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TECHNICAL
REPORT

Steam Dispatching Control System Demonstration at Fort Benjamin Harrison

by
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13. ABSTRACT (Maximum 200 words)
Currently most Army Central steam heating systems operate by maintaining a constant steam pressure regardless of actual steam demand. This method offers some operational convenience, but is often the cause of significant energy losses. Researchers at the U.S. Army Construction Engineering Research Laboratories (USACERL) have investigated the Steam Dispatching Control System (SDCS), a control system that lowers supply steam pressure—and therefore steam temperature—to slightly above the amount needed to meet the steam demand. The lower steam temperature and reduction in steam loss (from leaks and faulty traps) result in lower heat losses and higher energy savings. Limiting steam pressure can diminish the amount of excess heat loss in the distribution system while still meeting the demand.

The Army's Facilities Engineering Applications Program (FEAP) chose Fort Benjamin Harrison, IN, as the Army demonstration site for SDCS.

Researchers found that use of SDCS is technically and economically viable improvement over current operating procedures. Analysis based on demonstration results show that the simple payback for SDCS is less than 1 year. The results of this demonstration are generally applicable to installations with a large central heating plant and a substantial steam distribution system. Findings, indicate that energy savings form SDCS are significant regardless of what type of fuel powers the boiler. The authors note that, during the initial evaluation of a potential SDCS application, attention must be paid to the condensate return to ensure that it will operate properly.

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FOREWORD

This research was performed for the U.S. Army Engineering and Housing Support Center (USAEHSC) under the Facilities Engineering Applications Program (FEAP) Work Unit FEAP-EB-FJ1, "Installation Steam Dispatching System." The USAEHSC technical monitor was Satish Sharma, CEHSC-FU-M.

The demonstration was conducted by the Fuels and Power Systems Team (FEP) of the Energy and Utility Systems Division (FE), Infrastructure Laboratory (FL), U.S. Army Construction Engineering Research Laboratories (USACERL). The principal investigator was Ralph Moshage, CECER-FEP. The team leader is Gary Schanche, CECER-FEP. The division chief is Dr. David M. Joncich, CECER-FE. Chief of the Infrastructure Laboratory is Dr. Michael J. O'Connor, CECER-FL. Thanks go to Yaoxin Qian and Rama Katz for their contribution to this report. The USACERL technical editor was Gordon L. Cohen, Information Management Office.

LTC David J. Rehbein is Commander of USACERL and Dr. L.R. Shaffer is Director.

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1 INTRODUCTION

Background

Currently most military district steam heating systems operate by maintaining a constant steam pressure regardless of actual steam demand. This method of operation, while practical, is often the cause of significant energy losses. Energy conservation is a national goal and a practical necessity for the U.S. Army. In accordance with this outlook, researchers at the U.S. Army Construction Engineering Research Laboratories (USACERL) have investigated the Steam Dispatching Control System (SDCS), a control system for reducing energy losses in a distribution system by controlling the steam pressure. Lowering the steam pressure to slightly above the amount needed to meet thermal demand reduces the steam temperature with only slight reductions in steam enthalpy (heat content). Thermal losses at the lower temperature are reduced and leak losses are diminished.

Successful use of SDCS by industry indicated that the system might successfully be applied to Army installation central heating systems. Therefore, based on a feasibility study conducted by the Oak Ridge National Laboratory, the Facilities Engineering Applications Program (FEAP) chose Fort Benjamin Harrison as the first Army demonstration site for this technology.

Objective

The objective of this project was to demonstrate operation of the Steam Dispatching Control System on a central steam heat distribution system serving an Army installation.

Approach

The approach to this demonstration followed four specific phases: (1) selection of a candidate site, (2) computer modeling of the site's central heating system to estimate potential savings, (3) design and installation of the dispatching control system, and (4) collection and analysis of operating data to monitor the performance of the system. Using the analysis of this data, SDCS was fine-tuned to produce additional cost and energy savings.

Scope

In general, the results of this demonstration are applicable to installations with a large central heating plant and a substantial steam distribution system. Boiler fuel is not a critical factor in the level of energy savings achieved.

Mode of Technology Transfer

It is recommended that information about this technology be presented in a paper at the 1992 Electrical and Mechanical Engineering Conference sponsored by the Office of the Chief of Engineers (OCE), and published in *DEH Digest*. Information about this technology is also being prepared for publication in a *FEAP User Guide*.

2 STEAM DISPATCHING CONCEPTS

A study prepared by Oak Ridge National Laboratories (ORNL) has documented the benefits of SDCS, a control system that lowers the steam pressure in the steam distribution system to slightly above the amount needed to meet the system load (McLain and Karnitz, October 1986). Lowering the steam pressure in a distribution system saves energy by reducing heat transfer losses and leak losses.

Thermal Loss Reduction

Lowering the pressure of saturated steam reduces its temperature, diminishing heat loss in the distribution system while having little effect on the enthalpy (heat content) of the steam (Table 1). Lowering the steam pressure, for example, from 100 psig[*] to 50 psig results in a steam enthalpy drop of less than 0.9 percent while the reduction in heat transfer losses exceeds 14 percent.

Leak Loss Reduction

A second benefit of reducing the steam pressure includes savings accrued from the reduction in steam loss from leaks and faulty traps. Considerable savings may be expected due to the reduction of these losses. Steam losses due to leaks are proportional to the square root of the difference between steam pressure and atmospheric pressure (Lilly, February 1987). Equation 1 forms the basis for this comparison:

$$Q = A \times C \times \sqrt{2gh} \qquad \text{[Eq 1]}$$

where
Q = steam loss (lb/hr)
A = area of opening (sq in.)
C = discharge coefficient (constant)
g = gravity constant (ft/s^2)
h = pressure drop (psig).

Using this relationship under the same conditions as the thermal loss example, pressure reduction from 100 to 50 psig, for example, shows that the decrease in steam loss would be on the order of 29 percent.

In the case of thermal losses, the estimated savings are based on engineering estimates of pipe heat loss coefficients and a technical description of the distribution system layout and operation. Determination of leak loss reduction is not as straightforward, however. The integrity of the steam lines and steam traps can only be determined through a detailed evaluation of the distribution system. Short of this, engineering estimates of the losses are made, and then correlated and adjusted in the modeling phase of a project. Typically, however, experience shows that leak losses account for a majority of the energy losses in a distribution system and hold the greatest potential for savings.

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[*] psig: pounds per square inch gauge. U.S. standard units of measure are used in this report. A table of metric conversion factors may be found on p 38.

Table 1

Typical Conditions for Buried Steam Line*

Pressure (psig)	Enthalpy (Btu/lb)	Change (%)	Temp. (°F)	Heat Loss (Btu/h-ft)	Change (%)
100	1189.6	0.0	337.8	259	0.0
75	1185.2	-0.4	320.0	243	-6.4
50	1179.0	-0.9	297.6	223	-14.2
25	1169.7	-1.7	267.3	196	-24.7

*Source: McLain and Karnitz, October 1986.

Equipment Components

Control of the steam pressure in a distribution system can be accomplished by regulating the boiler drum pressure or through the use of pressure-reducing valves (PRVs) off of the main steam header in the plant. Generally, wide fluctuations in boiler drum pressure are not desirable, so the use of a PRV is the recommended strategy.

The major components required for this control strategy are the PRV, the control system, and pressure and temperature measuring devices. Figure 1 shows a typical layout of these components for one line.

The PRV is sized to function over the entire range of the expected flow. The equipment layout should allow for isolation of the PRV during repairs or for bypass during an equipment failure. In addition, the PRV must be set to fail in the fully open position.

The control system consists of a self-contained microprocessor-based instrument that continuously controls its process according to a programmed algorithm. This algorithm is based on a control curve developed during the modeling phase. This controller should have the capacity to operate as a PID (proportional integral derivative) controller or in a self-tuning mode. When used in the self-tuning mode, the controller adjusts the values of P, I, and D based on real-time distribution system dynamics. The degree of response is selected by choosing the desired damping and overshoot-to-load ratios. This ability allows SDCS to function optimally during periods of changing system dynamics, such as a major load variation or during seasonal transitions.

Data collection equipment for the system consists of standard, off-the-shelf components for measuring steam pressure, air temperature, and steam flow. Steam flow readings are not required for operation of SDCS, although this information is useful in evaluating and optimizing system operation.

Technical Considerations

Fort Benjamin Harrison was chosen as the FEAP demonstration site for SDCS due to its location and the characteristics of its distribution system. The heating plant at Fort Harrison consists of three gas/oil-fired water tube boilers capable of generating 190,000 lb/hr (pph) of steam at 100 psig. Natural gas (costing about $3.26/MBtu) is the primary fuel used, with No. 2 oil used as a backup fuel. Seven miles of buried steam lines laid out in three independent networks feed the buildings on the 2500 acre base. The three independent systems are connected to a common header at the heating plant, and are designated as the Alpha, Beta, and Delta lines. The average yearly temperature is 52 °F and the annual number of heating degree-days averages about 5455.

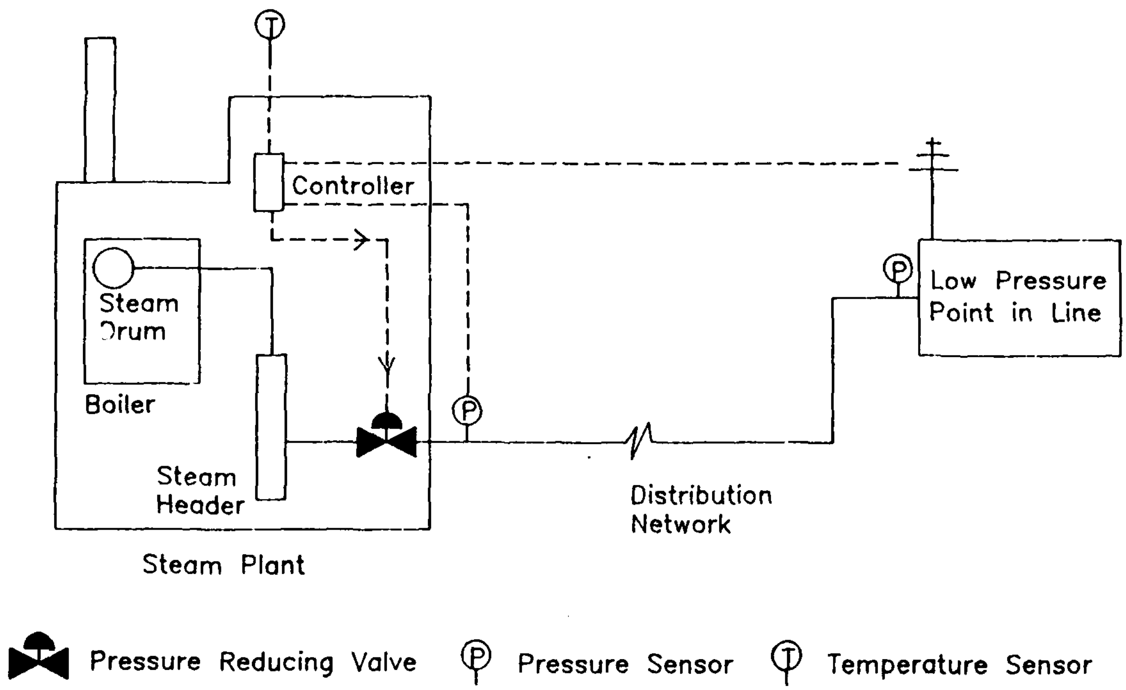

Figure 1. Steam Dispatching Control System Equipment.

During modeling and design of a SDCS several critical issues must be addressed. Careful evaluation will ensure that SDCS performs as expected with a minimal negative impact to the end user. Items for evaluation include process load requirements, distribution system steam velocity, steam trap capacities, end user PRV capacity, and PRV impact.

Process Load Requirements

Some buildings require steam at a pressure higher than what is needed for the heating load. An example of this at Fort Harrison is the base hospital, which houses a sterilizing unit that requires steam at a pressure of 65 psi or greater to work properly. The SDCS controller curves had to be calculated taking this requirement (and other similar ones) into account.

Steam Velocity

Another concern that must be evaluated is the velocity of the steam through the distribution system. Standards taken from the *ASHRAE Handbook* (American Society of Heating, Refrigerating, and Air-Conditioning Engineers 1985) suggest steam velocities of between 8,000 and 12,000 feet per minute (fpm), with a maximum of 15,000 fpm. Equation 2 (Lilly, February 1987) is used to determine the velocity of steam flow through a pipe:

$$V = (3.05 \times Q \times v) \ / \ d^2 \qquad \text{[Eq 2]}$$

where V = velocity (fpm)
Q = flow (lb/hr)
v = specific volume (cu ft/lb)
d = internal pipe diameter (in.).

Based on this relationship, maximum velocities for the Alpha, Beta, and Delta lines at Fort Benjamin Harrison would increase from about 3525, 3950, and 2750 fpm to 6350, 7100, and 4950 fpm, respectively, resulting from a decrease in pressure from 100 psig to 50 psig. The velocity increase is caused by a decrease in the specific volume due to the pressure decrease. The increase in velocity would cause an increase in the pressure drop in the lines due to increased friction. These velocities are well below the recommended ASHRAE limit of 12,000 fpm. Table 2 shows the maximum steam flow and velocity for each line at Fort Harrison, and presents steam velocities for various line sizes and flows.

Steam Trap Capacity

Steam trap capacity decreases as the steam pressure is reduced. The existing steam traps must be able to meet the expected capacity at the reduced pressure. As mentioned earlier, a pressure reduction from 100 to 50 psig decreases steam losses by 29 percent; this pressure reduction will also reduce the capacity of the steam traps by 29 percent. Traps that cannot meet the capacity must be replaced. If the steam trap capacity at a lower pressure is not sufficient, condensate will back up into the steam system, causing poor heater performance and increasing component corrosion.

End User PRV Capacity

Another concern faced in implementing an SDCS, both in general and in the Fort Benjamin Harrison demonstration in particular, is how to supply adequate heat energy to the buildings at a reduced sendout pressure. Each building on the installation's central heating system is equipped with a pressure-reducing station that has a known capacity at a given inlet pressure. When inlet pressure is reduced, the steam capacity will also decrease. Matching existing maximum steam capacities for each building involves replacing PRVs with larger valves (that is valves with a larger flow coefficient, Cv).

Consider the case where steam pressure is being reduced from 100 to 50 psig. Table 3 shows that the enthalpy of dry saturated steam is 1189 Btu/lb and 1180 Btu/lb for steam pressures of 100 and 50 psig, respectively. Therefore, the maximum amount of heat delivered to the equipment is 99 percent of the original maximum value, but the temperature is approximately 40 °F lower.

To determine the new, appropriate Cv, the Cv of the existing PRV must be known. (This value is available from the valve manufacturer.) The capacity is determined as follows:

$$Q = 2.1\, C_v \left(\sqrt{P_1 - P_2}\right)\left(\sqrt{P_1 + P_2}\right) \qquad \text{[Eq 3]}$$

Table 2

Maximum Steam Velocities

Lines	Pipe Diameter (inches)	Maximum Steam Flow (lb/hr)	Maximum Steam Velocity @ 100 psi (fpm)	Maximum Steam Velocity @ 50 psi (fpm)
Alpha	8	20,000	3527	6338
Beta	10	35,000	3950	7099
Delta	12	35,000	2743	4930

Table 3

Saturated Steam: Temperature Table

	Specific Volume			Enthalpy		
Temp °F T	Press. psig P	Saturated Liquid V_f	Saturated Vapor V_g	Saturated Liquid h_f	Saturated Evap. h_{fg}	Saturated Vapor h_g
290	42.83	0.017352	7.467	259.44	917.8	1177.2
300	52.28	0.017448	6.472	269.73	910.4	1180.2
310	62.94	0.017548	5.632	280.06	903.0	1183.0
320	74.90	0.17652	4.919	290.43	895.3	1185.8
330	88.30	0.017760	4.312	300.84	887.5	1188.4
340	103.23	0.017872	3.792	311.30	879.5	1190.8

where Q = flow in lb/hr (capacity)
P_1 = inlet pressure (psia*)
P_2 = outlet pressure (psia).

After the maximum capacity is determined for existing conditions, the new Cv can be easily found. As a precautionary measure, the maximum capacities that were calculated in this manner were compared with condensate measurements at each building. The calculated maximum capacities using the valve Cv proved to be the most conservative and were therefore employed (Lilly, February 1987).

PRV Impact

One problem with the Saturated Steam Model used by SHDP (see Chapter 3, "Site Modeling") is the effect of the PRVs on the steam. The steam becomes superheated as it passes through the PRV, returning to the saturated state some distance down the line. An example using worst-case conditions was compiled to study the effect of various pipe sizes and steam loads on this distance.

It was assumed that the input to the PRV was 100 psig saturated steam and the output was 50 psig superheated steam at a temperature of 313 °F (no enthalpy drop through the PRV). The model in Figure 2 was used to calculate the length of pipe needed for the steam to return to its saturated state at the lower pressure.

To determine the length of pipe that a given quantity of steam would flow through to reach a predetermined temperature and pressure, the following heat balance was used:

Heat lost by steam = Heat gained by ambient.

The pipe was assumed to be well insulated, and no frictional losses were taken into account. Substituting appropriate variables, it was found that:

*psia: pounds per square inch absolute.

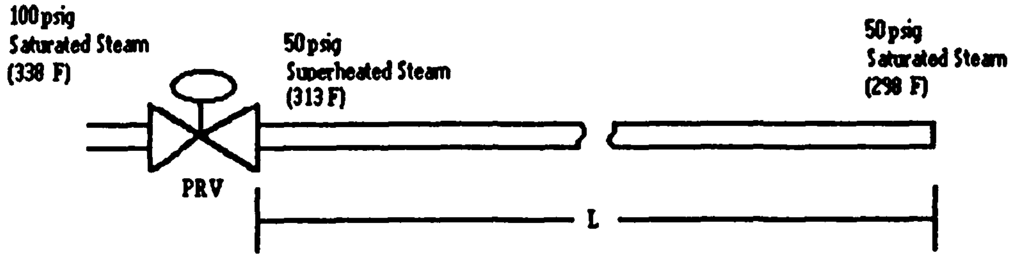

Figure 2. Model for Pipe Length Calculation.

$$PHLC \times (T_1 - T_2) \times L = Flow \times (T_{ave} - T_{amb}) \times cp_{ave} \qquad \text{[Eq 4]}$$

where PHLC = pipe heat loss coefficient (Btu/hr-ft-°F)
T_1 = initial steam temperature (°F)
T_2 = final steam temperature (°F)
L = pipe length (ft)
Flow = steam flow (lb/hr)
T_{ave} = average steam temperature (°F)
T_{amb} = ambient air temperature (°F)
cp_{ave} = average specific heat of steam (Btu/lb-°F).

This equation was then solved for pipe length:

Table 4 shows the results of the velocity and pipe length calculations from these equations for a variety of pipe sizes and steam flows. From Table 4 it can be seen that this effect of the PRV on the steam properties can be ignored for most calculations. The values for the physical properties of steam are from the *ASHRAE Handbook* (ASHRAE 1985) and *CRC** *Handbook* (Bolz and Tuve, eds., 1973). Pipe heat loss coefficients were found in the Steam Heat Distribution Program User's Manual (Miller and Waserman, August 1989).

Advantage of SDCS Over Fixed Pressure

Having looked at its benefits and concerns, another way to address questions about the viability and necessity of a system such as SDCS is to ask why a facility would require such a system—why not simply lower the pressure to a fixed value for different seasons? The reason is that if a facility fixes the pressure at a constant value, that pressure would have to supply enough steam at all possible loads during that

* CRC: Chemical Rubber Company.

Table 4

Superheated Steam to Saturated Steam Line Length Requirements

Pressure Drop from 100 PSIG Saturated Steam to 50 PSIG

ambient temperature (F)	50.000		
Saturated Steam Properties:		Superheated Steam Properties:	
steam pressure (psig)	50.000	steam pressure (psig)	50.000
steam temperature (F)	298.000	steam temperature (F)	313.000
specific heat (Btu/lb.- F)	0.540	specific heat (Btu/lb.- F)	0.522
density (lb./cu.ft.)	0.150	density (lb./cu.ft.)	0.140

	steam flow (lb./hr.):		50000		25000		10000		2000		500
diameter	heat loss coefficient of	velocity	length	velocity	length	velocity	length	velocity	length	velocity	length
(inches)	pipe (Btu/hr.-ft.- F)	(fpm)	(feet)	(fpm)	(feet)	(fpm)	(feet)	(fpm)	(feet)	(fpm)	(feet)
1	0.39	**********	**********	**********	**********	**********	**********	**********	**********	10524	40
1.5	0.59	**********	**********	**********	**********	**********	**********	**********	**********	4677	26
2	0.72	**********	**********	**********	**********	**********	**********	10524	87	2631	22
2.5	0.83	**********	**********	**********	**********	**********	**********	6735	75	1684	19
3	0.99	**********	**********	**********	**********	**********	**********	4677	63	1169	16
3.5	1.12	**********	**********	**********	**********	17181	278	3436	56	859	14
4	1.24	**********	**********	**********	**********	13154	251	2631	50	658	13
5	1.51	**********	**********	**********	**********	8419	206	1684	41	421	10
6	1.63	**********	**********	14616	478	5846	191	1169	38	292	10
8	2.07	16443	753	8221	376	3289	151	658	30	164	8
10	2.52	10524	619	5262	309	2105	124	421	25	105	6
12	2.82	7308	553	3654	276	1462	111	292	22	73	6
14	2.94	5369	530	2685	265	1074	106	215	21	54	5
16	2.97	4111	525	2055	262	822	105	164	21	41	5

period. To provide adequate steam flow throughout a season, the pressure would be set to supply an adequate load at the lowest temperature expected during the period. This approach may be fine during the summer when there is no heating load, but during the cooler months, considerable savings can be achieved using SDCS on a daily basis. With temperatures varying 20 to 30 degrees on a given day, the supply pressure required to meet the load could vary greatly.

A typical winter day at Fort Harrison, for example, could have a low of 15 °F and a high of 35 °F. The required pressures for the Alpha, Beta, and Delta lines at 15 °F are 55, 65, and 95 psig respectively (see "Selection of Control Points" in Chapter 3). Even if the facility were using a fixed pressure system and changing the pressure daily, 55, 65, and 95 psig would be the set points. At 35 degrees ambient temperature, however, the three lines require pressures of 40, 55, and 81 psig respectively—all lower than that day's setpoints. In some cases, the actual practice of changing a fixed pressure on a daily basis is not practical. The pressures may be set for a duration of 1 month or longer rather than adjusted daily. This would require the pressure to be set at a value that would meet the load at the lowest temperature expected during that time period. If temperatures varied significantly during that period, the loss in possible savings (compared to using a control system) could likewise be significant.

3 DEMONSTRATION PROJECT

Site Description

Fort Benjamin Harrison was chosen as the FEAP demonstration site for SDCS due to its location and the characteristics of its distribution system. Fort Harrison is located near Indianapolis, Indiana. The installation is a U.S. Army Soldier Support Center and houses the Army Finance Center. As noted previously, 7 miles of buried steam lines feed the buildings on the 2500 acre base. The average yearly temperature is 52 °F, and the annual number of heating degree-days averages about 5455.

The heating plant at Fort Harrison consists of three water tube boilers capable of generating 190,000 lb/hr (pph) of steam at 100 psig. Boiler 1 is an old gas-fired unit manufactured by Keystone. Its maximum capacity is 60,000 lb/hr, but it is in poor condition and rarely used. Boilers 2 and 3 are new units manufactured by Nebraska. Installed in 1989, they have maximum capacity ratings of 50,000 and 80,000 lb/hr respectively. Natural gas is the primary fuel used, with No. 2 oil used as a backup fuel.

Distribution System

The steam distribution system at Fort Harrison consists of approximately 7 miles of steam lines laid out in three independent networks. As noted previously, the three independent systems are connected to a common header at the heating plant, and are designated as the Alpha, Beta, and Delta lines. Figure 3 shows the layout of the heating plant, including the location of PRVs, pressure transducers, and the control panel. The Alpha line is a short line feeding Building 1, the large finance center. The Beta line feeds the buildings north and northwest of the heating plant. These consist mainly of Series 400, 500 and 600 buildings. The Delta line feeds the buildings to the east and northeast, including Series 300 and 400 buildings. Figure 4 shows a schematic of the Fort Harrison steam distribution system.

The Alpha line, Delta line, and portions of the Beta line are preinsulated, buried, Schedule 40 carbon steel pipe. The nominal pipe diameters are shown in Figure 4. A large portion of the distribution system is at least 7 years old. A shallow trench system was installed on the 8 in. portion of the Beta line in the summer of 1990, and the Series 600 buildings were added to the shallow trench system in the summer of 1991. Figure 5 shows the layout of the three main lines and the location of the remote sensing units that collect data for SDCS.

Operating Costs and Parameters

The boilers at Fort Harrison currently burn natural gas at $3.26/MBtu and produce steam at 100 psig. Boiler feedwater is preheated to 225 °F. In 1990, 388,195 MBtu of natural gas were used to produce 326,084 MBtu of steam. The average boiler efficiency was calculated at 84 percent. The heating value of the natural gas was 950 MBtu/mcf (Citizens Gas & Coke Utility of Indiana).

Table 5 shows fuel consumption and steam production data for January 1990 through December 1991.

Data pertaining to Fort Harrison building use, age, floor area, and the steam distribution system were obtained from the installation Facilities Engineering Office. These data were used with other data from the U.S. Air Force Environmental Technical Applications Center (ETAC) and building energy-use correla-

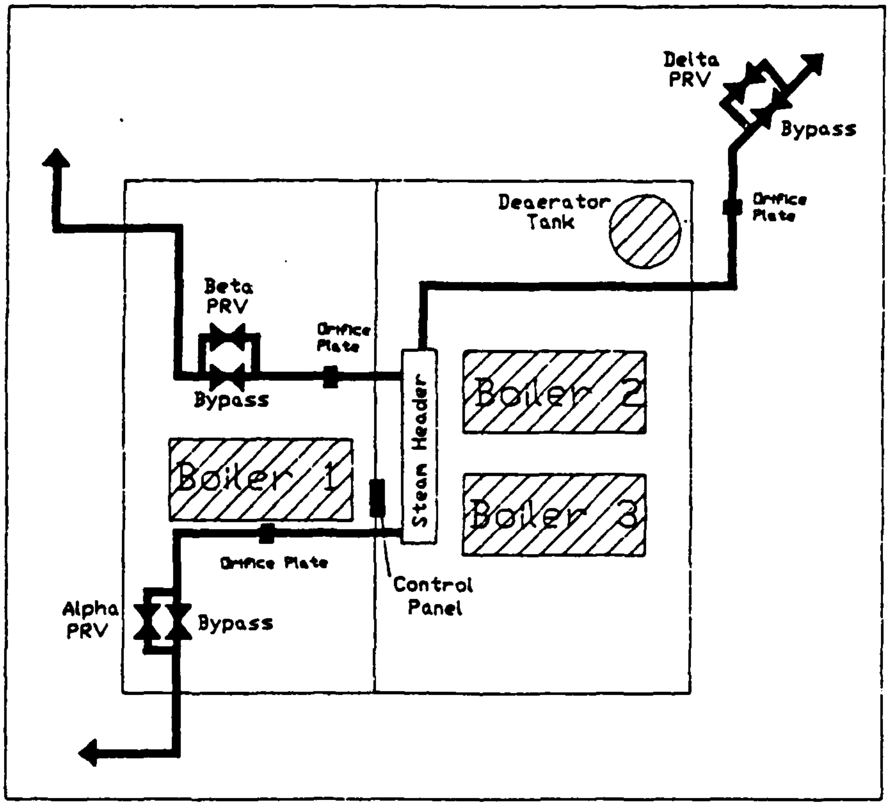

Figure 3. Fort Harrison Heating Plant Layout.

tions to estimate the amount of energy used at the base. The useful energy of the steam was estimated at 1046.2 Btu/lb, based on a saturated steam supply pressure to the building of 15 psig and a condensate return temperature of about 150 °F (McLain and Karnitz 1986). Also, based on the regression of the historical steam production data, it was assumed that the heating balance point temperature was 65 °F.

Site Modeling

Before the demonstration, a model of the steam distribution system at Fort Harrison was developed using the Steam Heat Distribution Program (SHDP), a pressure-flow thermal efficiency computer program for modeling steam distribution systems (Miller and Wasserman, August 1989). See Appendix A for SHDP input and output files. Models for building steam demand were created using studies by Northeast Utilities and USACERL. Functions relating outdoor temperature and required steam pressure were developed from these models. These models were reasonably accurate when used on large groups of buildings, but the model broke down for the large Finance Center building, and had to be adjusted using data taken during the demonstration. This modeling exercise showed potential estimated savings from heat loss reductions equalling $42,000 per year, or 10.8 x 10^9 MBtu/yr.

Building Load

One of the most important inputs needed for an SHDP model is the thermal energy use, or heat load, for each building in the distribution network. The heat load can be determined through various analysis technologies or procedures. Common tools include the Building Loads Analysis and System

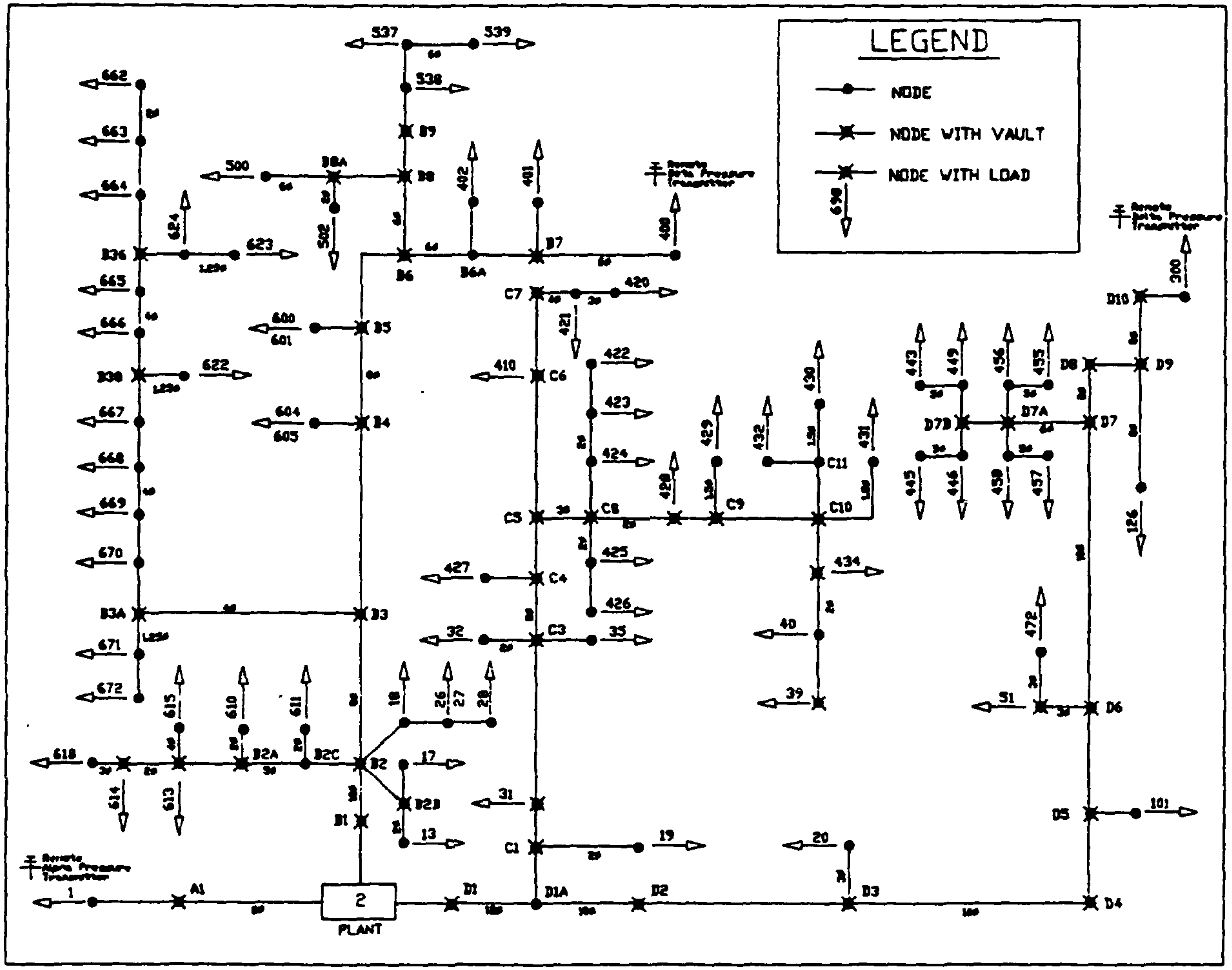

Figure 4. Schematic of Fort Harrison Steam Distribution System.

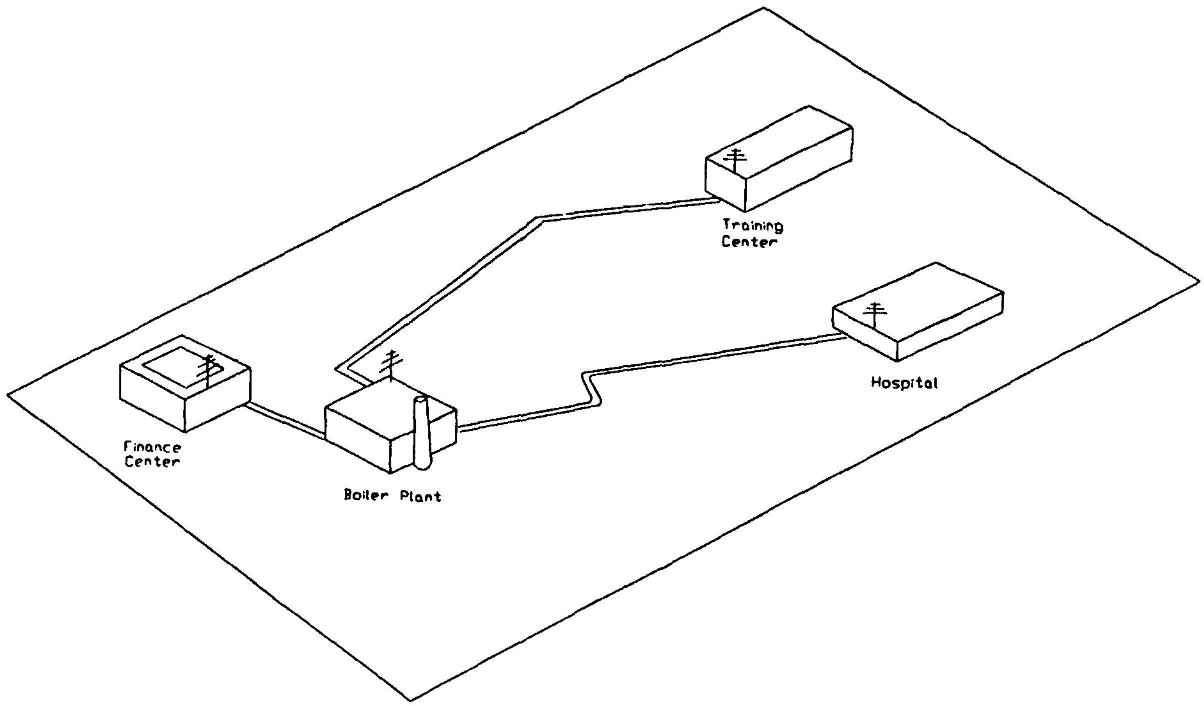

Figure 5. Location of Remote Sensing Units.

Thermodynamics (BLAST) program, developed by USACERL, DOE II, developed by the U.S. Department of Energy, and various manual methods developed by ASHRAE. However, these techniques can be very time-consuming when analyzing an entire installation. To work around this problem, USACERL developed an estimating procedure based only on building function, building floor area, and outside temperature. Linear correlations by building function were developed, based on study of building energy metering data from several Army installations. For each type of building a corresponding daily thermal energy consumption equation can be expressed in the form of:

$$E = a + (b \times HDD) \qquad \text{[Eq 6]}$$

where E = daily thermal energy consumption (Btu/sq ft/day)
HDD = daily heating degree-days
a = constant representing nonheating loads at zero HDD (hot water, cooking, etc.)
b = variable heating load dependent on HDD.

Table 6 shows the building categories available. Most of the buildings at Fort Harrison are more like commercial and residential buildings, and are appreciably more energy-efficient than typical Army family housing units. Therefore, the daily thermal energy balance equation used for the SHDP model was derived from data in studies by USACERL and the utility group Northeast Utilities (Sliwinski and Elischer, August 1983; Xenergy Inc., January 1986). The zero HDD parameter (a) was taken from the USACERL study. The variable energy usage parameter (b) was taken from the Northeast Utilities study after preliminary modeling showed the USACERL values for b to be too high. As is shown in the next section, "Model Verification," these data accurately characterize the daily thermal energy usage for Fort

Table 5

Fort Harrison Fuel Consumption and Steam Production (January - August 1990)

Month	Steam 1000 lbs	Gas M.C.F	Steam MBtus	Gas MBtus
JAN 90	39891	50263	39647665	47749850
FEB 90	37309	42594	37081415	40464300
MAR 90	35784	41898	35565718	39803100
APR 90	27905	31985	27734780	30385750
MAY 90	16584	21819	16482838	20728050
JUN 90	18340	21142	18228126	20084900
JUL 90	19290	23415	19172331	22244250
AUG 90	15910	21509	15812949	20433550
SEP 90	12381	16830	12305476	15988500
OCT 90	19598	24831	19478452	23589450
NOV 90	27031	32037	26866111	30435150
DEC 90	40389	48200	40142627	45790000
JAN 91	49288	57395	48987343	54525250
FEB 91	38413	44356	38178681	42138200
MAR 91	31087	35919	30897369	34123050
APR 91	19786	28011	19665305	26610450
MAY 91	17508	22143	17401201	21035850
JUN 91	18288	22617	18176443	21486150
JUL 91	19877	22025	19755750	20923750
AUG 91	19585	23488	19465532	22313600
SEP 91	13454	14971	13371931	14222450
OCT 91	13914	17890	13829125	16995500
NOV 91	29883	36217	29700714	34406150
DEC 91	35330	41970	35114487	39871500
Total	616825	743525	613062368	706348750

Harrison. HDD data was obtained from ETAC. Steam production data were acquired from the central heating plant operating logs, and building area measurements were obtained from the Real Property Detail Report for Fort Harrison.

Building number, use, and floor area are compiled in Appendix B. As noted above, studies by USACERL and by Northeast Utilities were used to develop a linear correlation between building energy demand and heating degree-days for each type of building found on the installation. The predicted intercept and slope were used along with the floor area data to calculate an intercept and slope for each building. See Appendix B (McLain and Karnitz 1986).

Model Verification

The calculated heating load for each of the three lines was plotted with the actual steam flow versus the outdoor temperature. The models for the Beta and Delta lines matched up very well, both having almost the identical slope as the plot of actual steam flow data (see Figures 6 and 7). The offset between the model flow and the actual steam flow depicts the losses due to heat loss and steam leaks.

The model for the Alpha line load consisted only of the Finance Center. A USACERL study indicated that the error in the model heating load equations increased as fewer buildings were involved (Sliwinski and Elischer, August 1983). The slope for the finance center required an adjustment from 332.1 lb/hr-deg F to 116.0 lb/hr-deg F. The new slope was calculated by taking a linear regression of data taken from the Alpha line (Figure 8). The small offset between the regression line and the actual data depicts the low losses from this line, which are attributable to the shortness of the line between the heating plant and Building 1.

Selection of Control Points

After the models were corrected, the low-pressure point in each subsystem was located. Initially, the remote pressure was going to be used to control the PRV. The setpoint would be held at a constant value for all temperatures. If the low-pressure point in the lines was kept at the lowest allowable pressure, then the pressure along the rest of the line would be adequate. Two problems arose from this method, however. One problem was the time delay in the response of the system: adding any time delay made the control system less stable. The other problem involved the reliability of the data transmitting equipment: many problems encountered in the demonstration were related to the remote data collection equipment. Because of these constraints, control of the PRVs was based on the line pressure readings at the boiler plant.

These locations (low-pressure points in the subsystems) were kept at the minimum allowable pressure. The steam pressure reaching the base hospital, for example, had to be sustained at a minimum of 65 psi. The required line pressure at the plant, used as the pressure setpoint, was calculated from the

Table 6

HEATLOAD Categories

Building Type	a	b
Family Housing	113.50	10.50
Barracks, pre-1966	130.50	10.53
Barracks, post-1966	81.90	7.40
Barracks, modular	295.90	10.53
Administration/Training	75.70	7.02
Dining Facilities	241.90	0.00
Medical/Dental	254.40	11.41
Production/Maintenance	138.25	10.53
Field Houses and Gymnasiums	73.70	4.39
Commissary	147.00	7.02
Storage Buildings	35.70	10.53
Theater/Rec Center	231.50	5.25
NCO/Officers Club	231.501	8.75

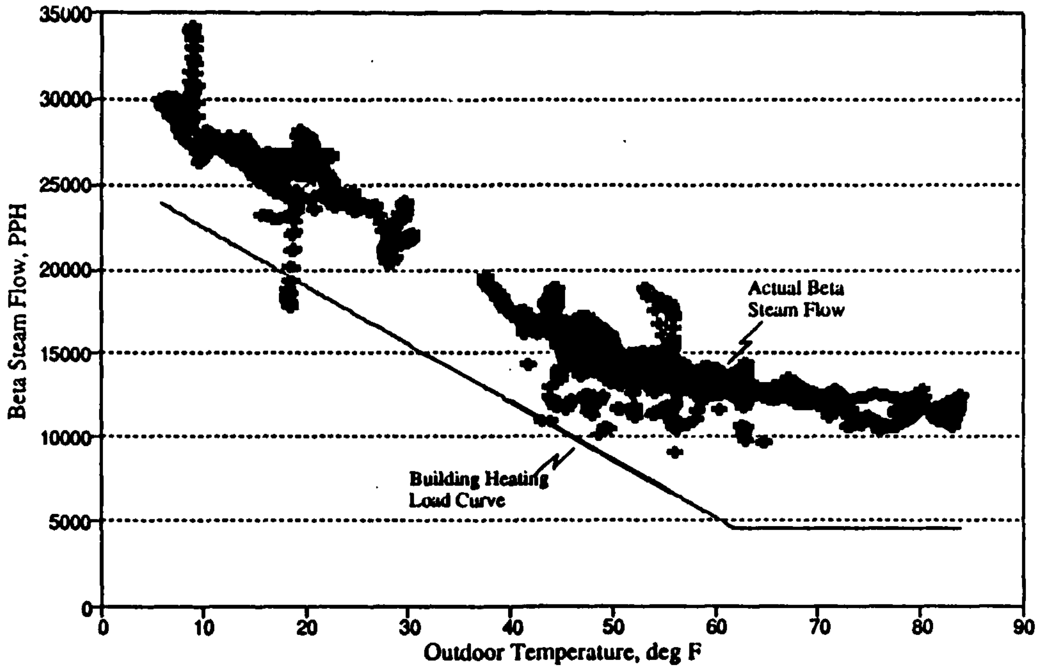

Figure 6. Model for Beta Line Load.

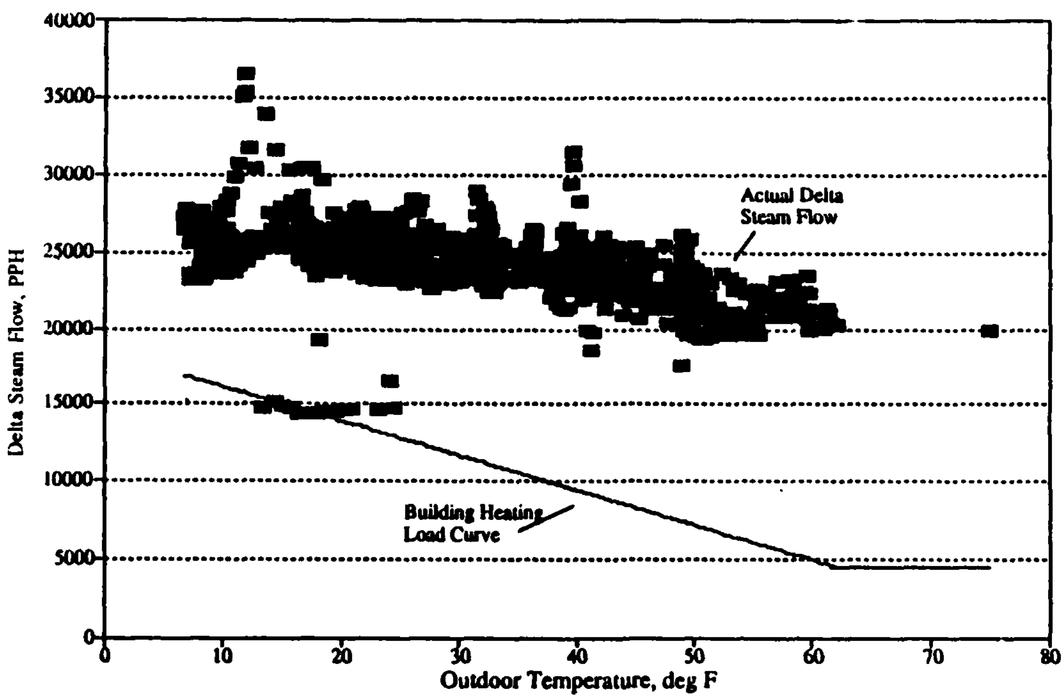

Figure 7. Model for Delta Line Steam Load.

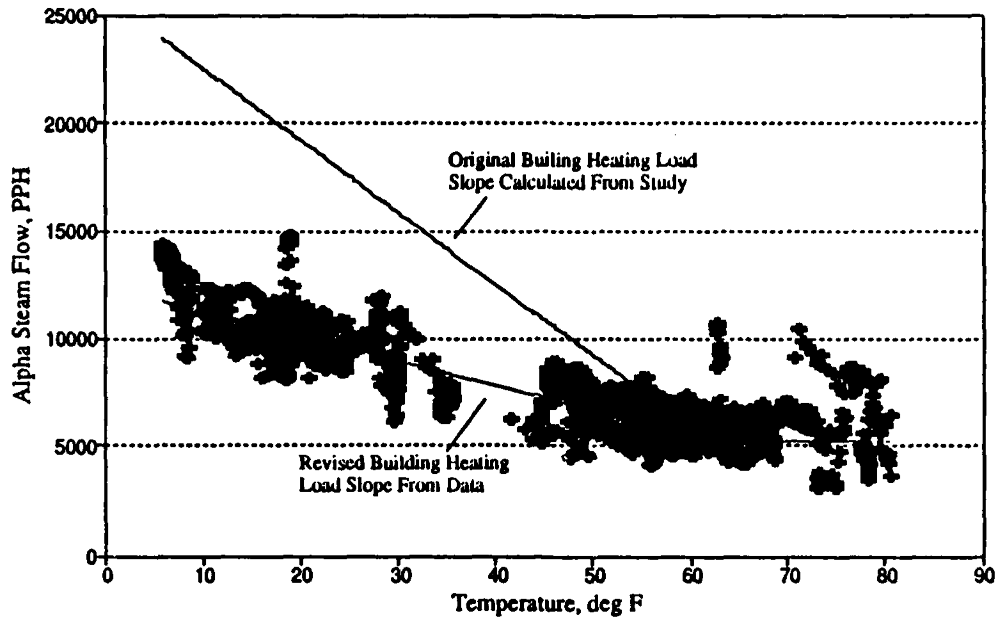

Figure 8. Model for Alpha Line Steam Load.

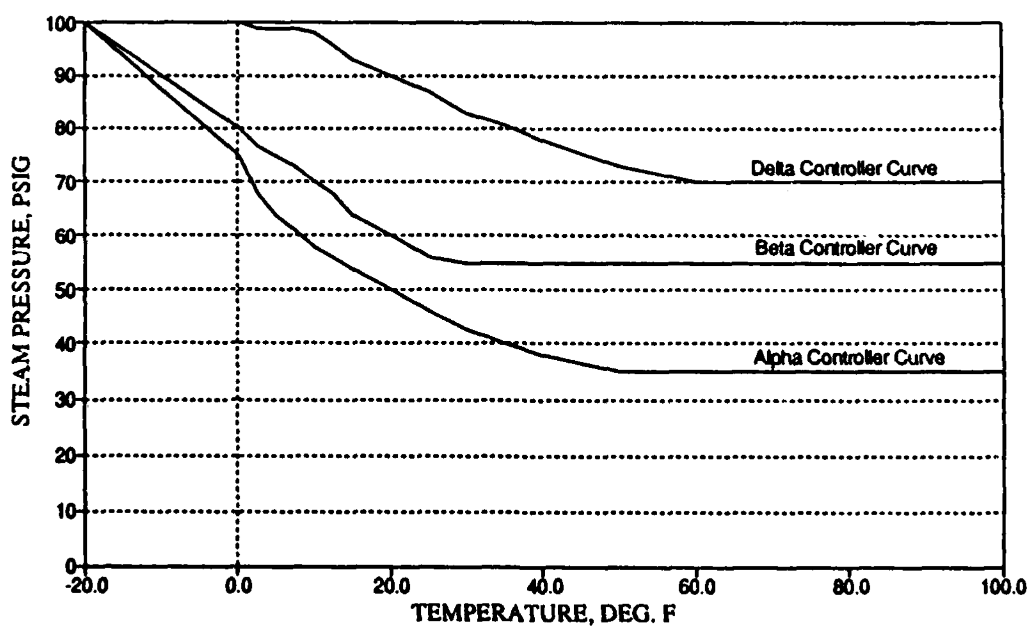

Figure 9. Controller Set Point Curves for Alpha, Beta, and Delta Lines.

model using SHDP. This procedure was repeated for four different temperatures—0, 25, 40, and 59 °F—and the control curve was derived from these points (Figure 9). The design temperature for Indianapolis was -2 °F. These original curves were very conservative estimates.

Equipment

Appendix C contains specification details and instrumentation configuration parameters for the equipment discussed below.

PRV

Fisher Controls Company PRVs were used for reducing the steam pressure from 100 psig to a set point as low as 25 psig. Specifications for the necessary three valves were acquired from the Fisher Control Company *Control Valve Specification* sheets. The PRVs use Fisher Controls type 3590 electro-pneumatic valve positioners to convert the controller signal from a 4-20 milliamp (ma) electrical signal to a pneumatic output signal.

Controllers

The Foxboro 761 Series Single-Station Micro Plus controller was used for the control system. This controller is a self-contained microprocessor-based instrument that continuously controls its process according to its programmed algorithm. This controller can function either in PID mode or in a self-tuning ("EXACT") mode. When not programmed to run in EXACT mode, the controller functions like any PID controller. However, when the 761 is in EXACT mode, the controller adjusts the values of P, I, and D based on real-time dynamics. The user selects the degree of response by choosing the desired damping and overshoot-to-load ratios.

The 761 controller allows two frequency inputs; four 4-20 ma, 10-50 ma, or 1-5 V analog inputs; a 25 V direct current (DC) power supply that can power one or two transmitters; and two contact inputs. It has two analog outputs—a 4-20 ma control output and a 1-5 V auxiliary output. There are also two contact outputs that can be programmed to represent any one of the signals on the Boolean logic gate list.

Temperature Transmitter

A Foxboro Model E94 Temperature Transmitter was used to sense the outdoor temperature. This two-wire transmitter contains a platinum Resistance Temperature Detector (RTD) and outputs a 4-20 ma signal. Its operating range is from -40 °F to +180 °F. It is powered by a DC power supply ranging from 12.5 to 50 V. It has both zero and span adjustments, and is accurate to within 0.15 percent of span or 0.08 °C, whichever is greater. The repeatability and deadband of this transmitter are 0.05 percent of span.

Uninterruptible Power Supply

An uninterruptible power supply (UPS) is needed to provide a constant voltage to the controllers. Line voltages in power plants are typically very noisy. An interruption in power to the controllers would interrupt the output signal to the PRV's. The PRV's are designed to fully open when they lose the output signal. This could result in a loss of boiler pressure possibly shutting down the boiler. At Fort Harrison a Mesta UPS was installed. It provided a very fast switching time and delivered a clean supply voltage to all of the equipment in the control panel. (A smaller model can be used if data acquisition equipment is not installed.)

Data Collection Equipment

Autograph 800 Data Logger. Data was collected using an Acurex Autograph 800 data logger. The data logger used was configured to collect up to 15 digital input channels, 20 analog input channels, and 15 channels for RTD inputs. It was programmed to collect data every 30 seconds and average those readings every 15 minutes. The averages were stored in the data logger's memory. The unit could store 2 weeks of data and was capable of downloading the data to USACERL via a modem.

Flow Totalizers and Orifice Plates. The Foxboro Model 75TUA Flow Totalizer was used to calculate steam flow in the three lines. It is a single loop, microprocessor-based instrument for calculating accurate flow rate measurements. Foxboro Model 843 differential pressure (D/P cell) transducers measured the pressure drop across an orifice plate. The accuracy and repeatability of this model are within 0.25 percent of span, and it has both zero and span adjustments. The flow was then calculated using a function based on the physical characteristics of the steam line, the orifice plate, and the steam. The flow was converted to a 4-20 ma signal and retransmitted by the totalizer across a 250 ohm resistor at the terminal board. From there it was measured by an Autograph 800 data logger.

Foxboro OP-FTT concentric bore orifice plates made of 316 stainless steel were used in this demonstration. Typical accuracy of the orifice plates and transmitters is 1 to 2 percent of the upper-range value.

Pressure Transmitters. Foxboro Model 841 Electronic Gauge Pressure Transmitters were used for all steam pressure measurements. These transmitters convert a 0-100 psig pressure reading into a proportional 4-20 ma signal. A supply voltage of 12.5 to 36 volts DC may be used to power the transmitter. Its accuracy is 0.25 percent of span, with repeatability of less than 0.1 percent. It has both zero and span adjustments.

Strip Chart Recorders. Foxboro Model E20-I electronic chart recorders were used to provide the status of various process control signals (i.e., local and remote pressures, outdoor temperatures, and steam flows). The model E20-I accepted 4-20 ma input signals across a 500 ohm input resistor.

Remote Data Transmission Equipment. An Intrac 2000 two-way radio system was used to transmit the remote pressures back to the controllers in the plant. The remote unit consists of an analog-to-digital converter module, an encoder module, and a two-way radio module. This modular system converts the 4-20 ma pressure signal from analog to digital, and adds an address to the signal. The signal is then encoded and broadcast to the central receiving unit using a VHF* radio signal. The central unit consists of a two-way radio module, a decoder module, and a digital-to-analog converter module for each controller. At the plant this signal is received, decoded, and a 4-20 ma signal is generated and transmitted to the controller corresponding to the correct address. Analog values are transmitted from the remote site as soon as they deviate by a fixed amount. The Intrac 2000 system could also be configured to poll the remote radio sites at a fixed time interval.

Equipment Cost

Table 7 is an estimate of the construction costs for installation of the SDCS at Fort Harrison. Table 8 lists the actual construction costs.

The cost of design for SDCS was $15,493. The estimated costs for the mechanical and electrical materials and labor were $65,317 and $70,000 respectively. The actual cost for materials and labor were $88,081 and $57,339. The total cost was $160,913, of which $22,049 was used for the radio equipment.

*VHF: very high frequency.

Table 7

Estimated Construction Costs*

Quantity	Equipment Item	Material Cost
6	Pressure Transmitter	2460
3	Orifice Plates	834
3	Orifice Flanges	2738
3	Pressure Indicating Controller	5550
3	Differential Pressure Transmitter	1650
3	Steam Flow Indicator/Totalizer	2925
1	Temperature Element and Transmitter	570
2	6 Inch Pressure Regulating Control Valves	10850
1	4 Inch Pressure Regulating Control Valve	3405
1	12 Inch Gate Valve 300# Flanged	2543
1	10 Inch Gate Valve 300# Flanged	1750
5	8 Inch Gate Valves 300 # Flanged	6080
2	6 Inch Gate Valves 300# Flanged	1514
6	12 Inch Flanges 300# Raised Face	864
6	10 Inch Flanges 300# Raised Face	756
6	8 Inch Flanges 300# Raised Face	408
6	3/4 Inch Globe Valves	120
6	Pressure Indicators	300
1	Radio Frequency Data Transmission System (3 remote sites transmitting to boilerhouse)	15000
1	Control Panel	5000
	Material Subtotal	65317
Installation (as per quotation from Freyn Brothers, Inc., Indianapolis, IN - represented by Larry Brooks)		70000
Contractor Overhead and Profit (10%)		13530
	Total Project Cost	148830

* Includes no contingency or design costs.

Table 8

Actual Construction Costs

Design	15493
Mechanical/Electrical Materials	88081
Labor	57339
Final Installed Cost	160913

This equipment was used mainly to acquire data for the demonstration, and is not essential to the operation of SDCS. Not including the radio equipment, the average cost per line of SDCS at Fort Harrison was about $47,000.

System Operation

Figure 10 shows the performance of SDCS on the Alpha line pressure during the period from February 16 to 22, 1991. The local pressure is adjusted according to an equation based on the outside temperature (see control curves in Figure 9). A large variance in temperature can be seen over this 1-week period, with temperatures ranging from 17 to 59 °F. The disturbance in the Alpha steam pressure on February 20 was due to a boiler shutdown.

System Response With SDCS

Figure 11 illustrates the impact of operating a distribution system at a reduced steam pressure. When steam pressure in the Beta line was increased from 56 psig to 95 psig during a period of stable temperature, the steam flow increased from approximately 12,300 pph to 13,800 pph. Since ambient conditions did not change significantly during this period, the increase in steam flow can be attributed to increased leak and thermal losses. The perturbations in the steam flow after the increase were due to maintenance on a feedwater valve. It is clear that a significant reduction in thermal energy losses can be realized through implementation of a system such as SDCS. The maximum possible reduction in steam pressure energy savings is initially determined through computer modeling and then verified through actual operation of the system.

Figure 12 shows the response of the control system to a 25 percent step decrease in the Beta steam flow. The initial pressure is 56 psi—the setpoint—before rising to 63 psi during the step decrease, then returning to the setpoint in approximately 12 minutes. The damped response does not overshoot the setpoint and the steam flow remains relatively constant during the pressure reduction. During this time period the temperature rose slightly, dropping the setpoint to 55 psi.

Condensate Return System

In terms of overall systems responses, the condensate return system was adversely impacted by the SDCS in this project demonstration. The main problem reported dealt with excess condensate in the steam lines and heating equipment and was not evident until the SDCS had been fully functional for an entire heating season. The excess condensate buildup was a result of the inability of the steam traps to effectively remove condensate at lower steam pressures. As discussed earlier (see "Technical Considerations" in Chapter 2), the capacity of the steam traps is reduced as the steam pressure is reduced.

A preliminary evaluation, conducted before the installation of SDCS at Fort Harrison, indicated that the existing steam traps had adequate capacity at the reduced steam pressures used by the SDCS. This conclusion was based on idealized conditions, however, and failed to take into account the impact of SDCS on the entire condensate return system. As discussed previously in "Technical Considerations," solutions to the problem of excess condensate buildup involve the replacement of steam traps and possible modifications to the operation of the condensate return system. Further studies at Fort Harrison will be made to better anticipate and solve problems of this nature.

Operator Training

An important lesson learned in the demonstration project was that boiler plant operators should be included in the design and installation of the equipment from the start. It is essential that operators feel comfortable with the design of the system so they can make repairs and adjustments as needed. Wiring diagrams, instrument specification sheets, and a concise list of startup and shutdown procedures are very useful as training aids.

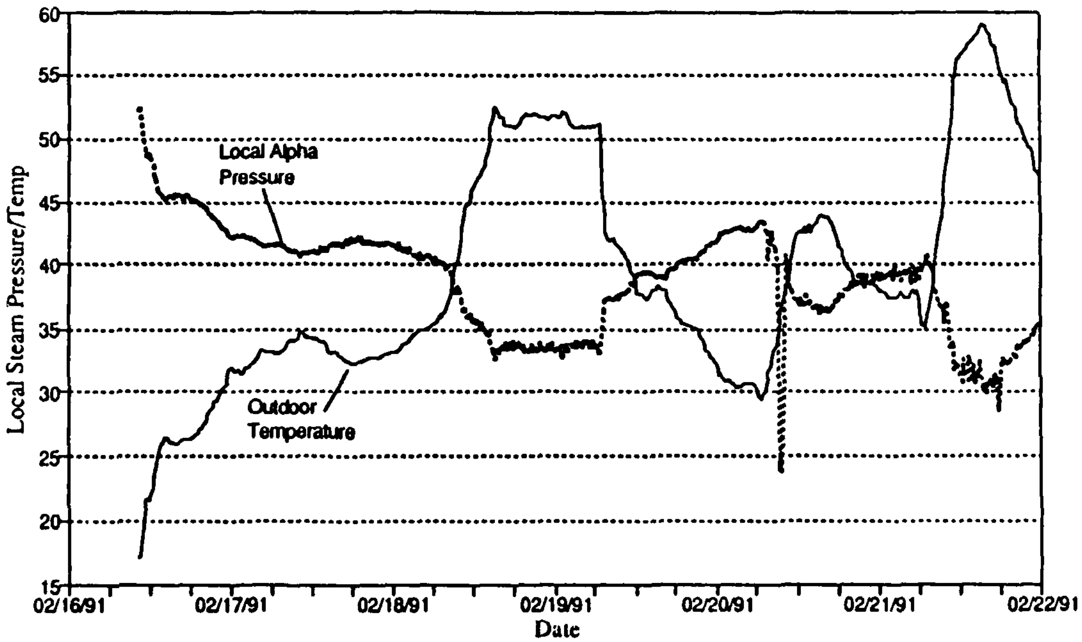

Figure 10. Local Alpha Steam Pressure/Temperature Graph, February 16-22, 1991.

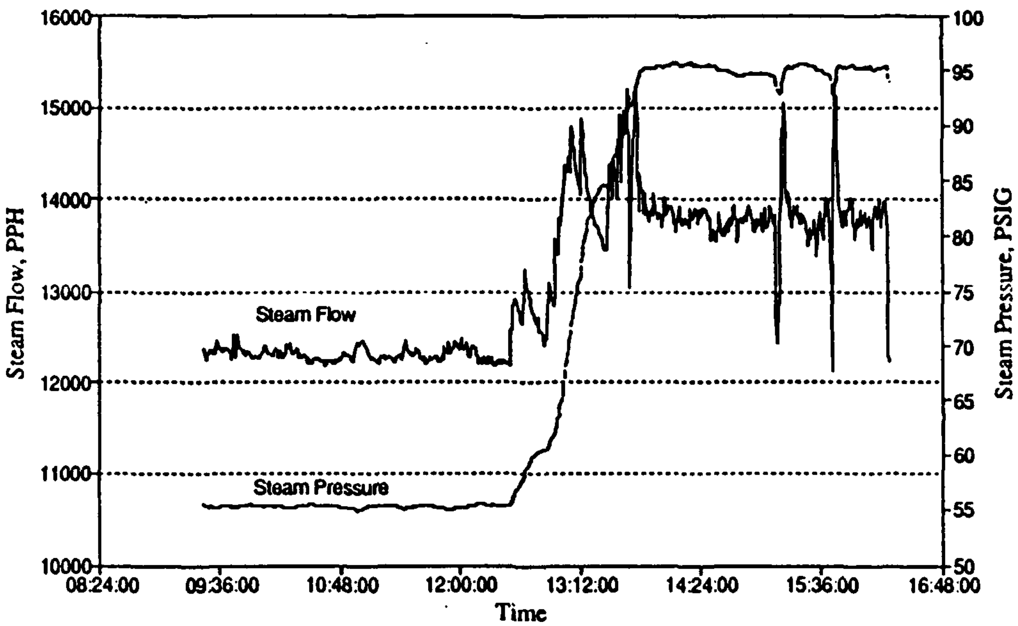

Figure 11. Beta Steam Flow vs Steam Pressure, June 25, 1991.

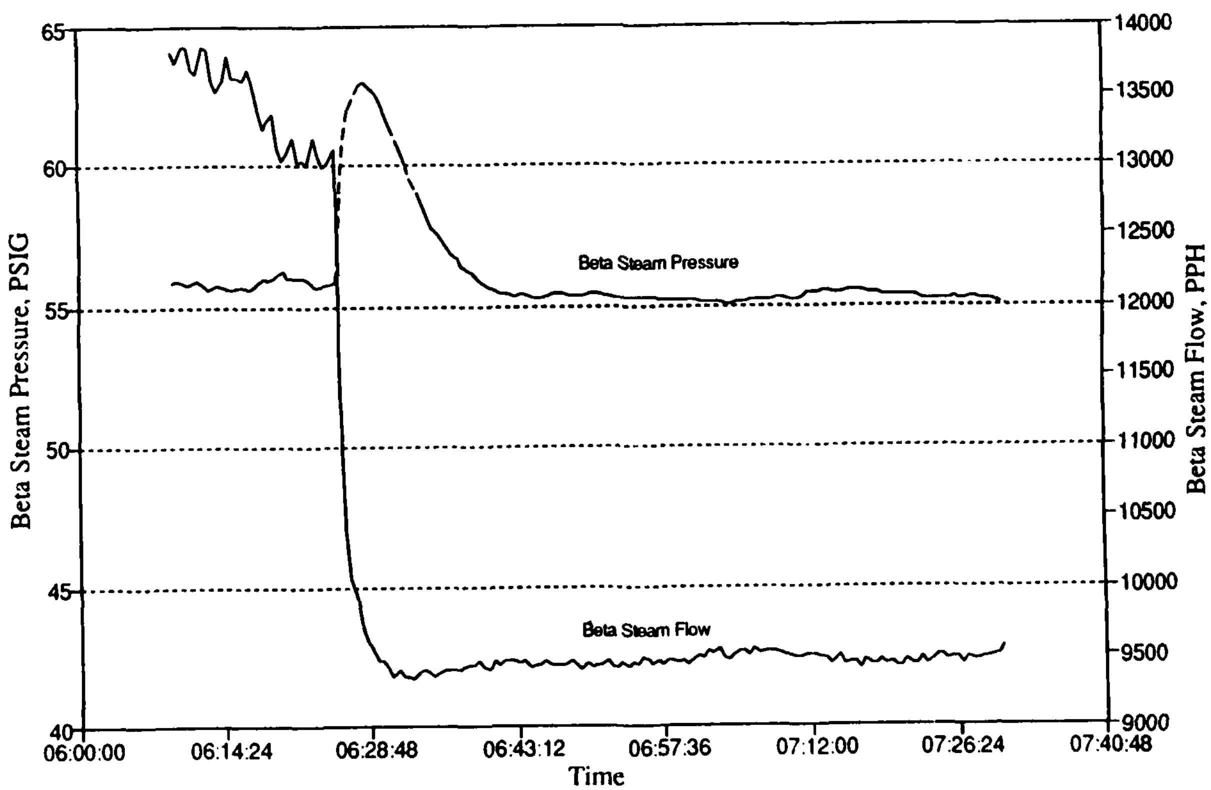

Figure 12. Control System Response to Change in Beta Steam Flow, April 24, 1991.

4 DATA COLLECTION

Data Collection and Analysis Scheme

To evaluate controller operation and calculate savings, a simple data collection and analysis scheme was needed. Local and remote steam pressure, outside air temperature, and line steam flow readings were taken every 30 seconds. These values were averaged over 15 minutes and stored in weekly files. An Acurex Autograph 800 was used to gather and store the data. A sample of the data is shown below. See Appendix D for a more detailed description. The data are presented in the following format:

		local steam press.				remote steam press.			steam flow		
date,	time,	alpha,	beta,	delta,	temperature,	alpha,	beta,	delta,	alpha,	beta,	delta
04/01/91,	00:12:30,	37.9,	55.5,	77.8,	40.5,	36.8,	52.3,	69.5,	1836.6,	15270.4,	1869.9
04/01/91,	00:27:30,	37.8,	55.0,	77.6,	40.8,	36.6,	52.1,	69.6,	1146.9,	15637.3,	1276.8
04/01/91,	00:42:30,	37.8,	55.2,	77.6,	40.7,	36.9,	52.1,	69.6,	1556.6,	15672.2,	1302.7
04/01/91,	00:57:30,	37.9,	55.6,	77.8,	40.6,	36.7,	52.5,	69.9,	1210.5,	15458.5,	1221.9

Data were transmitted from the sensors as 4-20 ma signals. All of the measurement signals were routed through a resistor on the terminal board to isolate the control loop from the data acquisition loop. See Appendix E for wiring diagrams and circuit drawings. The Acurex measured the signals and converted them into their respective engineering units of measure before storing them. The steam pressures and outside air temperature were used to evaluate the controller status. The line steam flows and total steam flow from monthly boiler log sheets supplied by Fort Harrison were used along with temperature data to determine the total savings generated by the system.

After the data were retrieved from the Autograph, they were converted into a database file. The data were averaged hourly and daily, and stored in monthly database files. Total daily steam flows were added to the daily averaged database file. These were retrieved from the monthly boiler plant log sheets. The daily averaged data were sorted by the local pressure into the following categories of files: (1) all three local pressures high (SDCS not functioning), (2) all three local pressures low (SDCS functioning), and (3) line pressures fluctuating (SDCS partially functional). The data sets for low and high pressure were then separated, and a regression analysis was carried out (see Appendix D).

Boiler Logs

The total daily steam flow data were taken from the daily log files of the boiler plant. The steam flow, expressed in thousands of pounds of steam, was converted to an average hourly flow for each day (by dividing by 24 hours). These data were then added to the data collected from the Acurex. Daily steam flows were used to reduce possible errors caused by inaccuracies in the meter reading interval. For example, if an operator was 10 minutes late in taking an hourly steam flow reading, that reading would be high by 17 percent. In using the daily steam flows, the error from a 10 minute late reading would affect the overall daily steam flow reading by only 0.7 percent.

ETAC Climate Data

Climate data for the Indianapolis Airport were obtained from ETAC. These data consisted of the mean maximum and minimum daily temperatures during the period of 1948 to 1989. The mean average daily temperature was calculated as the average of the maximum and minimum temperature for each particular day. A complete listing of the data is located in Appendix F.

Data Filtering

Summer vs Winter Loads

Data were collected from the heating plant daily log files between November 1988 and August 1991. Data collected during boiler shutdowns and large distribution system repairs were considered invalid and were not incorporated into the study. The remaining data were sorted by season—summer and winter loads. Data were categorized under summer load when the line to the Series 600 buildings was shut off between mid-April and mid-November.

The data were considered baseline if the Beta and Delta local pressures were above 80 psi and the Alpha line pressure was above 50 psi. The low cutoff point for the local Alpha pressure was used to better balance the data sets. The effect of the Alpha steam pressure on the Alpha steam flow—and therefore, the total steam flow—was slight. This insensitivity to pressure was caused by the Alpha line's physical characteristics. This gave researchers much leeway in the location of the Alpha cutoff point. Each set of data was first sorted and separated using the local Beta pressure as the key. This procedure was repeated on the remaining data using the local Delta and Alpha pressure respectively (see Appendix D). These data were separated from the rest and least squares linear regressions were done on both the winter and summer load data.

Steam Production Without SDCS

Figure 13 shows the linear regression for the baseline winter steam load. The equation of the regression line is:

$$\text{Steam Flow } (10^3 \text{ lb/hr}) = 88.7 - 0.8565 \times T \qquad \text{[Eq 7]}$$

where $R^2 = 0.720$ (correlation coefficient)
T = ambient temperature.

The average daily temperature ranged from 12 to 60 °F. An R^2 value of about 0.720 reflects a strong correlation between steam flow and temperature.

Figure 14 shows the linear regression for the summer baseline load. The baseline for the summer steam load showed a slight positive slope due to a cooling load generated by chillers in Building 400. The equation for the summer baseline regression line is:

$$\text{Steam Flow } (10^3 \text{ lb/hr}) = 3.93 + 0.319 \times T \qquad \text{[Eq 8]}$$

where $R^2 = 0.31$ (correlation coefficient)
T = ambient temperature.

The average daily temperatures ranged from 63 to 85 °F. The correlation shows a weak dependence on temperature. This weak correlation may be due partially to maintenance and repair of parts of the distribution system and the small range of temperatures that occurred.

Steam Production Using SDCS

Winter steam flow data collected while SDCS was in use were separated in the same manner as the baseline data. Datum was considered valid if it was within 10 psi of the setpoint corresponding to the outdoor temperature. Figure 15 shows the relationship between steam flow and average winter daily outdoor temperature when SDCS was in use.

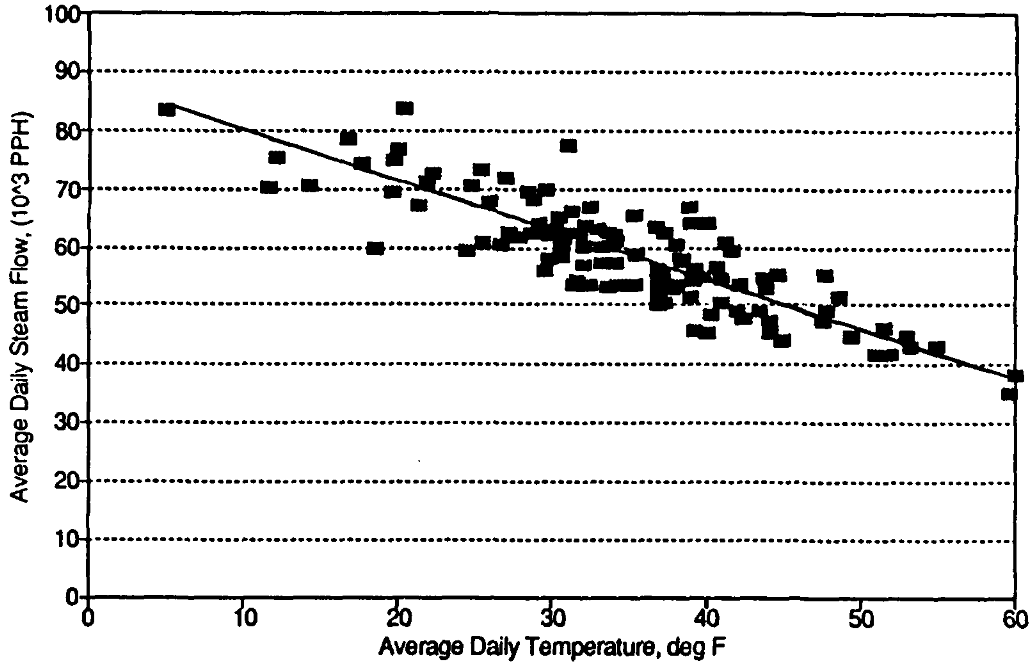

Figure 13. Winter Baseline Steam Load.

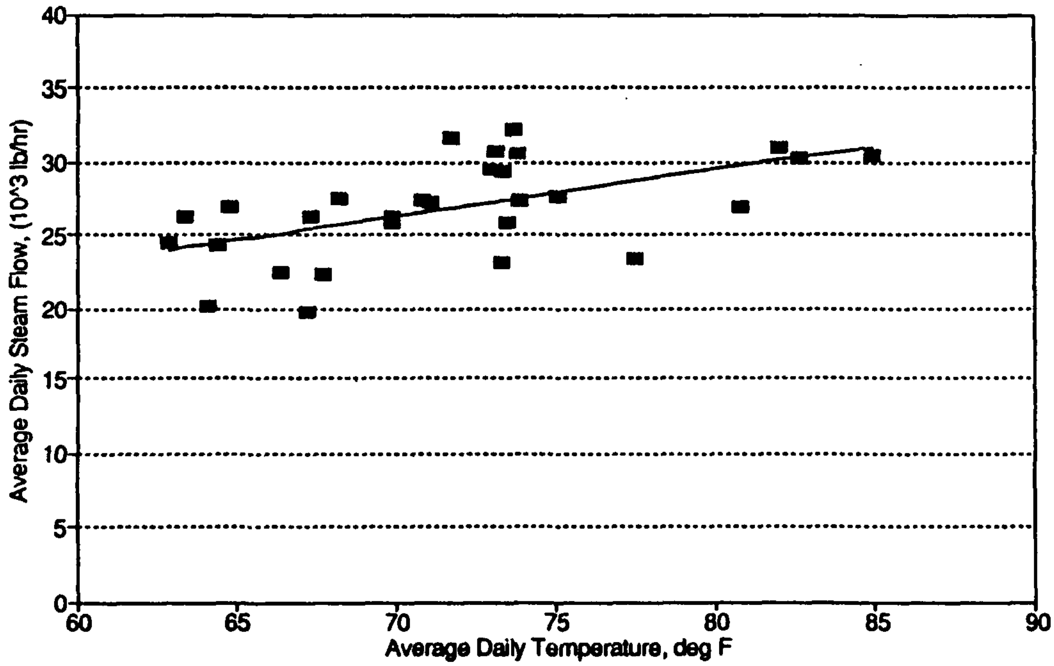

Figure 14. Summer Baseline Steam Load.

A multiple regression using the temperature and the square of the temperature was performed on the data. The resulting equation for the steam flow was:

$$\text{Steam Flow } (10^3 \text{ lb/hr}) = 91.9334 - (1.5073 \times T) + (0.00835 \times T^2) \quad \text{[Eq 9]}$$

where R^2 = 0.898 (correlation coefficient)
T = ambient temperature.

The quadratic nature of the curve is appropriate due to the quadratic nature of the pressure setpoints. A strong correlation can be seen in this quadratic relation.

Figure 16 shows the linear regression for the summer steam load with SDCS, which, like the summer baseline load (Figure 14), also showed a slight positive slope due to the cooling load generated by chillers in Building 400. The equation for the summer load regression line is:

$$\text{Steam Flow } (10^3 \text{ lb/hr}) = 9.36 + 0.20 \times T \quad \text{[Eq 10]}$$

where R^2 = 0.163 (correlation coefficient)
T = ambient temperature.

The average daily temperatures ranged from 63 to 85 °F. The correlation shows a weak dependence on temperature. Again, this weak correlation may be due partially to maintenance and repair of parts of the distribution system and the small range of temperatures that occurred. The summer load is linear in nature because the pressures are held constant at temperatures above 60 °F.

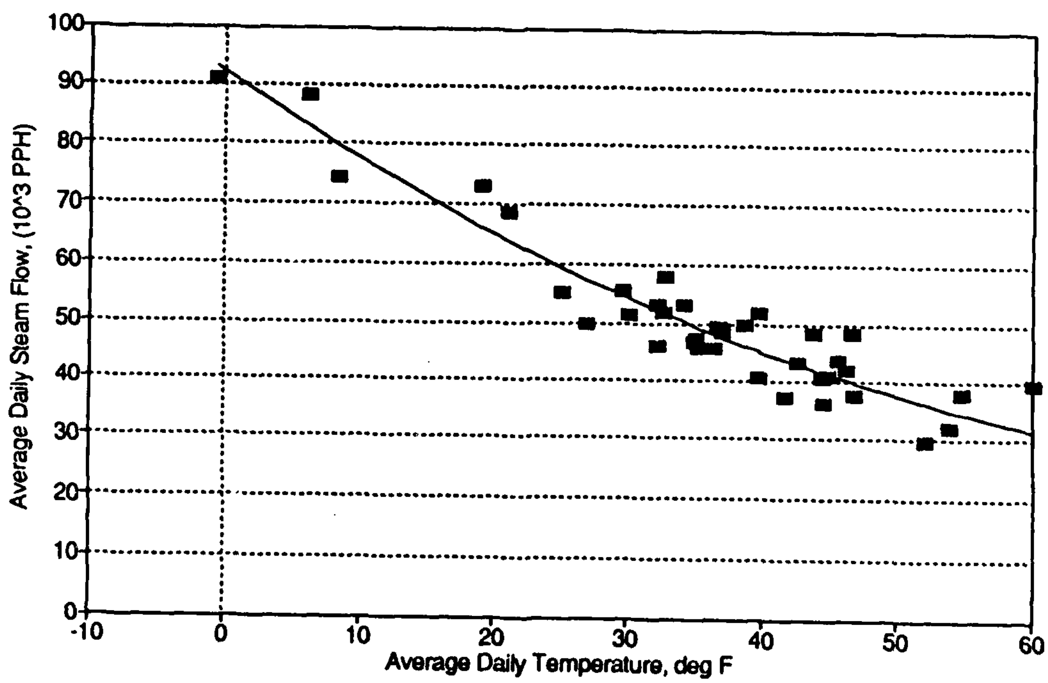

Figure 15. Winter Steam Load with SDCS.

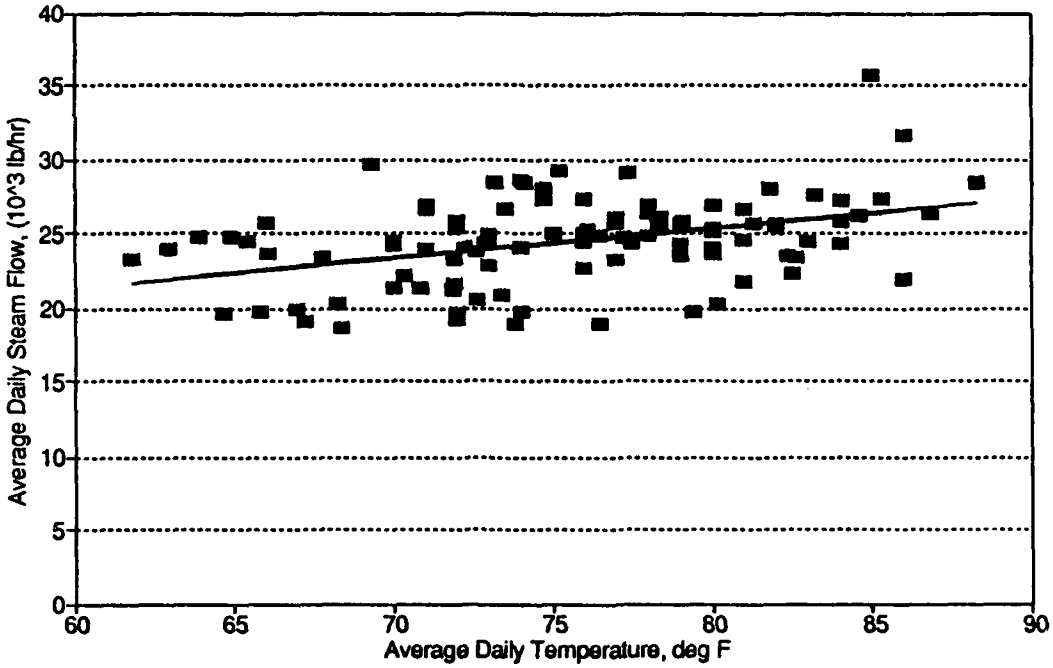

Figure 16. Summer Steam Load with SDCS.

5 RESULTS OF DATA ANALYSIS

Calculation of Savings

An equation for energy savings was calculated by taking the difference of the regressions of the baseline and SDCS loads for both summer and winter. Figures 17 and 18 show the steam savings as related to average ambient temperature. The operating parameters specified in Chapter 3 (see "Operating Costs and Parameters") were used for all savings calculations. The load equations were calculated in terms of average daily steam flow. The average daily temperatures from the ETAC climate data (Appendix F) were used with the equations for energy savings to calculate the total summer, winter, and annual savings. When the average daily temperature was below 60 °F, an estimated fixed savings of 1,710 lb/hr was used for the summer load. This estimated value was used because there were not enough data below 60 °F to calculate the actual figure.

Summary of Savings Using SDCS

Table 9 shows a summary of savings projected at Fort Harrison based on data from the demonstration of SDCS. The total steam savings were calculated using the methods described above. Values for fuel cost and boiler efficiency, as discussed in Chapter 3, were used to calculate the total gas savings and total dollar savings.

The actual steam and gas usage values were taken from the monthly boiler log summaries. These data were used to further verify the models. Differences between the actual values and model values are due to yearly temperature variations and to the use of SDCS during portions of 1990 and 1991.

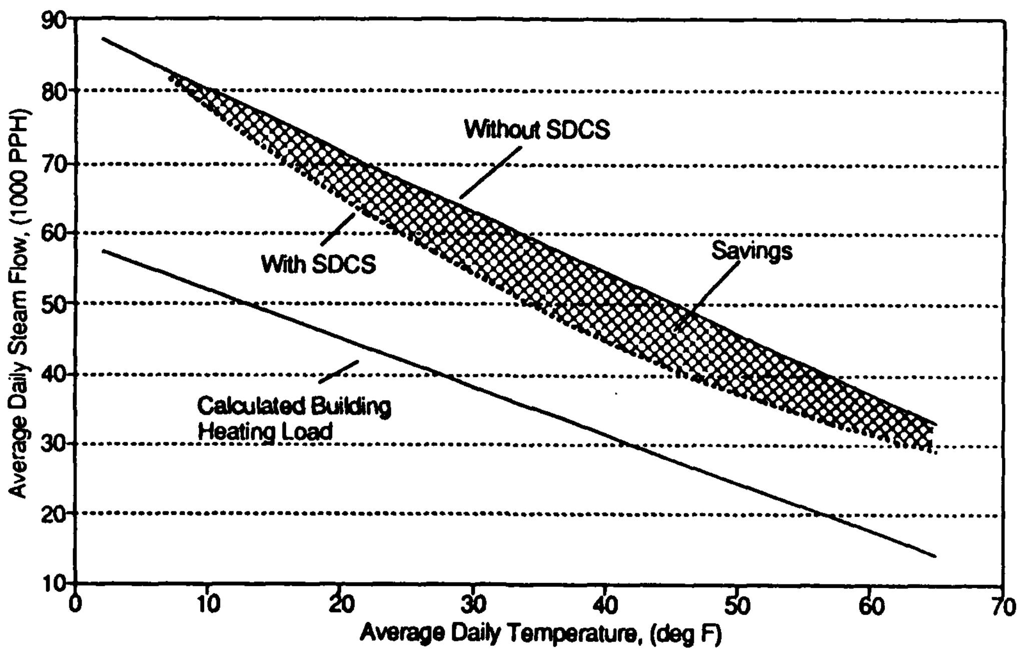

Figure 17. Winter Steam Savings.

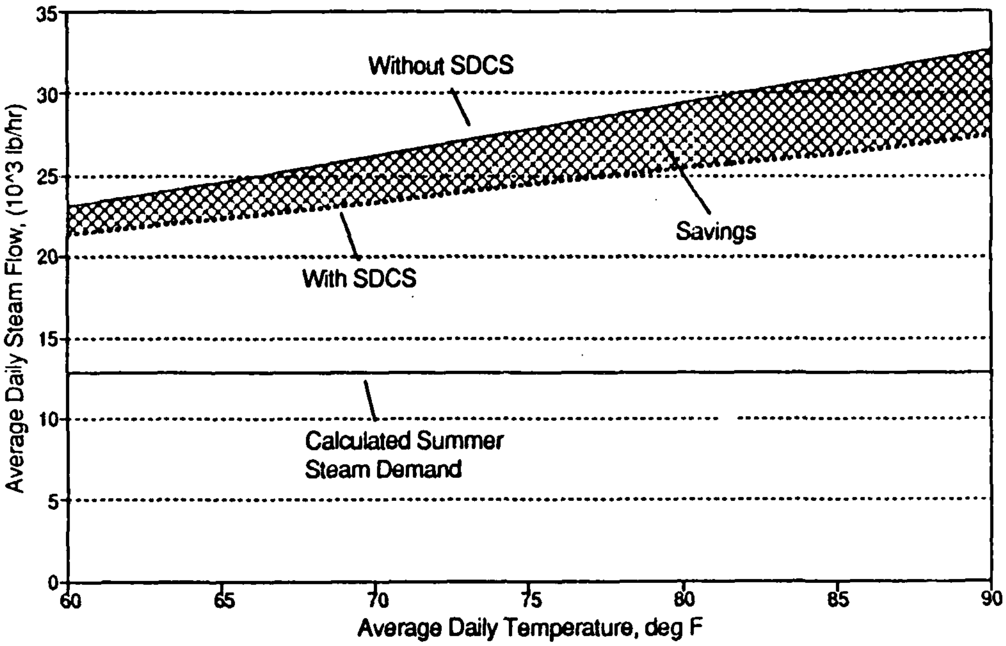

Figure 18. Summer Steam Savings.

Table 9

Projected Savings Using SDCS

	Summer	Winter	Total
Total Days	212	153	365
Total Steam Produced (10^3 lb)			
Without SDCS	129092	214529	343621
With SDCS	115983	182587	298570
Actual (90-91 average)*	130822	177591	308413
Savings	13109	31942	45051
Total Gas Used (KSCF**)			
Without SDCS	160783	267193	427976
With SDCS	144456	227410	371866
Actual (90-91 average)*	160467	211296	371763
Savings	16327	39783	56111
Total Gas Used (MBtu)			
Without SDCS	152743	253834	406577
With SDCS	137233	216040	353272
Actual (90-91 average)*	152444	200731	353175
Savings	15511	37794	53305
Total Gas Usage ($)			
Without SDCS	4[illegible]8402	828260	1326662
With SDCS	447790	704937	1152727
Actual (90-91 average)*	497424	654986	1152410
Savings ($)	50612	123323	173934

*Summer included the period of May through November, and winter consisted of the period from December through April. Averages were based on actual gas use of 376,523 KSCF for 1990 and 367,002 KSCF for 1991.
**KSCF: thousands of standard cubic feet.

Statistical Validation of Results

An external reference test was used to establish the validity of the data models (Box, Hunter, and Hunter 1978). Separate tests were done on the summer and winter loads. The baseline data were used as the reference. The winter loads were validated using R^2 values calculated from the data models. These R^2 values varied between 0.72 and 0.9, showing a strong correlation between the models and the actual data (when $R^2=1$, a perfect fit is indicated). Summer data R^2 values show a weak correlation (Equations 7, 8, 9, and 10). Factors contributing to the weak correlation may have included maintenance, a narrow outdoor temperature range during the summer test period, and general steam flow variability. Even with the weak correlation (0.16 to 0.31), however, the external reference test supported the savings estimates.

The null hypothesis was that if SDCS was not improving the efficiency of the steam distribution process, then average daily steam flow with SDCS operating would be distributed around the baseline data regression line. The linear regression of the baseline data was used as the mean reference line. The relevant reference set used was the average daily steam flow data taken while SDCS was operating. Determining factors for the separation of the data are explained in Chapter 3 under "Data Filtering."

Every data point in the relevant reference sets was compared to the mean reference lines for the winter and summer data. Only five of the 38 data points (13.2 percent) for the winter load were at or above the baseline regression. A frequency chart of the differences (Figure 19) was plotted to show the distribution of the data. The mean saving was 7,315 pph, and 76 percent of the data depict a savings of between 3,000 and 14,000 pph.

For the summer load, 18 of the 107 data points (16.8 percent) were at or above the baseline regression. A frequency chart of these data (Figure 20) was plotted to show its distribution. The mean saving was 3,360 pph, with 76 percent of the points showing a savings of between 1,000 and 7,500 pph.

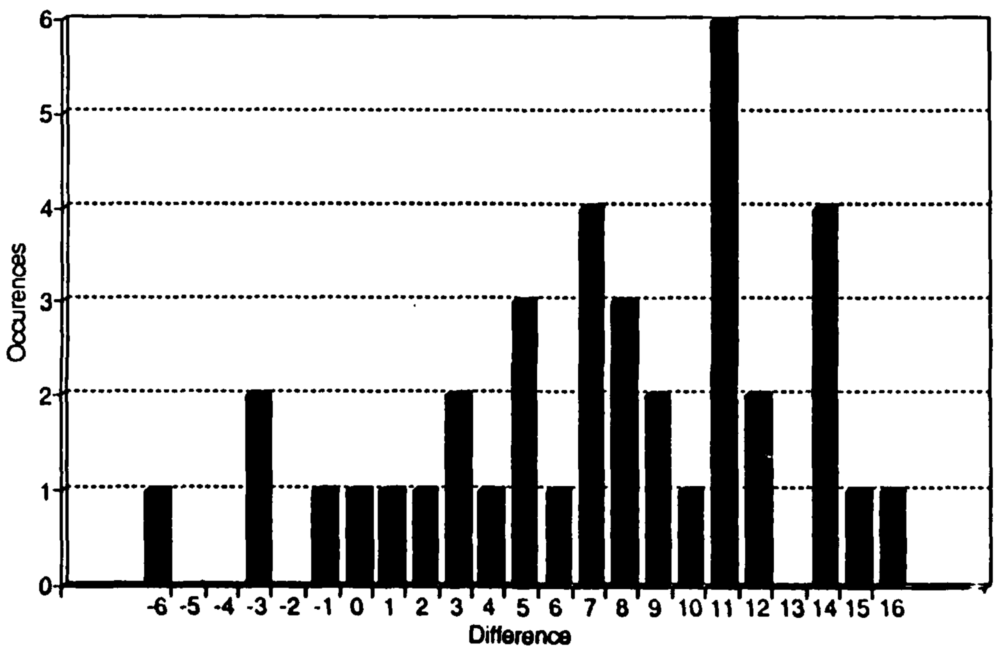

Figure 19. Frequency Chart for Winter Steam Savings.

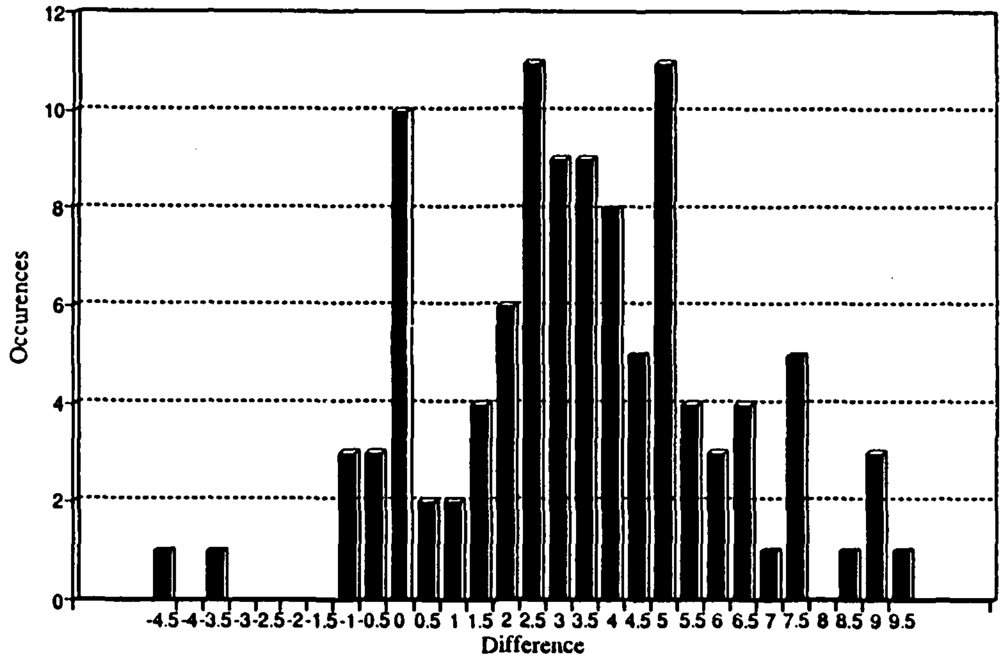

Figure 20. Frequency Chart for Summer Steam Savings.

6 CONCLUSIONS

Payback

Researchers found that SDCS is a technically and economically viable improvement over current operating procedures. Analyses of the demonstration results show that the simple payback for SDCS is less than 1 year. Steam consumption data collected during the demonstration portion of this project at Fort Benjamin Harrison indicate that a savings of approximately 53,305 MBtu can be achieved (Table 9). The savings correspond to a reduction in the annual steam production of about 45 million pounds of steam. Using a 1990 fuel cost of $3.26 per MBtu and a boiler efficiency of 84 percent, total fuel savings equalled about $174,000. This savings represents a 13 percent reduction in annual cost. The capital cost of equipment and installation (during FY87) for the demonstration project was approximately $161,000 (Table 8).

The demonstration of SDCS at Fort Benjamin Harrison showed a significant potential for savings from reduced thermal and leak losses in central steam heat distribution systems. A properly designed SDCS is an economical and technical improvement over current operating control procedures. Distribution system type and layout, and end user requirements can influence the effectiveness of the system.

A comprehensive preliminary evaluation of an installation's central heating system is essential to a properly working SDCS. Developing an accurate model of the distribution system and steam usage should be the first step. Then economic feasibility can be determined through life-cycle costing procedures. Also, it must be confirmed that steam traps and PRV are correctly sized to work efficiently throughout the operating range of the SDCS.

METRIC CONVERSION TABLE

1 in.	=	25.4 mm
1 ft	=	0.305 m
1 psi	=	6.89 kPa
1 lb	=	0.453 kg
1 cu ft	=	0.028 m^3
1 mi	=	1.61 km
1 sq ft	=	0.093 m^2
1 μm	=	1×10^{-6}m
1 gal	=	3.78 l
°F	=	(°C + 17.78) x 1.8
°C	=	0.55(°F-32)
1 yd	=	0.9144 m

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APPENDIX A: SHDP Input and Output Files

Ft. Harrison - 100 PSI and 0 deg F

SYSTEM VARIABLES AND EXECUTION CONTROLS

FLOW TOLERANCE = 10.00 lbm/hr
UNKNOWN PARAMETER TOLERANCE = .000500
UNKNOWN PRESSURE TOLERANCE = .000050
UNKNOWN NODE FLOW TOLERANCE = 1.000 lbm/hr

PC =	20	1	5	20	1	4	4	0	0	0
UNS =	1	2	2	2	4	3	1	1	2	2

PIPE DESCRIPTION SECTION

NCE NUM	FROM NODE	TO NODE	STATUS	DIAMETER (in)	LENGTH (ft)	RELATIVE ROUGHNESS	HEAT LOSS COEF (Btu/hr-ft-F)	TEMP (F)
1	2	A1		8.0	600.+ 0.	.313E-3	1.40	40.0
2	A1	1		8.0	500.+ 0.	.313E-3	1.40	40.0
3	2	B1		10.0	260.+ 0.	.250E-3	1.10	40.0
4	B1	B2		10.0	540.+ 0.	.250E-3	1.10	40.0
5	B2	B2B		4.0	340.+ 0.	.620E-3	.40	40.0
6	B2B	13		2.1	110.+ 0.	.121E-2	.20	40.0
7	B2B	17		2.1	120.+ 0.	.121E-2	.20	40.0
8	B2	18		2.1	150.+ 0.	.121E-2	.20	40.0
9	18	26		2.1	100.+ 0.	.121E-2	.20	40.0
10	26	28		2.1	100.+ 0.	.121E-2	.20	40.
11	B2	B2C		5.1	210.+ 0.	.495E-3	.60	40.
12	B2C	611		2.1	170.+ 0.	.121E-2	.20	40.0
13	B2C	B2A		5.1	280.+ 0.	.495E-3	.60	40.0
14	B2A	610		2.1	300.+ 0.	.121E-2	.20	40.0
15	B2A	613		5.1	280.+ 0.	.495E-3	.60	40.0
16	613	615		4.0	180.+ 0.	.620E-3	.40	40.0
17	613	614		2.1	270.+ 0.	.495E-3	.20	40.0
18	614	618		3.1	[illegible]0.+ 0.	.814E-3	.90	40.0
19	B2	B3		8.0	570.+ 0.	.313E-3	.90	40.0
20	B3	B3A		4.0	1020.+ 0.	.620E-3	.40	40.0
21	B3A	671		3.1	690.+ 0.	.814E-3	.90	40.0
22	671	672		3.1	690.+ 0.	.814E-3	.90	40.0
23	B3A	670		4.0	40.+ 0.	.620E-3	.40	40.0
24	670	669		4.0	330.+ 0.	.620E-3	.40	53.0
25	669	668		4.0	250.+ 0.	.620E-3	.40	40.0
26	668	667		4.0	290.+ 0.	.620E-3	.40	55.0
27	667	B3B		4.0	250.+ 0.	.620E-3	.40	57.0
28	B3B	622		1.4	140.+ 0.	.181E-2	.20	40.0
29	B3B	666		4.0	50.+ 0.	.620E-3	.40	40.0
30	666	665		4.0	260.+ 0.	.620E-3	.40	56.0
31	665	B3C		4.0	120.+ 0.	.620E-3	.40	52.0
32	B3C	624		1.4	50.+ 0.	.181E-2	.20	40.0
33	624	623		1.4	70.+ 0.	.181E-2	.20	40.0
34	B3C	664		2.1	80.+ 0.	.121E-2	.20	40.0
35	664	663		2.1	180.+ 0.	.121E-2	.20	40.0
36	663	662		2.1	190.+ 0.	.121E-2	.20	52.0
37	B3	B4		8.0	420.+ 0.	.313E-3	.90	40.0
38	B4	604		1.4	390.+ 0.	.181E-2	.20	40.0
39	B4	B5		8.0	430.+ 0.	.313E-3	.90	40.0
40	B5	600		3.1	340.+ 0.	.814E-3	.30	40.0
41	B5	B6		8.0	680.+ 0.	.313E-3	.90	40.0

PIPE DESCRIPTION SECTION

NCE NUM	FROM NODE	TO NODE	STATUS	DIAMETER (in)	LENGTH (ft)	RELATIVE ROUGHNESS	HEAT LOSS COEF (Btu/hr-ft-F)	TEMP (F)
42	B6	B6A		6.1	160.+ 0.	.412E-3	.70	40.0
43	B6A	402		3.1	120.+ 0.	.814E-3	.30	40.0
44	B6A	B7		6.1	240.+ 0.	.412E-3	.70	40.0
45	B7	401		3.1	120.+ 0.	.814E-3	.30	40.0
46	B7	400		6.1	770.+ 0.	.412E-3	.70	40.0
47	B7	C7		6.1	330.+ 0.	.412E-3	.50	40.0
48	B6	B8		8.0	1270.+ 0.	.313E-3	.90	40.0
49	B8	B8A		6.1	330.+ 0.	.412E-3	.70	40.0
50	B8A	502		2.1	440.+ 0.	.121E-2	.20	40.0
51	B8A	500		6.1	500.+ 0.	.412E-3	.70	40.0
52	B8	B9		6.1	520.+ 0.	.412E-3	.70	40.0
53	B9	538		6.1	120.+ 0.	.412E-3	.70	40.0
54	538	537		6.1	130.+ 0.	.412E-3	.70	40.0
55	537	539		6.1	240.+ 0.	.412E-3	.70	40.0
56	2	D1		11.9	70.+ 0.	.209E-3	1.30	40.0
57	D1	D1A		11.9	640.+ 0.	.209E-3	1.30	40.0
58	D1A	C1		10.0	90.+ 0.	.250E-3	.70	40.0
59	C1	19		2.1	150.+ 0.	.121E-2	.10	40.0
60	C1	31		10.0	800.+ 0.	.250E-3	.70	40.0
61	31	C3		10.0	270.+ 0.	.250E-3	.70	40.0
62	C3	32		4.0	200.+ 0.	.620E-3	.30	40.0
63	C3	35		4.0	200.+ 0.	.620E-3	.30	40.0
64	C3	C4		8.0	520.+ 0.	.313E-3	.50	40.0
65	C4	427		2.1	190.+ 0.	.121E-2	.10	40.0
66	C4	C5		8.0	300.+ 0.	.313E-3	.50	40.0
67	C5	410		6.1	260.+ 0.	.412E-3	.40	40.0
68	410	C7		6.1	220.+ 0.	.412E-3	.40	40.0
69	C7	421		4.0	140.+ 0.	.620E-3	.30	40.0
70	421	420		3.1	190.+ 0.	.814E-3	.20	40.0
71	C5	C8		3.1	340.+ 0.	.814E-3	.20	40.0
72	C8	424		2.1	90.+ 0.	.121E-2	.20	40.0
73	424	423		2.1	80.+ 0.	.121E-2	.20	40.0
74	423	422		2.1	70.+ 0.	.121E-2	.20	40.0
75	C8	425		2.1	60.+ 0.	.121E-2	.20	40.0
76	425	426		2.1	170.+ 0.	.121E-2	.20	40.0
77	C8	428		3.1	330.+ 0.	.814E-3	.30	40.0
78	428	C9		3.1	120.+ 0.	.814E-3	.30	40.0
79	C9	429		1.6	170.+ 0.	.155E-2	.20	40.0
80	C9	C10		3.1	210.+ 0.	.814E-3	.30	40.0
81	C10	C11		1.6	110.+ 0.	.155E-2	.20	40.0
82	C11	432		1.6	90.+ 0.	.155E-2	.20	40.0
83	C11	430		1.6	410.+ 0.	.155E-2	.20	40.0
84	C10	431		1.6	350.+ 0.	.155E-2	.20	40.0
85	C10	434		2.1	200.+ 0.	.121E-2	.20	40.0
86	434	40		2.1	590.+ 0.	.121E-2	.20	40.0
87	40	39		2.1	340.+ 0.	.121E-2	.20	40.0
88	D1A	D2		10.0	580.+ 0.	.250E-3	.70	40.0
89	D2	D3		10.0	790.+ 0.	.250E-3	.70	40.0
90	D3	20		3.1	330.+ 0.	.814E-3	.20	40.0
91	D3	D4		10.0	1190.+ 0.	.250E-3	.70	40.0
92	D4	D5		10.0	520.+ 0.	.250E-3	.70	40.0
93	D5	101		3.1	130.+ 0.	.814E-3	.20	40.0
94	D5	D6		10.0	840.+ 0.	.250E-3	.70	40.0
95	D6	51		3.1	330.+ 0.	.814E-3	.20	40.0

PIPE DESCRIPTION SECTION

NCE NUM	FROM NODE	TO NODE	STATUS	DIAMETER (in)	LENGTH (ft)	RELATIVE ROUGHNESS	HEAT LOSS COEF (Btu/hr-ft-F)	TEMP (F)
96	51	472		3.1	150.+ 0.	.814E-3	.20	40.0
97	D6	D7		10.0	950.+ 0.	.250E-3	.70	40.0
98	D7	D7A		6.1	280.+ 0.	.412E-3	.40	40.0
99	D7A	456		5.1	50.+ 0.	.495E-3	.40	40.0
100	456	455		2.1	70.+ 0.	.121E-2	.10	40.0
101	D7A	458		5.1	50.+ 0.	.495E-3	.40	40.0
102	458	457		2.1	70.+ 0.	.121E-2	.10	40.0
103	D7A	D7B		6.1	570.+ 0.	.412E-3	.40	40.0
104	D7B	444		5.1	50.+ 0.	.495E-3	.40	40.0
105	444	443		2.1	70.+ 0.	.121E-2	.10	40.0
106	D7B	446		5.1	50.+ 0.	.495E-3	.40	40.0
107	446	445		2.1	70.+ 0.	.121E-2	.10	40.0
108	D7	D8		8.0	510.+ 0.	.313E-3	.50	40.0
109	D8	D9		8.0	1150.+ 0.	.313E-3	.50	40.0
110	D9	126		8.0	530.+ 0.	.313E-3	.50	40.0
111	D9	D10		8.0	1230.+ 0.	.313E-3	.50	40.0
112	D10	300		8.0	280.+ 0.	.313E-3	.50	40.0

REGULATOR AND VALVE DESCRIPTION SECTION

NCE NUM	FROM NODE	TO NODE	STATUS	SIZING COEFFICIENT	CONFIGURATION CONSTANT	MINIMUM PRESSURE DROP
113	1	1A	UNKNOWN	256.60	35.00	.0
114	13	13A	UNKNOWN	3.00	35.00	.0
115	17	17A	UNKNOWN	2.40	35.00	.0
116	18	18A	UNKNOWN	1.20	35.00	.0
117	26	26A	UNKNOWN	4.60	35.00	.0
118	28	28A	UNKNOWN	2.70	35.00	.0
119	611	611A	UNKNOWN	1.40	35.00	.0
120	610	610A	UNKNOWN	1.50	35.00	.0
121	613	613A	UNKNOWN	15.30	35.00	.0
122	615	615A	UNKNOWN	15.30	35.00	.0
123	614	614A	UNKNOWN	1.00	35.00	.0
124	618	618A	UNKNOWN	3.35	35.00	.0
125	671	671A	UNKNOWN	10.10	35.00	.0
126	672	672A	UNKNOWN	10.10	35.00	.0
127	670	670A	UNKNOWN	10.10	35.00	.0
128	669	669A	UNKNOWN	3.40	35.00	.0
129	668	668A	UNKNOWN	10.10	35.00	.0
130	667	667A	UNKNOWN	10.10	35.00	.0
131	622	622A	UNKNOWN	.60	35.00	.0
132	666	666A	UNKNOWN	10.10	35.00	.0
133	665	665A	UNKNOWN	1.70	35.00	.0
134	624	624A	UNKNOWN	.50	35.00	.0
135	623	623A	UNKNOWN	.90	35.00	.0
136	664	664A	UNKNOWN	1.70	35.00	.0
137	663	663A	UNKNOWN	2.70	35.00	.0
138	662	662A	UNKNOWN	5.90	35.00	.0
139	604	604A	UNKNOWN	1.00	35.00	.0
140	600	600A	UNKNOWN	8.40	35.00	.0
141	402	402A	UNKNOWN	12.20	35.00	.0
142	401	401A	UNKNOWN	21.70	35.00	.0
143	400	400A	UNKNOWN	56.40	35.00	.0
144	502	502A	UNKNOWN	2.60	35.00	.0
145	500	500A	UNKNOWN	7.00	35.00	.0
146	538	538A	UNKNOWN	4.60	35.00	.0
147	537	537A	UNKNOWN	5.50	35.00	.0
148	539	539A	UNKNOWN	5.50	35.00	.0

149	19	19A	UNKNOWN	15.80	35.00	.0
150	31	31A	UNKNOWN	5.20	35.00	.0
151	32	32A	UNKNOWN	3.50	35.00	.0
152	35	35A	UNKNOWN	.80	35.00	.0
153	427	427A	UNKNOWN	5.30	35.00	.0
154	410	410A	UNKNOWN	11.00	35.00	.0
155	421	421A	UNKNOWN	8.20	35.00	.0
156	420	420A	UNKNOWN	8.20	35.00	.0
157	424	424A	UNKNOWN	2.90	35.00	.0
158	423	423A	UNKNOWN	.90	35.00	.0
159	422	422A	UNKNOWN	2.80	35.00	.0
160	425	425A	UNKNOWN	1.90	35.00	.0
161	426	426A	UNKNOWN	1.90	35.00	.0
162	428	428A	UNKNOWN	1.10	35.00	.0
163	429	429A	UNKNOWN	2.60	35.00	.0
164	432	432A	UNKNOWN	2.60	35.00	.0
165	430	430A	UNKNOWN	2.60	35.00	.0
166	431	431A	UNKNOWN	5.20	35.00	.0
167	434	434A	UNKNOWN	2.50	35.00	.0
168	40	40A	UNKNOWN	2.10	35.00	.0
169	39	39A	UNKNOWN	2.20	35.00	.0
170	20	20A	UNKNOWN	9.10	35.00	.0
171	101	101A	UNKNOWN	6.30	35.00	.0
172	51	51A	UNKNOWN	2.00	35.00	.0
173	472	472A	UNKNOWN	6.00	35.00	.0
174	456	456A	UNKNOWN	14.60	35.00	.0
175	455	455A	UNKNOWN	1.10	35.00	.0
176	458	458A	UNKNOWN	14.60	35.00	.0
177	457	457A	UNKNOWN	1.10	35.00	.0
178	444	444A	UNKNOWN	14.60	35.00	.0
179	443	443A	UNKNOWN	1.10	35.00	.0
180	446	446A	UNKNOWN	14.60	35.00	.0
181	445	445A	UNKNOWN	1.10	35.00	.0
182	126	126A	UNKNOWN	13.60	35.00	.0
183	300	300A	UNKNOWN	56.40	35.00	.0

TRAP INPUT DATA

5.0 percent trap leakage

VAULT INPUT DATA

VAULT NUMBER	NODE NAME	MAIN PIPE DIAMETER (in)	MAIN PIPE LENGTH (ft)	HEAT TRANSFER COEFFICIENT (Btu/hr-ft-F)	ENVIROMENT TEMPERATURE (F)
1	A1	7.98	10.00	.70	50.0
2	B1	10.02	10.00	.90	50.0
3	B2	10.02	10.00	.90	50.0
4	B2A	5.05	10.00	.60	50.0
5	B2B	4.03	10.00	.40	50.0
6	614	5.05	10.00	.60	50.0
7	B3	7.98	10.00	.70	50.0
8	B3A	4.03	5.00	.30	50.0
9	B3B	4.03	5.00	.30	50.0
10	B3C	4.03	5.00	.30	50.0
11	B4	7.98	10.00	.70	50.0
12	B5	7.98	10.00	.70	50.0
13	B6	7.98	10.00	.70	50.0
14	B6A	6.07	10.00	.60	50.0

15	B7	6.07	10.00	.60	50.0
16	B8	7.98	10.00	.70	50.0
17	B8A	6.07	10.00	.60	50.0
18	B9	6.07	10.00	.60	50.0
19	C1	10.02	10.00	.90	50.0
20	31	10.02	10.00	.90	50.0
21	C3	7.98	10.00	.70	50.0
22	C4	6.07	10.00	.70	50.0
23	C5	7.98	10.00	.70	50.0
24	410	6.07	10.00	.70	50.0
25	C7	7.98	10.00	.70	50.0
26	C8	3.07	10.00	.30	50.0
27	428	3.07	10.00	.30	50.0
28	C9	3.07	10.00	.30	50.0
29	C10	3.07	10.00	.30	50.0
30	434	2.07	10.00	.20	50.0
31	40	2.07	10.00	.20	50.0
32	39	2.07	10.00	.20	50.0
33	D1	11.94	10.00	1.30	50.0
34	D2	10.02	10.00	1.10	50.0
35	D3	10.02	10.00	1.10	50.0
36	D4	10.02	10.00	1.10	50.0
37	D5	10.02	10.00	1.10	50.0
38	51	3.07	10.00	.30	50.0
39	D6	10.02	10.00	1.10	50.0
40	D7	10.02	10.00	1.10	50.0
41	D7A	6.07	10.00	.70	50.0
42	D7B	6.07	10.00	.70	50.0
43	D8	7.98	10.00	.90	50.0
44	D9	7.98	10.00	.90	50.0
45	D10	7.98	10.00	.90	50.0

NODE INPUT DATA

NODE NAME	PRESSURE (psig)	NODE FLOW (lbm/hr)	NODE FLOW RETURNED	PIPE CONDS RETURNED	LOAD CONDS TEMPERATURE
2	100.00	80000.?	.00	.00	100.0
A1	95.00?	0.	.00	.00	100.0
1	90.00?	0.	.00	.00	100.0
1A	15.00	-12820.	.60	.00	100.0
B1	95.00?	0.	.00	.00	100.0
B2	95.00?	0.	.00	.00	100.0
B2B	95.00?	0.	.00	.00	100.0
13	95.00?	0.	.00	.00	100.0
13A	15.00	-314.	.60	.00	100.0
17	95.00?	0.	.00	.00	100.0
17A	15.00	-253.	.60	.00	100.0
18	95.00?	0.	.00	.00	100.0
18A	15.00	-124.	.60	.00	100.0
26	95.00?	0.	.00	.00	100.0
26A	15.00	-476.	.60	.00	100.0
28	95.00?	0.	.00	.00	100.0
28A	15.00	-283.	.60	.00	100.0
B2C	95.00?	0.	.00	.00	100.0
611	95.00?	0.	.00	.00	100.0
611A	15.00	-151.	.60	.00	100.0

B2A	95.00?	0.	.00	.00	100.0
610	95.00?	0.	.00	.00	100.0
610A	15.00	-158.	.60	.00	100.0
613	95.00?	0.	.00	.00	100.0
613A	15.00	-1603.	.60	.00	100.0
615	95.00?	0.	.00	.00	100.0
615A	15.00	-1603.	.60	.00	100.0
614	90.00?	0.	.00	.00	100.0
614A	15.00	-109.	.60	.00	100.0
618	90.00?	0.	.00	.00	100.0
618A	15.00	-352.	.60	.00	100.0
B3	95.00?	0.	.00	.00	100.0
B3A	95.00?	0.	.00	.00	100.0
671	90.00?	0.	.00	.00	100.0
671A	15.00	-1059.	.60	.00	100.0
672	90.00?	0.	.00	.00	100.0
672A	15.00	-1059.	.60	.00	100.0
670	90.00?	0.	.00	.00	100.0
670A	15.00	-1059.	.60	.00	100.0
669	90.00?	0.	.00	.00	100.0
669A	15.00	-354.	.60	.00	100.0
668	90.00?	0.	.00	.00	100.0
668A	15.00	-1059.	.60	.00	100.0
667	90.00?	0.	.00	.00	100.0
667A	15.00	-1059.	.60	.00	100.0
B3B	90.00?	0.	.00	.00	100.0
622	90.00?	0.	.00	.00	100.0
622A	15.00	-64.	.60	.00	100.0
666	90.00?	0.	.00	.00	100.0
666A	15.00	-1059.	.60	.00	100.0
665	90.00?	0.	.00	.00	100.0
665A	15.00	-173.	.60	.00	100.0
B3C	90.00?	0.	.00	.00	100.0
624	90.00?	0.	.00	.00	100.0

NODE INPUT DATA

NODE NAME	PRESSURE (psig)	NODE FLOW (lbm/hr)	NODE FLOW RETURNED	PIPE CONDS RETURNED	LOAD CONDS TEMPERATURE
624A	15.00	-50.	.60	.00	100.0
623	90.00?	0.	.00	.00	100.0
623A	15.00	-91.	.60	.00	100.0
664	85.00?	0.	.00	.00	100.0
664A	15.00	-174.	.60	.00	100.0
663	85.00?	0.	.00	.00	100.0
663A	15.00	-286.	.60	.00	100.0
662	85.00?	0.	.00	.00	100.0
662A	15.00	-622.	.60	.00	100.0
B4	95.00?	0.	.00	.00	100.0
604	95.00?	0.	.00	.00	100.0
604A	15.00	-103.	.60	.00	100.0
B5	95.00?	0.	.00	.00	100.0
600	95.00?	0.	.00	.00	100.0
600A	15.00	-883.	.60	.00	100.0
B6	95.00?	0.	.00	.00	100.0
B6A	90.00?	0.	.00	.00	100.0
402	90.00?	0.	.00	.00	100.0
402A	15.00	-1279.	.60	.00	100.0
B7	90.00?	0.	.00	.00	100.0

401	90.00?	0.	.00	.00	100.0
401A	15.00	-2278.	.60	.00	100.0
400	85.00?	0.	.00	.00	100.0
400A	15.00	-5908.	.60	.00	100.0
B8	95.00?	0.	.00	.00	100.0
B8A	90.00?	0.	.00	.00	100.0
502	90.00?	0.	.00	.00	100.0
502A	15.00	-274.	.60	.00	100.0
500	90.00?	0.	.00	.00	100.0
500A	15.00	-724.	.60	.00	100.0
B9	90.00?	0.	.00	.00	180.0
538	90.00?	0.	.00	.00	100.0
538A	15.00	-483.	.60	.00	100.0
537	90.00?	0.	.00	.00	100.0
537A	15.00	-582.	.60	.00	100.0
539	90.00?	0.	.00	.00	100.0
539A	15.00	-582.	.60	.00	100.0
D1	100.00?	0.	.00	.00	100.0
D1A	100.00?	0.	.00	.00	100.0
C1	95.00?	0.	.00	.00	100.0
19	95.00?	0.	.00	.00	100.0
19A	15.00	-1640.	.60	.00	100.0
31	95.00?	0.	.00	.00	100.0
31A	15.00	-544.	.60	.00	100.0
C3	95.00?	0.	.00	.00	100.0
32	95.00?	0.	.00	.00	100.0
32A	15.00	-369.	.60	.00	100.0
35	95.00?	0.	.00	.00	100.0
35A	15.00	-84.	.60	.00	100.0
C4	95.00?	0.	.00	.00	100.0
427	95.00?	0.	.00	.00	100.0
427A	15.00	-551.	.60	.00	100.0
C5	95.00?	0.	.00	.00	100.0
410	95.00?	0.	.00	.00	100.0

NODE INPUT DATA

NODE NAME	PRESSURE (psig)	NODE FLOW (lbm/hr)	NODE FLOW RETURNED	PIPE CONDS RETURNED	LOAD CONDS TEMPERATURE
410A	15.00	-1147.	.60	.00	100.0
C7	90.00?	0.	.00	.00	100.0
421	90.00?	0.	.00	.00	100.0
421A	15.00	-859.	.60	.00	100.0
420	90.00?	0.	.00	.00	100.0
420A	15.00	-859.	.60	.00	100.0
C8	90.00?	0.	.00	.00	100.0
424	90.00?	0.	.00	.00	100.0
424A	15.00	-302.	.60	.00	100.0
423	90.00?	0.	.00	.00	100.0
423A	15.00	-98.	.60	.00	100.0
422	90.00?	0.	.00	.00	100.0
422A	15.00	-291.	.60	.00	100.0
425	90.00?	0.	.00	.00	100.0
425A	15.00	-194.	.60	.00	100.0
426	90.00?	0.	.00	.00	100.0
426A	15.00	-194.	.60	.00	100.0
428	90.00?	0.	.00	.00	100.0
428A	15.00	-111.	.60	.00	100.0
C9	90.00?	0.	.00	.00	100.0

C10	90.00?	0.	.00	.00	100.0
C11	90.00?	0.	.00	.00	100.0
429	85.00?	0.	.00	.00	100.0
429A	15.00	-274.	.60	.00	100.0
432	85.00?	0.	.00	.00	100.0
432A	15.00	-274.	.60	.00	100.0
430	85.00?	0.	.00	.00	100.0
430A	15.00	-274.	.60	.00	100.0
431	80.00?	0.	.00	.00	100.0
431A	15.00	-545.	.60	.00	100.0
434	85.00?	0.	.00	.00	100.0
434A	15.00	-261.	.60	.00	100.0
40	80.00?	0.	.00	.00	100.0
40A	15.00	-219.	.60	.00	100.0
39	80.00?	0.	.00	.00	100.0
39A	15.00	-231.	.60	.00	100.0
D2	95.00?	0.	.00	.00	100.0
D3	95.00?	0.	.00	.00	100.0
20	95.00?	0.	.00	.00	100.0
20A	15.00	-943.	.60	.00	100.0
D4	95.00?	0.	.00	.00	100.0
D5	95.00?	0.	.00	.00	100.0
101	95.00?	0.	.00	.00	100.0
101A	15.00	-656.	.60	.00	100.0
D6	95.00?	0.	.00	.00	100.0
51	95.00?	0.	.00	.00	100.0
51A	15.00	-214.	.60	.00	100.0
472	90.00?	0.	.00	.00	100.0
472A	15.00	-628.	.60	.00	100.0
D7	95.00?	0.	.00	.00	100.0
D7A	95.00?	0.	.00	.00	100.0
456	95.00?	0.	.00	.00	100.0
456A	15.00	-1528.	.60	.00	100.0
455	95.00?	0.	.00	.00	100.0

NODE INPUT DATA

NODE NAME	PRESSURE (psig)	NOL FLOW (lbm/hr)	NODE FLOW RETURNED	PIPE CONDS RETURNED	LOAD CONDS TEMPERATURE
455A	15.00	-119.	.60	.00	100.0
458	95.00?	0.	.00	.00	100.0
458A	15.00	-1528.	.60	.00	100.0
457	95.00?	0.	.00	.00	100.0
457A	15.00	-119.	.60	.00	100.0
D7B	95.00?	0.	.00	.00	100.0
444	95.00?	0.	.00	.00	100.0
444A	15.00	-1528.	.60	.00	100.0
443	95.00?	0.	.00	.00	100.0
443A	15.00	-119.	.60	.00	100.0
446	95.00?	0.	.00	.00	100.0
446A	15.00	-1528.	.60	.00	100.0
445	95.00?	0.	.00	.00	100.0
445A	15.00	-119.	.60	.00	100.0
D8	95.00?	0.	.00	.00	100.0
D9	95.00?	0.	.00	.00	100.0
126	90.00?	0.	.00	.00	100.0
126A	15.00	-1426.	.60	.00	100.0
D10	90.00?	0.	.00	.00	100.0
300	90.00?	0.	.00	.00	100.0

300A	15.00	-4340.	.60	.00	100.0

NODE CORRESPONDENCE TABLE AND LIST OF ADJACENT NODES

NODE NUMBER	NODE NAME	ADJACENT NODES(BY NAME)				
1	2	A1	B1	D1		
2	A1	1	2			
3	1	1A	A1			
4	1A	1				
5	B1	B2	2			
6	B2	B2B	18	B2C	B3	B1
7	B2B	13	17	B2		
8	13	13A	B2B			
9	13A	13				
10	17	17A	B2B			
11	17A	17				
12	18	26	18A	B2		
13	18A	18				
14	26	28	26A	18		
15	26A	26				
16	28	28A	26			
17	28A	28				
18	B2C	611	B2A	B2		
19	611	611A	B2C			
20	611A	611				
21	B2A	610	613	B2C		
22	610	610A	B2A			
23	610A	610				
24	613	615	614	613A	B2A	
25	613A	613				

NODE CORRESPONDENCE TABLE AND LIST OF ADJACENT NODES

NODE NUMBER	NODE NAME	ADJACENT NODES(BY NAME)		
26	615	615A	613	
27	615A	615		
28	614	618	614A	613
29	614A	614		
30	618	618A	614	
31	618A	618		
32	B3	B3A	B4	B2
33	B3A	671	670	B3
34	671	672	671A	B3A
35	671A	671		
36	672	672A	671	
37	672A	672		
38	670	669	670A	B3A
39	670A	670		
40	669	668	669A	670
41	669A	669		
42	668	667	668A	669
43	668A	668		
44	667	B3B	667A	668
45	667A	667		

46	B3B	622	666	667	
47	622	622A	B3B		
48	622A	622			
49	666	665	666A	B3B	
50	666A	666			
51	665	B3C	665A	666	
52	665A	665			
53	B3C	624	664	665	
54	624	623	624A	B3C	
55	624A	624			
56	623	623A	624		
57	623A	623			
58	664	663	664A	B3C	
59	664A	664			
60	663	662	663A	664	
61	663A	663			
62	662	662A	663		
63	662A	662			
64	B4	604	B5	B3	
65	604	604A	B4		
66	604A	604			
67	B5	600	B6	B4	
68	600	600A	B5		
69	600A	600			
70	B6	B6A	B8	B5	
71	B6A	402	B7	B6	
72	402	402A	B6A		
73	402A	402			
74	B7	401	400	C7	B6A
75	401	401A	B7		
76	401A	401			
77	400	400A	B7		
78	400A	400			
79	B8	B8A	B9	B6	

NODE CORRESPONDENCE TABLE AND LIST OF ADJACENT NODES

NODE NUMBER	NODE NAME	ADJACENT NODES (BY NAME)			
80	B8A	502	500	B8	
81	502	502A	B8A		
82	502A	502			
83	500	500A	B8A		
84	500A	500			
85	B9	538	B8		
86	538	537	538A	B9	
87	538A	538			
88	537	539	537A	538	
89	537A	537			
90	539	539A	537		
91	539A	539			
92	D1	D1A	2		
93	D1A	C1	D2	D1	
94	C1	19	31	D1A	
95	19	19A	C1		
96	19A	19			
97	31	C3	31A	C1	
98	31A	31			
99	C3	32	35	C4	31

100	32	32A	C3		
101	32A	32			
102	35	35A	C3		
103	35A	35			
104	C4	427	C5	C3	
105	427	427A	C4		
106	427A	427			
107	C5	410	C8	C4	
108	410	C7	410A	C5	
109	410A	410			
110	C7	421	B7	410	
111	421	420	421A	C7	
112	421A	421			
113	420	420A	421		
114	420A	420			
115	C8	424	425	428	C5
116	424	423	424A	C8	
117	424A	424			
118	423	422	423A	424	
119	423A	423			
120	422	422A	423		
121	422A	422			
122	425	426	425A	C8	
123	425A	425			
124	426	426A	425		
125	426A	426			
126	428	C9	428A	C8	
127	428A	428			
128	C9	429	C10	428	
129	C10	C11	431	434	C9
130	C11	432	430	C10	
131	429	429A	C9		
132	429A	429			
133	432	432A	C11		

NODE CORRESPONDENCE TABLE AND LIST OF ADJACENT NODES

NODE NUMBER	NODE NAME	ADJACENT NODES(BY NAME)		
134	432A	432		
135	430	430A	C11	
136	430A	430		
137	431	431A	C10	
138	431A	431		
139	434	40	434A	C10
140	434A	434		
141	40	39	40A	434
142	40A	40		
143	39	39A	40	
144	39A	39		
145	D2	D3	D1A	
146	D3	20	D4	D2
147	20	20A	D3	
148	20A	20		
149	D4	D5	D3	
150	D5	101	D6	D4
151	101	101A	D5	
152	101A	101		
153	D6	51	D7	D5

154	51	472	51A	D6	
155	51A	51			
156	472	472A	51		
157	472A	472			
158	D7	D7A	D8	D6	
159	D7A	456	458	D7B	D7
160	456	455	456A	D7A	
161	456A	456			
162	455	455A	456		
163	455A	455			
164	458	457	458A	D7A	
165	458A	458			
166	457	457A	458		
167	457A	457			
168	D7B	444	446	D7A	
169	444	443	444A	D7B	
170	444A	444			
171	443	443A	444		
172	443A	443			
173	446	445	446A	D7B	
174	446A	446			
175	445	445A	446		
176	445A	445			
177	D8	D9	D7		
178	D9	126	D10	D8	
179	126	126A	D9		
180	126A	126			
181	D10	300	D9		
182	300	300A	D10		
183	300A	300			

***** PROBLEM SUMMARY *****

183 NODES IN THE SYSTEM
112 PIPES IN THE SYSTEM
71 VALVES OR REGULATORS
5 PERCENT TRAP LEAKAGE
45 VAULTS IN THE SYSTEM
71 UNKNOWN PARAMETERS
111 UNKNOWN PRESSURES
1 UNKNOWN FLOWS

Ft. Harrison - 100 PSI and 0 deg F

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SOLUTION COMPLETED IN  9 ITERATIONS
 SOME NODES MAY NOT BE BALANCED
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  *** PROBLEM SUMMARY ***
 183 NODES IN THE SYSTEM
 112 PIPES IN THE SYSTEM
  71 VALVES OR REGULATORS
   5 PERCENT TRAP LEAKAGE
  45 VAULTS IN THE SYSTEM
  71 UNKNOWN PARAMETERS
 111 UNKNOWN PRESSURES
   1 UNKNOWN FLOWS
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COMPUTED NODE DATA

NODE NAME	PRESSURE (psig)	NODE FLOW (lbm/hr)	CONDS FLOW (lbm/hr)	FLOW LOSS (Btu/hr)	CONDS LOSS (Btu/hr)	TEMP (F)	RESIDUAL (lbm/hr)
2	100.00	71445.8?	-204.0	.0	63045.4	337.9	-.34
A1	99.30?	.0	-258.6	.0	79773.8	337.4	-.09
1	98.74?	.0	-117.4	.0	36186.4	337.1	.53
1A	15.00	-12819.8	.0	337409.8	.0	249.7	.00
B1	99.68?	.0	-146.6	.0	45261.3	337.7	.96
B2	99.02?	.0	-232.3	.0	71619.1	337.2	-4.84
B2B	98.98?	.0	-30.7	.0	9460.9	337.2	9.74
13	98.88?	.0	-3.7	.0	1142.6	337.1	-2.16
13A	15.00	-313.9	.0	8261.7	.0	249.7	.00
17	98.90?	.0	-4.0	.0	1247.0	337.2	-1.43
17A	15.00	-252.9	.0	6656.2	.0	249.7	.00
18	98.01?	.0	-8.3	.0	2553.6	336.6	-.02
18A	15.00	-124.1	.0	3266.2	.0	249.7	.00
26	97.51?	.0	-6.7	.0	2054.2	336.2	-.01
26A	15.00	-476.4	.0	12538.6	.0	249.7	.[illegible]
28	97.44?	.0	-3.4	.0	1031.3	336.2	-.06
28A	15.00	-283.3	.0	7456.3	.0	249.7	.00
B2C	98.71?	.0	-55.0	.0	16950.7	337.0	-.40
611	98.66?	.0	-5.7	.0	1764.9	337.0	-.07
611A	15.00	-151.3	.0	3982.1	.0	249.7	.00
B2A	98.33?	.0	-66.4	.0	20445.3	336.8	.08
610	98.25?	.0	-10.1	.0	3108.1	336.7	-.07
610A	15.00	-158.4	.0	4169.0	.0	249.7	.00
613	98.00?	.0	-49.3	.0	15152.7	336.6	-1.08
613A	15.00	-1602.7	.0	42182.1	.0	249.7	.00
615	97.88?	.0	-12.1	.0	3718.3	336.5	-.18
615A	15.00	-1602.7	.0	42182.1	.0	249.7	.00
614	97.08?	.0	-113.1	.0	34734.2	336.0	3.89
614A	15.00	-108.5	.0	2855.7	.0	249.7	.00
618	96.91?	.0	-104.1	.0	31955.0	335.8	-2.90
618A	15.00	-352.2	.0	9269.7	.0	249.7	.00
B3	97.74?	.0	-196.2	.0	60314.5	336.4	-.19
B3A	77.[illegible]4?	.0	-146.2	.0	42705.4	321.6	-.21
671	72.05?	.0	-191.2	.0	55061.1	317.7	.17
671A	15.00	-1058.9	.0	27869.6	.0	249.7	.00
672	70.80?	.0	-95.7	.0	27461.4	316.7	-.16
672A	15.00	-1058.9	.0	27869.6	.0	249.7	.00
670	76.58?	.0	-20.3	.0	5931.4	321.3	.22
670A	15.00	-1058.9	.0	27869.6	.0	249.7	.00
669	73.91?	.0	-32.7	.0	9458.0	319.2	-.01
669A	15.00	-353.8	.0	9311.8	.0	249.7	.00
668	72.12?	.0	-30.9	.0	8905.3	317.7	.01
668A	15.00	-1058.9	.0	27869.6	.0	249.7	.00
667	70.85?	.0	-30.6	.0	8795.1	316.7	.03
667A	15.00	-1058.9	.0	27869.6	.0	249.7	.00
B3B	70.27?	.0	-21.6	.0	6192.1	316.2	-.15
622	70.19?	.0	-4.3	.0	1233.1	316.2	-.02
622A	15.00	-63.8	.0	1679.2	.0	249.7	.00
666	70.17?	.0	-18.1	.0	5173.5	316.1	.15
666A	15.00	-1058.9	.0	27869.6	.0	249.7	.00
665	69.97?	.0	-22.1	.0	6315.2	316.0	-.02
665A	15.00	-172.8	.0	4548.0	.0	249.7	.00
B3C	69.90?	.0	-10.9	.0	3115.4	315.9	-.17
624	69.78?	.0	-3.7	.0	1053.2	315.8	.00

COMPUTED NODE DATA

NODE NAME	PRESSURE (psig)	NODE FLOW (lbm/hr)	CONDS FLOW (lbm/hr)	FLOW LOSS (Btu/hr)	CONDS LOSS (Btu/hr)	TEMP (F)	RESIDUAL (lbm/hr)
624A	15.00	-49.8	.0	1310.7	.0	249.7	.00
623	69.71?	.0	-2.1	.0	614.4	315.8	-.02
623A	15.00	-90.8	.0	2389.8	.0	249.7	.00
664	68.86?	.0	-7.6	.0	2170.1	315.1	.09
664A	15.00	-174.3	.0	4587.5	.0	249.7	.00
663	67.18?	.0	-10.7	.0	3048.9	313.7	.00
663A	15.00	-286.4	.0	7537.9	.0	249.7	.00
662	66.34?	.0	-5.4	.0	1541.8	312.9	-.07
662A	15.00	-621.7	.0	16362.8	.0	249.7	.0[illegible]
B4	97.49?	.0	-141.2	.0	43376.9	336.2	.[illegible]
604	97.04?	.0	-13.1	.0	4016.5	335.9	-.[illegible]
604A	15.00	-102.8	.0	2705.6	.0	249.7	.0[illegible]
B5	97.24?	.0	-184.3	.0	56605.7	336.1	.30
600	96.94?	.0	-17.1	.0	5243.6	335.9	-.16
600A	15.00	-882.7	.0	23232.2	.0	249.7	.00
B6	96.95?	.0	-312.8	.0	95996.0	335.9	-.28
B6A	96.86?	.0	-52.9	.0	16232.8	335.8	.54
402	96.65?	.0	-6.0	.0	1843.1	335.7	-.08
402A	15.00	-1278.5	.0	33649.4	.0	249.7	.00
B7	96.80?	.0	-151.4	.0	46439.3	335.8	-.69
401	96.16?	.0	-5.9	.0	1808.1	335.4	-.10
401A	15.00	-2277.7	.0	59947.8	.0	249.7	.00
400	95.99?	.0	-89.8	.0	27499.4	335.2	.28
400A	15.00	-5907.6	.0	155484.7	.0	249.7	.00
B8	96.83?	.0	-291.3	.0	89381.5	335.8	-16.5[illegible]
B8A	96.82?	.0	-112.1	.0	34399.0	335.8	15.6[illegible]
502	96.48?	.0	-14.7	.0	4516.8	335.6	-.1[illegible]
502A	15.00	-273.9	.0	7208.9	.0	249.7	.00
500	96.81?	.0	-58.7	.0	17998.7	335.8	-.20
500A	15.00	-724.1	.0	19057.9	.0	249.7	.00
B9	96.78?	.0	-75.1	.0	23032.6	335.8	.60
538	96.76?	.0	-29.3	.0	8996.6	335.8	-.43
538A	15.00	-482.8	.0	12707.0	.0	249.7	.00
537	96.76?	.0	-43.4	.0	13315.4	335.7	.32
537A	15.00	-581.9	.0	15315.3	.0	249.7	.00
539	96.75?	.0	-28.2	.0	8637.0	335.7	-.10
539A	15.00	-581.9	.0	15315.3	.0	249.7	.00
D1	99.94?	.0	-154.2	.0	47643.7	337.8	.00
D1A	99.37?	.0	-217.6	.0	67139.9	337.5	-1.00
C1	99.32?	.0	-106.7	.0	32929.2	337.4	-.01
19	96.16?	.0	-2.1	.0	636.2	335.4	-.04
19A	15.00	-1639.6	.0	43153.3	.0	249.7	.00
31	98.98?	.0	-125.8	.0	38794.2	337.2	-.86
31A	15.00	-544.1	.0	14320.4	.0	249.7	.00
C3	98.88?	.0	-95.1	.0	29324.6	337.1	.29
32	98.87?	.0	-10.1	.0	3117.9	337.1	.00
32A	15.00	-368.9	.0	9709.2	.0	249.7	.00
35	98.88?	.0	-10.1	.0	3118.1	337.1	.12
35A	15.00	-83.9	.0	2208.2	.0	249.7	.00
C4	98.29?	.0	-71.2	.0	21930.5	336.8	-.03
427	97.80?	.0	-3.2	.0	975.4	336.4	-.08
427A	15.00	-550.8	.0	14496.7	.0	249.7	.00
C5	97.99?	.0	-51.9	.0	15975.6	336.6	-.14
410	97.44?	.0	-31.6	.0	9718.1	336.2	-.71

COMPUTED NODE DATA

NODE NAME	PRESSURE (psig)	NODE FLOW (lbm/hr)	CONDS FLOW (lbm/hr)	FLOW LOSS (Btu/hr)	CONDS LOSS (Btu/hr)	TEMP (F)	RESIDUAL (lbm/hr)
410A	15.00	-1147.1	.0	30191.0	.0	249.7	.00
C7	97.10?	.0	-49.1	.0	15074.0	336.0	.92
421	96.99?	.0	-13.4	.0	4109.0	335.9	-.03
421A	15.00	-859.1	.0	22611.0	.0	249.7	.00
420	96.83?	.0	-6.4	.0	1951.2	335.8	-.13
420A	15.00	-859.1	.0	22611.0	.0	249.7	.00
C8	93.51?	.0	-30.8	.0	9379.6	333.6	.23
424	93.12?	.0	-5.6	.0	1706.3	333.3	-.02
424A	15.00	-302.3	.0	7956.4	.0	249.7	.00
423	93.00?	.0	-5.0	.0	1510.7	333.2	.02
423A	15.00	-97.9	.0	2576.7	.0	249.7	.00
422	92.94?	.0	-2.3	.0	705.2	333.2	-.06
422A	15.00	-290.9	.0	7656.3	.0	249.7	.00
425	93.42?	.0	-7.6	.0	2322.8	333.5	.02
425A	15.00	-194.3	.0	5113.9	.0	249.7	.00
426	93.35?	.0	-5.6	.0	1717.1	333.5	-.07
426A	15.00	-194.3	.0	5113.9	.0	249.7	.00
428	91.44?	.0	-21.7	.0	6576.9	332.1	-.03
428A	15.00	-111.1	.0	2924.1	.0	249.7	.00
C9	90.76?	.0	-21.6	.0	6522.4	331.7	.00
C10	89.85?	.0	-31.4	.0	9485.6	331.0	-.13
C11	88.58?	.0	-19.8	.0	5963.9	330.2	-.11
429	90.29?	.0	-5.6	.0	1686.7	331.4	.04
429A	15.00	-274.3	.0	7219.4	.0	249.7	.0[illegible]
432	88.33?	.0	-2.9	.0	883.1	330.0	.[illegible]
432A	15.00	-274.3	.0	7219.4	.0	249.7	.[illegible]
430	87.37?	.0	-13.3	.0	4005.4	329.3	.02
430A	15.00	-274.3	.0	7219.4	.0	249.7	.00
431	86.26?	.0	-11.2	.0	3359.6	328.5	.01
431A	15.00	-544.8	.0	14338.8	.0	249.7	.00
434	88.75?	.0	-25.7	.0	7728.5	330.3	.00
434A	15.00	-260.8	.0	6864.1	.0	249.7	.00
40	87.38?	.0	-30.3	.0	9082.9	329.3	.11
40A	15.00	-219.3	.0	5771.9	.0	249.7	.00
39	87.17?	.0	-11.1	.0	3320.8	329.2	-.08
39A	15.00	-230.6	.0	6069.3	.0	249.7	.00
D2	99.03?	.0	-160.6	.0	49511.6	337.2	2.49
D3	98.57?	.0	-243.0	.0	74859.1	336.9	.04
20	98.25?	.0	-11.1	.0	3412.2	336.7	-.15
20A	15.00	-942.6	.0	24808.7	.0	249.7	.00
D4	97.97?	.0	-200.2	.0	61596.9	336.5	-.39
D5	97.71?	.0	-163.5	.0	50267.5	336.4	.34
101	97.65?	.0	-4.4	.0	1341.8	336.3	-.09
101A	15.00	-655.7	.0	17257.7	.0	249.7	.00
D6	97.34?	.0	-220.5	.0	67729.6	336.1	.28
51	97.06?	.0	-16.1	.0	4936.7	336.0	-.30
51A	15.00	-213.7	.0	5624.5	.0	249.7	.00
472	97.00?	.0	-5.0	.0	1543.2	335.9	.13
472A	15.00	-627.7	.0	16520.7	.0	249.7	.00
D7	96.98?	.0	-172.4	.0	52904.9	335.9	-.17
D7A	96.60?	.0	-63.4	.0	19434.2	335.6	.40
456	96.59?	.0	-4.5	.0	1386.4	335.6	-.18
456A	15.00	-1528.3	.0	40224.0	.0	249.7	.00
455	96.58?	.0	-1.2	.0	359.5	335.6	.00

COMPUTED NODE DATA

NODE NAME	PRESSURE (psig)	NODE FLOW (lbm/hr)	CONDS FLOW (lbm/hr)	FLOW LOSS (Btu/hr)	CONDS LOSS (Btu/hr)	TEMP (F)	RESIDUAL (lbm/hr)
455A	15.00	-119.4	.0	3142.5	.0	249.7	.00
458	96.59?	.0	-4.5	.0	1386.4	335.6	-.18
458A	15.00	-1528.3	.0	40224.0	.0	249.7	.00
457	96.58?	.0	-1.2	.0	359.5	335.6	.00
457A	15.00	-119.4	.0	3142.5	.0	249.7	.00
D7B	96.41?	.0	-44.8	.0	13737.4	335.5	.00
444	96.39?	.0	-4.5	.0	1385.0	335.5	.85
444A	15.00	-1528.3	.0	40224.0	.0	249.7	-.61
443	96.38?	.0	-1.2	.0	359.2	335.5	.00
443A	15.00	-119.4	.0	3142.5	.0	249.7	-.02
446	96.39?	.0	-4.5	.0	1385.0	335.5	.00
446A	15.00	-1528.3	.0	40224.0	.0	249.7	-.61
445	96.38?	.0	-1.2	.0	359.2	335.5	.00
445A	15.00	-119.4	.0	3142.5	.0	249.7	-.02
D8	96.83?	.0	-138.8	.0	42594.6	335.8	.00
D9	96.50?	.0	-243.4	.0	74632.7	335.6	.42
126	96.50?	.0	-44.4	.0	13606.4	335.6	785.42
126A	15.00	-1425.8	.0	37526.2	.0	249.7	-787.41
D10	96.32?	.0	-126.3	.0	38707.9	335.5	.00
300	96.28?	.0	-23.4	.0	7175.7	335.4	1.39
300A	15.00	-4339.6	.0	114215.8	.0	249.7	-.33
							.00

COMPUTED PIPE FLOWS AND PARAMETERS

FROM NODE	TO NODE	STATUS	FLOW (lbm/hr)	CONDENSATE (lbm/hr)	HEAT LOSS (Btu/hr)	DIAMETER (in)	RE NUMBER	FRIC FACTOR
2	A1		13211.6	282.26	250027.2	7.98	5.13E+5	1.66E-2
A1	1		12944.8	234.87	208067.8	7.98	5.03E+5	1.66E-2
2	B1		24774.6	95.37	85163.4	10.02	7.66E+5	1.57E-2
B1	B2		24617.9	197.79	176687.7	10.02	7.61E+5	1.57E-2
B2	B2B		632.6	45.87	40422.6	4.03	4.86E+4	2.31E-2
B2B	13		322.5	7.41	6538.0	2.07	4.83E+4	2.50E-2
B2B	17		262.6	8.09	7132.5	2.07	3.93E+4	2.57E-2
B2	18		923.0	9.95	8907.2	2.07	1.38E+5	2.28E-2
18	26		783.6	6.66	5928.3	2.07	1.17E+5	2.31E-2
26	28		293.6	6.71	5924.5	2.07	4.39E+4	2.53E-2
B2	B2C		4448.6	42.25	37439.2	5.05	2.73E+5	1.86E-2
B2C	611		164.0	11.46	10098.7	2.07	2.45E+4	2.76E-2
B2C	B2A		4224.4	56.32	49881.4	5.05	2.59E+5	1.87E-2
B2A	610		175.4	20.20	17805.7	2.07	2.63E+4	2.73E-2
B2A	613		3974.6	56.31	49842.4	5.05	2.44E+5	1.88E-2
613	615		1621.6	24.18	21350.3	4.03	1.25E+5	2.05E-2
613	614		695.1	18.03	15998.4	2.07	1.04E+5	2.03E-2
614	618		460.4	208.26	183757.0	3.07	4.65E+4	2.40E-2
B2	B3		18377.3	168.70	152268.3	7.98	7.13E+5	1.63E-2
B3	B3A		8914.9	97.05	118141.3	4.03	6.85E+5	1.87E-2
B3A	671		2416.2	190.98	173694.0	3.07	2.44E+5	2.05E-2
671	672		1160.1	191.43	172127.4	3.07	1.17E+5	2.15E-2
B3A	670		6347.7	4.40	4503.3	4.03	4.88E+5	1.89E-2
670	669		5262.2	36.27	35275.5	4.03	4.05E+5	1.90E-2
669	668		4869.9	29.07	27846.5	4.03	3.74E+5	1.91E-2
668	667		3774.4	32.77	30418.4	4.03	2.90E+5	1.93E-2
667	B3B		2679.1	28.53	25947.1	4.03	2.06E+5	1.97E-2
B3B	622		73.7	8.61	7733.7	1.38	1.66E+4	3.07E-2
B3B	666		2579.2	6.09	5523.8	4.03	1.98E+5	1.98E-2
666	665		1496.4	30.05	27047.0	4.03	1.15E+5	2.07E-2
665	B3C		1295.9	14.09	12670.0	4.03	9.96E+4	2.10E-2
B3C	624		157.7	3.07	2758.8	1.38	3.54E+4	2.76E-2
624	623		98.6	4.30	3861.2	1.38	2.21E+4	2.93E-
B3C	664		1122.8	4.62	4408.0	2.07	1.68E+5	2.26E-
664	663		935.2	10.59	9877.1	2.07	1.40E+5	2.28E-2
663	662		632.5	10.89	9929.3	2.07	9.47E+4	2.34E-2
B3	B4		9258.2	126.60	112007.1	7.98	3.59E+5	1.70E-2
B4	604		122.8	26.17	23094.7	1.38	2.76E+4	2.84E-2
B4	B5		8985.9	129.56	114611.1	7.98	3.49E+5	1.70E-2
B5	600		906.6	34.17	30189.3	3.07	9.15E+4	2.20E-2
B5	B6		7886.5	204.90	181136.0	7.98	3.06E+5	1.72E-2
B6	B6A		4210.8	37.49	33134.9	6.07	2.15E+5	1.84E-2
B6A	402		1291.4	12.02	10647.0	3.07	1.30E+5	2.14E-2
B6A	B7		2858.2	56.29	49694.2	6.07	1.46E+5	1.91E-2
B7	401		2290.4	11.80	10640.4	3.07	2.31E+5	2.06E-2
B7	400		6004.6	179.59	159280.2	6.07	3.06E+5	1.79E-2
B7	C7		-5595.2	55.04	48819.9	6.07	2.86E+5	1.80E-2
B6	B8		3355.0	383.18	338143.3	7.98	1.30E+5	1.87E-2
B8	B8A		1220.6	77.44	68328.9	6.07	6.23E+4	2.14E-2
B8A	502		295.5	29.47	26019.6	2.07	4.42E+4	2.53E
B8A	500		789.5	117.33	103525.3	6.07	4.03E+4	2.32E
B8	B9		1851.5	122.00	107664.8	6.07	9.45E+4	2.01E-
B9	538		1768.1	28.15	24843.8	6.07	9.02E+4	2.03E-2
538	537		1249.4	30.50	26913.5	6.07	6.38E+4	2.13E-2

COMPUTED PIPE FLOWS AND PARAMETERS

FROM NODE	TO NODE	STATUS	FLOW (lbm/hr)	CONDENSATE (lbm/hr)	HEAT LOSS (Btu/hr)	DIAMETER (in)	RE NUMBER	FRIC FACTOR
537	539		616.9	56.31	49685.9	6.07	3.15E+4	2.43E-2
2	D1		33250.3	30.43	27105.1	11.94	8.63E+5	1.51E-2
D1	D1A		33085.5	277.98	247647.5	11.94	8.58E+5	1.51E-2
D1A	C1		15962.3	21.14	18739.5	10.02	4.94E+5	1.60E-2
C1	19		1648.5	4.15	4446.1	2.07	2.47E+5	2.22E-2
C1	31		14198.0	188.16	166503.1	10.02	4.39E+5	1.62E-2
31	C3		13518.4	63.50	56167.6	10.02	4.18E+5	1.62E-2
C3	32		386.1	20.23	17828.8	4.03	2.97E+4	2.52E-2
C3	35		101.2	20.23	17828.9	4.03	7.78E+3	3.41E-2
C3	C4		12927.5	86.31	77208.9	7.98	5.02E+5	1.66E-2
C4	427		560.9	6.34	5635.5	2.07	8.39E+4	2.37E-2
C4	C5		12287.1	49.83	44499.6	7.98	4.77E+5	1.67E-2
C5	410		8592.7	34.16	30824.0	6.07	4.39E+5	1.75E-2
410	C7		7405.1	29.10	26056.1	6.07	3.78E+5	1.77E-2
C7	421		1751.7	14.06	12429.6	4.03	1.35E+5	2.04E-2
421	420		872.3	12.72	11242.4	3.07	8.80E+4	2.21E-2
C5	C8		3634.4	19.88	20066.1	3.07	3.67E+5	2.02E-2
C8	424		724.2	5.92	5281.9	2.07	1.08E+5	2.32E-2
424	423		409.5	5.30	4692.2	2.07	6.13E+4	2.44E-2
423	422		299.9	4.64	4104.8	2.07	4.49E+4	2.53E-2
C8	425		415.4	3.98	3522.5	2.07	6.22E+4	2.43E-2
425	426		206.6	11.28	9978.5	2.07	3.09E+4	2.66E-2
C8	428		2457.3	31.83	28993.8	3.07	2.48E+5	2.05E-2
428	C9		2316.7	11.58	10509.0	3.07	2.34E+5	2.06E-2
C9	429		286.5	11.16	9911.6	1.61	5.51E+4	2.56E-2
C9	C10		2002.3	20.38	18356.1	3.07	2.02E+5	2.07E-2
C10	C11		602.8	7.06	6393.3	1.61	1.16E+5	2.43E-2
C11	432		283.8	5.87	5221.2	1.61	5.46E+4	2.57E-2
C11	430		294.2	26.70	23757.7	1.61	5.66E+4	2.56E-2
C10	431		562.5	22.46	20285.7	1.61	1.08E+5	2.44E-2
C10	434		799.5	12.95	11626.6	2.07	1.20E+5	2.31E-2
434	40		505.7	38.40	34195.8	2.07	7.57E+4	2.39E-2
40	39		248.8	22.15	19668.0	2.07	3.72E+4	2.59E-2
D1A	D2		16901.0	136.04	120726.7	10.02	5.23E+5	1.60E-2
D2	D3		16728.1	185.11	164293.3	10.02	5.17E+5	1.60E-2
D3	20		960.5	22.17	19591.3	3.07	9.69E+4	2.19E-2
D3	D4		15514.7	278.78	247190.7	10.02	4.80E+5	1.61E-2
D4	D5		15305.1	121.71	107913.5	10.02	4.73E+5	1.61E-2
D5	101		667.0	8.73	7705.4	3.07	6.73E+4	2.28E-2
D5	D6		14464.6	196.58	174200.0	10.02	4.47E+5	1.61E-2
D6	51		877.4	22.11	19539.0	3.07	8.85E+4	2.21E-2
51	472		639.8	10.06	8877.9	3.07	6.46E+4	2.29E-2
D6	D7		13356.7	222.30	196850.5	10.02	4.13E+5	1.62E-2
D7	D7A		6793.1	37.11	33126.5	6.07	3.47E+5	1.78E-2
D7A	456		1667.1	6.70	5912.9	5.05	1.02E+5	2.03E-2
456	455		127.5	2.34	2069.5	2.07	1.91E+4	2.89E-2
D7A	458		1667.1	6.70	5912.9	5.05	1.02E+5	2.03E-2
458	457		127.5	2.34	2069.5	2.07	1.91E+4	2.89E-2
D7A	D7B		3387.0	76.24	67392.9	6.07	1.73E+5	1.88E-2
D7B	444		1666.6	6.69	5910.3	5.05	1.02E+5	2.03E-2
444	443		127.5	2.34	2068.5	2.07	1.91E+4	2.89E-2
D7B	446		1666.6	6.69	5910.3	5.05	1.02E+5	2.03E-2
446	445		127.5	2.34	2068.5	2.07	1.91E+4	2.89E-2
D7	D8		6381.8	85.34	75440.8	7.98	2.48E+5	1.75E-2

COMPUTED PIPE FLOWS AND PARAMETERS

FROM NODE	TO NODE	STATUS	FLOW (lbm/hr)	CONDENSATE (lbm/hr)	HEAT LOSS (Btu/hr)	DIAMETER (in)	RE NUMBER	FRIC FACTOR
D8	D9		6233.6	192.31	170021.6	7.98	2.42E+5	1.75E-2
D9	126		689.7	88.76	78329.1	7.98	2.68E+4	1.92E-2
D9	D10		4506.2	205.77	181744.9	7.98	1.75E+5	1.81E-2
D10	300		4369.6	46.83	41362.3	7.98	1.70E+5	1.81E-2

COMPUTED VALVE AND REGULATOR FLOWS AND PARAMETERS

FROM NODE	TO NODE	STATUS	FLOW (lbm/hr)	Cs
1	1A	?	12821.2	113.7
13	13A	?	315.3	2.8
17	17A	?	254.3	2.3
18	18A	?	125.5	1.1
26	26A	?	477.8	4.3
28	28A	?	284.7	2.6
611	611A	?	152.7	1.4
610	610A	?	159.8	1.4
613	613A	?	1604.1	14.3
615	615A	?	1604.1	14.3
614	614A	?	109.9	1.0
618	618A	?	353.6	3.2
671	671A	?	1060.3	12.4
672	672A	?	1060.3	12.6
670	670A	?	1060.3	11.8
669	669A	?	355.2	4.1
668	668A	?	1060.3	12.4
667	667A	?	1060.3	12.6
622	622A	?	65.2	.8
666	666A	?	1060.3	12.7
665	665A	?	174.2	2.1
624	624A	?	51.2	.6
623	623A	?	92.2	1.1
664	664A	?	175.7	2.1
663	663A	?	287.8	3.6
662	662A	?	623.1	7.9
604	604A	?	104.2	.9
600	600A	?	884.1	8.0
402	402A	?	1279.9	11.6
401	401A	?	2279.1	20.7
400	400A	?	5909.0	53.7
502	502A	?	275.3	2.5
500	500A	?	725.5	6.5
538	538A	?	484.2	4.4
537	537A	?	583.3	5.3
539	539A	?	583.3	5.3
19	19A	?	1641.0	14.9
31	31A	?	545.5	4.8
32	32A	?	370.3	3.3
35	35A	?	85.3	.8
427	427A	?	552.2	4.9
410	410A	?	1148.5	10.3
421	421A	?	860.5	7.8
420	420A	?	860.5	7.8
424	424A	?	303.7	2.8
423	423A	?	99.3	.9
422	422A	?	292.3	2.7
425	425A	?	195.7	1.8
426	426A	?	195.7	1.8
428	428A	?	112.5	1.1
429	429A	?	275.7	2.6
432	432A	?	275.7	2.7
430	430A	?	275.7	2.7
431	431A	?	546.2	5.5

VAULT HEAT AND CONDENSATE LOSSES

VAULT NUMBER	NODE NAME	HEAT LOSS (Btu/hr)	CONDENSATE (lbm/hr)	CONDS LOSS (Btu/hr)
1	A1	2352.1	2.7	823.7
2	B1	3026.4	3.4	1061.0
3	B2	3025.2	3.4	1058.6
4	B2A	2014.1	2.3	703.4
5	B2B	1347.2	1.5	471.4
6	614	2014.5	2.3	701.0
7	B3	2353.4	2.7	820.5
8	B3A	482.1	.5	157.6
9	B3B	474.0	.5	151.2
10	B3C	473.6	.5	150.9
11	B4	2349.4	2.7	818.5
12	B5	2351.1	2.7	818.5
13	B6	2346.9	2.7	816.4
14	B6A	2013.7	2.3	700.3
15	B7	2011.1	2.3	699.3
16	B8	2347.8	2.7	816.4
17	B8A	2013.5	2.3	700.2
18	B9	2009.2	2.3	698.6
19	C1	3028.8	3.4	1060.7
20	31	3031.3	3.4	1060.6
21	C3	2353.7	2.7	823.3
22	C4	2351.0	2.7	821.0
23	C5	2353.1	2.7	821.0
24	410	2350.6	2.7	818.9
25	C7	2349.0	2.7	817.5
26	C8	999.5	1.1	344.2
27	428	995.2	1.1	340.6
28	C9	994.4	1.1	339.7
29	C10	991.9	1.1	337.9
30	434	659.7	.7	224.0
31	40	657.8	.7	222.4
32	39	657.9	.7	222.3
33	D1	4389.2	5.0	1539.9
34	D2	3707.4	4.2	1297.3
35	D3	3704.1	4.2	1294.5
36	D4	3699.8	4.2	1290.8
37	D5	3690.3	4.2	1286.5
38	51	1007.3	1.1	350.5
39	D6	3687.6	4.2	1284.2
40	D7	3691.5	4.2	1284.2
41	D7A	2343.2	2.7	814.3
42	D7B	2343.7	2.7	814.0
43	D8	3019.4	3.4	1050.0
44	D9	3013.9	3.4	1047.1
45	D10	3016.4	3.4	1047.4

COMPUTED VALVE AND REGULATOR FLOWS AND PARAMETERS

FROM NODE	TO NODE	STATUS	FLOW (lbm/hr)	Cs
434	434A	?	262.2	2.6
40	40A	?	220.7	2.2
39	39A	?	232.0	2.3
20	20A	?	944.0	8.4
101	101A	?	657.1	5.9
51	51A	?	215.1	1.9
472	472A	?	629.1	5.7
456	456A	?	1529.7	13.8
455	455A	?	120.8	1.1
458	458A	?	1529.7	13.8
457	457A	?	120.8	1.1
444	444A	?	1529.7	13.9
443	443A	?	120.8	1.1
446	446A	?	1529.7	13.9
445	445A	?	120.8	1.1
126	126A	?	1427.2	12.9
300	300A	?	4341.0	39.4

COMPUTED TRAP LOSSES

5 percent trap leakage rate

Trap Steam Losses	Trap Heat Losses
694.3 lbs/hr	822613.1 Btus/hr

Ft. Harrison - 100 PSI and 0 deg F

SYSTEM MASS FLOWS

(1)	Steam to loads:	63625.	lbm/hr
(2)	Steam condensed in pipes:	7013.	lbm/hr
(3)	Steam condensed in vaults:	113.	lbm/hr
(4)	Steam lost to trap leakage:	694.	lbm/hr
(5)	Total steam plant output:	71446.	lbm/hr
(6)	Pipe and vault condensate returned:	0.	lbm/hr
(7)	Load condensate returned:	38175.	lbm/hr
(8)	Total condensate returned:	38175.	lbm/hr

SYSTEM HEAT LOSSES AND DISTRIBUTION EFFICIENCY
(M = Million)

(1)	Total pipe conduction heat losses:	6.270	MBtus/hr	56.77 %
(2)	Total pipe condensate heat losses:	2.143	MBtus/hr	19.40 %
(3)	Total load condensate heat losses:	1.675	MBtus/hr	15.16 %
(4)	Total vault conduction heat losses:	.100	MBtus/hr	.91 %
(5)	Total vault condensate heat losses:	.035	MBtus/hr	.32 %
(6)	Total trap heat losses:	.823	MBtus/hr	7.45 %
(7)	Total heat losses:	11.045	MBtus/hr	100.00 %
(8)	Total heat to loads:	69.839	MBtus/hr	
(9)	Total heat input to supply:	84.994	MBtus/hr	
(10)	Total heat returned to plant:	2.512	MBtus/hr	
(11)	Net heat input from plant:	82.482	MBtus/hr	

DISTRIBUTION EFFICIENCY: 86.6% [1.0-(7)/(11)]

APPENDIX B: Fort Benjamin Harrison Building Heating Loads

Building Number	Use	Steam Line	Area Sq. ft.	Intercept (lb/hr)	Slope (lb/hr/ F)
1	Admin	A	1584531	5266.50	116.20
13	Whs	B	16024	22.80	6.72
17	Sply	B	11916	36.40	3.33
18	Admin	B	5846	17.90	1.63
19	Commiss	D	59835	552.40	16.73
20	PX	D	41235	380.70	8.65
26	Maint	B	14074	77.60	5.90
27	Maint	B	465	2.60	0.20
28	Admin	B	13344	40.80	3.73
31	Lib	D	25511	77.90	7.13
32	Training	D	17379	53.10	4.86
35	Crdt Un	D	3948	36.40	0.83
39	Theater	D	10090	93.10	2.12
40	Bowling	D	15344	45.00	2.68
51	Gst Hse	D	9568	31.20	2.81
101	NCO Club	D	20527	189.50	7.17
126	Rsv Ctr	D	67179	205.20	16.43
127	Maint	D	11541	63.60	4.03
300	Hosp/Dent	D	109424	1108.70	49.71
400	Training	B	327374	1000.20	75.50
401	EN Brk	B	70184	364.80	29.43
402	EM Brk	B	39396	204.80	16.52
410	EM Dng	D	31439	290.20	13.18
420	EN Brk	D	38455	125.40	11.29
421	EN Brk	D	38455	125.40	11.29
422	Maint	D	10308	56.80	4.32
423	Vhl Wash	D	3470	19.10	1.46
424	QM Repair	D	10711	59.00	4.49
425	Salv/Spls	D	9919	14.10	4.16
426	Whs	D	9919	14.10	4.16
427	EN Brk	D	24657	80.40	7.24
428	Admin	D	5233	16.00	1.46
429	EM Brk	D	11300	133.20	4.74
430	EM Brk	D	11300	133.20	4.74
431	EM Brk	D	22441	264.50	9.41
432	EN Brk	D	11300	133.20	4.74
434	Training	D	12288	37.50	3.44
457	Admin	D	0	0.00	0.00
458	EM Brk	D	0	0.00	0.00
472	Phys Fit	D	43922	128.90	7.67
500	Off Club	B	22667	209.30	7.92
502	Off Qtr	B	8437	43.90	3.54

529	Training	B	11636	35.50	2.85
537	Off Qtr	B	26042	85.00	7.64
538	Off Qtr	B	21611	70.50	6.34
539	Off Qtr	B	26042	85.00	7.64
600	Post HQ	B	37583	114.80	10.51
601	Post HQ	B	4006	12.20	1.12
604	Pump Hse	B	3728	20.50	1.04
605	Pump Hse	B	615	3.40	0.17
610	Music Ctr	B	9564	88.30	2.01
611	Rec Ctr	B	9065	83.70	1.90
613	EM Brk	B	49385	256.70	20.71
614	Admin	B	5111	15.60	1.43
615	EM Brk	B	49385	256.70	20.71
618	Chapel	B	16587	50.70	4.64
622	Admin	B	3004	9.20	0.84
623	Fire Sta	B	3835	21.10	1.61
624	Fire Sta	B	2103	11.60	0.88
662	Off Qtr	B	19157	99.60	8.03
663	Admin	B	13495	41.20	3.77
664	Admin	B	8213	25.10	2.30
665	Police	B	8137	24.90	2.28
666	Off Qtr	B	32630	169.60	13.68
667	Off Qtr	B	32630	169.60	13.68
668	EN Brk	B	32630	169.60	13.68
669	NCO Dug	B	11075	102.20	3.87
670	EM Brk	B	32630	169.60	13.68
671	Off Qtr	B	32630	169.60	13.68
672	Off Qtr	B	32630	169.60	13.68
	Totals		3336115	14286.5	685.9

APPENDIX C: Equipment Specifications and Instrumentation Configuration Parameters

ATTACHMENT I

Fisher Controls Company
MARSHALLTOWN, IOWA

Customer: Fort Benjamin Harrison
Reference:
Order No.
Quote No.
Date ______ Page 1 of 2

CONTROL VALVE SPECIFICATION

Item			
Quantity			2
Application			Pressure Regulating
Tag			
Size and Type			6" ED
Body	Style		☐ Angle ☐ Globe ■
Body	End Connections		☐ SWE Scrd. ☐ Flg. 300 # ANSI RF ■ ☐ BWE Sched. ____ Casting Rating ____ ☐
Body	Material		316 SST ☐ WCB Steel ■ ☐ Iron ☐
Body	Number of Ports		Two ☐ One ■
Body	Push Down to		Open ■ Close ☐
Body	Flow Direction		Up ■ Down ☐
Trim	Trim Number		
Trim	Cage and/or Bushing Material		Std. ■ ☐
Trim	Seat Ring Material		☐ Std. ■
Trim	Valve Plug	Material	☐ Std. ■
Trim	Valve Plug	Guiding	Top ☐ Cage ■ Top & Bottom ☐ Port ☐
Trim	Valve Plug	Balance	Unbalanced ☐ Balanced ■
Trim	Port Size		■ REDUCED Full ☐
Trim	Plug or Cage		Linear ☐ Q.O. ☐ ☐ Equal Percent. ■
Trim	Shutoff Class		☐ Std. ■
Bonnet	Style		☐ Ext.# Std. ■
Bonnet	Boss Size		☐ Std. ■
Bonnet	Packing		☐ Lam. Graphite TFE ■ ☐ Lubr. & Iso. Valve TFE Asb. ☐ ☐
Bonnet	Bolting	Bonnet	☐ Std. ■
Bonnet	Bolting	Pack. Flg.	☐ Std. ■

Notes and/or Special Constructions

ED = % @ 1-78 (6" Reduced Port 4 3/8" Ø
43% - 100%)

Actuator	Style	☐ Diaph. ■ Piston ☐
Actuator	Size	60
Actuator	Air to Actuator	☐ 6-30 ☐ 3-15 ☐
Actuator	Air Fails Valve to	Lock ☐ Open ■ Close ☐
Actuator	Handjack	☐ Top ■ Side
Positioner	Type	3570 ☐ 3582 ☐ 3590 ■
Positioner	Input Signal	☐ 4-20 mA ■ 10-50 mA ☐ ☐ 6-30 psi ☐ 3-15 psi ☐
Positioner	Output Signal (Psi)	☐ 6-30 ☐ 3-15 ■
Positioner	Accessories	Bypass ☐ Gauges ☐ Airset ■
Positioner	Increase Signal Valve	Opens ☐ Closes ■
Wizard Pilot	Type	
Wizard Pilot	Action	Reverse ☐ Direct ☐
Wizard Pilot	Measuring Element	Bourdon Tube ☐ Bellows ☐ Range. ____ Psig / Bronze ☐ Steel ☐ SST ☐
Wizard Pilot	Output (Psig)	☐ 6-30 ☐ 3-15 ☐
Wizard Pilot	Mounting	Remote ☐ Csg. ☐ Yoke ☐
Wizard Pilot	Airset	☐ 67FR-221 ☐
Wizard Pilot	Airset Mounting	Nipple ☐ Yoke ☐
546	Input Signal (mA)	☐ 4-20 ☐ 10-50 ☐
546	Output Signal (Psig)	☐ 6-30 ☐ 3-15 ☐
546	Action	Reverse ☐ Direct ☐
546	Mounting	Pipe ☐ Csg. ☐ Yoke ☐
546	Airset W/Gauge	☐ 67FR-362 ☐

Service Conditions

Throttling ■ On-Off ☐ PVR ■ Relief ☐

Flowing Media	Sat. Steam @ 100 psig		
	Minimum	Normal	Maximum
Specific Gravity	0.25		0.25
Inlet Temperature Saturated			
Inlet Pressure (Psig)	100	100	100
Inlet Vapor Pressure			
ΔP Sizing (Psi)	70		20
ΔP Shutoff (Psi)	—	—	125
Flow Rate, Give Units lbs/hr	6000		40,000
Req'd Flow Coeff., C_v ☐ C_g ☐ C_s ■	54		460
Valve Coefficient	33 or 35		
Recovery Coeff., K_m ☐ C_1 ☐	36.1		
Noise Level (dBA)			
Line Size (In.)			

Worksheet

Approximate Shipping Weight	List Price	$
	Unit Net Price	$
	Total Net Price	$

Fisher Controls Company
M A R S H A L L T O W N , I O W A

Customer: Fort Benjamin Harrison
Reference:
Order No.
Quote No.
Date ______ Page 2 of 2

CONTROL VALVE SPECIFICATION

Item			
Quantity			1
Application			Pressure Regulating
Tag			6
Size and Type			4" ED
Body	Style		☐ Angle ☐ Globe ■
Body	End Connections		☐ SWE Scrd. ☐ / Flg. 300 # ANSI RF ☐ / ☐ BWE Sched. ____ / Casting Rating ____ / ☐
Body	Material		316 SST ☐ WCB Steel ■ / ☐ Iron ☐
Body	Number of Ports		Two ☐ One ■
Body	Push Down to		Open ■ Close ☐
Body	Flow Direction		Up ■ Down ☐
Trim	Trim Number		
Trim	Cage and/or Bushing Material		Std. ■ / ☐
Trim	Seat Ring Material		☐ Std. ■
Trim	Valve Plug	Material	☐ Std. ■
Trim	Valve Plug	Guiding	Top ☐ Cage ■ / Top & Bottom ☐ Port ☐
Trim	Valve Plug	Balance	Unbalanced ☐ Balanced ■
Trim	Port Size		☐ Full ■
Trim	Plug or Cage		Linear ☐ Q.O. ☐ / ☐ Equal Percent. ■
Trim	Shutoff Class		☐ Std. ■
Bonnet	Style		☐ Ext.# Std. ■
Bonnet	Boss Size		☐ Std. ■
Bonnet	Packing		☐ Lam. Graphite TFE ■ / ☐ Lubr. & Iso. Valve TFE Asb. ☐ / ☐
Bonnet	Bolting	Bonnet	☐ Std. ■
Bonnet	Bolting	Pack. Flg.	☐ Std. ■

Actuator	Style	☐ Diaph. ■ Piston ☐
Actuator	Size	40
Actuator	Air to Actuator	☐ 6-30 ☐ 3-15 ☐
Actuator	Air Fails Valve to	Lock ☐ Open ■ Close ☐
Actuator	Handjack	☐ Top ■ Side
Positioner	Type	3570 ☐ 3582 ☐ 3590 ■
Positioner	Input Signal	☐ 4-20 mA ■ 10-50 mA ☐ / ☐ 6-30 psi ☐ 3-15 psi ☐
Positioner	Output Signal (Psi)	☐ 6-30 ☐ 3-15 ■
Positioner	Accessories	Bypass ☐ Gauges ☐ Airset ■
Positioner	Increase Signal Valve	Opens ☐ Closes ■
Wizard Pilot	Type	
Wizard Pilot	Action	Reverse ☐ Direct ☐
Wizard Pilot	Measuring Element	Bourdon Tube ☐ Bronze ☐ / Bellows ☐ Steel ☐ / Range. ____ Psig SST ☐
Wizard Pilot	Output (Psig)	☐ 6-30 ☐ 3-15 ☐
Wizard Pilot	Mounting	Remote ☐ Csg. ☐ Yoke ☐
Wizard Pilot	Airset	☐ 67FR-221 ☐
Wizard Pilot	Airset Mounting	Nipple ☐ Yoke ☐
546	Input Signal (mA)	☐ 4-20 ☐ 10-50 ☐
546	Output Signal (Psig)	☐ 6-30 ☐ 3-15 ☐
546	Action	Reverse ☐ Direct ☐
546	Mounting	Pipe ☐ Csg. ☐ Yoke ☐
546	Airset W/Gauge	☐ 67FR-362 ☐

Service Conditions

Throttling ■ On-Off ☐ PVR ■ Relief ☐

Flowing Media	Sat. Steam @ 100 psig		
	Minimum	Normal	Maximum
Specific Gravity	.25		.25
Inlet Temperature Saturated			
Inlet Pressure (Psig)	100	100	100
Inlet Vapor Pressure			
ΔP Sizing (Psi)	70		20
ΔP Shutoff (Psi)	100		125
Flow Rate, Give Units lbs/hr	4000		30000
Req'd Flow Coeff., C_v ☐ C_g ☐ C_s ■	31		350
Valve Coefficient	33 or 35		
Recovery Coeff., K_m ☐ C_1 ☐			
Noise Level (dBA)			
Line Size (In.)			

Worksheet

Approximate	List Price	$
Shipping Weight,	Unit Net Price	$
lb.	Total Net Price	$

Notes and/or Special Constructions

ED = %@ 1-78 (4" Full 31%-95%)

FORT HARRISON
FLOW METER PARAMETERS

	ALPHA VALUE	BETA VALUE	DELTA VALUE
SERIAL #	5316102	5316164	5316163
TEMPERATURE (DEG F)	337.6	337.6	337.6
PRESSURE (PSIA)	114.3	114.3	114.3
SPECIFIC GRAVITY	0.6220236	0.6220236	0.6220236
COMPRESSIBILITY (ZF)	0.9395093	0.9395093	0.9395093
VISCOSITY (CENTIPOISES)	0.0147	0.0147	0.0147
DENSITY (LBM./CU.FT.)	0.2561655	0.2561655	0.2561655

PARAM. N	MNEM.	ALPHA VALUE	BETA VALUE	DELTA VALUE
1	REVN	2-10-1	2-10-1	2-10-1
2	HSS	200010	200010	200010
3	SSS	20000	20000	20000
4	MPS	316161	316161	316161
5	FIS	10000	10000	10000
6	SCODE	0	0	0
7	INVT	0	0	0
8	PSDT	0	0	0
9	KF	0	0	0
10	VHMAX	100	100	100
11	ALMHI	100	100	100
12	ALMLO	0	0	0
13	OMIN	0	0	0
14	TRAMP	0	0	0
15	TMAX	797.27	797.27	797.27
16	TMIN	797.27	797.27	797.27
17	TREF	0	0	0
18	DTMAX	0	0	0
19	DTMIN	0	0	0
20	PMAX	114.3	114.3	114.3
21	PMIN	114.3	114.3	114.3
22	PREF	0	0	0
23	GDMAX	0.2561655	0.2561655	0.2561655
24	GDMIN	0.2561655	0.2561655	0.2561655
25	DO	5.6239	5.8382	5.1876
26	OP	7.981	10.02	11.938
27	YK	0.4962957	0.4503379	0.4224798

28	RK0	0.69341	0.6421313	0.6121461
29	RK1	44.03954	25.26589	11.62487
30	APE	9.500001	9.500001	9.500001
31	AIN	50	50	50
32	AOUT	50	50	50
33	BIN	50	50	50
34	BOUT	50	50	50
35	KZ	0.974514	0.974514	0.974514
36	TC	1165.14	1165.14	1165.14
37	PC	3208.24	3208.24	3208.24
38	KC	1.3	1.3	1.3
39	MCP	0.0147	0.0147	0.0147
40	CL	0	0	0
41	RS	0	0	0
42	FMAX	39.88622	39.88622	29.94338
43	CFMAX	150000	150000	150000
44	CFMIN	31000	31000	31000
45	C1MAX	0	0	0
46	C1MIN	0	0	0
47	C2MAX	0	0	0
48	C2MIN	0	0	0
49	C3MAX	0	0	0
50	C3MIN	0	0	0
51	CVMAX	0	0	0
52	CVMIN	0	0	0
53	CAMAX	1250	1325	1800
54	CAMIN	6200	6200	6500
	INPUT 80%: DISPLAY	35.3	35.3	26.7
	INPUT 40%: DISPLAY	25.2	25.2	19

Controller Parameters

Controller		Alpha	Beta	Delta
SECURE ALLTUNE				
MODES P				
	PF	75.00	232.00	183.00
	IF	0.76	2.60	3.60
	DF	0.00	0.43	0.39
	EXACT STATE	ON	ON	ON
	NB	2.00	1.00	1.40
	WMAX	3.00	8.67	12.00
	DMP	0.30	0.30	0.30
	OVR	0.50	0.50	0.50
	CLM	4.00	4.00	4.00
	DFCT	0.00	0.00	0.00
	LIM	80.00	80.00	80.00
	BUMP	8.00	8.00	8.00
SETLIMP				
	HIGH	100	100	100
	LOW	25	30	30
SETLIMS				
	HIGH	0	0	0
	LOW	0	0	0
OUTLIMS				
	HIGH	0	0	0
	LOW	0	0	0
ALARMS				
ALARM1	LEVEL1	25	30	30
	LEVEL2	25	30	30
	DB	2	2	2
CONFIG CTLR				
CTRL PRIMARY				
	TAG DISP	ALPHA 1	BETA 400	DELTA 300
	SEL DISP TYPE	LIN	LIN	LIN
	ENG UNITS	PSI	PSI	PSI
	SCALING URV	100	100	100
	LRV	0	0	0
	ALARMS MEAS	ALARM1	ALARM1	ALARM1
	OUT	NONE	NONE	NONE
	MET REV	YES	YES	YES
PRIMARY RATIO		OFF	OFF	OFF

PRIMARY SET POINT				
	TYPE	R/L	R/L	R/L
	INBIAS	0	0	0
	LOCTRK	NONE	NONE	NONE
	SOURCE	D	B	B
	SWITCH	NONE	NONE	NONE
	STARTUP	L	L	L
	MEAS TRK	NONE	NONE	NONE
	FORMAT	LIN	LIN	LIN
PRIMARY MEAS				
	FORMAT	LIN	LIN	LIN
	SOURCE	A	A	A
PRIMARY A/M				
	STARTUP	M	M	M
	FLUNK	M	M	M
	SWITCH	NONE	NONE	NONE
PRIMARY NONLIN		NO	NO	NO
PRIMARY ACTION		INC/INC	INC/INC	INC/INC
PRIMARY TYPE		EXACT	EXACT	EXACT
(EXACT)		NONE	NONE	NONE
PRIMARY OUTPUT				
	FORMAT	LIN	LIN	LIN
	MODIFIER	NO	NO	NO
OUTTRK				
	SWITCH	NONE	NONE	NONE
	EXTLIM	NONE	NONE	NONE
	STARTUP	LAST VAL	LAST VAL	LAST VAL
PRIMARY BATCH		OFF	OFF	OFF
PRIMARY EXTRES		OUT P	OUT P	OUT P
CTLR SECONDRY				
	TAG DISP	LOC.PRESS		AMB.TEMP.
SEL DISP				
	TYPE	LIN		LIN
	ENG UNITS	PSI		DEG.F
SCALING	URV	100		100
	LRV	0		-20
ALARMS	MEAS	NONE		NONE
	OUT	NONE		NONE
	MET REV	NO		NO

SECONDARY RATIO	OFF		OFF
SECONDARY MEAS	NONE	NONE	IN2
CONFIG INPUTS			
INPUTS A			
OUTBIAS	0	0	0
GAIN	1	1	1
INBIAS	0	0	0
FORMAT	LIN	LIN	LIN
FILTER	0	0	0
INPUTS B			
OUTBIAS	0	0	0
GAIN	1	1	1
INBIAS	0	0	0
FORMAT	LIN	CHAR 1	CHAR 1
FILTER	0	0	0
INPUTS C			
OUTBIAS	0	0	0
GAIN	1	1	1
INBIAS	0	0	0
FORMAT	LIN	LIN	LIN
FILTER	0	0	0
INPUTS D			
OUTBIAS	0	0	0
GAIN	1	1	1
INBIAS	0	0	0
FORMAT	CHAR 1	LIN	LIN
FILTER	0	0	0
CONFIG ALARMS			
ALARM 1			
TYPE	LO/LO	LO/LO	LO/LO
ACTION	NON LAT	NON LAT	NON LAT
FORM	ABS	ABS	ABS
ATTACH	MEAS P	MEAS P	MEAS P
ALARM 2 TYPE	NO	NO	NO
ALARM 3 TYPE	NO	NO	NO
ALARM 4 TYPE	NO	NO	NO
ALARMS EXT ACK	NONE	NONE	NONE

CONFIG CALC			
CALC CHAR 1			
POINTS	16	16	16
X1..X16	TABLE 7	TABLE 7	TABLE 7
Y1..Y16	TABLE 7	TABLE 7	TABLE 7
CONFIG CASCADE	YES	NO	YES
(YES)	OFF	OFF	OFF
CONFIG W/P	OFF	OFF	OFF
CONFIG NEW PASS	ACK ACK ACK	ACK ACK ACK	ACK ACK ACK
CONFIG TOGGLE	OFF	OFF	OFF
CONFIG PH DISPLAY	OFF	OFF	OFF
CONFIG OUT 2	IN4	IN2	IN2
CONFIG CO O/PS			
CO 1	NONE	NONE	NONE
CO 2	NONE	NONE	NONE

Fort Harrison Controller Set Points
Temperature vs. Steam Pressure

Temp, X (% of Signal)		Actual Temp	Alpha Steam Pressure, Y Alpha		Beta Steam Pressure, Y Beta	Delta Steam Pressure, Y Delta
X01	0	-20.0	Y01	100	100	100
X02	16.7	0.0	Y02	75	80	100
X03	18.8	2.6	Y03	68	77	99
X04	20.8	5.0	Y04	64	75	99
X05	22.9	7.5	Y05	61	73	99
X06	25	10.0	Y06	58	70	98
X07	27.1	12.5	Y07	56	68	96
X08	33.3	15.0	Y08	54	64	93
X09	37.5	20.0	Y09	50	60	90
X10	41.7	25.0	Y10	46	56	87
X11	50	30.0	Y11	43	55	83
X12	45.8	35.0	Y12	40	55	81
X13	50	40.0	Y13	38	55	78
X14	58.3	50.0	Y14	35	55	73
X15	66.7	60.0	Y15	35	55	70
X16	100	100.0	Y16	35	55	70

APPENDIX D: Daily Operating Data for April 1991

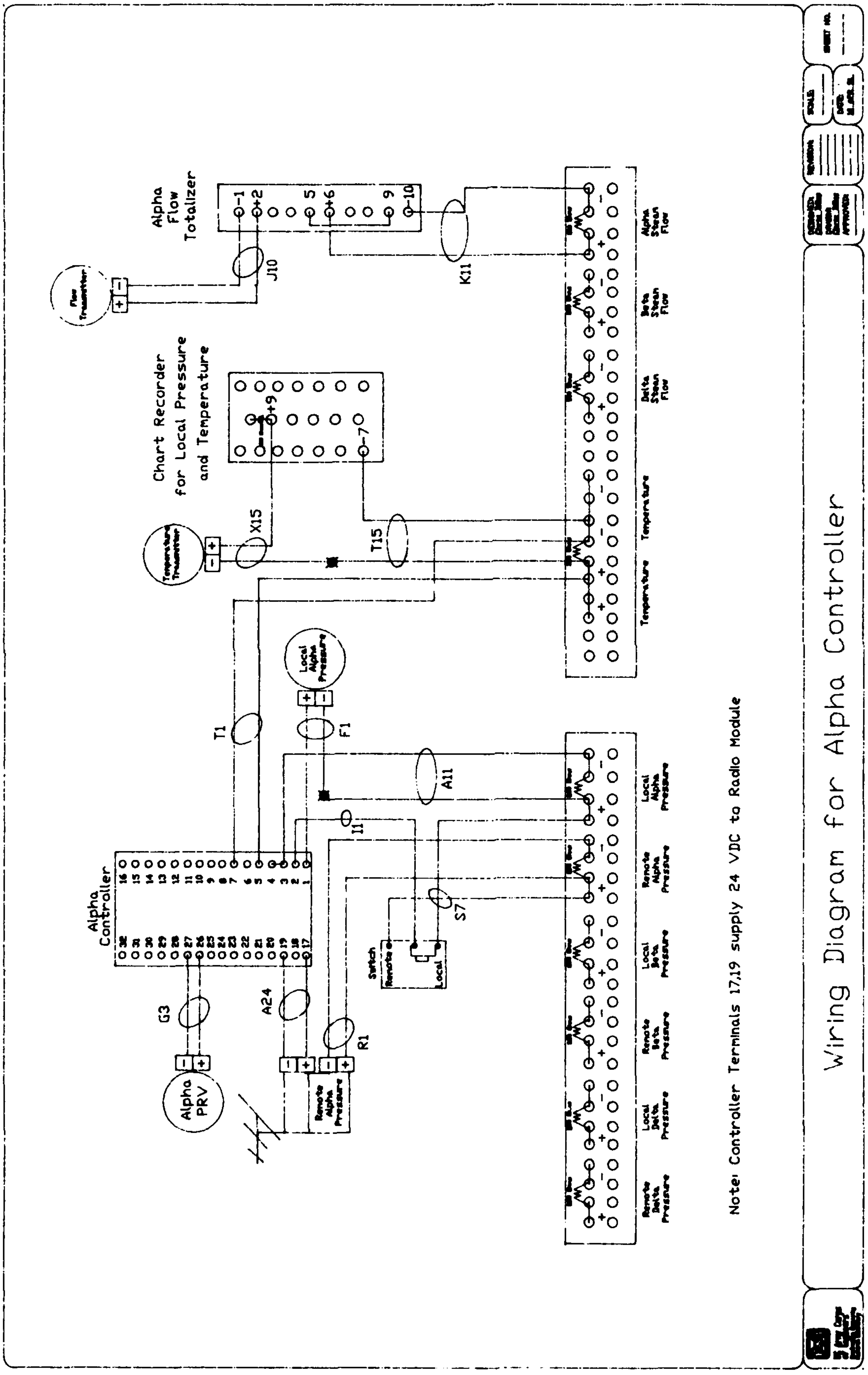
This appendix includes the April 1991 daily database file. This month's file is characteristic of the majority of the other files, showing many of the situations that arose during the demonstration that needed to be addressed.

In April 1991, four different events require comment. From April 1-4, the SDCS was working and the data gathered was considered "winter load data with SDCS." On April 5, all three line pressure reducing valves were fully opened, and on April 20 SDCS was placed back into operation; both events were planned. The data taken on April 5 and April 20 were considered mixed data, and were not used. Also, on April 5, the plant totalizer for the total steam flow was recalibrated. None of the data taken after April 5 could be compared with the data taken previously. However, only 2.5 weeks of winter load data were lost due to the recalibration. Data from April 6-19 would have been put into the baseline winter load data. Likewise, the data from April 21-23 would have been considered winter load data with SDCS. On April 24 the steam line feeding the Series 600 buildings was closed. This marked the start of the summer load data. All of the April data after the 24th was considered "summer load data with SDCS working."

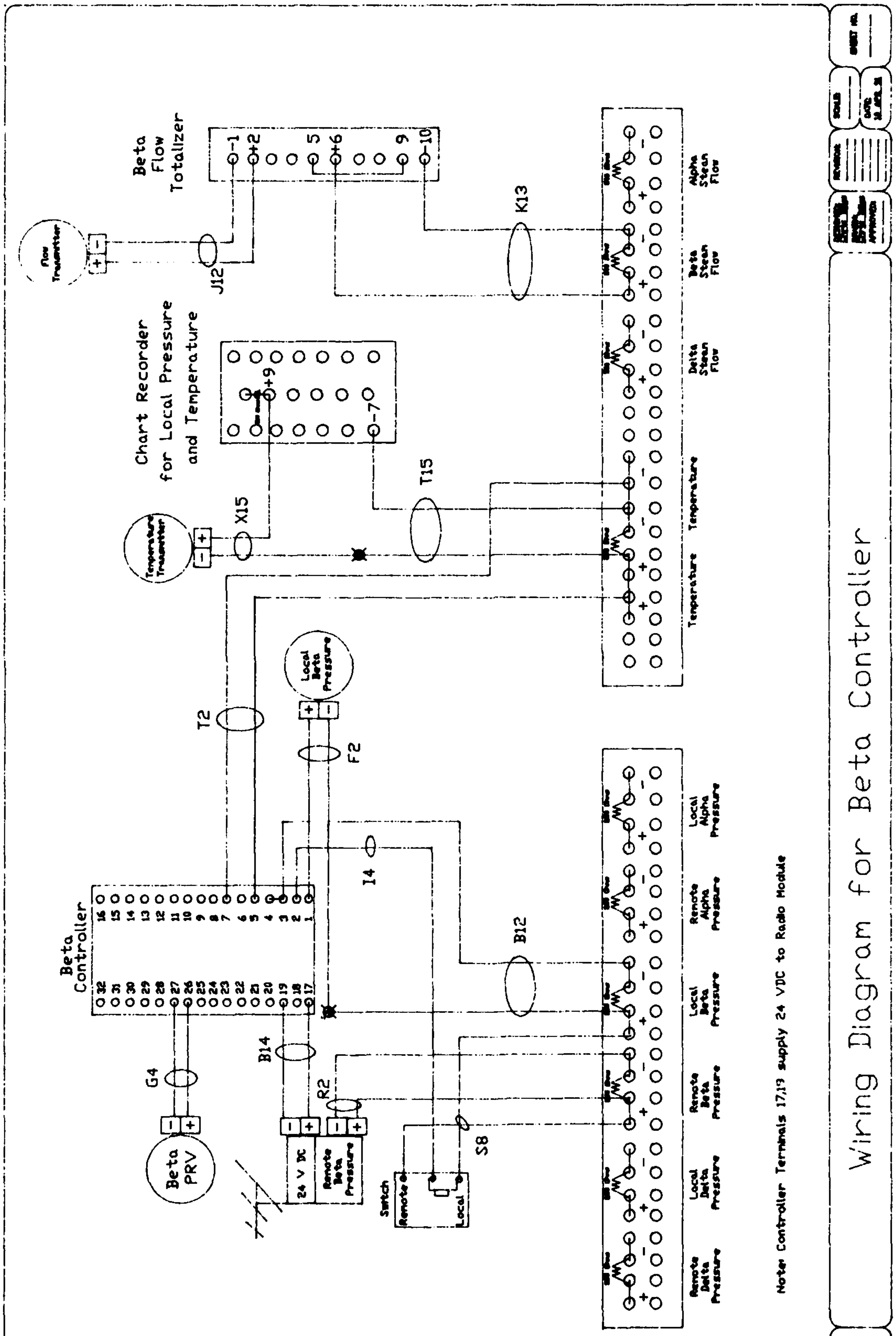
The remote Beta pressure instrumentation was not working correctly during this period, however, due to equipment failure. Also, the Delta flow totalizer was rewired to record the Alpha steam flow. This was done as a check on the Alpha totalizer, which had just been repaired.

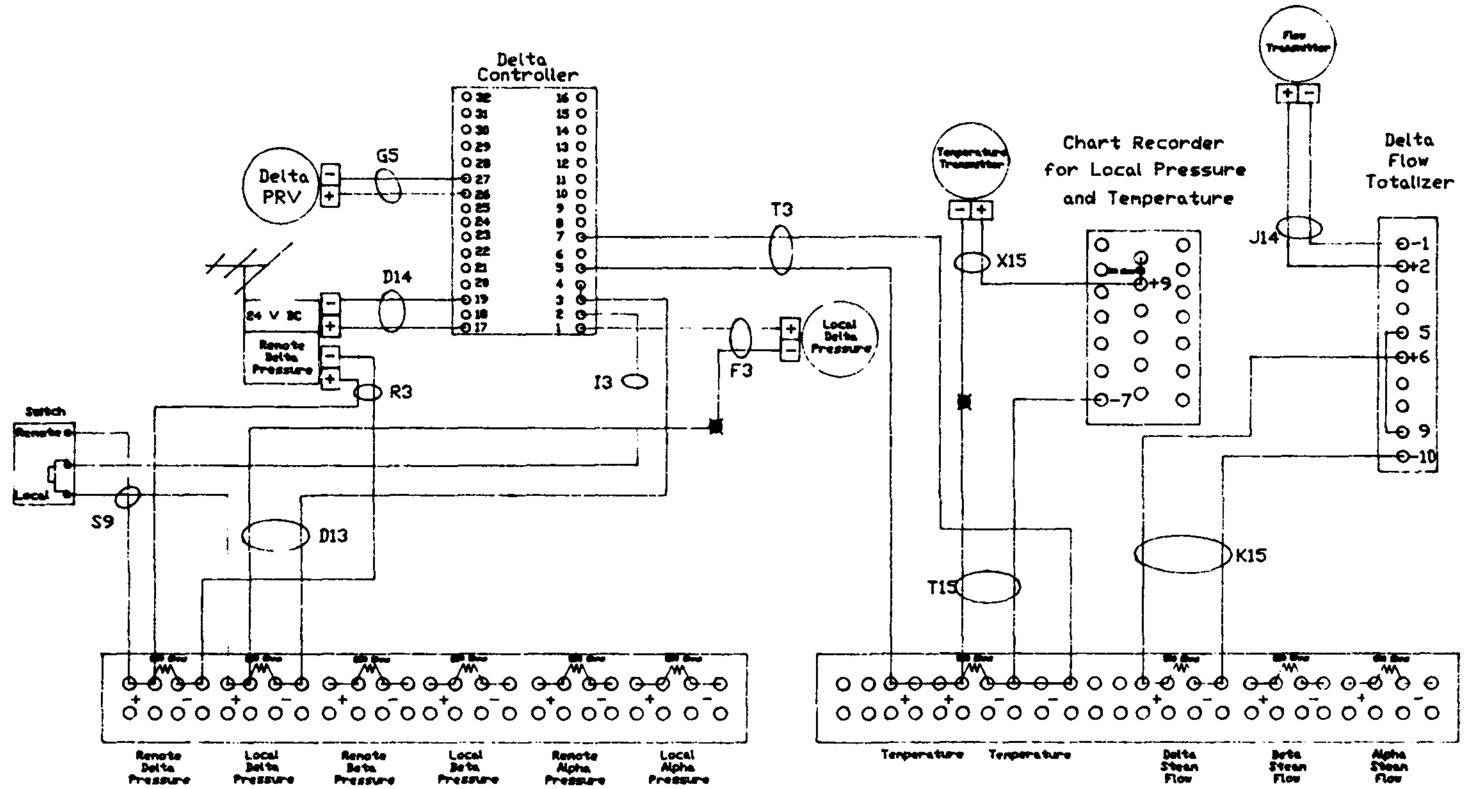
Date	Alpha Local Pressure (psig)	Beta Local Pressure (psig)	Delta Local Pressure (psig)	Temp (deg F)	Alpha Remote Pressure (psig)	Beta Remote Pressure (psig)	Delta Remote Pressure (psig)	Alpha Steam Flow (lbs/hr)	Beta Steam Flow (lbs/hr)	Delta Steam Flow (lbs/hr)	Total Steam Flow (1000 lbs)
04/01/91	36.2	55.3	75.9	44.9	35.2	-0.7	67.6	1177.5	14959.7	1176.2	983
04/02/91	37.6	55.2	75.9	41.7	36.6	-0.7	67.6	1047.5	14831.4	1041.6	899
04/03/91	33.7	55.1	72.9	52.1	32.9	-0.7	64.6	1049.3	13893.4	1053.7	713
04/04/91	32.5	55.3	71.9	53.9	31.6	-0.7	63.6	972.7	13615.1	957.7	770
04/05/91	60.9	71.6	62.1	62.0	59.7	-0.7	53.9	774.8	13224.3	772.3	544
04/06/91	94.5	94.2	94.6	66.7	93.2	-0.7	86.1	356.7	12414.7	356.7	570
04/07/91	94.6	94.4	95.2	69.4	93.0	-0.7	86.6	372.3	12182.6	378.0	558
04/08/91	94.7	94.5	95.8	64.4	93.3	-0.7	87.4	381.3	12121.3	375.5	567
04/09/91	94.2	94.1	94.9	59.3	93.2	-0.7	86.5	1103.2	12303.5	1103.1	669
04/10/91	93.3	92.4	90.3	43.6	92.0	-0.7	82.4	472.0	14248.0	463.8	843
04/11/91	93.2	92.1	90.1	44.9	91.7	-0.7	82.2	412.1	14554.1	414.5	831
04/12/91	93.2	92.3	90.6	48.7	91.7	-0.8	82.6	373.0	14319.8	367.1	771
04/13/91	94.0	93.4	93.7	58.6	92.4	-0.7	85.4	400.8	13751.4	402.4	665
04/14/91	94.4	94.1	90.5	64.6	92.8	-0.7	82.2	392.2	12642.4	396.3	613
04/15/91	94.2	93.9	94.3	59.3	92.9	-0.7	86.2	389.9	12829.3	390.6	648
04/16/91	94.7	94.4	95.5	64.4	93.4	-0.7	87.4	395.0	12416.5	398.9	526
04/17/91	94.7	94.4	95.3	58.8	93.3	-0.7	87.2	387.4	12348.1	381.8	580
04/18/91	94.6	94.4	95.1	55.0	93.6	-0.7	87.1	445.6	12301.4	448.8	559
04/19/91	94.1	93.3	92.4	45.6	93.0	-0.7	84.4	347.7	13760.1	349.3	734
04/20/91	44.2	60.9	77.8	44.7	42.8	-0.7	69.9	789.3	13318.9	789.0	732
04/21/91	36.9	55.3	76.3	43.2	35.4	-0.7	68.4	387.3	13664.6	382.9	801
04/22/91	34.3	55.3	73.9	49.7	33.1	-0.7	47.1	792.7	13155.6	795.8	635
04/23/91	33.6	55.2	72.3	51.6	32.5	-0.7	64.2	3079.5	12973.4	3070.8	755
04/24/91	33.7	55.3	73.2	51.0	32.8	-0.7	64.7	1142.6	11225.7	1158.9	532
04/25/91	32.3	55.3	71.9	54.7	31.6	-0.7	61.9	646.8	10465.4	642.3	388
04/26/91	30.7	54.5	70.5	64.9	30.1	-0.7	61.9	766.5	10304.0	775.3	595
04/27/91	30.1	54.7	70.0	65.4	29.5	-0.7	62.0	815.0	10132.6	814.9	588
04/28/91	30.2	54.9	70.0	63.9	29.6	-0.7	61.9	773.4	10070.7	770.7	595
04/29/91	30.1	54.4	70.0	67.8	29.5	-0.7	62.0	705.7	9946.7	706.5	563
04/30/91	30.2	54.6	70.0	66.1	29.5	-0.7	62.0	670.8	9970.9	671.3	568

APPENDIX E: Circuit Drawings



Wiring Diagram for Alpha Controller


Wiring Diagram for Beta Controller
Beta Flow Totalizer
Flow Transmitter
J12
K13
Chart Recorder for Local Pressure and Temperature
Temperature Transmitter
X15
T15
Local Beta Pressure
T2
F2
Beta Controller
I4
B12
G4
B14
R2
S8
Beta PRV
24 V DC
Remote Beta Pressure
Switch
Remote
Local
Remote Delta Pressure
Local Delta Pressure
Remote Beta Pressure
Local Beta Pressure
Remote Alpha Pressure
Local Alpha Pressure
Temperature
Temperature
Delta Steam Flow
Beta Steam Flow
Alpha Steam Flow
Note: Controller Terminals 17,19 supply 24 VDC to Radio Module



Note: Controller Terminals 17,19 Supply 24 VDC to Radio Module

Wiring Diagram for Delta Controller

APPENDIX F: ETAC Weather Data

Climate data for the Indianapolis Airport were obtained from the U.S. Air Force Environmental Technical Applications Center (ETAC). These data consisted of the mean maximum and minimum daily temperatures during the period of 1948 to 1989. The mean average daily temperature was calculated as the average of the maximum and minimum temperature for each particular day. A complete listing of the data follows.

Mean Temperatures
for Ft. Benjamin Harrison, IN

Date	Maximum Temp	Minimum Temp	Average Temp
01-Jan	37	21	29.0
02-Jan	36	22	29.0
03-Jan	37	22	29.5
04-Jan	35	19	27.0
05-Jan	34	19	26.5
06-Jan	35	20	27.5
07-Jan	34	18	26.0
08-Jan	33	16	24.5
09-Jan	34	17	25.5
10-Jan	33	17	25.0
11-Jan	33	16	24.5
12-Jan	34	17	25.5
13-Jan	37	19	28.0
14-Jan	35	20	27.5
15-Jan	34	17	25.5
16-Jan	32	15	23.5
17-Jan	33	18	25.5
18-Jan	36	19	27.5
19-Jan	36	19	27.5
20-Jan	34	19	26.5
21-Jan	35	19	27.0
22-Jan	36	21	28.5
23-Jan	36	19	27.5
24-Jan	37	20	28.5
25-Jan	37	20	28.5
26-Jan	35	17	26.0
27-Jan	32	17	24.5
28-Jan	33	15	24.0
29-Jan	33	16	24.5
30-Jan	33	16	24.5
31-Jan	34	17	25.5
01-Feb	36	20	28.0
02-Feb	35	17	26.0
03-Feb	33	18	25.5
04-Feb	35	17	26.0
05-Feb	37	19	28.0
06-Feb	33	19	26.0
07-Feb	33	16	24.5
08-Feb	34	17	25.5
09-Feb	36	18	27.0
10-Feb	38	19	28.5

Date	Maximum Temp	Minimum Temp	Average Temp
11-Feb	36	20	28.0
12-Feb	37	20	28.5
13-Feb	39	22	30.5
14-Feb	40	23	31.5
15-Feb	40	23	31.5
16-Feb	39	23	31.0
17-Feb	40	23	31.5
18-Feb	44	25	34.5
19-Feb	41	25	33.0
20-Feb	42	23	32.5
21-Feb	41	24	32.5
22-Feb	43	24	33.5
23-Feb	44	26	35.0
24-Feb	43	26	34.5
25-Feb	42	25	33.5
26-Feb	42	23	32.5
27-Feb	43	24	33.5
28-Feb	44	27	35.5
01-Mar	44	25	34.5
02-Mar	45	27	36.0
03-Mar	47	29	38.0
04-Mar	47	29	38.0
05-Mar	45	28	36.5
06-Mar	46	28	37.0
07-Mar	45	28	36.5
08-Mar	47	26	36.5
09-Mar	47	27	37.0
10-Mar	46	29	37.5
11-Mar	48	30	39.0
12-Mar	47	31	39.0
13-Mar	48	30	39.0
14-Mar	48	31	39.5
15-Mar	48	30	39.0
16-Mar	48	30	39.0
17-Mar	49	29	39.0
18-Mar	50	30	40.0
19-Mar	51	33	42.0
20-Mar	52	32	42.0
21-Mar	51	32	41.5
22-Mar	50	31	40.5
23-Mar	53	32	42.5
24-Mar	52	32	42.0
25-Mar	52	33	42.5
26-Mar	53	34	43.5

Date	Maximum Temp	Minimum Temp	Average Temp	Date	Maximum Temp	Minimum Temp	Average Temp
27-Mar	55	34	44.5	10-May	71	49	60.0
28-Mar	58	37	47.5	11-May	71	52	61.5
29-Mar	58	39	48.5	12-May	71	52	61.5
30-Mar	55	36	45.5	13-May	73	50	61.5
31-Mar	57	36	46.5	14-May	74	53	63.5
01-Apr	58	38	48.0	15-May	74	52	63.0
02-Apr	58	38	48.0	16-May	74	52	63.0
03-Apr	58	38	48.0	17-May	74	52	63.0
04-Apr	57	36	46.5	18-May	76	52	64.0
05-Apr	57	37	47.0	19-May	76	53	64.5
06-Apr	58	38	48.0	20-May	75	54	64.5
07-Apr	60	36	48.0	21-May	78	54	66.0
08-Apr	57	36	46.5	22-May	77	55	66.0
09-Apr	54	35	44.5	23-May	76	54	65.0
10-Apr	59	36	47.5	24-May	76	54	65.0
11-Apr	61	38	49.5	25-May	77	54	65.5
12-Apr	62	40	51.0	26-May	76	54	65.0
13-Apr	62	41	51.5	27-May	76	55	65.5
14-Apr	62	40	51.0	28-May	75	55	65.0
15-Apr	61	41	51.0	29-May	76	55	65.5
16-Apr	62	40	51.0	30-May	77	56	66.5
17-Apr	65	43	54.0	31-May	78	56	67.0
18-Apr	66	44	55.0	01-Jun	78	57	67.5
19-Apr	66	45	55.5	02-Jun	78	56	67.0
20-Apr	67	45	56.0	03-Jun	78	56	67.0
21-Apr	68	47	57.5	04-Jun	80	57	68.5
22-Apr	68	46	57.0	05-Jun	81	60	70.5
23-Apr	66	47	56.5	06-Jun	82	60	71.0
24-Apr	66	45	55.5	07-Jun	82	60	71.0
25-Apr	68	44	56.0	08-Jun	82	61	71.5
26-Apr	68	46	57.0	09-Jun	82	61	71.5
27-Apr	68	47	57.5	10-Jun	81	60	70.5
28-Apr	66	46	56.0	11-Jun	82	60	71.0
29-Apr	67	45	56.0	12-Jun	82	61	71.5
30-Apr	69	47	58.0	13-Jun	82	62	72.0
01-May	70	47	58.5	14-Jun	82	60	71.0
02-May	71	47	59.0	15-Jun	82	61	71.5
03-May	70	46	58.0	16-Jun	82	61	71.5
04-May	71	46	58.5	17-Jun	81	60	70.5
05-May	73	49	61.0	18-Jun	82	61	71.5
06-May	72	50	61.0	19-Jun	84	62	73.0
07-May	69	49	59.0	20-Jun	84	62	73.0
08-May	70	48	59.0	21-Jun	82	62	72.0
09-May	70	49	59.5	22-Jun	82	63	72.5

Date	Maximum Temp	Minimum Temp	Average Temp
23-Jun	82	63	72.5
24-Jun	84	62	73.0
25-Jun	84	62	73.0
26-Jun	85	62	73.5
27-Jun	85	63	74.0
28-Jun	85	64	74.5
29-Jun	85	64	74.5
30-Jun	86	65	75.5
01-Jul	86	64	75.0
02-Jul	86	65	75.5
03-Jul	85	64	74.5
04-Jul	84	64	74.0
05-Jul	84	63	73.5
06-Jul	85	63	74.0
07-Jul	85	64	74.5
08-Jul	86	65	75.5
09-Jul	85	65	75.0
10-Jul	85	65	75.0
11-Jul	86	64	75.0
12-Jul	86	64	75.0
13-Jul	85	65	75.0
14-Jul	87	66	76.5
15-Jul	86	65	75.5
16-Jul	86	65	75.5
17-Jul	86	65	75.5
18-Jul	86	66	76.0
19-Jul	86	67	76.5
20-Jul	85	67	76.0
21-Jul	86	65	75.5
22-Jul	86	67	76.5
23-Jul	85	66	75.5
24-Jul	85	66	75.5
25-Jul	86	66	76.0
26-Jul	86	65	75.5
27-Jul	86	66	76.0
28-Jul	86	66	76.0
29-Jul	85	65	75.0
30-Jul	85	64	74.5
31-Jul	85	65	75.0
01-Aug	85	64	74.5
02-Aug	84	64	74.0
03-Aug	85	64	74.5
04-Aug	84	64	74.0
05-Aug	84	63	73.5

Date	Maximum Temp	Minimum Temp	Average Temp
06-Aug	84	64	74.0
07-Aug	85	64	74.5
08-Aug	85	64	74.5
09-Aug	84	65	74.5
10-Aug	83	64	73.5
11-Aug	83	62	72.5
12-Aug	83	61	72.0
13-Aug	84	62	73.0
14-Aug	84	63	73.5
15-Aug	84	64	74.0
16-Aug	84	64	74.0
17-Aug	84	63	73.5
18-Aug	85	63	74.0
19-Aug	84	63	73.5
20-Aug	83	62	72.5
21-Aug	83	62	72.5
22-Aug	83	61	72.0
23-Aug	83	61	72.0
24-Aug	83	61	72.0
25-Aug	83	61	72.0
26-Aug	84	61	72.5
27-Aug	84	63	73.5
28-Aug	83	63	73.0
29-Aug	84	62	73.0
30-Aug	84	62	73.0
31-Aug	83	62	72.5
01-Sep	82	61	71.5
02-Sep	82	61	71.5
03-Sep	81	61	71.0
04-Sep	82	60	71.0
05-Sep	82	59	70.5
06-Sep	81	57	69.0
07-Sep	81	57	69.0
08-Sep	81	57	69.0
09-Sep	81	57	69.0
10-Sep	80	58	69.0
11-Sep	79	57	68.0
12-Sep	79	56	67.5
13-Sep	80	56	68.0
14-Sep	78	54	66.0
15-Sep	78	55	66.5
16-Sep	76	55	65.5
17-Sep	78	55	66.5
18-Sep	78	56	67.0

Date	Maximum Temp	Minimum Temp	Average Temp
19-Sep	78	56	67.0
20-Sep	77	56	66.5
21-Sep	76	54	65.0
22-Sep	75	53	64.0
23-Sep	73	50	61.5
24-Sep	73	50	61.5
25-Sep	74	51	62.5
26-Sep	75	51	63.0
27-Sep	73	50	61.5
28-Sep	73	50	61.5
29-Sep	74	49	61.5
30-Sep	73	50	61.5
01-Oct	74	49	61.5
02-Oct	72	48	60.0
03-Oct	71	48	59.5
04-Oct	71	48	59.5
05-Oct	69	48	58.5
06-Oct	68	46	57.0
07-Oct	67	45	56.0
08-Oct	69	46	57.5
09-Oct	68	47	57.5
10-Oct	69	45	57.0
11-Oct	68	46	57.0
12-Oct	68	45	56.5
13-Oct	68	45	56.5
14-Oct	69	45	57.0
15-Oct	69	46	57.5
16-Oct	67	45	56.0
17-Oct	67	44	55.5
18-Oct	64	43	53.5
19-Oct	63	41	52.0
20-Oct	64	41	52.5
21-Oct	65	43	54.0
22-Oct	66	43	54.5
23-Oct	64	43	53.5
24-Oct	60	41	50.5
25-Oct	60	39	49.5
26-Oct	60	39	49.5
27-Oct	62	38	50.0
28-Oct	61	39	50.0
29-Oct	60	37	48.5
30-Oct	62	39	50.5
31-Oct	63	43	53.0
01-Nov	62	43	52.5

Date	Maximum Temp	Minimum Temp	Average Temp
02-Nov	59	40	49.5
03-Nov	56	38	47.0
04-Nov	55	38	46.5
05-Nov	54	36	45.0
06-Nov	53	33	43.0
07-Nov	54	34	44.0
08-Nov	55	36	45.5
09-Nov	55	35	45.0
10-Nov	53	34	43.5
11-Nov	53	34	43.5
12-Nov	52	34	43.0
13-Nov	54	35	44.5
14-Nov	54	34	44.0
15-Nov	54	36	45.0
16-Nov	55	35	45.0
17-Nov	52	35	43.5
18-Nov	52	33	42.5
19-Nov	50	34	42.0
20-Nov	49	32	40.5
21-Nov	46	30	38.0
22-Nov	47	31	39.0
23-Nov	49	29	39.0
24-Nov	44	28	36.0
25-Nov	47	29	38.0
26-Nov	48	32	40.0
27-Nov	46	31	38.5
28-Nov	42	27	34.5
29-Nov	40	26	33.0
30-Nov	42	26	34.0
01-Dec	43	26	34.5
02-Dec	44	28	36.0
03-Dec	46	29	37.5
04-Dec	44	29	36.5
05-Dec	44	29	36.5
06-Dec	43	26	34.5
07-Dec	43	27	35.0
08-Dec	41	26	33.5
09-Dec	38	24	31.0
10-Dec	37	23	30.0
11-Dec	39	24	31.5
12-Dec	40	25	32.5
13-Dec	37	23	30.0
14-Dec	38	24	31.0
15-Dec	39	22	30.5

Date	Maximum Temp	Minimum Temp	Average Temp
16-Dec	36	21	28.5
17-Dec	37	21	29.0
18-Dec	36	20	28.0
19-Dec	38	22	30.0
20-Dec	38	23	30.5
21-Dec	36	22	29.0
22-Dec	39	21	30.0
23-Dec	39	25	32.0
24-Dec	38	22	30.0
25-Dec	36	21	28.5
26-Dec	36	22	29.0
27-Dec	37	22	29.5
28-Dec	38	21	29.5
29-Dec	37	22	29.5
30-Dec	38	22	30.0
31-Dec	38	22	30.0

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