTPUT
- *ALLOWS DETERMINATION OF TEMPERATURE DIFFERENCES TO BETTER THAN 0.1°C BY ARITHMETIC SUBTRACTION OF INDIVIDUAL RTD TEMPERATURES, THUS PROVIDES TEMPERATURE AND ΔT WITH SMALLEST NUMBER OF SENSORS (AND MEASUREMENT CHANNELS)

TEMPERATURE DIFFERENCE IN AIR DUCTS

10-JUNCTION TYPE K THERMOPILE, EACH JUNCTION PLACED IN THE CENTER OF ONE OF 10 DUCT SEGMENTS OF EQUAL CROSS-SECTIONAL AREA.

PREMIX AIR STREAM UPSTREAM OF TEMPERATURE MEASUREMENT SECTION.

FOLLOW ASHRAE STANDARD 41-66 "TEMPERATURE MEASUREMENTS", 1966.

FLOW MEASUREMENT: GENERAL

MAIN PROBLEM IS THE COMBINATION OF:

- 1) LOW FLOW RATE
- 2) SOME FLOWS HAVE A VERY WIDE RANGE
- 3) ELECTRICAL OUTPUT SIGNAL IS REQUIRED
- 4) HIGH ACCURACY IS REQUIRED

MAJOR APPLICABLE INSTRUMENTS:

1) TURBINE METER:	*HIGHEST ACCURACY (~0.25% OF READING)
*BEARING PROBLEMS
2) TARGET METER:	*RELIABLE: NO MOVING PARTS
*RELATIVELY HIGH PRESSURE DROP
3) MAGNETIC FLOWMETER:	*LOWEST PRESSURE DROP
*HIGHEST COST

ALL ARE EXPENSIVE.

SPECIFIC FLOWMETERS

SYSTEM	FLUID	MAXIMUM FLOW	COMMENTS	MODEL	TOTAL PRICE
Collector loop	water	14 gpm		RAMAPO 1" (Target)	\$ 719
Demand loop	water	8 gpm	low head available	INVALCO 3/4" (Turbine)	623
DHW	water	12 gpm	wide flow range needed	FLOW TECHNOLOGY 5/8" (Turbine)	1140
Warm air	air	1500 cfm	very low ΔP ($\approx 0.05"$ w.c.) for measurement	AIR MONITOR FAN-E (averaged Pitot)	144+ 1300?
Furnace fuel	fuel oil #2	2 gph	very low flow rate	CONAMETER CORP #13	710
DHW Heater	natural gas	75 cfh	gas supply pressure very low: 5.5" w.c.	AMERICAN METER AC-80 (DIAPHRAGM), $\Delta P = 0.5"$ w.c.; with in-house modification to provide electric signal	~600

PRESSURE

- 1) MECHANICAL INDICATING PRESSURE GAUGES
- 2) STRAIN GAUGE TYPE TRANSDUCERS

ELECTRIC POWER

SOLAR LOOP CIRCULATION PUMP
DEMAND LOOP PUMP
WARM AIR FAN

ALL USE LEEDS & NORTHRUP #759 TRANSDUCERS

KEEP VOLTAGE TERMINALS ALWAYS CONNECTED TO AVOID START
AND STOP TRANSIENT ERRORS

DATA ACQUISITION SYSTEM

*TO AVOID ERRORS DUE TO TRANSIENTS AND YET HAVE A
MANAGEABLE QUANTITY OF DATA, RECORD AVERAGES OF THE
MOST TRANSIENT PARAMETERS EITHER BY INTEGRATION OF
ANALOG SIGNAL PRIOR TO INPUT TO DAS, OR BY DIGITAL
AVERAGING OF OUTPUTS FROM FREQUENT SCANS (PERFORMED
INSIDE DAS). THUS, A SCAN EVERY 5-10 MINUTES IS
SUFFICIENT.

*RECORD DATA ON

- 1) DIGITAL MAGNETIC TAPE, FOR COMPLETE PROCESSING.
- 2) WIDE-CARRIAGE PRINTER FOR IMMEDIATE DATA MONITORING
AND FOR REDUNDANCY.

University of Pennsylvania
 PERFORMANCE ANALYSIS AND OPTIMIZATION OF
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INSTRUMENTATION TABLE

MEASUREMENT	DESCRIPTION	RANGE	SENSOR MODEL
<u>Climatological:</u>			
H001	Outdoor humidity	0 to 100% RH	WEATHERMEASURE HM111
I001	Total insolation	0 to 1150 W/m ² (0 to 365 Btu/hr.ft ²)	EPPLEY PSP
I002	Diffuse insolation	0 to 500 W/m ² (0 to 158 Btu/hr.ft ²)	EPPLEY PSP with shadowband
P001	Outdoor barometric pressure	98.2 to 105 kN/m ² (29" to 31" Hg)	
T001	Outdoor dry-bulb temperature	-40 to 50°C (-40 to 122°F)	ARI [†]
V001	Wind velocity and direction (3-dimensional, UVW)	0 to 34 m/s (0 to 80 mph); 0 to 360°	R. M. Young 27004/21282/27503
<u>Collector System:</u>			
EP600	Electrical power to circulation pump	0 to 1500 W	LEEDS & NORTHRUP 759
P100	Circulation pump discharge	0 to 413.7 kN/m ² gauge (0 to 60 psig)	Indicating gauge
P101	Inlet to first collector row	0 to 172.4 kN/m ² gauge (0 to 25 psig)	BELL & HOWELL CEC 4-312-0002
P102	Outlet from last collector row	0 to ±68.9 kN/m ² gauge (0 to ± 10 psig)	BELL & HOWELL CEC 4-312-0002

[†] ARI R-50172-6 FlCO-12 Platinum RTD

MEASUREMENT	DESCRIPTION	RANGE	SENSOR MODEL
<u>Collector System</u> cont'd:			
P103	Inlet to storage tanks	0 to 413.7 kN/m ² gauge (0 to 60 psig)	Indicating gauge
P.04	Circulation pump suction	0 to 172.4 kN/m ² abs (0 to 25 psia)	Indicating gauge
T100	Outlet from thermal storage tank #1 (w.SDHWH*)	-10 to 110°C (14 to 230°F)	ARI [†]
T101	Outlet from thermal storage tank #2	-10 to 110°C (14 to 230°F)	ARI [†]
T102	Outlet from thermal storage tank #3	-10 to 110°C (14 to 230°F)	ARI [†]
T103	Inlet to first collector row	-10 to 110°C (14 to 230°F)	ARI [†]
T104	Inlet to second collector row	-10 to 110°C (14 to 230°F)	ARI [†]
T105	Inlet to third collector row	-10 to 110°C (14 to 230°F)	ARI [†]
T106	Inlet to fourth collector row	-10 to 110°C (14 to 230°F)	ARI [†]
T107	Inlet to fifth collector row	-10 to 110°C (14 to 230°F)	ARI [†]
T108	Outlet from fifth collector row	-10 to 110°C (14 to 230°F)	ARI [†]
T109	Thermal storage tank inlet manifold	-10 to 110°C (14 to 230°F)	ARI [†]
W100	Collector loop	0.09 to 0.9 x 10 ⁻³ m ³ /s (1.4 to 14 GPM)	RAMAPO 1 in. Mark V
W101	Inlet to storage tank #1	0.12 to 0.63 x 10 ⁻³ m ³ /s (2 to 10 GPM)	BELL & GOSSETT TB - 1"
W102	Inlet to storage tank #2	0.12 to 0.63 x 10 ⁻³ m ³ /s (2 to 10 GPM)	BELL & GOSSETT TB - 1"
W103	Inlet to storage tank #3	0.12 to 0.63 x 10 ⁻³ m ³ /s (2 to 10 GPM)	BELL & GOSSETT TB - 1"

* SDHWH - Solar Domestic Hot Water Heater

† ARI R-50172 - 6F100-12 Platinum RTD

MEASUREMENT	DESCRIPTION	RANGE	SENSOR MODEL
<u>Collector System: cont'd</u>			
W104	Outlet from storage tank #1	0.12 to 0.63 x 10 ⁻³ m ³ /s (2 to 10 GPM)	BELL & GOSSETT TB - 1"
W105	Outlet from storage tank #2	0.13 to 0.64 x 10 ⁻³ m ³ /s (2 to 10 GPM)	BELL & GOSSETT TB - 1"
W106	Outlet from storage tank #3	0.13 to 0.64 x 10 ⁻³ m ³ /s (2 to 10 GPM)	BELL & GOSSETT TB - 1"
<u>Thermal Storage System:</u>			
T200	Temperature distribution in thermal storage tank #1	-10 to 110°C (14 to 230°F)	ARI ^{††}
T201	Temperature distribution in thermal storage tank #1	-10 to 110°C (14 to 230°F)	ARI ^{††}
T202	Temperature distribution in thermal storage tank #1	-10 to 110°C (14 to 230°F)	ARI ^{††}
T203	Temperature distribution in thermal storage tank #1	-10 to 110°C (14 to 230°F)	ARI ^{††}
T204	Temperature distribution in thermal storage tank #1	-10 to 110°C (14 to 230°F)	ARI ^{††}
T205	Temperature distribution in thermal storage tank #1	-10 to 110°C (14 to 230°F)	ARI ^{††}
T206	Temperature distribution in thermal storage tank #1	-10 to 110°C (14 to 230°F)	ARI ^{††}
T207	Temperature distribution in thermal storage tank #2	-10 to 110°C (14 to 230°F)	ARI ^{††}
T208	Temperature distribution in thermal storage tank #2	-10 to 110°C (14 to 230°F)	ARI ^{††}
T209	Temperature distribution in thermal storage tank #2	-10 to 110°C (14 to 230°F)	ARI ^{††}
T210	Temperature distribution in thermal storage tank #2	-10 to 110°C (14 to 230°F)	ARI ^{††}
T211	Temperature distribution in thermal storage tank #2	-10 to 110°C (14 to 230°F)	ARI ^{††}

†† ARI R-50171 - 24E100-12 Platinum RTD

MEASUREMENT	DESCRIPTION	RANGE	SENSOR MODEL
<u>Thermal Storage System cont'd</u>			
T212	Temperature distribution in thermal storage tank #2	-10 to 110°C (14 to 230°F)	ARI ^{††}
T213	Temperature distribution in thermal storage tank #2	-10 to 110°C (14 to 230°F)	ARI ^{††}
<u>Domestic Hot Water System:</u>			
F300	Gas flow rate to DHW gas-fired heater	$0.59 \times 10^{-3} \text{ m}^3/\text{s}$ (0 to 75 ft ³ /hr)	AMERICAN METER AC-80
P300	Inlet to SDHWH	0 to 413.7 kN/m ² gauge (0 to 60 psig)	Indicating gauge
P301	Outlet from SDHWH	0 to 413.7 kN/m ² gauge (0 to 60 psig)	Indicating gauge
P302	Outlet from gas-fired heater	0 to 413.7 kN/m ² gauge (0 to 60 psig)	Indicating gauge
T300	Inlet to SDHWH	-10 to 40°C (14 to 101°F)	ARI [†]
T301	Outlet from SDHWH	-10 to 110°C (14 to 230°F)	ARI [†]
T302	Outlet from gas heater	-10 to 110°C (14 to 230°F)	ARI [†]
T303	Inlet to appliances	-10 to 110°C (14 to 230°F)	ARI [†]
W300	Into SDHWH	$0.085 \text{ to } 0.84 \times 10^{-3} \text{ m}^3/\text{s}$ (0-13 GPM)	FLOW TECHNOLOGY FT-10N15-LJ turbine meter.
W301	Tempering Cold Water Supply		Domestic water meter
<u>Space Heating System:</u>			
EP601	Electrical power to demand loop		LEEDS & NORTHROP 759
EP603	Electrical power to warm air fan		LEEDS & NORTHROP 759
† ARI R-50172-6 F100-12 Platinum RTD			
†† ARI R-50171 - 24E100-12 Platinum RTD			

MEASUREMENT	DESCRIPTION	RANGE	SENSOR MODEL
<u>Space Heating System cont'd</u>			
F400	Oil flow rate to furnace	0 to $2.1 \times 10^{-6} \text{ m}^3/\text{s}$ (0 to 2 gph)	CONAMETER Series 13 Oscillating piston meter
P400	Demand loop pump discharge pressure	0 to 172.4 kN/m^2 gauge (0 to 25 psig)	Indicating Gauge
P401	Demand loop pump suction pressure	0 to 172.4 kN/m^2 abs (0 to 25 psia)	Indicating Gauge
PD400	Pressure difference between fan inlet and discharge	0-250 N/m^2 (0 to 1" w.c.)	DWYER MAGNEHELIC 2001
T400	Demand loop water exit from thermal storage tank #1	-10 to 110°C (14 to 230°F)	ARI [†]
T401	Demand loop water exit from thermal storage tank #2	-10 to 110°C (14 to 230°F)	ARI [†]
T402	Demand loop water at inlet to water-to-air space heater	-10 to 110°C (14 to 230°F)	ARI [†]
T403	Demand loop water at exit from water-to-air space heater	-10 to 110°C (14 to 230°F)	ARI [†]
T404	Return air temperature	-10 to 50°C (14 to 120°F)	ARI [†]
T405	Air temperature at exit from furnace	-10 to 65°C (14 to 150°F)	ARI [†]
T600	Basement air temperature	-10 to 50°C (14 to 120°F)	ARI [†]
T602	First floor air temperature	-10 to 50°C (14 to 120°F)	ARI [†]
T603	Second floor air temperature	-10 to 50°C (14 to 120°F)	ARI [†]
TD400	Air temperature difference across water-to-air exchanger	0- 20°C (0- 36°F)	10-junction type K thermopile
TD401	Air temperature difference across air heating furnace	0- 50°C (0- 90°F)	10-junction type K thermopile

[†]ARI R-50172-6 F100-12 Platinum RTD

(6)

MEASUREMENT	DESCRIPTION	RANGE	SENSOR MODEL
<u>Space Heating System cont'd</u>			
W400	Demand loop water outlet from thermal storage tank #1	$0.13 \text{ to } 0.64 \times 10^{-3} \text{ m}^3/\text{s}$ (2 to 5 gpm)	BELL & GOSSETT TB - 1" Indicator
W401	Demand loop water outlet from thermal storage tank #2	$0.13 \text{ to } 0.64 \times 10^{-3} \text{ m}^3/\text{s}$ (2 to 10 gpm)	BELL & GOSSETT TB - 1" Indicator
W402	Demand loop water outlet from thermal storage tank #3		BELL & GOSSETT TB - 1" Indicator
W403	Total flow rate through demand loop	$0.084 \text{ to } 0.84 \times 10^{-3} \text{ m}^3/\text{s}$ (1.3 to 13 gpm)	INVALCO W3/0750 turbine meter
W404	Demand loop water inlet to thermal storage tank #1	$0.13 \text{ to } 0.64 \times 10^{-3} \text{ m}^3/\text{s}$ (2 to 10 gpm)	BELL & GOSSETT TB - 1" Indicator
W405	Demand loop water inlet to thermal storage tank #2	$0.13 \text{ to } 0.64 \times 10^{-3} \text{ m}^3/\text{s}$ (2 to 10 gpm)	BELL & GOSSETT TB - 1" Indicator
W406	Demand loop water inlet to thermal storage tank #3	$0.13 \text{ to } 0.64 \times 10^{-3} \text{ m}^3/\text{s}$ (2 to 10 gpm)	BELL & GOSSETT TB - 1" Indicator
W407	Warm air total flow rate	0 to $0.75 \text{ m}^3/\text{s}$, 0 to 5.6 m/s (0 to 1600 cfm, 0 to 1100 fpm)	AIR MONITOR 10" x 22" FAN-E/

University of Pennsylvania
Department of Mechanical Engineering and Applied Mechanics

Purchase Order for ESTERLINE-ANGUS Data Acquisition System

<u>Description</u>	<u>Price</u>
Model PD 2064 Key Programmable Data System	\$ 4150.00
80 Channels	3040.00
Solder Terminals	
Programmable Zero Offset Range	400.00
Digital Averaging	300.00
Dual Rate Option 253	300.00
Dual Rate Channel Group Scan	300.00
24 Channels Dual Setpoints Hi-Lo Alarms	450.00
Dual Common Alarm Relays	125.00
Delete Seiko Printer	-550.00
RS 232C Interface Adapted for DEC LA36-KG	950.00
Full Carriage Printing Modification for Above	275.00
Program Bank	200.00
3 Additional Files for Program Bank	225.00
Memory Save	200.00
Remote Control Connector	120.00
Program Printout	50.00
Rack Slides	50.00
Manual Update Service	30.00
Kennedy 9832-9 Buffered Continuous 9-Track Magnetic Tape Recorder, IBM compatible, including interface, cable, interface and system checkout.	<u>6450.00</u>

TOTAL \$17065.00

Above prices less 5% GSA Contract GS-00S-49174

OUR COST TOTAL \$16211.75

Same specifications as Quotations PH-146 and PH-153 except various items eliminate or added per our request.

Accuracy: $\pm 0.01\%$ of full scale $\pm 0.015\%$ of reading ± 5 microvolts.

Notes: 1. Field Service is to be available in our Philadelphia office.

2. System contains one scan memory buffer for scan speed independent of output device speed.
3. The system shall scan a programmable number of the channels continuously and average them, and would scan all the channels at a programmable time interval. At that interval, it would output to the two output devices (Kennedy tape recorder and LA36 Decwriter) the average values of the continuously scanned group of channels, and the instantaneous value of the rest of the channels.
4. The LA36 Decwriter II would be drop-shipped by the University of Pennsylvania to Esterline-Angus Company for interfacing and system checkout.

Shipment: 8-10 weeks after receipt of order, at most.