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AN INVESTIGATION OF COSTS FOR HEATING AND POWER GENERATION AT SOUTH DAKOTA STATE COLLEGE

BY

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A thesis submitted
in partial fulfillment of the requirements for the
degree Master of Science, Department of
Mechanical Engineering, South Dakota
State College of Agriculture
and Mechanic Arts

December, 1958

AN INVESTIGATION OF COSTS FOR HEATING AND POWER GENERATION AT SOUTH DAKOTA STATE COLLEGE

This thesis is approved as a creditable, independent investigation by a candidate for the degree, Master of Science, and acceptable as meeting the thesis requirements for this degree; but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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CHAPTER I

INTRODUCTION

This investigation is to determine the amount of steam necessary to heat the buildings and to generate power on the campus of South Dakota State College. It is also concerned with a comparison of the cost of producing steam by burning coal and by burning natural gas.

The building heat losses were calculated as were the distribution piping losses. In the case of many of the older buildings on the campus there is insufficient information regarding the type of construction and materials used. Determination of a reasonable overall coefficient of heat transfer was not practical, so an average value of British thermal units (Btu) per hour per cubic foot of building volume was used. This average value is sufficiently accurate because there are uncontrollable factors which enter into an investigation of this nature. For example, in controlling the room temperature in some of the older buildings, windows are often opened and steam to radiators may or may not be turned off. Also there are occasions where windows may be left open all night, resulting in increased steam consumption.

Part of the campus buildings are heated by low pressure steam. When the turbo-generator is in operation, the turbine exhaust steam is used for heating purposes. During periods of cold weather the turbine exhaust steam is not sufficient, and therefore steam at boiler pressure is reduced to the turbine exhaust pressure through a pressure reducing valve in the power plant. The piping losses of transporting this low pressure steam to the various buildings are greater than of transporting the steam at a higher pressure. It may prove desirable to supply a smaller number of buildings with turbine exhaust steam and to raise the pressure in the remaining low pressure lines. This could serve two purposes: (1) to reduce piping losses and (2) to reduce the need for adding part of the new pipe lines as new buildings are added and therefore saving in installation and maintenance costs.

During periods of warm weather the plant load is comparatively low and natural gas is a very convenient fuel to use. Should natural gas also prove to be a cheaper fuel, then there will be no question that its use will be continued and should be extended. At present only the largest boiler is equipped to burn natural gas and boiler efficiency decreases as the load decreases below rated output. Thus it may prove desirable to install gas burning equipment on a lower capacity boiler to gain the advantages of the perhaps cheaper, more convenient fuel and to operate at a higher percent of rated boiler output.

Small steam turbines power various pieces of auxiliary power plant equipment, such as boiler feed pumps and forced and induced draft fans. At present there is no way of knowing just how efficiently these units operate or what their operating expenses are. In view of the fact that there is always one and sometimes more than one of these units in operation (depending upon which boilers are in use) it would appear desirable to try to obtain some figures regarding the operating expenses of these various auxiliaries.

A complete study of the entire power plant has never been made. The annual fuel costs approach $150,000 per year and they will be increasing as the college grows. This fact, combined with the depreciated value of boilers, turbines, piping, heating, control and auxiliary equipment of well over one million dollars, might make annual savings of several thousand dollars possible and justifies this study.

Data on steam and power generated and fuel burned were obtained from metering equipment in the power plant.

The results of this investigation could: (1) provide information relative to increasing the efficiency of the college power plant, (2) provide a basis for better estimating future steam requirements, (3) indicate the desirability of periodically testing fuel, (4) provide a better basis for future power contracts with the Bureau of Reclamation and (5) suggest desirable considerations.

CHAPTER II

HEAT-TRANSFER THEORY

In heating and air conditioning, the design of every heating or cooling system is based primarily on the heat-transfer characteristics of the building structure. Heat is gained or lost through the walls and structure of a building by two general methods: first, by transmission through the wall from the air on one side to the air on the other side, and second, by actual leakage of warmer or colder air into the building. The first of these methods immediately points to the fact that to reduce heat transfer the insulating quality of the walls must be improved. For this reason, building insulation has been developed and insulating air spaces are provided in many walls and between roofs and ceilings under them. The second method, leakage, is reduced by the installation of weather strips, double windows and doors, and by caulking or otherwise reducing air leakage through cracks.

Transfer of heat takes place by conduction, convection, radiation, or by some combination of these processes whenever a temperature difference exists. In conduction, heat is transmitted from and to adjacent molecules along the path of flow by a process whereby some thermal agitation of the hotter molecules is passed on to the adjacent cooler molecules.

Convection is the transfer of heat (1) between a moving fluid medium and a surface, or (2) the transfer of heat from one point to another within a fluid by movements within the fluid, by which different portions of the fluid are mixed. The final method of heat transfer in convection is eventually some form of conduction or radiation.

Radiation. Hot bodies give off radiant energy in all directions. A colder body on which this energy falls absorbs some of this energy from the source and as a result evidences an increase in internal energy and usually a rise in temperature. Two bodies at different temperatures both emit radiation and absorb impinging radiation, but the hotter body emits more than it receives. The net result is a transfer of heat from the hotter to the colder body.

The theory of conduction was first presented by the French mathematician J. B. Fourier.[1] For the very usual case of equilibrium in heat transfer the temperature (t) depends only on position (x), the heat transferred is constant and Fourier's equation is

$$q = - kA \frac{dt}{dx} \qquad (1)$$

q = Btu per unit of time (usually Btu/hr).

A = the area of the section through which heat is flowing.

---

[1] William H. McAdams, Heat Transmission, p. 7, McGraw-Hill: New York, 1954.

dt = the temperature difference causing the heat flow. The flow is inversely proportional to dx.

dx = the length of path through the material in the direction of the heat flow.

k = a proportionality factor called thermal conductivity.

Conduction through a plain wall yields, from equation (1),

$$q = -k \frac{A}{x} (t_1 - t_2) = - \frac{(t_1 - t_2)}{\frac{x}{kA}} \qquad (2)$$

where q = Btu transferred per unit time (hr).

A = wall area (sq.ft.).

x = thickness of the wall (usually in).

$k = \frac{(\text{Btu})\ (\text{in.})}{(\text{hr})\ (\text{sq.ft.})\ (^{\circ}\text{F})}$

$(t_1 - t_2)$ is the temperature difference in degrees Fahrenheit on the two sides of the wall causing heat flow.

In heat flow between a fluid and a solid there always exists a thin fluid film, which tends to cling to the surface as relatively stagnant layer, and acts as an additional resistance to heat flow. The values of the film-surface-conductance coefficient (f) increase (1) with the increasing roughness of the surface involved (2) almost linearly with wind velocity over the surface and (3) with increasing temperature difference. Because surface, wind and temperature conditions are often rather indeterminate, the American Society of Heating and Ventilating Engineers Guide recommends that a value of $f_i = 1.65$ be taken as representative for inside conditions with relatively still air, and a value of $f_o = 6.0$ be taken for outside conditions when the wind is not over 15 mph.

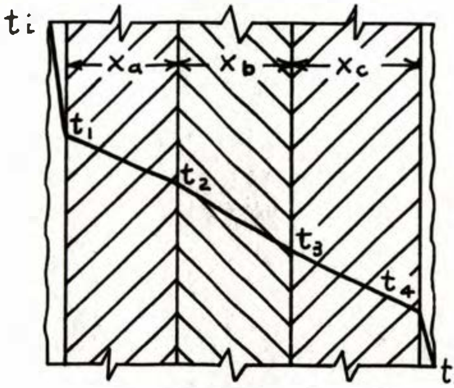

Figure 1. Sketch of a Composite Wall.

Conductance through a composite wall as shown in Figure 1 can be determined by using equation (2).

$$q = - \frac{(t_i - t_o)}{\frac{1}{f_i A} + \frac{x_a}{k_a A_a} + \frac{x_b}{k_b A_b} + \frac{x_c}{k_c A_c} + \cdots + \frac{1}{f_o A}} \qquad (3)$$

Btu per hr through the whole wall or in the case of flat walls per sq ft of surface

$$q = - \frac{(t_i - t_o)}{\frac{1}{f_i} + \frac{x_a}{k_a} + \frac{x_c}{k_c} + \cdots + \frac{1}{f_o}} \text{ Btu/hr/sq ft} \qquad (4)$$

It is often impracticable to calculate the heat-flow conditions through the various sub-sections of a heat-transfer barrier, but an over-all heat-transfer coefficient can be found, either experimentally or from tabulations for surfaces built up in similar manner. Under this condition equation (4) becomes

$$q = - UA\,(t_i - t_o) \text{ Btu per hr} \qquad (5)$$

where U is the overall coefficient of heat transfer expressed in Btu per hr per sq ft per deg F, found by direct experiment or calculation from various items in equation (4).

For composite walls of standard construction actual tests to determine U have been made by various investigators and where these can be found they should be used in preference to making detailed calculations to find such items.

In the case of pipe lagging and similar annular covering the cross section of the path through which heat must flow varies in proportion to the linear distance through the section.

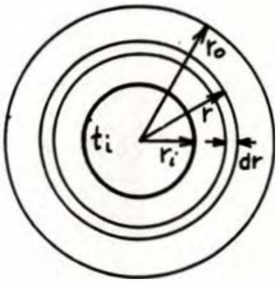

Figure 2. Section Through a Cylindrical Pipe Covered With Lagging.

Referring to Figure 2 consider the heat flow through a section of lagging of unit length along the axis of a pipe, and situated at radius r from the center of the pipe. For this case Fourier's equation (1) or

$$q = - kA \frac{dt}{dx}$$

becomes

$$q = - k(2\pi r.1) \frac{dt}{dr} \qquad (6)$$

Integrating for the whole insulation

$$q \int_{r_i}^{r_o} \frac{dr}{r} = - 2\pi k \int_{t_i}^{t_o} dt$$

For a length of pipe L, the heat transferred per hour becomes

$$q = \frac{2\pi kL(t_i - t_o)}{\ln \frac{r_o}{r_i}} \qquad (7)$$

where q = Btu per hr transferred through lagging.

t_1 and t_o = temperatures in degrees Fahrenheit on each side of lagging.

L = length of lagging measured along axis of pipe in ft.

k = specific conductivity.

r_1 and r_o = radii to innermost and outermost section of lagging.

CHAPTER III

BUILDING HEAT LOSSES

The items entering into the heating load in a building or space are:

1. Heat loss through exposed wall area to the outside.
2. Heat loss through roofs, or ceiling to unheated attics.
3. Heat loss through floors to the earth.
4. Heat loss through glass surfaces and doors.
5. Heat required to warm air entering by infiltration, through outside windows and door cracks and other points of leakage.

For items 1 to 4 the heat loss is determined by the basic relationship, equation (5):

$$q = UA\ (t_i - t_o) \text{ Btu per hr.}$$

The minus sign can be omitted here because it merely indicates the direction of heat flow, which is out of the building.

With reference to the following tables on the respective building heat losses the overall coefficients of heat transfer are:

U_1= coefficient for insulating glass, i.e. Thermopane.

U_2= coefficient for glass block.

U_3= coefficient for single glazed windows and doors.

U_4= coefficient for exterior wall above grade.

U_5= coefficient for exterior wall below grade.

U_6= coefficient for special treatment of exterior walls, i.e. aluminum panels on Engineering Hall.

In the case of the older buildings on the campus there are no specifications available regarding wall and roof construction materials. The loss for Central building was determined and the heat loss per cubic foot was calculated. This value was used or adjusted where necessary in the determination of the other similar building losses.

The value of Btu per cubic foot for the frame buildings was obtained as an average of similar determinations for over 20 similarly constructed buildings.

The values of heated volume are from the 1949 Building Survey for South Dakota State College.

Coefficients of heat transfer and values of infiltration losses are based on data from the American Society of Heating and Ventilating Engineers Guide.

In the case of special purpose buildings, such as the Foundation Seed Stock building, the loss was taken as the installed radiation.

The design inside temperature was taken as 72 F° and design outside temperature as -28°F.

The enthalpy difference for heating purposes is 970 Btu per pound of steam.

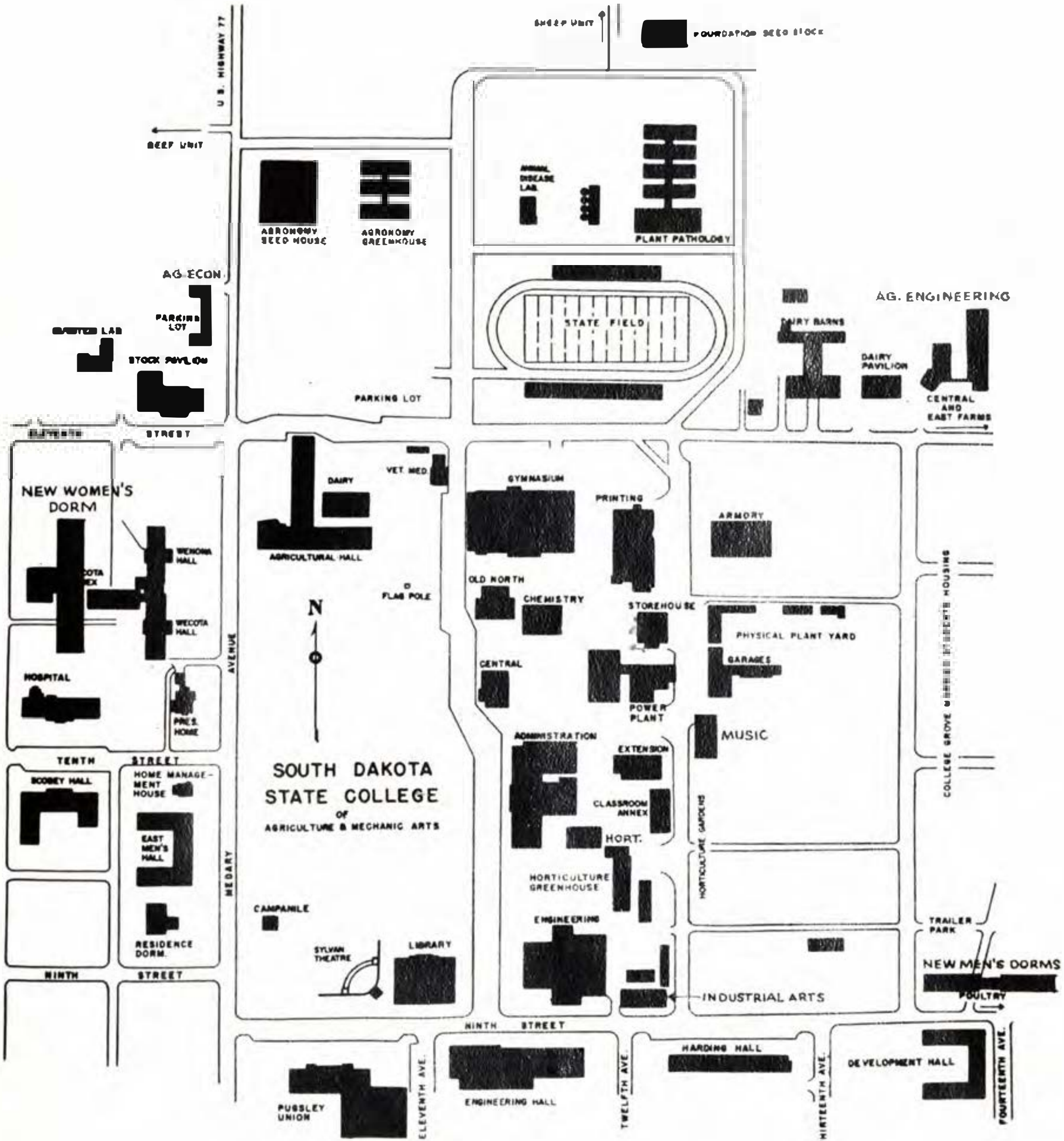

Figure 3. Campus Map

TABLE I. PRINTING AND RURAL JOURNALISM BUILDING HEAT LOSS

	Total exposed wall area sq.ft.	Glass	Net wall	Building heat losses		
		U_1= U_2= 0.56 U_3= 0.61 Δt= 100F	U_4= 0.24 U_5= U_6= Δt= 100F	Glass Btu/hr	Net wall Btu/hr	Infiltration Crack - ft Btu/hr/F/ft
North wall	2568		2060		49440	200
		83		4648		1.58
		185		11285		31600
South wall	2568		2055		49320	
		216		12096		
		337		20557		
East wall	4694		3500		84000	
		511		28616		
		683		41663		
West wall	4694		2730		65520	300
		1113		62328		1.58
		851		51911		47400
Floor	15632	U= 0.04	Δt= 20F	12506		
Ceiling	15632	U= 0.19	Δt= 100F	297008		
				Total loss	869,898	Btu/hr

TABLE II. ENGINEERING HALL HEAT LOSS

	Total exposed wall area sq.ft.	Glass	Net wall	Building heat losses		
		U_1= 1.13 U_2= U_3= 0.61 Δt= 100F	U_4= 0.35 U_5= 0.06 U_6= 0.19 Δt= 100F	Glass Btu/hr	Net wall Btu/hr	Infiltration Crack - ft Btu/hr/F/ft
North wall	11090	4162	4366	470306	152810	781
			690		4140	1.30
		208	1664	12688	31616	101530
South wall	11090	3370	7720	360810	270200	
East wall	3052	100	2088	11300	73080	
			864		5184	
West wall	3052		2400		84000	
			402		7638	
		250		15250		
Floor	22040	U= 0.04	Δt= 20F	17632		
Ceiling	22040	U= 0.12	Δt= 100F	264480		
				Total loss 1,902,664	Btu/hr	

TABLE III. AGRICULTURAL HALL HEAT LOSS

	Total exposed wall area sq.ft.	Glass	Net wall	Building heat losses		
		U_1= 1.13 U_2= 0.56 U_3= Δt= 100F	U_4= 0.33 U_5= U_6= Δt= 100F	Glass Btu/hr	Net wall Btu/hr	Infiltration Crack - ft Btu/hr/F/ft
North wall	7840	2702	5138	305326	169554	1510 1,94 292940
South wall	7840	3918	3922	442734	129426	
East wall	11638	5372 9	6257	607036 504	206481	
West wall	11638	4501 49	7088	508313 2744	233904	2680 1,94 519920
Floor	21273	U= 0.04	Δt= 20F	17018		
Ceiling	21273	U= 0.19	Δt= 100F	404187		
				Total loss 3,840,387 Btu/hr		

TABLE IV. HARDING HALL HEAT LOSS

	Total exposed wall area sq.ft.	Glass	Net wall	Building heat losses		
		U_1= 1.13 U2= U_3= 0.61 Δt= 100F	U_4= 0.33 U_5= U_6= Δt= 100F	Glass Btu/hr	Net wall Btu/hr	Infiltration Crack - ft Btu/hr/F/ft
North wall	8040	1489	6425	168257	212025	930
						1,30
		126		7686		120900
South wall	8040	1463	6577	165319	217041	
East wall	1410		1410		46530	
West wall	1410	21	1309	2373	43197	38
						1.30
		80		4880		4940
Floor	9112	U= 0.04	Δt= 20F	7290		
Ceiling	9112	U= 1.12	Δt= 100F	109344		

Total loss 1,109,800 Btu/hr

TABLE V. UNION AND UNION ADDITION BUILDING HEAT LOSS

	Total exposed wall area sq.ft.	Glass	Net wall	Building heat losses		
		U_1= 1.13 U_2= 0.56 U_3= Δt= 100F	U_4= 0.30 U_5= U_6= Δt= 100F	Glass Btu/hr	Net wall Btu/hr	Infiltration Crack - ft Btu/hr/F/ft
North wall	9375	1722	7503	194586	225090	1340
		150		8400		0.28
						37520
South wall	9375	1398	7977	157974	239310	
East wall	7105	1035	6070	116955	182100	
West wall	7105	849	6256	95937	187680	468
						0.28
						13104
Floor	23264	U= 0.04	Δt= 20F	18611		
Ceiling	23264	U= 0.12	Δt= 100F	279168		
				Total loss 1,756,435 Btu/hr		

TABLE VI. LIBRARY BUILDING

	Total exposed wall area sq.ft.	Glass	Net wall	Building heat losses		
		U_1= 1.13 U_2= U_3= Δt= 100F	U_4= 0.26 U_5= U_6= Δt= 100F	Glass Btu/hr	Net wall Btu/hr	Infiltration Crack - ft Btu/hr/F/ft
North wall	4666	1055	3611	119215	93886	518 1.94 100492
South wall	4666	1310	3356	148030	87256	
East wall	3780	752	3028	84976	78728	
West wall	3780	952	2808	107576	73008	310 1,94 60140
Floor	13552	U= 0.04	Δt= 20F	10842		
Ceiling	13552	U= 0.25	Δt= 100F	338800		
				Total loss	1,302,949	Btu/hr

TABLE VII. SCOBEY HALL HEAT LOSS

	Total exposed wall area sq.ft.	Glass	Net wall	Building heat losses		
		U_1= 1.13 U_2= 0.60 U_3= Δt= 100F	U_4= 0.33 U_5= U_6= Δt= 100F	Glass Btu/hr	Net wall Btu/hr	Infiltration Crack - ft Btu/hr/F/ft
North wall	5796	1195	4601	135035	151833	1079 0.28 30212
South wall	5796	390 74	5332	44070 4440	175956	
East wall	4354	465	3889	52545	128337	
West wall	4354	1390 74	2890	157070 4440	95370	996 0.28 27888
Floor	8887	U= 0.04	Δt= 20F	7110		
Ceiling	8887	U= 0.15	Δt= 100F	133305		
				Total loss 1,147,611 Btu/hr		

TABLE VIII. CHEMISTRY BUILDING HEAT LOSS

	Total exposed wall area sq.ft.	Glass	Net wall	Building heat losses		
		$U_1=$ 1.13 $U_2=$ $U_3=$ $\Delta t=$ 100F	$U_4=$ 0.27 $U_5=$ 0.06 $U_6=$ $\Delta t=$ 100F	Glass Btu/hr	Net wall Btu/hr	Infiltration Crack - ft Btu/hr/F/ft
North wall	4080	1413	1817 850	159669	49059 5100	300 1.94 58200
South wall	4080	967	2263 850	109271	61101 5100	
East wall	3072	815	1617 640	92095	43659 3840	
West wall	3072	234	2198 640	26442	59346 3840	100 1.94 19400
Floor	5440	U= 0.04	$\Delta t=$ 20F	4352		
Ceiling	5440	U= 0.19	$\Delta t=$ 100F	103360		
				Total loss	803,834	Btu/hr

TABLE IX. ROTC ARMORY BUILDING HEAT LOSS

	Total exposed wall area sq.ft.	Glass	Net wall	Building heat losses		
		$U_1 = 1.13$ $U_2 =$ $U_3 =$ $\Delta t = 100F$	$U_4 = 0.50$ $U_5 = 0.06$ $U_6 =$ $\Delta t = 100F$	Glass Btu/hr	Net wall Btu/hr	Infiltration Crack - ft Btu/hr/F/ft
North wall	4992	420	3804 768	47460	190200 4608	200 1.94 38800
South wall	4992	480	3744 768	54240	187200 4608	
East wall	3002	282	2286 434	31866	114300 2604	
West wall	3002	500	1712 790	56500	85600 4740	100 1.94 19400
Floor	10112	$U = 0.04$	$\Delta t = 20F$	8090		
Ceiling	10112	$U = 0.16$	$\Delta t = 100F$	161792		
				Total loss	1,012,008	Btu/hr

TABLE X. AGRONOMY SEED HOUSE HEAT LOSS

	Total exposed wall area sq.ft.	Glass	Net wall	Building heat losses		
		$U_1=$ 1.13 $U_2=$ 0.56 $U_3=$ $\Delta t=$ 100F	$U_4=$ 0.35 $U_5=$ $U_6=$ $\Delta t=$ 100F	Glass Btu/hr	Net wall Btu/hr	Infiltration Crack - ft Btu/hr/F/ft
North wall	1714	481	1212	54353	42420	100
		22		1232		1.94
						19400
South wall	1714	689	961	77857	33635	
		64		3584		
East wall	1464	464	1000	52532	35000	
West wall	1464	464	1000	52532	35000	100
						1.94
						19400
Floor	16860	U= 0.04	$\Delta t=$ 20F	13488		
Ceiling	16860	U= 0.19	$\Delta t=$ 100F	320340		
				Total loss	760,773	Btu/hr

TABLE XI. AGRONOMY HEADHOUSE HEAT LOSS

	Total exposed wall area sq.ft.	Glass	Net wall	Building heat losses		
		U_1= 1.13 U_2= U_3= Δt= 100F	U_4= 0.35 U_5= U_6= Δt= 100F	Glass Btu/hr	Net wall Btu/hr	Infiltration Crack - ft Btu/hr/F/ft
North wall	1302	324	978	36612	34230	110 1.94 21340
South wall	1302	314	988	35482	34580	
East wall	360		360		12600	
West wall	360	75	285	8475	9975	60 1.94 11640
Floor	3255	U= 0.04	Δt= 20F	2604		
Ceiling	3255	U= 0.19	Δt= 100F	61845		
				Total loss	269,383	Btu/hr

TABLE XII. AGRONOMY GREENHOUSE HEAT LOSS

	Total exposed wall area sq/ft	Glass	Net wall	Building heat losses		
		U_1= 1.13 U_2= U_3= Δt= 100F	U_4= 0.60 U_5= U_6= Δt= 100F	Glass Btu/hr	Net wall Btu/hr	Infiltration Crack - ft Btu/hr/F/ft
North wall	1520	912	608	103056	36480	440 1.94 85360
South wall	1520	912	608	103056	36480	
East wall	942	646	296	72998	17760	
West wall	942	646	296	72998	17760	
Floor	6878	U= 0.04	Δt= 20F	5502		
Ceiling	7958	U= 1.13	Δt= 100F	899,254		
				Total loss 1,450,704 Btu/hr		

TABLE XIII. PLANT PATHOLOGY BUILDING HEAT LOSS

	Total exposed wall area sq.ft.	Glass	Net wall	Building heat losses		
		U_1= 1.13 U_2= 0.56 U_3= Δt= 100F	U_4= 0.40 U_5= U_6= Δt= 100F	Glass Btu/hr	Net wall Btu/hr	Infiltration Crack - ft Btu/hr/F/ft
North wall	1450	440	1010	49720	40400	180 1.94 34920
South wall	1450	530 280	640	59890 15680	25600	
East wall	490	20	470	2260	18800	
West wall	490	20	470	2260	18800	
Floor	7250	U= 0.04	Δt= 20F	5800		
Ceiling	7250	U= 0.10	Δt= 100F	72500		
				Total loss	346,630	Btu/hr

TABLE XIV. PLANT PATHOLOGY GREENHOUSE HEAT LOSS

	Total exposed wall area sq.ft.	Glass	Net wall	Building heat losses		
		U_1= 1.13 U_2= U_3= Δt= 100F	U_4= 0.60 U_5= U_6= Δt= 100F	Glass Btu/hr	Net wall Btu/hr	Infiltration Crack - ft Btu/hr/F/ft
North wall	2160	1080	1080	122040	64800	684 1.94 132696
South wall	2160	1080	1080	122040	64800	
East wall	1318	818	500	92434	30000	
West wall	1318	818	500	92434	30000	
Floor	10182	U= 0.04	Δt= 20F	8146		
Ceiling	11458	U= 1.13	Δt= 100F	1294754		
				Total loss	2,054,144	Btu/hr

TABLE XV. PLANT PATHOLOGY HEADHOUSE HEAT LOSS

	Total exposed wall area sq.ft.	Glass	Net wall	Building heat losses		
		$U_1=$ 1.13 $U_2=$ 0.56 $U_3=$ $\Delta t=$ 100F	$U_4=$ 0.40 $U_5=$ $U_6=$ $\Delta t=$ 100F	Glass Btu/hr	Net wall Btu/hr	Infiltration Crack - ft Btu/hr/F/ft
North wall	1180	310	870	35030	34800	120 1.94 23280
South wall	1180	350	830	39550	33200	
East wall	300	162	138	18306	5520	
West wall	300		300		12000	
Floor	3540	$U=$ 0.04	$\Delta t=$ 20F	2832		
Ceiling	3540	$U=$ 0.10	$\Delta t=$ 100F	35400		
				Total loss	239,918	Btu/hr

TABLE XVI. CLASSROOM ANNEX BUILDING HEAT LOSS

	Total exposed wall area sq.ft.	Glass	Net wall	Building heat losses		
		$U_1=$ 1.13 $U_2=$ $U_3=$ $\Delta t=$ 100F	$U_4=$ 0.30 $U_5=$ $U_6=$ $\Delta t=$ 100F	Glass Btu/hr	Net wall Btu/hr	Infiltration Crack - ft Btu/hr/F/ft
North wall	504	63	441	7119	13230	20 1.94 3880
South wall	504	63	441	7119	13230	
East wall	1152	252	900	28476	27000	
West wall	1152	230	922	25990	27660	100 1.94 19400
Floor	4032	U= 0.04	$\Delta t=$ 20F	3226		
Ceiling	4032	U= 0.40	$\Delta t=$ 55F	88704		
				Total loss	265,034	Btu/hr

TABLE XVII. CENTRAL BUILDING HEAT LOSS

	Total exposed wall area sq.ft.	Glass	Net wall	Building heat losses		
		U_1= 1.13 U_2= U_3= Δt= 100F	U_4= 1.20 U_5= 0.06 U_6= Δt= 100F	Glass Btu/hr	Net wall Btu/hr	Infiltration Crack - ft Btu/hr/F/ft
North wall	3663	400	2936	45200	58720	458
			327		1962	1,24
						56792
South wall	3663	300	3036	33900	60720	
			327		1962	
East wall	4242	620	3244	70060	64880	
			378		2268	
West wall	4242	560	3304	63280	66080	442
			378		2268	1,24
						54808
Floor	4923	U= 0.04	Δt= 20F		3938	
Ceiling	4923	U= 0.29	Δt= 100F		142767	
				Total loss	729,605	Btu/hr

TABLE XVIII. STEAM REQUIRED FOR HEATING BUILDINGS

Building	Heated volume cu ft	Heat loss Btu/hr/cu ft	Total building load Btu/hr	Steam required #/hr
Printing and Rural Journalism	366,600	2.373	869,898	897
Engineering Hall	716,120	2.658	1,902,684	1,960
Agricultural Hall	908,734	4.225	3,840,387	3,920
Harding Hall	273,360	4.06	1,109,800	1,040
Union and Union Addition	989,602	1.763	1,753,435	1,810
Library	591,049	2.205	1,302,949	1,340
Scobey Hall	401,080	2.86	1,147,611	1,180
Chemistry	278,968	2.881	803,834	826
ROTC Armory	452,790	2.235	1,012,008	1,040
Agronomy Seed House	205,692	3.698	760,773	782
Agronomy Head House	39,060	6.896	269,383	277
Agronomy Green House	61,902	23.435	1,450,704	1,492
Plant Pathology	72,500	4.781	346,630	356

TABLE XVIII. (CONT'D) STEAM REQUIRED FOR HEATING BUILDINGS

Building	Heated volume cu ft	Heat loss Btu/hr/cu ft	Total building load Btu/hr	Steam required #/hr
Plant Pathology - Green House	76,000	26.335	2,054,144	2,110
Plant Pathology - Head House	35,400	6.777	239,918	247
Brookings Municipal Hospital	215,400	3.2	689,280	710
Central	260,000	2.8	729,605	750
Old North	247,153	2.8	692,028	710
Extension	173,822	2.8	486,702	500
Engineering	665,800	2.9	1,930,820	1,984
Entomology - Zoology	134,300	2.8	376,040	386
Dairy	88,090	2.8	246,652	254
Stock Pavilion	253,179	2.8	708,900	728
Wecota Hall	385,420	2.9	1,117,718	1,150
Wenona Hall	339,740	2.9	985,275	1,013
Wecota Annex	207,000	2.9	600,300	617

TABLE XVIII. (CONT'D) STEAM REQUIRED FOR HEATING BUILDINGS

Building	Heated volume cu ft	Heat loss Btu/hr/cu ft	Total building load Btu/hr	Steam required #/hr
Administration	1,043,643	2.8	2,922,200	3,000
Gymnasium	1,312,857	2.9	3,807,285	3,910
Veterinary Medicine	47,163	2.8	132,056	136
Dairy Pavilion	74,382	5.5	409,100	421
East Mens Hall	738,000	3.5	2,583,000	2,660
Storehouse	78,850	2.5	197,152	203
Maintenance Shops	35,000	5.5	192,500	197
Old Power Plant	54,000	5.5	297,000	414
Aviation Mechanics	70,222	5.5	386,221	397
Development Hall	93,536	4.0	374,144	384
Classroom Annex	48,160	5.5	265,034	272
President's Home	84,330	4.0	337,320	346
Home Management House	35,660	4.0	142,640	147

TABLE XVIII. (CONT'D) STEAM REQUIRED FOR HEATING BUILDINGS

Building	Heated volume cu ft	Heat loss Btu/hr/cu ft	Total building load Btu/hr	Steam required #/hr
Residence Dormitory	35,000	4.0	140,000	144
Horticulture	103,500	2.9	300,150	309
Nutrition Laboratory	12,800	5.0	64,000	66
Dairy Barn	20,000	5.0	100,000	103
Rabbit House	19,100	5.0	95,500	98
Foundation Seed Stocks *			322,560	331
Music Hall *			195,130	201
Animal Disease Laboratory	20,000	4.0	80,000	82
Horticulture Green House *			373,200	383
Grand totals			41,143,650	42,283

*Installed Radiation.

CHAPTER IV

PIPING LOSSES

In determining the piping heat losses, only the campus distributing mains were calculated. The losses due to individual building mains, risers, runouts, and returns do not need to be determined as they contribute to the building load, which has been determined.

The steam lines are insulated with 1½" of 85% magnesia insulation. The pressure carried in the high pressure lines is 80 pounds per square inch gage (psig) and the pressure in the low pressure lines is 5 psig. The steam temperature is 324 F and the temperature at the surface of the insulation is 90 F for the high pressure lines and 228 F inside and 75 F outside for the low pressure lines.

Equation (7) is used to determine the piping losses. The results are tabulated in Tables XVIV and XX where

$k = 0.5$ (Btu) (in) per (hr) (F) (sq ft).

$(t_1 - t_o) = 234$ F for the high pressure lines.

$(t_1 - t_o) = 153$ F for the low pressure lines.

The change in enthalpy for steam condensing in the high pressure lines is 890 Btu/# and the change for the low pressure lines is 990 Btu/#.

Figure 4 is a map showing the campus steam distribution system.

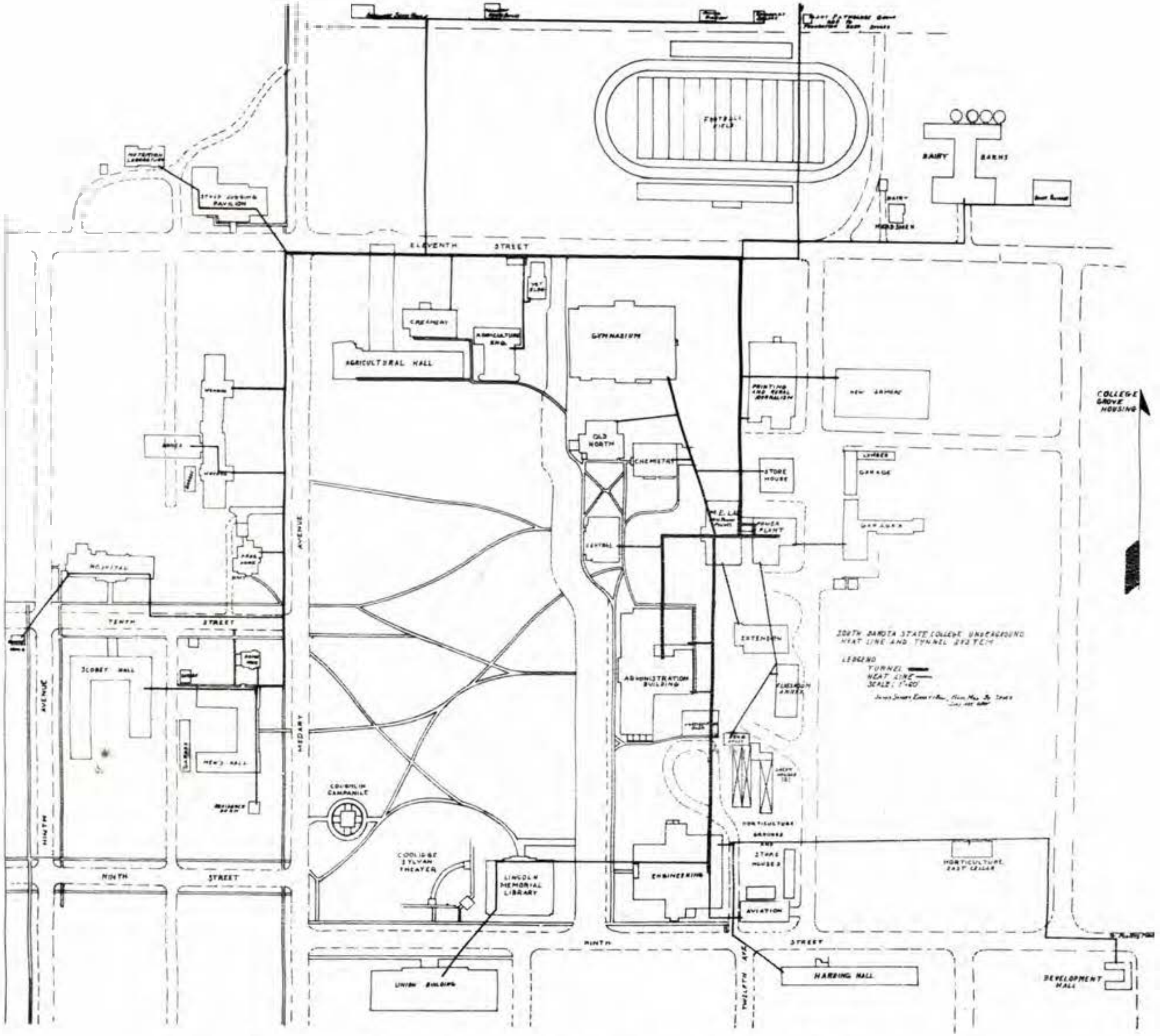

Figure 4. Campus Distribution Piping

TABLE XVIV. HIGH PRESSURE PIPING HEAT LOSS

Pipe diameter inches	Pipe length feet	Heat loss Btu/hr	Steam required #/hr
1½	330	21,294	24
2½	600	96,870	109
3	585	58,534	67
4	3,320	390,780	440
6	870	142,506	160

The total steam required to account for the high pressure piping heat loss shown in Table XVIV is 800 pounds per hour. This value will, of course, vary with the steam tunnel temperature.

TABLE XX. LOW PRESSURE PIPING HEAT LOSS

Pipe diameter inches	Pipe length feet	Heat loss Btu/hr	Steam required #/hr
2	665	32,660	33
2½	720	40,980	41
3	860	55,527	56
4	205	16,450	17
5	2,315	215,458	207
6	1,275	136,553	138
8	1,192	159,120	161
10	882	143,055	144
14	2,050	427,788	430
18	150	38,877	39

The total steam required to account for the low pressure piping heat loss shown in Table XX is 1,266 pounds per hour. The total amount of steam required for heating the campus buildings and to account for piping loss is 44,349 pounds per hour at the design conditions.

CHAPTER V

COST OF GENERATING STEAM AND ELECTRIC POWER

A series of tests were conducted to determine the cost of generating steam, under various loads, by burning natural gas. Due to the fact that the power plant was undergoing changes in the coal handling equipment, only one test was run using coal. The plant was generating part of the college power requirements on the first test and purchasing the remainder from the Bureau of Reclamation. On the remaining tests all of the required power was purchased.

The heating unit of natural gas, as used by the gas company for billing purposes, is the therm which is 100,000 Btu. The gas is metered in cubic feet and the heating value is taken as 1000 Btu/cu ft. The cost of natural gas is $425.00 for the first 10,000 therms and $0.03 for each additional therm.

The heating value of natural gas was checked by use of a constant pressure gas calorimeter and found to be 987 Btu/cu ft. The heating value of the coal burned was reported by the supplier to be 11,790 Btu/#. This value was checked by use of an oxygen bomb calorimeter and was found to be 11,694 Btu/#.

Data recorded consisted of the following information:

1. Amount of fuel burned.
2. Amount of steam generated.

3. Steam pressure and condition.
4. Feedwater temperature.
5. Orsat analysis.
6. Flue gas and air temperatures.
7. Turbine steam consumption.
8. Turbine inlet and exhaust pressures.
9. Generator output.

The coal was purchased under two separate contracts as follows:

	Contract #11421	Contract #11423
	Indiana Screenings	Kentucky #9
Heating value - Btu/#	11,790.0	12,200.0
Moisture - %	10.0	8.97
Sulphur - %	3.1	2.92
Ash - %	6.8	7.1
Volatile matter - %	39.40	38.58
Fixed carbon - %	43.8	45.35
Fusion point - F	2,100.0	2,120.0
Cost per ton - $	3.75	3.90
Freight per ton - $	5.85	6.13
Total delivered cost per ton - $	9.60	10.03

TABLE XXI. TEST DATA - #4 BOILER BURNING NATURAL GAS

Test number	1	2	3	4	5	6
Duration - hrs	360.5	25.2	26	25	24	30.75
Fuel input - cu ft/hr	38,300	32,200	24,800	15,380	11,660	9,268
Steam generated - #/hr	31,122	26,800	18,702	12,600	7,970	6,179
Steam pressure - psig	130	130	130	135	117	138
Feedwater temperature - F	210	208	204	214	196	187
Flue gas temperature - F	510	500	490	460	410	409
Air temperature - F	70	75	75	75	75	75
Average outside temperature - F	22	39.2	43.8	59.6	60.7	62
Turbine input - #/hr	18,578					
Inlet pressure - psig	130					
Exhaust pressure - psig	19					
Generator output - kw hrs	445.4					

TABLE XXII. TEST RESULTS - #4 BOILER BURNING NATURAL GAS

Test number	1	2	3	4	5	6
Input-Btu/hr 1000	36,984	32,200	24,800	15,380	11,660	9,268
Output-Btu/hr 1000	31,588.8	27,202	18,980	12,500	8,193.2	6,413.8
Boiler efficiency-%	85.2	84.5	76.4	81.3	70.2	69.2
Cost per therm-¢	3.05	3.06	3.08	3.12	3.16	3.19
Cost per 1000# of steam-¢	36.2	36.6	40.8	38.1	46.1	46.5
Turbine input-Btu/hr 1000	2,793					
Generator output-Btu/hr 1000	1,542					
Turbo-gen. efficiency-%	55.3					
Cost of generating power (No heating load - ¢/kw hr)	1.56					
Power, a by-product of heating load-¢/kw-hr	0.191					

TABLE XXIII. COST OF GENERATING STEAM WITH COAL

Coal burned - #/hr	1,260
Steam generated - #/hr	10,600
Steam pressure - psig	130
Steam quality - %	100
Feed water temperature - F	211
Enthalpy of steam leaving - Btu/#	1,194
Enthalpy of entering feedwater - Btu/#	179
Enthalpy difference - Btu/#	1,015
Heating value of coal - Btu/#	11,700
Heat input - Btu/hr	14,976,000
Heat absorbed - Btu/hr	10,759,000
Boiler efficiency - %	72
Coal cost - $/ton	9.60
Cost per 1000# of steam generated - $	0.58

The cost of generating steam by burning natural gas, from Table XXII, varies from 36.2 cents per 1000 pounds of steam to 46.5 cents per 1000 pounds of steam depending on the boiler load. The cost of generating steam by burning coal, from Table XXIII, is 58 cents per 1000 pounds of steam. This figure is based on fuel costs only and does not include hauling expenses from the railroad yard to the college, stockpiling, hauling the ash out, labor or depreciation of equipment.

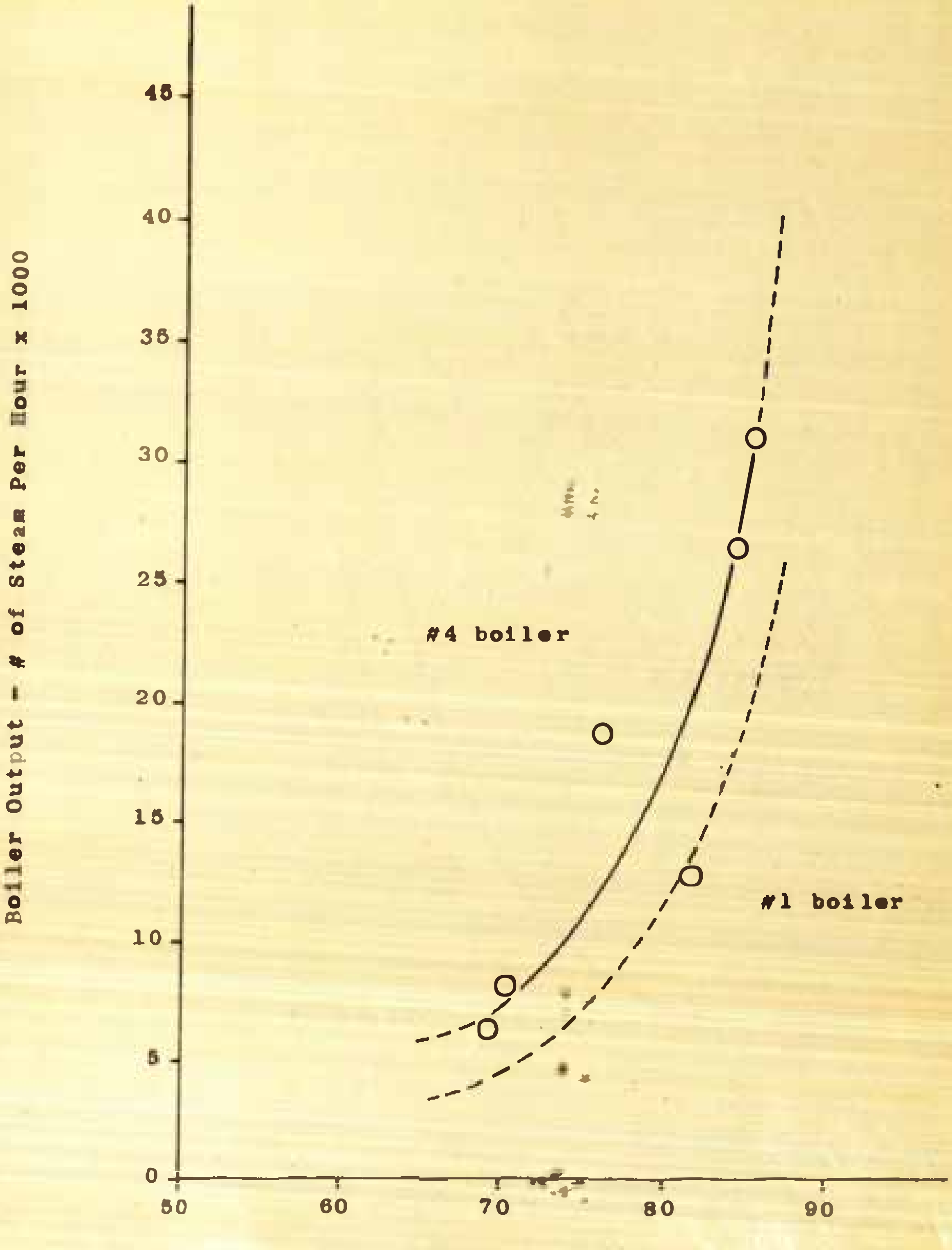

Figure 5. Boiler Efficiency vs Output

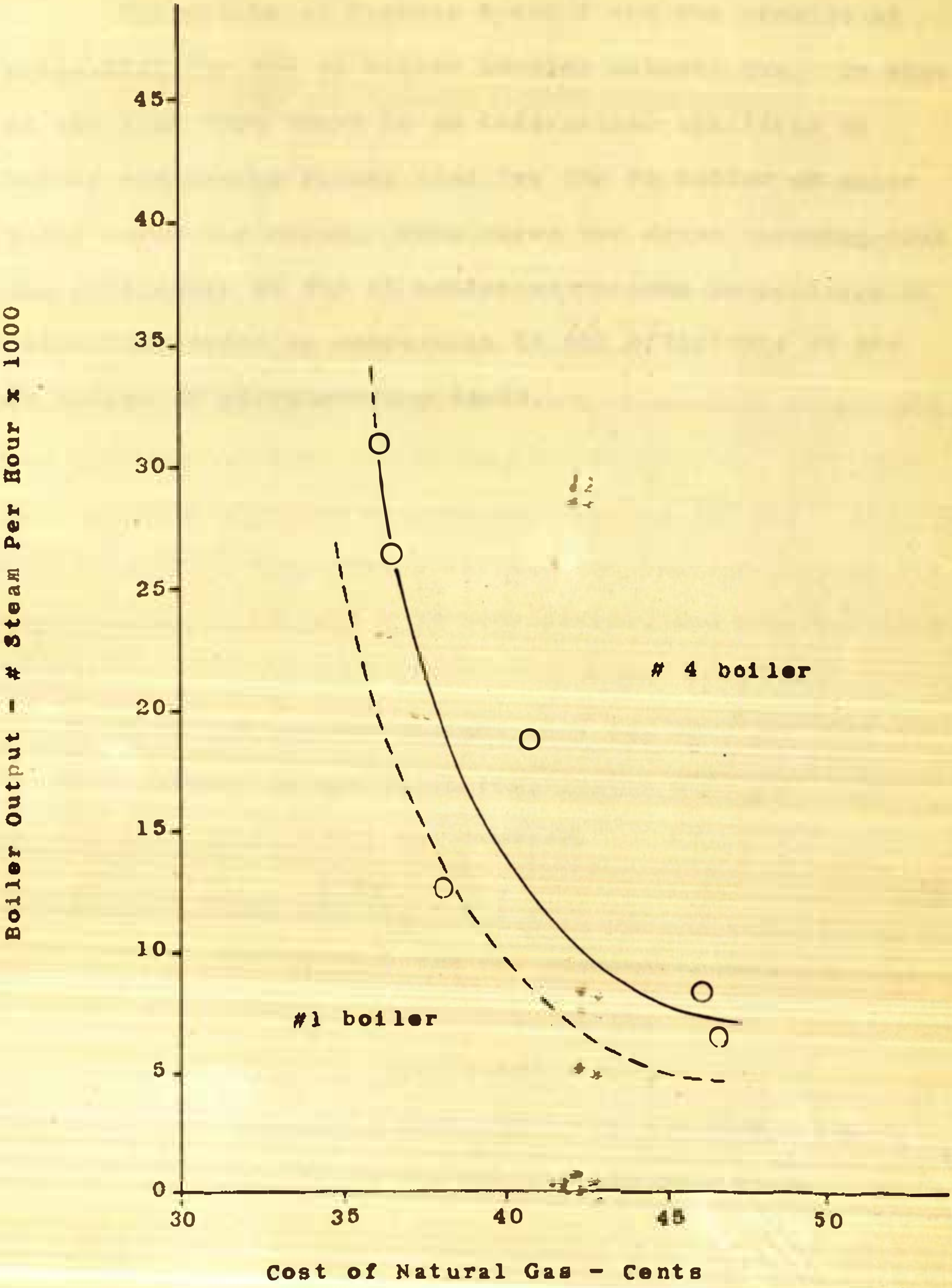

Figure 6. Cost of Generating Steam vs Output

The graphs of Figures 5 and 6 are the results of Table XXII for the #4 boiler burning natural gas. In view of the fact that there is no information available on boiler efficiency versus load for the #1 boiler an estimated curve was drawn. This curve was drawn assuming that the efficiency of the #1 boiler at various percentages of rated load might be comparable to the efficiency of the #4 boiler at corresponding loads.

CHAPTER VI

ANNUAL COST OF HEATING CAMPUS BUILDINGS

The fuel costs for seasonal heating requirements should not be calculated directly on the basis of the minimum outside design temperature, as this temperature exists, in general, for reasonably short periods of time. The most practical method of estimating heating-fuel consumption over a period of time is the degree-day method.[2] For any one day there exist as many degree-days as there are degrees F difference in temperature between the average outside air temperature, taken over a 24-hour period, and a temperature of 65 F.

Since the maximum heating load has been calculated, it is convenient to use it in conjunction with the degree-day for estimating total consumption.

$$C = \frac{24cQD}{1{,}000{,}000\ (t_i - t_o)} \qquad (8)$$

where C = cost of fuel for the heating season.

c = cost per million Btu output.

Q = Btu/hr for the design day.

$(t_i - t_o)$ = temperature difference for the design day.

D = degree-days for the heating season.

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[2] W. H. Carrier, R. E. Cherne and W. A. Grant, <u>Modern Air Conditioning, Heating and Ventilating,</u> p. 81, Pitman Publishing Company: New York, 1950.

The number of degree-days vary greatly from place to place and for a given locality should be based on averages for several years. The average value for this area is 8200[3] degree-days per year.

c for natural gas = $0.37

c for coal = $0.58

Q from Table XVIII = 41,143,650 Btu/hr.

$(t_i - t_o)$ = 100 F

Substitution of these values in equation (8) yields, for natural gas, $29,957 and for coal, $46,960 per heating season.

The annual heating season is generally considered to be from October 1st to May 1st, 212 days, 5088 hours. The expense during the heating season for piping losses would be 2066 x 5088 x 0.37 ÷ 1000 = $3890 for natural gas and $6100 for coal.

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[3] B. H. Jennings and S. R. Lewis, Air Conditioning and Refrigeration. International Textbook Company: Scranton, Pennsylvania, 1957.

TABLE XXIV. CHANGE IN STEAM CONSUMPTION FOR BUILDING HEATING PURPOSES WITH CHANGE IN OUTSIDE TEMPERATURE

Outside temp. °F	Inside temp. °F	# steam per hour
-30	72	43,028
-28	72	42,283
-20	72	38,900
-10	72	34,772
0	72	30,644
10	72	26,516
20	72	22,388
30	72	18,260
40	72	14,132
50	72	10,004
60	72	5,876

Figure 7 shows how the steam consumption for building heating purposes increases with decrease in outside temperature. The curve of total load is the average steam consumption recorded for each of the six tests on natural gas at the average outside temperature for the test periods.

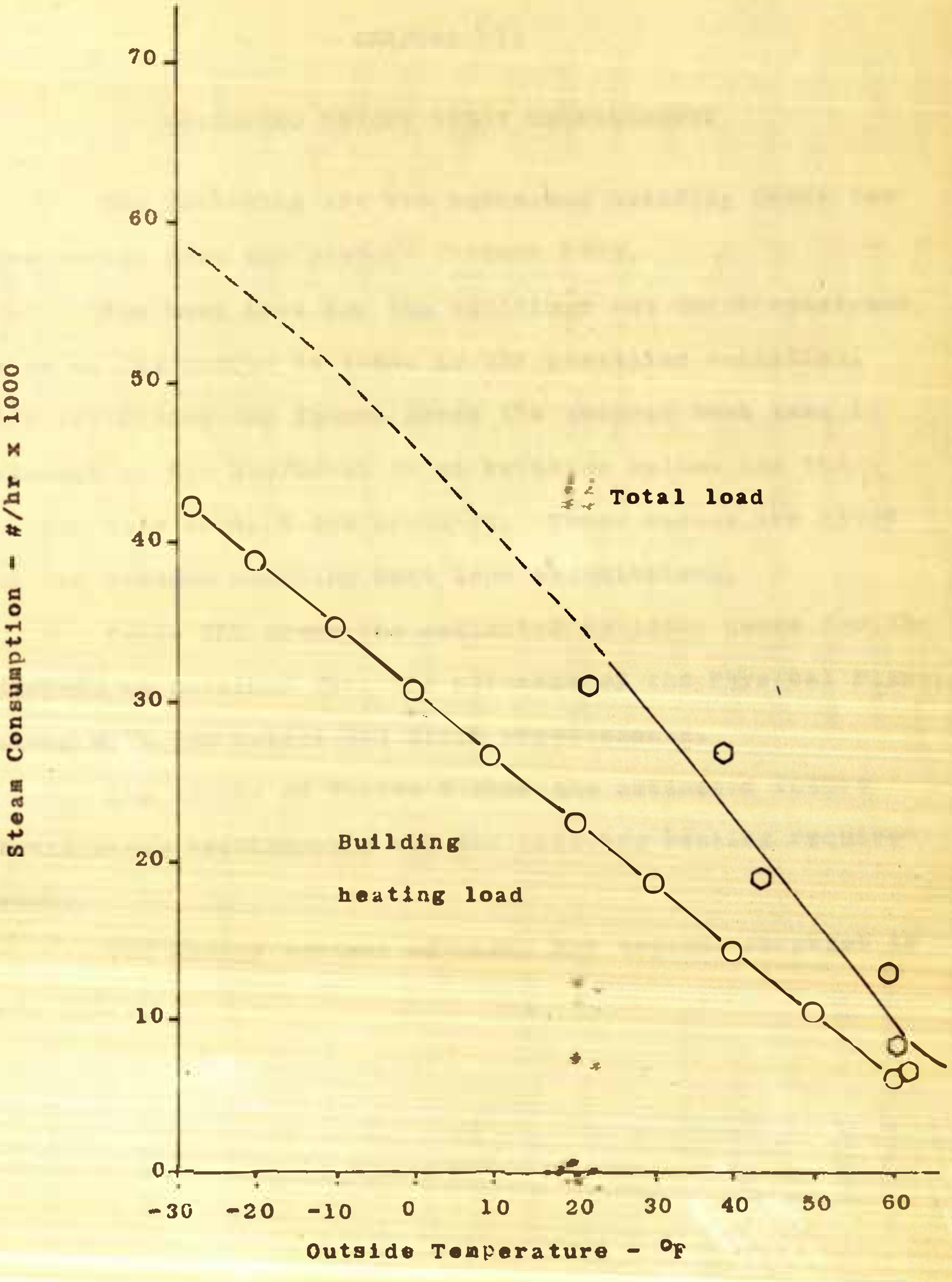

Figure 7. Steam Consumption vs Outside Temperature

CHAPTER VII

ESTIMATED FUTURE STEAM REQUIREMENTS

The following are the estimated building needs for the period from the present through 1970.

The heat loss for the buildings now under construction on the campus is taken as the installed radiation. For estimating the future needs the average heat loss is assumed as 3.2 Btu/hr-cu ft of building volume and the piping loss as 0.15 Btu/hr-cu ft. These values are based on the present building heat loss calculations.

Table XXV shows the estimated building needs for the period, as obtained from the Director of the Physical Plant, along with the calculated steam requirements.

The curves of Figure 8 show the estimated future total steam requirements and the building heating requirements.

The energy content of steam for heating purposes is 970 Btu/#.

TABLE XXV. ESTIMATED FUTURE STEAM REQUIREMENTS FOR HEATING BUILDINGS

Year	Building	Heated volume cu ft	Heat loss Btu/hr	Building steam #/hr	Total steam required #/hr
1958					44,349
1959	Agricultural Engineering		2,020,320	2,083	46,432
	Men's Dormitory		2,035,900	2,100	48,532
	Women's Dormitory		1,533,500	1,582	50,114
1960	Dairy Building	556,000	1,862,600	1,922	52,036
	Science Hall	695,000	2,328,300	2,400	54,436
1961	Field House	2,500,000	8,378,000	8,640	63,076
1962	Wing on Agricultural Hall	200,000	670,000	691	63,767
1963	Horticulture Classroom	150,000	502,500	518	64,285
1964	Poultry	140,000	469,000	484	64,768
1965	Home Economics	660,000	2,211,000	2,280	67,049
1966	Auditorium	400,000	1,340,000	1,380	68,429
1967	Veterinary	150,000	502,500	518	68,947
1968	Livestock Arena	400,000	1,340,000	1,380	70,327
1969	Entomology-Zoology	300,000	1,005,000	1,036	71,363
1970	Agronomy	400,000	1,340,000	1,380	72,743

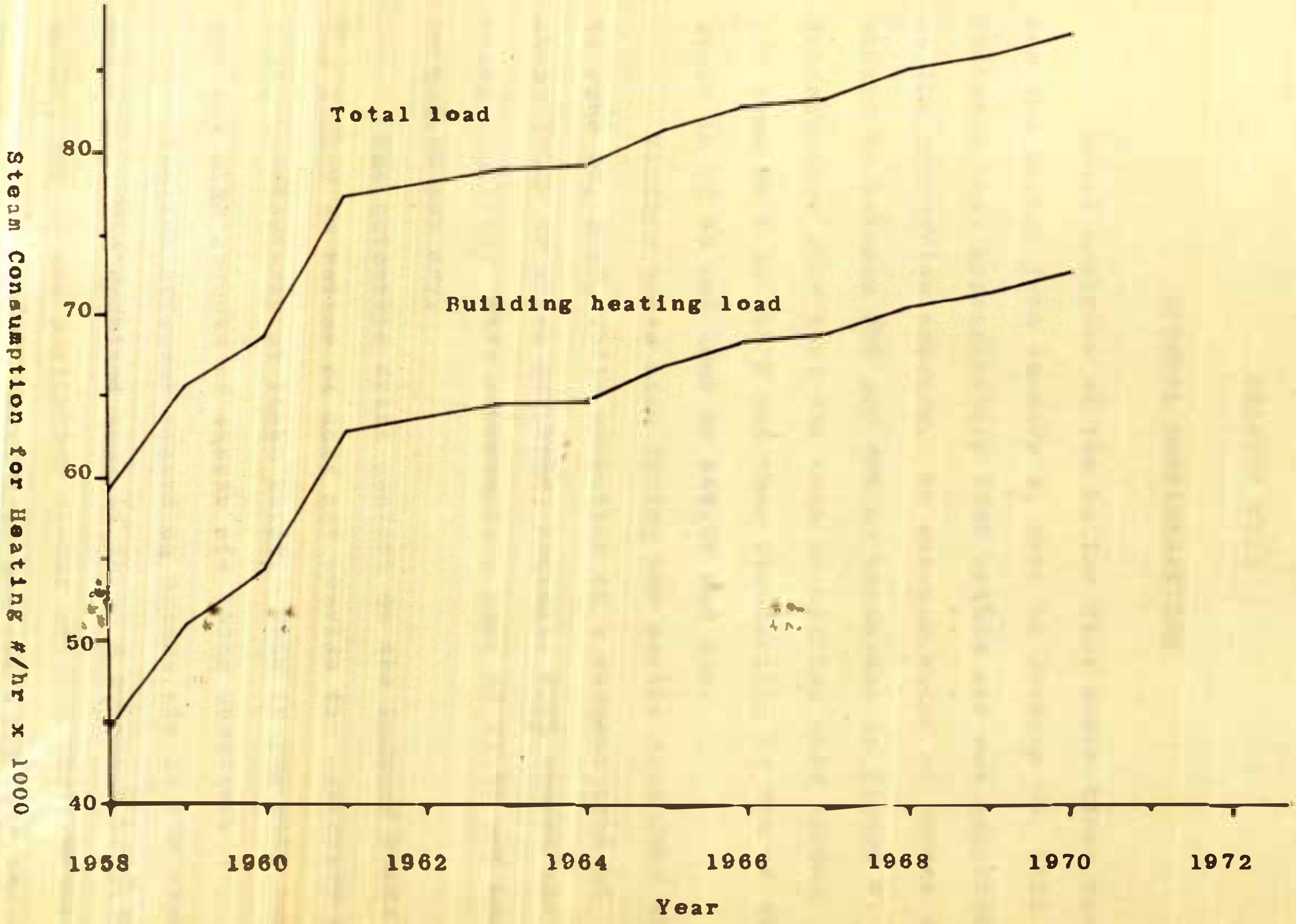

Figure 8. Estimated Future Steam Consumption

CHAPTER VIII

SPECIAL CONSIDERATIONS

Orsat analysis of the boiler flue gases taken during the period from January 1, 1958 to January 29, 1958 indicate that approximately 164% excess air was supplied to the combustion process. An average value of excess air should be between 30% and 40% as indicated in Figure 9. Calculations show that the cost of heating this excess air from 80 F to 510 F and then discharging it out of the stack is $2.05 per hour or $49.20 per day.

Similar tests made during the period from June 19 to June 20, 1958, while operating at a reduced load of about 7900# of steam per hour, indicate 600% excess air being supplied. This represents a loss of $1.71 per hour or $41.10 per day.

The automatic draft control on the induced draft fan damper on boiler #4 does not provide the necessary control, particularly at light loads. This is the main reason for the high amounts of excess air being supplied.

Another offender regarding excess air is the stoker openings. The combined area of these 4 openings is 1.65 sq ft, and at one particular damper setting the average velocity of air through these openings was 1400 feet per minute. This resulted in 10,420# of excess air entering into the combustion process per hour.

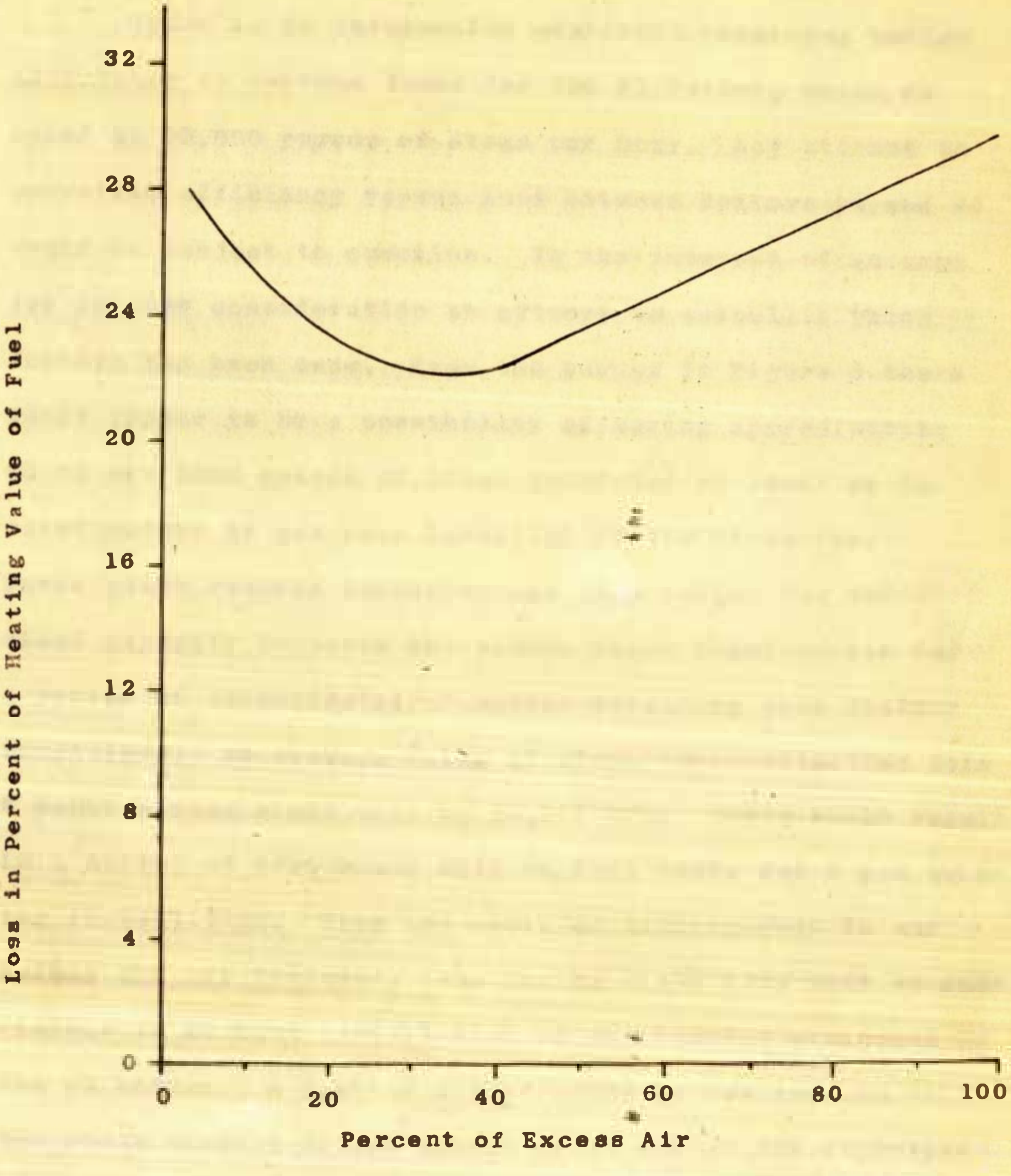

Figure 9.[4] Effect of Excess Air Upon Total Boiler Losses

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[4] H. L. Solberg, O. C. Cromer, A. R. Spaulding, Elementary Heat Power, John Wiley and Sons: New York, 1952.

There is no information available regarding boiler efficiency at various loads for the #1 boiler, which is rated at 25,000 pounds of steam per hour. Any attempt to correlate efficiency versus load between boilers #1 and #4 would be subject to question. In the interest of an area for further consideration an attempt to correlate these factors has been made. From the curves in Figure 5 there would appear to be a possibility of saving approximately $0.02 per 1000 pounds of steam generated at loads up to rated output if gas were installed in the #1 boiler. Power plant records indicate that this boiler has sufficient capacity to serve the campus steam requirements for a period of approximately 5 months depending upon weather conditions. An average value of steam consumption for this 5 month period might well be 10,000 #/hr. This could result in a saving of $720 based only on fuel costs for a gas burning installation. When the costs of hauling coal in and refuse out are included, the saving might very well be sufficient to warrant installation of gas burning equipment in the #1 boiler. A further saving could be realized in that the steam turbine driven forced draft fan on the #1 boiler would not have to be operated with gas burning equipment, with a corresponding saving of about 1000# of steam per hour.

Another interesting consideration is in regard to the heat loss in Agricultural Hall. Based on the design conditions there is a heat loss through the glass area of 1,866,957 Btu/hr and by infiltration 812,860 Btu/hr for a total loss of 2,679,817 Btu/hr. Calculated on a degree-day basis this would require 5,020,000# steam per heating season. If insulating glass and weatherstripping had been provided initially, this loss could have been cut almost in half. At current natural gas costs this would have resulted in a saving of about $930 per year. A further advantage would be the decrease in heat gain through the summer months, which could increase personnel efficiency. A current estimate on an aluminum type permanent awning for the south and west sides of Agricultural Hall is $35,000. Insulating glass would not provide equal benefits during the summer months as would an awning, but it may have been adequate.

The annual fuel expense previously mentioned of $180,000 was entirely for coal. The calculated expense of heating buildings and piping losses is $53,060, using the figures for coal. In addition during the summer months the high pressure lines are used to supply steam for building hot water heaters, hospital use and food service equipment. The expense of piping losses for the period from May 1st to October 1st would approach $1,700.

Figures[5] indicate that the steam requirements for heating hot water during the heating season are 0.41 # of steam per 1000 cu ft of heated space per degree-day for office buildings. This value should perhaps be adjusted for the campus buildings, but this value will be used in lieu of any other data. The total building volume is approximately 12,000,000 cu ft and the fuel cost would amount to $23,400.

Assuming an annual average value of 100% excess air, Figure 9 indicates that approximately 30% of the heating value of the fuel, or $45,000, is a loss in the boiler process.

The sum of these annual losses is $123,160. The following areas might quite possibly account for the remaining $27,000.

1. Conversion of a portion of the heat energy supplied to the turbo-generator into electrical energy.
2. Heating hot water during the summer months.
3. Hospital requirements for the year, other than heating.
4. Food service equipment requirements.
5. Snow and ice melting facilities.
6. Gymnasium laundry equipment.

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[5] Jennings and Lewis, op. cit., p. 149.

7. Leaks and unaccountable losses.

The breakdown of the annual fuel bill is an estimate, but it does indicate the various areas involved. It is quite apparent that savings in some of the areas would be very small at best, while in others the saving might be substantial.

CHAPTER IX

CONCLUSIONS

The foregoing investigation results in definite conclusions regarding fuel cost comparisons in this steam generating plant. In view of the fact that the annual fuel expense of this power plant approaches $150,000, an increase in efficiency of even 1% would result in substantial savings.

The calculated maximum steam consumption (for the current campus buildings) of 44,349# of steam per hour appears reasonable. This would indicate that the calculated values of building heat losses and distribution piping losses of 3.2 and 0.15 Btu per hour per cubic foot of heated building volume respectively can be used for estimating steam requirements as future buildings are added.

The foregoing results indicate that natural gas is a more economical fuel to use, particularly so when coal handling expenses are considered. There is no question as to gas being a cleaner more convenient fuel to use.

A series of tests of boiler efficiency and costs of burning coal with a high degree of accuracy was not possible. This was due to the fact that in the new coal handling installation there are no facilities for weighing the coal burned or ash removed. The accuracy of the one test conducted with the combustion of coal is therefore subject to question even though it was conducted in the best possible manner. It would seem that installation of fuel and ash weighing equipment would be very desirable and that the testing program be continued.

The cost of buying electrical energy from the Bureau of Reclamation is approximately 3.5 mills per killowatt-hour. The cost of producing electrical energy in this plant was determined as 1.91 mills per kilowatt-hour. This figure does not include depreciation of the turbo-generator unit. It should be noted that the turbine converts a comparitively small percentage of the heat energy supplied it into electrical energy so the above figure is valid only when all of the turbine exhaust steam can be utilized for heating purposes. When there is no heating load the cost of producing electrical energy goes up to 1.51 cents per kilowatt-hour. These figures indicate that the turbo-generator unit should be operated at a reasonable percentage of its rated capacity during the heating season and shut down for the remainder of the year.

From the calculated boiler losses and the expense of heating excess combustion air of up to $2.11 per hour some improvements are indicated. The basic problem appears to be the damper setting on the induced draft fan on the #4 boiler.

The automatic draft control will not adjust air requirements to load changes. If the steam load were to remain constant, the damper could be adjusted manually and the result would be satisfactory. Because the load is not constant for any great period of time, and the damper adjustment is located about 40 feet above the operating floor, accessable only by climbing a steel ladder, the draft control is not adjusted as load changes for optimum conditions. Part of the problem then appears to be malfunctioning of the automatic draft control at changing loads and the other part a manual adjustment of the draft control linkage each time a change of fuel is made. Changing the adjustment with changes of fuel is necessary because of the differing fuel compositions and correspondingly different air-fuel ratios for optimum combustion.

Any malfunctioning of the automatic control equipment is, in general, beyond the scope of the operating personnel while manual adjustments are not. But in order for proper manual adjustments to be made, they have to be based on flue gas analysis. The hand operated Orsat equipment would give the required analysis, but it is not the most convenient to use and depends upon the skill of the operator, and frequent change of the chemical solutions.

A much more satisfactory device is an electronic device that indicates and records carbon dioxide or oxygen. Current prices of these two devices are $1785 for the carbon dioxide recorder and $2283 for the oxygen recorder. Either of these instruments can be cross-connected to at least two boilers. Of the two devices the oxygen recorder would prove the more desirable as indicated by reference to Figures 10 and 11.

For example; assuming 10% CO_2 in the products of combustion, we see, by reference to Figure 10, that the percent of excess air varies from about 10% for natural gas to about 120% for coke. This indicates that to correctly interpret the results a knowledge of the carbon content of the fuel is necessary.

Now, referring to Figure 11, with a representative value of 6% O_2, we see that the range of excess air based on the same range of fuels varies from about 36% for natural gas to about 50% for coke. This indicates that as a change from one fuel to another is made the amount of oxygen present in the products of combustion will remain essentially constant for good combustion practices. The O_2 recorder is thus a much more convenient instrument for operating personnel to use.

It should be noted that neither recorder is an end in itself; and, if the results are not utilized by properly adjusting the boiler controls, then the original investment represents a waste of money.

In the case of this power plant indications are that

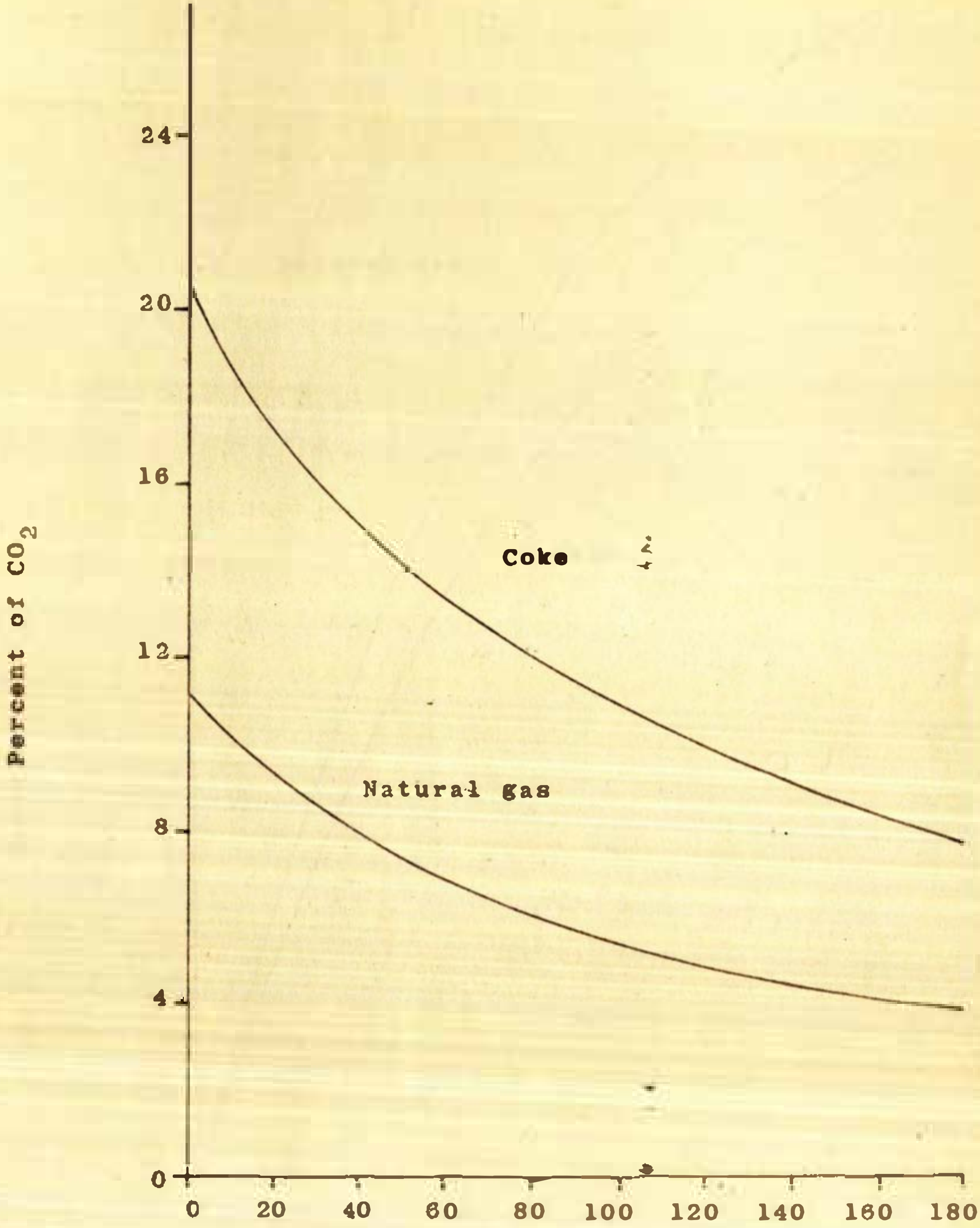

Figure 10.[6] Relation Between Excess Air and CO_2 and Representative Fuels

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[6] Solberg, Cromer, Spaulding, *op. cit.*, p. 103.

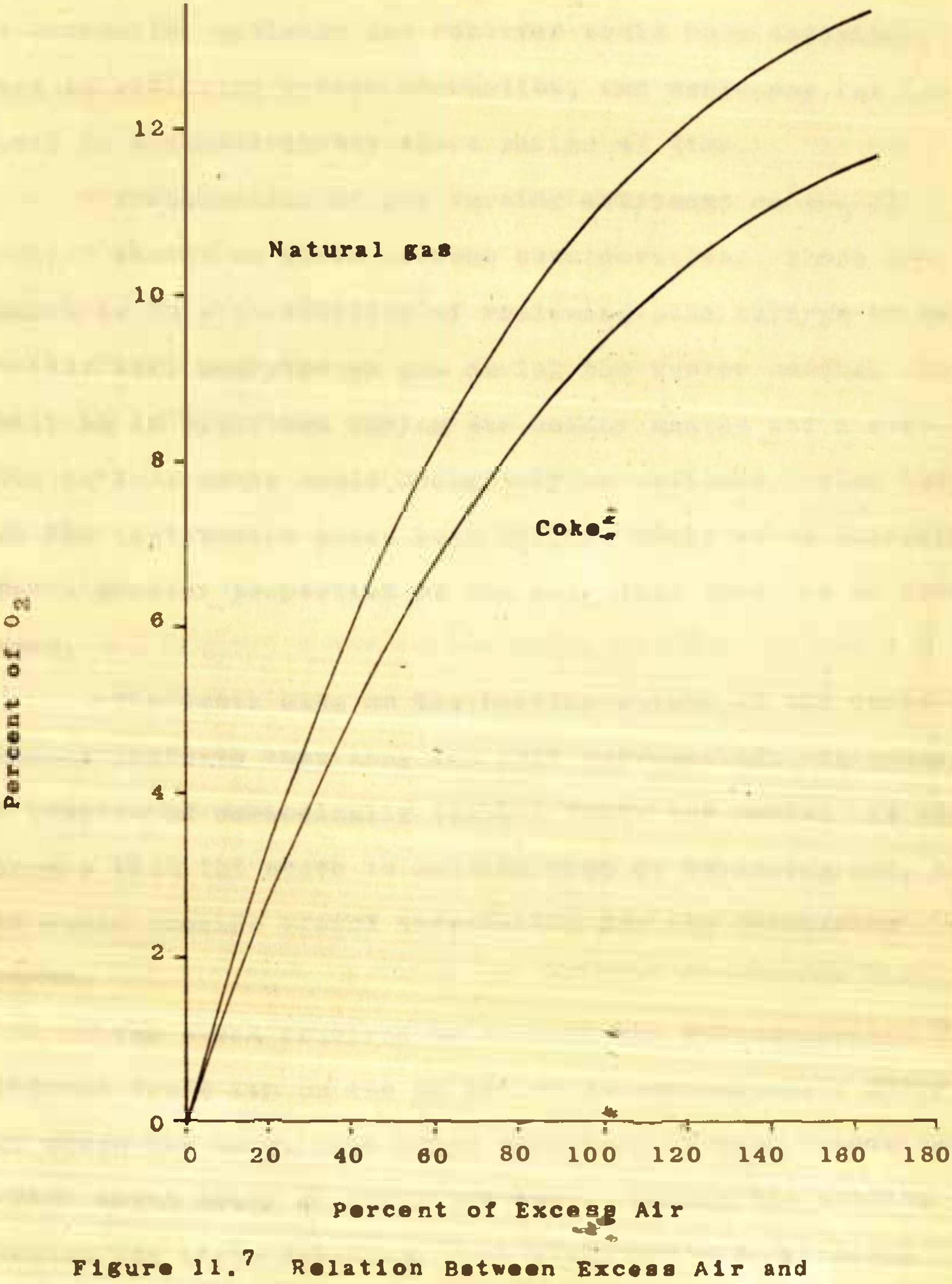

Figure 11.[7] Relation Between Excess Air and O_2 for Representative Fuels

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[7] Solberg, Cromer, Spaulding, *op. cit.*, 104.

a combustion analyzer and recorder would be a definite aid in obtaining proper combustion, and could pay for itself in a comparatively short period of time.

Installation of gas burning equipment on the #1 boiler should be given serious consideration. There appears to be a possibility of realizing some savings if this boiler were operated on gas during the summer months. It will be in operation during the colder months and a saving in fuel costs would definitely be realized. Then too, as the institution grows both boilers would be in operation for a greater proportion of the year than they are at present.

The tests made on the heating values of the fuels burned indicate that they are well represented. In general, a program of periodically testing fuels has merit. It would insure that the state is getting what it is paying for, and it could provide useful information for the purchasing agent.

The steam required to operate the turbine driven induced draft fan on the #1 boiler is approximately 2000# of steam per hour. The other auxiliary turbine drives require about 1000# of steam per hour. During the heating season the steam exhausted from these units is utilized in the low pressure heating system. If the #1 boiler were to be used during the summer months, the induced draft fan would have to be in operation and consideration might be given to a more economical drive for this unit.

The existing boiler capacity is adequate for the present college requirements, provided the #4 boiler does not break down. Should the large boiler be shut down for repairs during a period of very cold weather the remaining units would have to operate at rated capacity to supply the necessary steam. If this situation should occur after the three buildings now under construction are put in use, the chances are very good that sufficient steam could not be supplied.

At present a new boiler rated at about 60,000 # of steam per hour is in the planning stage and it would probably be about 2 years, after funds were appropriated, before such a unit could be in operation.

The results of this investigation indicate that there are various areas in connection with the steam generating, distribution, heating and related facilities that warrant further consideration. Probably a long range program should be organized and set up to investigate and correlate the entire system. There appear to be certain areas where reasonably substantial savings could be made. Increased instrumentation would provide additional information as deemed necessary. From the annual expenditures, including maintenance costs, it would appear very desirable to give serious consideration to the full time employment of a qualified engineer.

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