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Analysis of a Small Steam District Heating System at Ft. McClellan, Alabama

G. D. Pine

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ENERGY DIVISION

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OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
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ABSTRACT

An analysis to identify major causes for heat loss from one steam district heating system at Ft. McClellan, Alabama, has been made. Because only limited information based on measurements was available, we took measurements of condensate ejected from traps and of ground temperature profiles above buried steam pipes and combined these limited data with analyses of the building heat loads, heat loss from the buried pipelines, and the steam flow through the pipes to develop estimates of the energy efficiency of the distribution system.

Based on these estimates, we concluded that the system efficiency (steam delivered to the buildings/steam entering the distribution system) is approximately 53%. Major identified sources of heat loss include conduction losses enhanced by the deterioration of the pipe insulation and flooding of valve pits and pipe conduits by the buildup of groundwater and condensate after failures of sump pumps. Leaks of prime steam do not appear to be a significant source of loss.

Measures recommended to reduce the heat losses include providing better maintenance for sump pumps in vaults and reducing the operating pressure of the steam system. The latter measure is the more effective of the two. We estimate that reducing the operating pressure from its present 100 to 50 psig would reduce heat losses by 15% and would save the Army an estimated $43,000/year.

1. EXECUTIVE SUMMARY

An analysis has been made which identifies major causes for heat loss from one steam district heating system serving 24 buildings on the Army base located at at Ft. McClellan, Alabama. The system analyzed is the distribution system connected to boiler plants 2 and 3. Other than the daily steam production and fuel use by the boilers, makeup water requirements, steam pressure at the boilers, and the estimated pressure of delivered steam at the hospital, very little metered data were available. None of the buildings connected to the steam system have steam meters, condensate meters, or other ways of measuring their steam demands; also, there is no monitoring of steam flows through any parts of the distribution piping system to determine steam flow, condensate flow, or pressure drop at points along the distribution system. Consequently, a major part of the analysis was concerned with developing estimates of the building loads, modeling the steam flow through the piping system, making measurements of dumped condensate, and making ground temperature measurements. Based on the analysis and measurements, a reasonably accurate view of the operation of the system and the causes for heat loss have been obtained, including estimates of the magnitudes of the different sources of loss. Some uncertainty in our estimates remains which can be resolved only by an additional measurements of condensate loss supplemented by analysis of the mass balance for steam, condensate loss, and makeup water.

On the basis of our analysis, the annual efficiency of the district heating system (delivered steam energy/steam entering the pipes at the boiler plant) is 53.4%. We assumed that 5% of the steam produced by the boilers is used for auxiliaries inside the boiler plants. Of the steam entering the distribution piping system, approximately 24% is lost by normal conduction losses, steam trap losses, and occasional flooding of vaults by groundwater. The flooding of vaults was assumed to be sufficient to partially or entirely cover the steam pipes in three vaults for 30 days each year. Such flooding has been observed in three vaults along the steam line between boiler plant 2 and the hospital, but we have no actual record of the frequency of occurrence of the flooding. The above estimate is merely a first guess, made in order to illustrate the relative size of this loss. The losses caused by vault flooding under these assumptions is about 3% of the identified losses from conduction on all lines connected to boiler plants 2 and 3, but nearly 8% of the losses from the steam line between the hospital and boiler plant 2.

A significant fraction of the steam entering the distribution system is not accounted for by normal conduction losses, trap losses, or the above estimate of vault flooding losses. These unaccounted-for losses amount to about 23% of the steam entering the system. These losses could arise from two sources: (1) leaks of steam from the system and (2) enhanced conduction losses caused by wet earth or wet insulation around the pipes. Based on the pressure/flow analysis we conclude that leaks are not a major source of loss; the losses are probably due to enhanced conduction of heat from the steam pipes to the surrounding earth; however, additional measurements of condensate dumped from the system rather than being returned to the boilers are needed to verify this conclusion. When the condensate measurement results are obtained, a mass-balance calculation to identify the amount of condensate lost from the system will give us an upper limit to losses resulting from leakage.

The steam pressure at the plant is maintained at a constant 100 psig year-round. This corresponds to a temperature of about 338°F. Conduction losses are driven by the temperature gradient between the pipe and the surrounding earth, which is at an average temperature of about 80°F. If the steam temperature can be reduced, the conduction losses will also be reduced. However, the temperature can only be reduced by reducing the steam pressure, and this pressure must be maintained at a level sufficient to ensure an adequate flow of steam through the pipes to meet the building loads. In addition, some constraints presently exist on the delivered pressure because of pressure and temperature requirements of end-user controls. We modeled the steam pressure/flow relationships for the system to identify the potential reduction in the losses if the sendout pressure is reduced. Our conclusion is that, if a delivered pressure of 30 psig is adequate, the sendout pressure can be reduced to 75 psig year round and to 50 psig for about 300 d/year. The savings from a reduction to 75 psig would be 7% of the boiler fuel input and would be worth more than $20,000/year assuming a fuel price of $5 per million Btu. Reduction to 50 psig/year would save 15% of the fuel input and would be worth nearly $43,000/year. Balanced against this savings, of course, would be any additional capital investments in the buildings or the boiler plants to allow lower pressure operation or any additional operating costs. These additional costs were not estimated.

Based on condensate and temperature measurements, the steam line conduction losses are 5 to 8 times the ideal conduction losses for the steam line with dry insulation in good condition. Even for a relatively new section of steam line (about one year old), the losses are at least triple the ideal losses. The reasons for these high losses cannot be identified because of limited available information; however, we suspect the reasons are intrusion of groundwater into the conduit early in the lifetime of the system and the subsequent breakdown of the insulation. The overall higher than ideal conduction losses from the steam lines are not a unique phenomenon at Ft. McClellan but appear to be a problem of steam systems in general. Further investigation of the causes of the enhanced losses may be warranted if the Army anticipates the expanded use of steam systems at its installations. In addition, low-temperature hot water distribution systems, because of their generally lower temperatures and impermeable insulation jacket, appear to suffer less from enhanced conduction losses and may be a better choice for new distribution systems and for replacement of sections of existing steam systems. Consideration should be given to this alternative when losses are sufficiently high to warrant replacement of line sections. The hospital line may well be an example of such a case, but we have not performed a feasibility analysis for replacement of the line. Consideration of a hot water line for this section would require a detailed analysis of the hospital requirements.

2. INTRODUCTION

Because of the convenience of generating heat at a central boiler plant and distributing the heat to numerous buildings in the form of steam or hot water rather than installing, operating and maintaining boilers or furnaces in individual buildings, the practice of using steam or hot water district heating is rather commonplace at large facilities such as military bases, universities, and large industrial complexes. Many of the boilers supplying heat to these district heating systems burn natural gas or oil. With the increases in fuel prices during the past few years and with the commitment by the Department of Defense to reduce fuel consumption at their facilities, measures to improve the end fuel-use efficiency and to reduce the operating costs have received increasing emphasis.

Steam district heating systems have often been found to deliver surprisingly low fractions (about 50%) of the steam to the ultimate users. Most of this heat is lost by normal conduction from the pipes into the ground; by condensate discharge from steam traps; by leaks caused by corrosion of pipes or from failure of seals, valves, or steam traps; or by enhanced conduction losses caused by wetting of the insulation. Visible signs of these losses often show up as steam plumes rising from valve pits and steam traps or by marked differences in the appearance of vegetation above the buried steam lines compared with that away from the steam line, i.e., near the steam line the vegetation may be green in the winter and brown in the summer. ORNL was asked to perform an assessment of the potential for improving the efficiency of the steam system at the Ft.

McClellan Army base in Anniston, Alabama. All the visible signs pointed toward the conclusion that the system is relatively inefficient; the analysis has confirmed this initial hypothesis.

2.1 PHYSICAL DESCRIPTION OF THE STEAM SYSTEM

The Ft. McClellan facility has three physically independent district heating systems serving geographically separated sections of the base. ORNL has performed an analysis of one of these systems — the system connected to boiler plants 2 and 3. The boilers can burn either gas or oil to produce steam, which is then distributed to 24 buildings. The system operates with a constant steam pressure of 100 psig as the steam enters the pipelines at the boiler plants. Plant 2, the major operating system, is capable of supplying the entire load to buildings that are connected to the two plants. Plant 3 is now operated only in unusual circumstances such as during necessary shutdowns of plant 2. The entire steam pipeline is underground and consists of steel outer conduit, steel steam carrier pipe, and calcium silicate insulation. Condensate is returned from most of the buildings and from some steam traps on the steam distribution system. A map of the steam distribution system is shown in Fig. 1.

2.2 BUILDINGS SERVED

The buildings served include 11 enlisted men's barracks, three officer's quarters, a hospital, a chapel, three mess buildings, a clinic, a service club, two academic/office buildings, and a museum/ office building. Thus the buildings include a broad distribution of

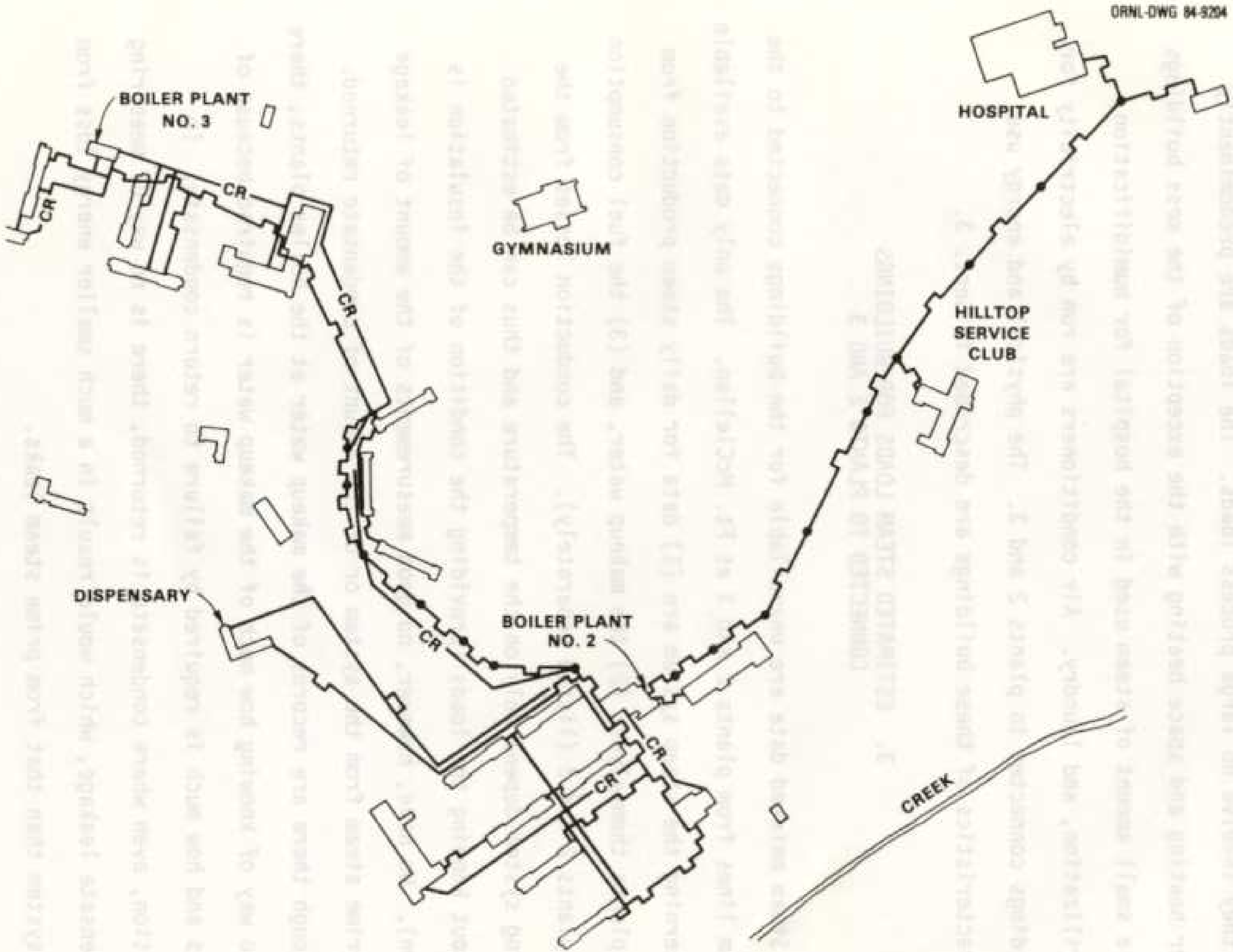

Fig. 1. Physical Layout of Plant 2/Plant 3 Steam Distribution System at Ft. McClellan.

buildings required to provide housing and essential services to personnel, but they involve no large process loads. The loads are predominantly water heating and space heating with the exception of the mess buildings and a small amount of steam used in the hospital for humidification, sterilization, and laundry. Air conditioners are run by electricity for buildings connected to plants 2 and 3. The physical and energy use characteristics of these buildings are described in Sect. 3.

3. ESTIMATED STEAM LOADS FOR BUILDINGS CONNECTED TO PLANTS 2 AND 3

Steam metered data are unavailable for the buildings connected to the steam lines from plants 2 and 3 at Ft. McClellan. The only data available concerning the steam system are (1) data for daily steam production from the plants themselves, (2) the makeup water, and (3) the fuel consumption for plants 2 and 3 (listed separately). The conduction losses from the piping system depend only on the temperature and thus can be estimated without knowing the loads (providing the condition of the insulation is known). We have, however, no good measurements of the amount of leakage of prime steam from the system or of the amount of condensate returned. Although there are records of the makeup water at the boiler plants, there is no way of knowing how much of the makeup water is required because of leaks and how much is required by failure to return condensate. In addition, even where condensate is returned, there is no way of measuring condensate leakage, which would result in a much smaller energy loss from the system than that from prime steam leaks.

With good estimates of the building loads, measured data for the steam produced, and independent estimates of conduction losses, we can bound the potential losses from leaks in traps, leaks of prime steam and condensate, and failure to return condensate. This section contains descriptions of the estimated building loads for the connected buildings. Other sections of the report describe the conduction loss estimates and the overall energy balance calculations.

Although we did not have measured data for the buildings, we did have a report[1] documenting algorithms developed by the U.S. Army Corps of Engineers correlating the building fuel use (electricity and heating fuels) with floor area and with heating degree-days for seven major types of buildings found at Army facilities. These correlations were based on statistical analyses for buildings located at three bases: Ft. Belvoir, Virginia; Ft. Carson, Colorado; and Ft. Hood, Texas. The data were taken between September 1976 and February 1978. No estimates were given for the amounts of fuel used for either water heating or space heating, nor were estimates of the efficiencies of the space heating and water heating equipment given. The form of the correlations for fuel supplied to the buildings for space and water heating is as follows:

$$\text{Fuel input} = A + B \times HDDd$$

where

A and B = constants,

HDDd = heating-degree days per day (°F-days),

Fuel input = daily fuel consumption in Btus equivalent per square foot of building.

We assumed that the constant A represented the water heating load since it was independent of weather. The second term was assumed to represent the space heating load. In order to convert the above fuel consumption data to actual heat delivered into the spaces or into the water, we assumed an efficiency of 75% for the water heating systems and 50% for the space heating systems.

Peak hourly steam loads per square foot of building were estimated by assuming that the water heating load was constant throughout the day for the peak day (i.e., the peak load is 0.75 x A/24) and that the peak space heating load was given by

$$\text{Peak load} = 0.50 \times B/24 \times (65 - T_{outside}),$$

where $T_{outside}$ is in degrees Farenheit. The floor areas, appropriate values for A and B, and the calculated minimum, peak, and annual steam loads of all buildings are displayed in Table 1. If the equipment efficiencies differ from those assumed, the load estimates will also differ. For example, assuming a 60% efficiency for water heaters and 40% efficiency for space heaters (very conservatively low), the result would be an annual load of 44.6 million pounds as compared with 51.3 million pounds. Assuming a water heating efficiency of 80% and a space heating efficiency of 80%, the result would be an annual load estimate of 72.9 million pounds. Since the annual water heating and space heating loads are about the same, changes in the efficiencies of both will be about equally important.

Table 1. Calculated Demands for Steam for Buildings Connected to Steam System

Building type	Building Number	Area (ft^2)	A	B	Steam min. (lb/d)	Slope (lb/HDD)	Peak (lb/h)	Annual Loads (10^6 lb/year)
Hospital	292	155,867	NA[a]	NA	24,000	4,250	10,208	18.54
Service Club	2213	26,932	231.80	12.42	4,682	167	557	2.09
Barracks	295	11,964	130.50	15.99	1,004	96	249	0.59
Barracks	1020	36,416	130.50	15.99	3,055	291	758	1.78
Barracks	1021	36,416	130.50	15.99	3,055	291	758	1.78
Barracks	1022	36,416	130.50	15.99	3,055	291	758	1.78
Barracks	1023	36,416	130.50	15.99	3,055	291	758	1.78
Academic/Offices	1081	80,329	76.71	18.97	4,622	762	1,843	2.91
Chapel	2293	8,072	130.50	15.99	790	65	173	0.44
Officer Quarters	2275	25,147	130.50	15.99	2,110	201	524	1.23
Officer Quarters	2276	25,147	130.50	15.99	2,110	201	524	1.23
Officer Quarters	2277	25,147	130.50	15.99	2,110	201	524	1.23
Mess	1001	11,834	231.80	12.42	2,057	73	245	0.92
Clinic	2290	8,876	254.40	24.31	1,694	108	304	0.67
Barracks	2220	36,416	130.50	15.99	3,055	291	758	1.78
Barracks	2221	36,416	130.50	15.99	3,055	291	758	1.78
Barracks	2223	36,416	130.50	15.99	3,055	291	758	1.78
Barracks	2224	36,416	130.50	15.99	3,055	291	758	1.78
Barracks	2225	36,416	130.50	15.99	3,055	291	758	1.78
Barracks	2227	36,416	130.50	15.99	3,055	291	758	1.78
Academic/Offices	2281	46,334	76.71	18.97	2,666	439	1,063	1.68
Mess	2202	11,816	231.80	12.42	2,054	73	245	0.18
Mess	2203	11,817	231.80	12.42	2,054	73	245	0.92
Museum/Offices	2299	23,739	76.71	18.97	1,366	225	545	0.86
Totals					83,868	9,844	24,829	51.33
Peak lb/d							595,896	

[a]NA = not applicable.

The Ft. McClellan hospital loads were not calculated on the basis of the above report because hospitals were not included in the report. Hospital estimates were based on data obtained for similar hospitals at U.S. Navy shore facilities.[2] The data were adjusted to account for the size of the Ft. McClellan hospital and for the Anniston, Alabama, weather data. An independent estimate of the steam pressure at the hospital during the time of peak load (80 psig) was used to estimate the peak steam load. This estimate was obtained by using the pressure flow model and adjusting the load to obtain a delivered pressure of 80 psig. The peak load estimate obtained in this way agreed well with the estimate obtained from the Navy data.

4. STEAM PRODUCTION FROM BOILER PLANTS 2 AND 3

Records are available for the calendar year 1982 showing daily steam production by boiler plants 2 and 3. These data are useful (1) for calculating the total annual steam production for comparing estimated load and loss data and (2) for estimating the maximum and minimum loads for checking the consistency of our load data. These data are displayed in Table 2.

The peak daily load (662,000 lb/d or an average of 27,600 lb/h) occurred in January; the minimum (129,000 lb/d or 5,400 lb/h) occurred in September. The peak load occurred for a day with an average outdoor temperature of 13°F; the minimum occurred for an average outdoor temperature of 76°F. Since there was probably little need for heating on the day of minimum load, the minimum load can be assumed to be primarily a

Table 2. Summary of Steam Production at Boiler Plants

Month	Peak daily loads for each month (10^6 lb/d)			Minimum Loads	Monthly loads (10^6 lb/month)		
	Plant 2	Plant 3	Total		Plant 2	Plant 3	Total
January	470	192	662	338	9,050	6166	15,216
February	325	215	540	424	7,702	5516	13,218
March	316	216	532	249	6,494	5080	11,574
April	228	193	421	210	6,877	2468	9,345
May	214		214	214	5,634		5,634
June	0	228	228	141	4,245	980	5,225
July	173		173	143	4,817		4,817
August	156		156	134	4,415		4,415
September	166		166	129	4,353		4,353
October	304		304	152	6,250		6,250
November	411		411	226	9,804		9,804
December	489		489	224	11,121		11,121
Annual total (10^6 lb)							100,972

result of the water heating load in the buildings served. The maximum load represents the combination of both the water heating and the space heating loads for a day with 52 heating degree-days (65 - 13 = 52).

Of the 101 million pounds of steam produced, we estimate that approximately 96 million pounds enter the steam distribution system, and 5 million lbs are used within the boiler plants to power auxiliaries. A portion of the steam entering the distribution system is lost enroute to the buildings, and the remaining steam supplies building heat loads. Later sections contain independent estimates of the conduction losses and of the building loads. Those estimates together with this load data are used to derive an efficiency for the distribution system. On the basis of the estimate of 51.3 million pounds per year of steam required to supply the building loads, the distribution system efficiency is about 53%.

5. PRIMARY HEAT LOSS MECHANISMS AND ESTIMATED MAGNITUDES

The results of analyses performed to estimate the size of the heat loss under various conditions of the pipe line that are likely to be seen in practice are summarized in this section. These conditions include dry, insulated pipe in the original design condition; bare, dry pipe that is exposed to the air as seen in vaults; and pipe that is submerged in water as is the case for a flooded vault. In addition, the results of two sets of measurements that are used to estimate the magnitude of the heat loss for specific sections of buried pipe are also presented. The first set consists of measurements of the ground temperature above a section of buried steam pipe and the use of a heat flow model to infer the rate of heat loss from the hot steam pipe to the earth. The second set consists of measurements of the condensate ejected by steam traps along a relatively new section of buried line; the condensate on this line section is entirely due to condensation of steam as a result of conduction heat loss to the surrounding earth.

5.1 HEAT LOSSES FROM DRY PIPES

To minimize heat losses from steam and condensate pipe lines, the lines are usually insulated. Sometimes the pipes may run above ground, but more commonly the pipes are buried from 2 to 6 feet below the surface. If the insulation is intact and dry, the ground helps to insulate the pipe from cold temperatures in the winter and to reduce the heat losses. We prepared estimates of the heat losses for well insulated pipes in order to provide a reference for judging the significance of the heat losses from pipe with wet or deteriorated insulation and to use in modeling the heat losses from a typical system.

5.1.1 Heat Losses From Dry, Insulated, Buried Pipes

Heat losses have been calculated for varied soil conditions and various types of insulation by King et al.[3] For the example of a 6-in. steam line at 325°F, with 4-in. of calcium silicate insulation in clay of average moisture and a soil temperature of 50°F, the rate of heat loss would be approximately 55 Btu/(h·ft). For the Ft. McClellan system with a steam temperature of 338°F and a ground temperature of 80°F, the loss rate would be about 52 Btu/(h·ft).

5.1.2 Heat Losses From Bare Pipes in Air

The simplest case to consider is a bare pipe exposed to ambient air on a dry, still day. For this case, the two major heat loss mechanisms are natural convection and radiation. We consider the case of a pipe with 338°F steam and ambient air at 150°F (a typical temperature inside a dry vault, where much of the bare pipe is found). The estimated loss due to natural convection under these conditions is about 350 Btu/(h·ft). Kreith[4] (in Table 5.1) gives a value of emissivity of 0.8 for oxidized steel pipe. Assuming that the steam pipe is 6-in. in diameter, the estimated radiation loss is approximately 570 Btu/(h·ft). The total loss per foot of bare pipe (radiation and convection) is then 920 Btu/(h·ft).

5.2 HEAT LOSSES FROM PIPES IN CONTACT WITH WATER

Steam pipes are normally kept dry and protected from intrusion of groundwater or the buildup of condensate from leaks in the steam or condensate lines or the associated valves, expansion joints, steam traps, etc. Unfortunately, components of steam lines fail, and the protective mechanisms sometimes prove unequal to the task of protecting the line as intended. When this happens, the losses of heat from the steam lines can be enhanced appreciably from the losses during "normal" operating conditions. Estimates of the magnitude of these enhancements for two types of failures that are frequently observed in operating steam systems are presented in Sects. 5.2.1 and 5.2.2.

5.2.1 Pipes with Entrapped Moisture and Deteriorated Insulation

Observations of actual steam lines indicate that the heat losses are substantially higher than the theoretical losses. Consideration of the magnitudes of the observed losses suggests that the pipe is behaving as though there were no insulation and that the pipe is in direct contact with the surrounding soil. The most likely physical explanation is that the conductivity has been greatly enhanced by the deterioration of the insulation from the combined effects of heat and moisture that gets into the system by steam leaks or by the intrusion of groundwater. Entrapped moisture could be boiling on the surface of the pipe and condensing on the jacket or, perhaps more likely, subcooled boiling could be occurring on pipes covered by water, and a thermal convection loop could be forming between the pipe and the conduit. Both of these processes produce extremely high heat transfer rates compared to the rate through dry insulation. If it is assumed that the conductivity of the insulation is infinite, the model of King et al. yields a heat transfer factor of about 1.8 Btu/(h·ft·°F). For the 6-in. pipe at 338°F and a 80°F ground temperature, the rate of heat loss per foot of pipe would be 460 Btu/(h·ft). This compares well with the observed value of about 275 Btu/(h·ft).

5.2.2 Heat Loss from Flooding of Vaults

A commonly observed failure of steam lines is the failure of sump pumps in valve pits and the subsequent covering of the steam pipe with water. The source of the water can be either condensate from steam traps (which occurs when traps leak or when condensate is not designed to be returned and when sump pumps fail to remove collections of condensate from pits), or intrusion of groundwater into the pits because of seepage through cracks in the pit wall or around pipes that penetrate the pit walls. Water in the vaults is commonly heated to temperatures that are rather hot; we assume here that the water in the vault is heated to 150°F. The estimated rate of heat loss from a bare, 6-in. steam pipe carrying 338°F steam and covered by 150°F water is 50,000 Btu/(h·ft). This estimate could be higher, perhaps as high as 150,000 Btu/(h·ft) depending on the assumed heat transfer mechanism). Notice that the loss is nearly 60 times as large as the loss from dry, bare pipe. We estimate that 6 to 8 ft of bare pipe or its equivalent in valves, traps, and fittings is found in a typical vault (typical of both Ft. McClellan and ORNL steam systems). Then the heat loss of the pipe in the vaults that are so badly flooded that the pipe is completely covered is equivalent to the heat loss in 1000 ft of dry, insulated, 6-in. steam line with 4-in. of calcium silicate insulation. Perhaps even more interesting, the rate of heat loss would be 190 times greater than the losses per foot of pipe with deteriorated insulation, as is observed in practice.

5.3 ESTIMATED CONDUCTION LOSSES BASED ON SYSTEM MEASUREMENTS

Two sets of measurements were made to estimate the heat losses from the Ft. McClellan steam distribution systems that are connected to boiler plants 2 and 3. The first set consisted of ground temperature measurements above the section of line between plant 2 and the hospital (building

292). From these temperature measurements and an assumed steam temperature, the rate of heat loss from the pipe was estimated at three points along the line. The second set of measurements consisted of measurements of the condensate dumped from traps on a relatively new section (about 1 year old) of the line between plant 2 and building 2277. No condensate is returned from this line, so measured condensate reflects the heat loss on that section of the line. These measurements were used as a basis for estimating the approximate magnitudes of the heat loss from the entire piping network and for determining appropriate coefficients for use in the pressure/flow modeling analysis.

5.3.1 Temperature Measurements.

Temperature measurements (summarized in Table 3) were taken at the following points on the steam line between plant 2 and the hospital: (1) between the first and second vaults going from plant 2, approximately one-third of the way from the first to the second vault; (2) approximately 30 ft from the fourth vault in the direction of the third vault; and (3) a few feet from the vault containing the service line to the Hilltop Service Club (building 2213). In addition, two measurements were made of the soil temperature far from the steam lines. All temperature measurements were made at a depth of about 9 in. The measurements over the steam line were made on a line perpendicular to the pipe at five points--over the pipe center, at 2 ft each side of center, and at 4 ft each side of center. Since the exact position of the center of the pipe was not known, it was estimated both by sighting between points where the pipe entered adjacent vaults and by the appearance of the surface vegetation, which was usually

Table 3. Summary of temperature measurements

	Points Measured X1	X2	Depth (ft)	Heat Loss (Btu ft)
Set 1	0	-2.5	4	400
	1.5	-2.5	5.2	500
	-1.5	3.5	6.2	450
	0	3.5	3.8	400
Set 2	0	-1.75	3.2	300
	-1.75	2.25	3.2	300
	-3.75	4.25	3	400
	0	4.25	3.8	450
Set 3	0	-2.0	5.5	250
	0	4.0	6.5	250

quite different in appearance from that far from the pipe. In some cases, temperature measurements showed a symmetry about a point a few inches from our estimated centerline position. When this happened, the centerline was assumed to be at the axis of symmetry, that is why the distances shown in Table 3 are not always exactly 2 and 4 ft from the centerline position.

Kusuda et al.[5] developed an expression for the conduction losses from a buried pipe given the temperature in the soil above the pipe, the soil conductivity, the depth of the pipe, and the normal temperature of the soil at the depth of measurement. That relationship is shown as follows:

$$Q = \frac{4\pi K_s \Delta T}{\ln \dfrac{x^2 + (y + D)^2}{x^2 + (y - D)^2}} \qquad (1)$$

where

K_s = soil conductivity,

ΔT = (Txy - Tg),

x = perpendicular distance from pipe centerline,

y = depth of probe in soil,

D = pipe depth,

Txy = soil temperature at distance x, depth y,

Tg = temperature of undisturbed soil far from pipe.

Following a method developed by McLain et al.,[6] we measured the temperature above the pipe and far from it at the same depth; independent estimates of soil conductivity were available for clays similar to that found at Ft. McClellan. Consequently, two independent measurements at nearby points are enough to yield estimates of the two estimates of the two remaining unknowns, heat loss rate and the pipe depth. Equation (1) assumes that the soil is homogenous, that the surface of the soil is an infinite plane, and that the pipe diameter is much smaller than the pipe depth. Deviations from these assumptions will produce inaccuracies in the results. We assumed a value for the thermal conductivity of the soil of 0.75 Btu/(h·ft·°F). In practice, the conductivity varies not only with soil type, but also with moisture content, compaction, etc. This means that the conductivity may differ greatly from an assumed value, even if the soil type is correctly identified, and that the conductivity may vary seasonly from the dryest to the wettest seasons. For example, an increase in the conductivity from 0.75 to 1.0 increases our estimated heat loss rate by about 50%.

The heat loss estimates shown in Table 3 display a large amount of scatter. However, the loss rates are much higher than the ideal loss rate of about 52 for a 6-in. pipe with 4 in. of insulation in good shape. The average calculated loss rate at point 1 is 440 Btu/(h·ft) at point 2, 360 Btu/(h·ft); and at point 3, 250 Btu/(h·ft). These measurements were taken during a relatively dry period of the year and there was little water standing in the vaults as there had been during other visits to the base. Consequently, it is expected that the losses during wet periods are considerably higher than estimated here. As indicated previously, the losses from pipe sections covered by water in flooded vaults may be two orders of magnitude greater than these estimates.

Because visual observation of the vegetation above the steam line between plant 2 and the hospital suggests that most of the line is similar to the two measurements yielding heat loss rate estimates of 360 and 440 Btu/(h·ft), and because the loss rate is likely to be considerably higher than this during wet periods, we used a value of 400 Btu/(h·ft) for the entire line in our analysis of the system heat loss.

5.3.2 Condensate Measurements

Along one new section of the steam line between plant 2 and building 2275, condensate is dumped from steam traps rather than being returned to the boiler plant. Condensation in the line can be entirely attributed to conduction losses. For simplicity, we assumed that the steam is 100-psig, dry, saturated steam. Although it is likely that the steam has a small amount of superheat when it enters the line, the superheat would be lost in a very short distance and would affect our calculations only slightly. The condensate was collected until at least 400 to 500 mL had been obtained and the time for collection measured. Measurements were taken for six points, and the flow for a seventh point (where collection was not possible but flow was observable) was set equal to the flow from a measured point where flow appeared to be similar to that from the unmeasurable point. Since the flow for the estimated point was relatively small compared to that from measured points, the error from a poor estimate is not important.

The measurements (and the estimate) are shown in Table 4 along with both the calculated flow rates and the inferred rates of heat loss. The average overall heat loss rate for the pipe section is about 150 Btu/(h·ft). This rate is triple that expected [52 Btu/(h·ft)] from a 6-in. pipe with 4-in. of calcium silicate insulation in good condition. Even allowing for higher than assumed soil thermal conductivities, the loss rate is at least double the rate predicted for the ideal case of a new pipe with dry insulation in good condition. Since the pipe section in question is only about 1 year old, the observation suggests that ideal heat loss rates may seldom be achieved. There is nothing unusual about this pipe section based on visual observation of the soil or the vaults.

5.4 ESTIMATED HEAT LOSSES BY CONDUCTION FROM THE PIPING SYSTEM

Section 5.3 summarized measurements of the ground temperatures and the condensate flow from steam traps which were used to infer the rates of heat loss from two sections of the steam line connected to the plant 2/

Table 4. Summary of condensate measurements

Measurement Point	Collected Condensate (mL)	Collection Time (min)	Flow Rate (mL/min)	Heat Loss Rate (Btu/h)
1			100	12,859
2	1000	1.5	700	90,011
3	600	6	100	12,859
4	750	1.25	600	77,152
5	850	7	100	12,859
6	1000	4.75	200	25,717
7	400	6	70	9,001
Total			1870	240,457
		Loss per foot (1600 ft)		150

plant 3 steam system. The ground temperature measurements were made for the section of the steam line between plant 2 and the hospital. Visual observations along with the measurements indicate that this area is the most inefficient section of the steam system. The temperature measurements imply a loss rate of approximately 400 Btu/(h·ft) of steam line for the better sections (nearer the hospital). These measurements were made for sections of the steam line that are 6 in. in diameter.

The condensate measurements were made for a 1-year-old section of the 6-in. steam line connecting plant 2 and building 2275. The condensate measurements showed a heat loss of approximately 150 Btu/(h·ft) of this steam line section. This rate of heat loss is about triple the expected heat loss [52 Btu/(h·ft)] for a 6-in. line with 4 in. of dry calcium silicate insulation in good condition.

In estimating the conduction heat loss for the entire system, we assume that the steam is kept at a constant presure of 100 psig/year-round (hence the pipe is at approximately 338°F). Further, we assume that the 1460-ft line section between plant 2 and the Hilltop Service Club (building 2213) loses heat at the rate of 400 Btu/(h·ft) and that the remaining 6-in. line loses heat at the rate of 250 Btu/(h·ft). The section of 6-in. line between plant 2 and building 2275 is assumed to lose heat at the rate of 150 Btu/(h·ft). Remaining sections of the distribution system are assumed to lose heat at the rate of 250 Btu/(h·ft) times the ratio of their diameters to 6 in. The resulting heat loss estimates for the component pipe sections of the plant 2/plant 3 distribution system are shown in Table 5. These losses are constant and independent of the steam loads because of the constant steam pressure assumption.

The above estimates of conduction losses apply to a relatively dry period of the year. At the time the measurements were made, there was no evidence of significant flooding of any vaults from either leaks, steam trap failures, or groundwater intrusion into the system vaults or conduits. During previous visits to Ft. McClellan, flooding of the vaults sufficient to partially or entirely cover the steam line in three vaults on the line between the hospital and plant 2 was observed. Calculations summarized in Sect. 5.2 show that the heat losses per foot of pipe for pipe in contact with water can be more than 100 times as large as the 400 Btu/(h·ft) estimated for the worst sections of the 6-in. hospital/plant 2 line. Three such flooded vaults have been estimated to add 100 lb/h to the estimated steam losses on that section of the steam line. If these

Table 5. Conduction heat loss summary for the plant 2/plant 3 system

Diameter	Length (ft)	Heat loss ($Btu \cdot h^{-1} \cdot ft^{-1}$)	Total Heat loss (Btu/h)	Annual Heat loss (Btu)	Annual Steam loss (lb)
2	425	83	35,417	310,250,000	310,250
3	200	125	25,000	219,000,000	219,000
8	175	333	58,333	511,000,000	511,000
6	175	250	43,750	383,250,000	383,250
6	450	250	112,500	985,500,000	985,500
2	300	83	25,000	219,000,000	219,000
5	475	208	98,958	866,875,000	866,875
2	500	83	41,667	365,000,000	365,000
4	200	167	33,333	292,000,000	292,000
3	650	125	81,250	711,750,000	711,750
6	1200	150	180,000	1,576,800,000	1,576,800
3	900	125	112,500	985,500,000	985,500
3	475	125	59,375	520,125,000	520,125
8	200	333	66,667	584,000,000	584,000
2	125	83	10,417	91,250,000	91,250
5	100	208	20,833	182,500,000	182,500
3	775	125	96,875	848,625,000	848,625
5	150	208	31,250	273,750,000	273,750
3	400	125	50,000	438,000,000	438,000
4	200	167	33,333	292,000,000	292,000
3	550	125	68,750	602,250,000	602,250
6	280	250	70,000	613,200,000	613,200
6	1,260	250	315,000	2,759,400,000	2,759,400
6	1,460	400	584,000	5,115,840,000	5,115,840
6	160	250	40,000	350,400,000	350,400
2.5	280	104	29,167	255,500,000	255,500
Total annual conduction losses					20,352,765

conditions occur for 30 d/year, the annual losses would amount to an additional 0.7 million pounds per year. The estimated failure rate for steam traps on the ORNL steam distribution system is 2%.[7] Based on an analysis for the ORNL system, the contribution of the 18 traps on the plant 2/plant 3 system is about 0.4 million pounds per year (~115 lb/h from a failed trap with 1/16-in. orifice completely open). Heat losses from insulated piping in the vaults may further increase the system losses by 1.0 million pounds per year (another 115-lb/h average). A higher moisture content in the soil than on the day the measurements were made could also increase the conduction losses appreciably. A plausible increase in the soil thermal conductivity from 0.75 to 1.0 for 30 d/year could increase the conduction losses by 50% for that period and the annual losses by up to about 0.8 million pounds. Thus, even without leaks, we could account for a minimum loss of 20 to 23 million pounds per year in conduction losses; wet soil conditions would add to this minimum. We had no way of estimating the magnitude of leakage from the system. Not all the condensate is returned from the buildings and the steam traps, and we had no estimate of the size of the condensate losses. Future measurements of condensate coupled with reported quantities of makeup water will allow estimates of the amount of leakage.

For our estimates of the pounds of steam lost as a result of conduction losses, we will have assumed that 1 lb of steam is lost for every 1000 Btu of conduction heat loss. The use of 1000 Btu/lb assumes that some cooling of condensate occurs before it is ejected by the traps and that most of the condensate is returned to the plant with a temperature range of

150° to 200°F. Because we do not know how much condensate is returned, the loss estimate may be low. To obtain an upper limit to the conduction losses under ordinary conditions, we can assume that the condensate is not cooled below the steam temperature (338°F) before it enters the traps and that no condensate is returned to the boiler plants. Under these conditions, the estimated annual steam losses from normal conduction heat loss processes are increased by 6.0 million pounds per year (from 20.4 to 26.4 million pounds per year).

5.5 EFFECTS OF REDUCED STEAM PRESSURE ON THE EFFICIENCY OF THE SYSTEM

The steam system connected to boiler plants 2 and 3 at Ft. McClellan operates at a constant pressure of 100 psig year-round. The pressure at the boiler plants must be somewhat higher than the required pressures at the buildings in order to overcome the friction losses of the steam flowing in the pipes between the plants and the buildings. However, the system heat losses increase with increasing steam pressure. The conduction losses are directly proportional to the temperature difference between the pipe and the surrounding earth, and the pipe temperature increases as the steam pressure increases. Losses from leaks increase with pressure; consequently, there is an incentive to decrease the operating pressure as much as possible consistent with acceptable system operation. Most of the buildings connected to the steam system require delivered steam at pressures of no more than 15 psig; the hospital is an exception in that the sterilizers require steam at 60 psig, but, were the savings from reduced pressure for the steam system great enough, alternate means of operating the sterilizers might be found.

The estimated lower bound on conduction losses from the steam system connected to plants 2 and 3 is 23 million pounds of steam per year, or about 23% of the steam produced by the boilers. Reducing the steam pressure from 100 to 50 psig would reduce these losses by about 15%, or 3.4 million pounds per year. If the boiler efficiency is assumed to be 75% and the cost of gas is assumed to be $5.00 per thousand cubic feet, the savings in gas costs would be about $22,000/year. Some additional savings might be achieved because of reduced leakage of steam from the system, but our analysis indicates that steam leaks are not a major problem at the Ft. McClellan system.

After accounting for all the losses that we could based on our observations and measurements, more than 21 million pounds of steam per year are unaccounted for. We are confident that our loads estimates are not in error by a significant amount based on the excellent agreement we obtained with the observed plant leak loads, annual loads, and the pressure-flow modeling results. Consequently, we conclude that the unaccounted-for 21 million pounds of steam per year are actually losses, most likely conduction losses caused by more extensive intrusion into the conduit of groundwater and water from vault flooding than we assumed. A portion of this 21 million pounds of loss could result from leakage of prime steam from the system, but we judge this unlikely based on our pressure-flow modeling results.

Although the source of the additional 21 million pounds of losses is not completely understood, we can say with confidence that reducing the system pressure will reduce these losses. If the losses are (as we believe) conduction losses, reducing the pressure will decrease the heat losses to the same extent as the 23 million pounds per year of identified conduction losses were decreased. Thus the savings from reducing the presure from 100 to 50 psig would be 15% of 21 million pounds per year, or 3.2 million pounds per year, which would have a value of $21,000/year using the same assumptions as above. If the 21 million pounds were losses from leaks rather than conduction losses, reducing the pressure would have an even more significant impact. Reducing the pressure from 100 to 50 psig would reduce the losses by at least 29% (proportional to the square root of the pressure), or 6.1 million pounds per year, which would have a value of $39,000/year. As we indicated above, however, we believe that the unidentified losses are conduction losses rather than leakage losses.

Reducing the sendout pressure from 100 to 50 psig (based on the above estimates) would reduce annual losses by approximately 6.6 million pounds of steam per year, worth some $43,000/year, assuming a boiler efficiency of 75% and a gas price of $5 per thousand cubic feet. A more modest reduction from 100 to 75 psig would reduce losses by 7%, or 3.1 million pounds per year, worth $20,000/year.

We performed analyses of the pressure-flow relationships for the piping network connected to boiler plants 2 and 3 for sendout steam pressures of 100 and 50 psig in order to determine whether the capacity of the steam system is adequate at reduced pressures. At the system peak load, we found that the steam pressure at the hospital fell to about 52 psig for a sendout pressure of 75 psig and to 28 psig at a sendout pressure of 60 psig. It should be noted that the assumption was made that plant 3 was not operating; all the load was assumed to be supplied by plant 2. The peak load was assumed to occur at an outdoor temperature of 13°F. For much of the year, the steam load would be considerably less than the peak load. For example, the load would be half the peak when the outdoor temperature is above 48°F. During calendar year 1982, for example, there were a total of about 50 d during which the average temperature fell below 48°F, and on many of those days the temperature was in the 40s. Table 6 shows the results of pressure-flow analyses for the plant 2/plant 3 system for full- and half-load conditions. Even when the sendout pressure is reduced to 50 psig, the pressure of the delivered steam is above 40 psig for all buildings at half load. If these pressures are adequate, the analysis suggests that the steam pressures can be reduced to 50 psig for at least 300 d/year.

5.6 POTENTIAL FOR REDUCTION IN LOSSES ON A HYPOTHETICAL STEAM LINE

Losses expected from a steam line connecting plant 2 to the hospital at the Ft. McClellan Army base under three conditions are examined in this section. The first conduction is a steam line with good insulation and no flooding of vaults. The second is a model of the steam line with deteriorated insulation and some flooding of vaults, which were actually observed. The third case also assumes that the insulation is deteriorated and that little can be done to mitigate the losses other than to replace the line but that the vaults are dry.

Table 6. Pressure distribution summary

Building	Full load		Half load	
	Pressure (psi)	Load (lb/h)	Pressure (psi)	Load (lb/h)
Plant 2	100		50	
2221	98.9	758	49.3	379
2220	98.2	758	48.9	379
2290	97.8	304	48.6	152
2277	97.2	524	48.0	262
2276	95.5	524	47.7	262
2275	94.2	524	47.5	262
2293	94.6	173	46.1	87
1081	93.3	1,843	45.8	922
1023	93.0	758	44.0	379
1022	93.0	758	45.5	379
1001	93.0	245	45.5	123
1021	92.2	758	45.1	379
1020	87.9	758	44.6	379
2224	98.4	758	49.2	379
2223	97.8	758	48.4	379
2281	96.4	1,063	48.2	532
2225	99.8	758	49.6	379
2203	99.7	245	49.8	123
2227	99.2	758	49.5	379
2213	91.4	557	45.1	279
295	84.8	249	41.5	125
292	83.5	11,200	40.8	5,600

5.6.1 Losses from a Steam Line in Good Condition

The losses from a 6-in. steam line with 4 in. of calcium silicate insulation carrying 338°F (100-psig) steam and a ground temperature of 80°F were estimated to be 52 Btu(h·ft). The line under consideration has about 3280 ft of pipe. The expected losses would be 170,000 Btu/h, or 1.5 billion Btu per year, which is the magnitude of losses expected from a new steam line (excluding condensate losses) that has been properly installed and maintained.

5.6.2 Actually Observed Losses for Relatively Old Steam Lines

Assuming that the system has the relatively high rate of loss of heat mentioned in Sect. 5.2 for pipe with deteriorated insulation and entrapped moisture, the rate of heat loss would be about 460 Btu/(h·ft). Then the losses for the same steam and soil conditions mentioned in Sect. 5.6.1 would be 1.5 million Btu/h, or 13 billion Btu per year, which is the approximate level of losses that might be expected if all reasonable repairs (short of replacing the steam line) were performed.

5.6.3 Losses Caused by Groundwater Intrusion and Sump Failures

We estimate that some 20 ft of pipe are covered by water in vaults flooded either by groundwater intrusion or by combined steam trap and sump pump failures. We assume that the flooding occurs for up to 30 d/year. As mentioned in Sect. 5.2.2, the rate of heat loss for a pipe covered by water at 150°F rises to 50,000 Btu/(h·ft). Thus, the 20 ft of submerged pipe increases the losses by some 1 million Btu per hour, or by 720 million

Btu over a 30-d period. These losses could be eliminated if flooding of the vaults were eliminated.

5.6.4 Reduction in Losses by Reducing Sendout Pressure

We have used a pressure-flow model developed at ORNL to estimate the reduction in conduction heat losses which would result from a decrease in the sendout pressure for the plant 2/hospital line. We found that reducing the plant pressure from 100 to 60 psig would reduce the rate of conduction heat loss by about 300,000 Btu/h, or by about 2.6 billion Btu-per year, while maintaining a pressure of 50 psig at the hospital in summer months and 30 psig in winter months. Yet lower pressures might be used in the summer months with an acceptable delivery pressure at the hospital, but gains for sendout pressure lower than 60 psig are rather small (150,000 Btu/h over the summer months).

5.6.5 Summary: Potential Improvements in Efficiency for an Example Line

By eliminating the flooding in the vaults of the steam line under consideration and by reducing the sendout pressure from 100 to 60 psig, the losses could be reduced by some 3.3 billion Btu per year. Assuming a boiler efficiency of 75% (estimates for two boilers examined are 65 to 75%), the amount of fuel savings is about 4.4 million cubic feet of gas per year. For comparison, the potential savings from construction of a new steam line would be about 21.4 billion Btu per year or 28 million cubic feet of gas per year.

6. CONCLUSIONS AND RECOMMENDATIONS

Documenting information was very limited; however, by taking measurements of pipe sections, by visually observing the surrounding soil, and by the use of engineering analysis and expert judgment, some interesting conclusions were reached (Sects. 6.1 through 6.3) and some recommendations are suggested (Sect. 6.4).

6.1 PRIMARY LOSS MECHANISMS

The primary loss mechanism for the Ft. McClellan steam distribution system connected to plants 2 and 3 appears to be conduction through the pipe to the surrounding earth. This source of loss is much larger than would be expected if the insulation on the buried pipes were dry and in good condition. Even during dry periods of the year, the conduction losses appear to be three times as high as the ideal losses on a section of buried line only 1 year old and 5 to 8 times the ideal losses for older sections of buried pipe.

The overall distribution system efficiency (percentage of steam entering the system that is delivered to the buildings) is about 53% on an annual basis, with about half of the losses being accounted for by conduction losses under dry conditions. A summary of the annual steam balance based on our analysis is shown in Table 7. Estimated losses from steam trap failures have been included in the "identified source" term and add a modest amount (~5%) to conduction losses. The peak steam load for the buildings is estimated to be about 596,000 lb/d (for a day when the average outdoor temperature is 13°F), and the peak reported daily steam

Table 7. Steam system mass balance (million pounds per year)

Annual steam production	101.0
In-plant consumption by auxiliaries	5.0
Estimated steam delivered to buildings	51.3
Losses from identified sources (conduction and trap losses)	23.3
Losses from unidentified sources	21.4

production for plants 2 and 3 for a similar day is 662,000 lb/d; the difference between steam production and delivered steam is about 10%, assuming that the loads estimate is valid. These figures are in good agreement with the estimated losses only if conduction losses are considered and leaks are unimportant. This agreement has led us to conclude that leaks are not significant in the plant 2/plant 3 distribution system. Nevertheless, a substantial amount of steam remains unaccounted for on an annual basis after deducting conduction losses, steam trap losses, and enhanced conduction losses caused by flooding of the vaults by groundwater (30 d/year on the average). If leaks are indeed not a very important source of steam loss, then the enhanced losses from groundwater intrusion into the conduit surrounding the pipes or other enhanced conduction mechanisms must be much more important than indicated by our assumed 30 d/year of vault flooding. We are not able, based on the information available to us at this time, to identify the exact source of the unaccounted-for losses. It is interesting to note, however, that if the entire distribution system is assumed to have a heat loss rate of 400 Btu/(h·ft) (the same as that for the worst section of the plant 2/hospital line), then the conduction losses predicted are about the same as the sum of our "identified losses" and our "unaccounted-for" losses. Alternatively, our estimated losses from three flooded vaults for 30 d/year was 0.7 million pounds per year; if we further assume that water fills the conduit for 100 ft in each direction from the flooded vault during the flooding period, the additional losses would equal the "unidentified loss" term.

6.2 EFFECTS OF REDUCED STEAM SENDOUT PRESSURE

The steam pressure in the distribution system is now kept at a constant 100 psig year-round. It appears from our analysis that a reduction of this presure to 75 psig is possible during a large portion of the year (300 d or more). We have not, however, investigated the pressure requirements of the buildings in detail. The reduced pressure of 50 psig is adequate if delivered pressures of 30 psig are sufficient to deliver the building requirements. We know that this is not presently true in the hospital, where sterilizers require a higher pressure of about 60 psig. Other examples of higher pressure requirements may also exist. Whether alternative arrangements could be made to meet the demands that require high steam pressures at present would require an application-specific analysis that was beyond the scope of this work.

We have, however, quantified the potential benefits of reduced pressure based on improved steam distribution efficiency alone. Reduction of the steam pressure to 50 psig would reduce the losses by 15% and the fuel bill by about $43,000/year, assuming a boiler efficiency of 75% and a fuel cost of $5.00 per million Btu. Reduction to 75 psig would reduce the losses by 7% and the fuel bill by approximately $20,000/year. Any decision to reduce the pressures would need to consider the additional costs of building system modifications or of system monitoring and operation as well as the potential savings from the pressure reductions.

6.3 IMPROVEMENTS TO THE PLANT 2/HOSPITAL STEAM LINE

Based on our inspections and measurements, the steam line section between boiler plant 2 and the hospital appears to be the least efficient of those sections connected to Plants 2 and 3. Even during dry periods of the year, when losses to the surrounding soil should be the lowest, the losses on this section are about eight times as high as ideal calculated losses and almost double the losses on other sections that are of identical size and that are maintained at the same temperature. During wet periods, the estimated losses based on heat flow calculations are at least double the losses during dry conditions. These enhanced losses are caused by flooding of vaults by intrusion of groundwater or by failures of sump pumps that are supposed to remove groundwater and condensate ejected from steam traps from the vaults. Each foot of pipe that is covered by water in a flooded vault has a loss rate 1000 times as high as the ideal loss rate for buried pipe with 4 in. of dry, calcium silicate insulation in good condition and 125 times as high as the actual losses from the hospital line under dry conditions. There are approximately 20 ft of steam line inside vaults (in the vicinity of building 2213, the Hilltop Service Club) that become partially or entirely covered by water at times during the year and probably many more feet underground. These 20 ft alone would account for 1000 lb/h in increased losses when they are immersed in water. This loss is worth $7.00/h, or about $5000/month, in fuel costs. We do not know at this time how many hours per year such flooding exists. It is clear, however, that the value of maintenance to ensure that the groundwater intrusions are minimized and to ensure that the sump pumps operate satisfactorily may be worth a substantial amount of money. Efforts to reduce these problems should receive continued emphasis.

6.4 RECOMMENDED ADDITIONAL MEASURES OR ANALYSES

Two major areas of uncertainty remain after our initial analysis, and both have been discussed previously. First, a substantial amount (about 20%) of the steam that enters the distribution system at the boiler plants is not accounted for by building demands, conduction losses, or other known loss mechanisms. The information presently available indicates that there are no substantial steam leaks in the system based on a comparison of peak steam production and peak building loads. Because the building loads are based on statistical data rather than on actual metered data for Ft. McClellan, we cannot rule out the possibility that the estimated building loads are in error, but our opinion is that these loads probably do not contain large errors. Additional work to estimate the amount of condensate that is dumped after condensation of steam in the buildings and the amount that is ejected from the steam traps without being returned to the boiler plants would be useful in combination with the measured makeup water at the boilers to estimate the potential losses due to leaks. Such data would either verify or refute our conclusion that leaks are not an important cause of loss.

Second, the potential savings from reducing the steam pressure at the boiler plants is significant, but we have not investigated the acceptability of the resulting reduced pressures at the buildings. The question in simplest terms is "Would a steam pressure of 30 psig be adequate to supply most of the building loads, and if not, are alterations in the building equipment to use lower pressure steam or changes of these critical demands to other energy sources worth considering?" The savings from reduced distribution losses are substantial--at least $10,000/year if the pressure is reduced to 75 psig and perhaps as much as $43,000/year if the pressure can be reduced to 50 psig.

Finally, if the decision is made at some time in the future to make major improvements in the steam system comparable to the conduit replacements made in the plant 1 system, two alternative options should be explored. The first is replacement of the steam distribution system with a hot water system. Hot water systems are likely to have reduced losses and to require less maintenance than steam systems. The second alternative is abandonment of the steam distribution system in favor of individual boilers and furnaces in the buildings served. This option would almost certainly be more energy efficient than the steam system, but the trade-offs between the labor costs, fuel costs, and capital costs would need to be explored in detail. At Ft. McClellan, with only about 2300 heating degree-days per year, we believe that there is a good chance that using individual boilers would be cheaper than using the steam systems or hot water systems.

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42. Robert P. Groberg, HUD, 451 7th Street, SW, Washington, DC 20410
43. Herbert Jaehne, St. Paul District Heating Development Co., Inc., 138 Bremer Bldg., 417 North Robert Street, St. Paul, MN 55101
44. Clarence Kadrmas, P.O. Box 937, 704 Litchfield Ave., Willmar, MN 56201
45. Jake Kaminsky, Department of Energy, 1000 Independence Avenue, S.W., Washington, DC 20585
46. Allen Kennedy, Argonne National Laboratory, EES Division, 9700 South Cass Avenue, Building 362, Argonne, IL 60439
47. John King, Code L63, Naval Civil Engineering Laboratory, Port Hueneme, CA 93043
48. Kjell Larsson, Plogvagen 1 B, S-18351 TABY, Sweden
49. R. Eric Leber, American Public Power Association, 2301 M Street, NW, Washington, DC 20037
50. John Millhone, Department of Energy, 1000 Independence Avenue, SW, Washington, DC 20585

51. Hans Nhman, District Heating Development Company, 417 N. Robert Street, 138 Bremer Building, St. Paul, MN 55101
52-61. G. D. Pine, Gas Research Institute, 8600 W. Bryn Mawr Avenue, Chicago, ILL 60631
62. Alan Rubin, Nuclear Regulatory Commission, 7920 Norfolk Avenue, Room 266, Bethesda, MD 20555
63. K. L. Stierhoff, 1735 Eye Street, NW, Suite 611, Washington, DC 20006
64. Norman Taylor, International District Heating Association, 1735 Eye Street NW, Suite 611, Washington, DC 20006
65. Office of the Assistant Manager for Energy Research and Development, Oak Ridge Operations Office, Oak Ridge, TN 37831
66-93. Technical Information Center, Department of Energy, P.O. Box 62, Oak Ridge, TN 37831