RADIATION LOSS IN STEAM DISTRIBUTION SYSTEM

A THESIS

SUBMITTED BY

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For

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TABLE OF CONTENTS

PREFACE

This thesis is divided into three parts:- (1) Radiation loss in the two main pipe lines on the University Campus; (2) Construction of Iso-Temperature curves, showing the temperature distribution around the conduit carrying the steam main; and, (3) Determination of the total heating load supplied from the present heating plant.

This subject was chosen for a thesis because comparatively little is known about the subject. Each individual installation is at best only an experiment. Also, the fact that no previous tests have been made on these two pipe lines, was a chief influence in selecting the subject. It was thought that the construction of Iso-Temperature curves, showing the temperature distribution around the pipe line, would be very interesting, as no such data is at present available.

At this time we wish to express our indebtedness to W. R. Woolrich, Proffessor of Mechanical Engineering at the University of Tennessee, and Leo Holdredge, Instructor of Mechanical Engineering at the University of Tennessee, for their valuable assistance. It is hoped that the information obtained in this thesis can be of use to Mr. Holdredge in his lectures on "Heating and Ventilating".

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May 25, 1927

CHAPTER I

RADIATION LOSS IN THE STEAM DISTRIBUTION SYSTEM OF THE UNIVERSITY OF TENNESSEE

1. GENERAL SURVEY. A short time ago the authorities of the University of Tennessee, desiring to heat all the buildings on the campus as economically as possible, decided to replace the several small low-pressure heating plants with one large central heating plant.

In preparing plans and specifications for an underground system of insulation, the McColl system was decided upon. In this system 85% Magnesia is used, and is placed on the pipe in sections. Open joint underdrains were placed in sub-trenches at the bottom of the conduit trenches. The bottom halves of the conduit were then laid on a crushed stone bed, and at 14 foot centers roll frames, with rollers to allow for the steam pipe expansion, were set in concrete piers. The piping was then lowered onto the roll frames and the joints were screwed. After the piping had been subjected to a hydrostatic test, the sectional insulation was placed around the pipes and the top sections of the tile-containing members were applied. All joints were cemented and waterproofed and the tunnel backfilled. (See plan map of campus, in Appendix, for details of construction of conduit, expansion joints and manholes for the Strong Hall line). Work on the main to Strong Hall was completed in the Spring of 1925.

The line to the new Home Economics Building, however, was not installed until the Summer of 1926. A new system was employed throughout on this line. All joints were welded, except on the high-pressure return line, which was screwed pipe. The method of anchoring the pipe line was different from that shown in the detail drawing in the Appendix. The insulation was sealed to prevent heat transfer between manholes. Also different types of expansion joints were used. On the whole, however, it may be said that this method used on this line is a better system of underground insulation.

2. PURPOSE OF TEST. The purpose of this thesis test was to determine the radiation loss, expressed in B.t.u. per sq. ft. of exterior pipe area per deg. Fahr. difference in temperature per hour; and also to determine the efficiency of the insulation on the pipes. It is also intended to show the decrease of efficiency caused by the radiation in the manholes.

3. GENERAL THEORY. The heat losses from bare pipe in still air have been determined by numerous investigators under various differences of temperature between outside and inside of pipe, and these agree very closely. There is, therefore, no reason why the loss from bare pipe should not be adopted as the standard on which the efficiency of underground covering should be based. The thermal efficiency of underground pipe insulation can, therefore, be stated as follows:

"The thermal efficiency of an underground pipe covering is the ratio of the saving effected by the insulation, to the loss from bare pipes under similar temperatures installed in still air; or, in other words, it is the saving of heat effected by the insulation over what the same area of bare pipe would lose in still air at the same temperature difference".

The above expressed in a formula would be $E = \frac{B-C}{B}$

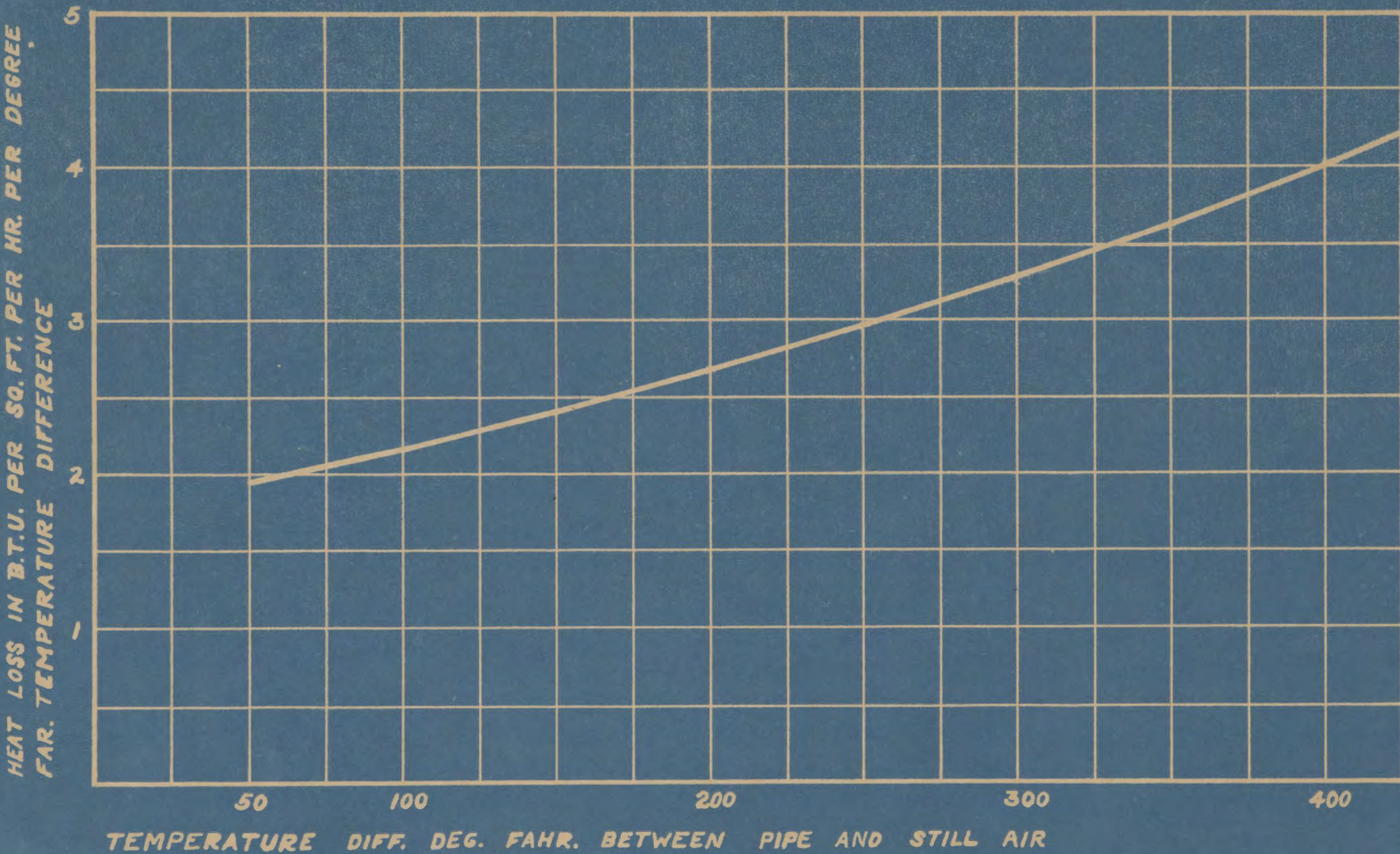
E = the thermal efficiency of the pipe covering

B = the loss from bare pipe

C = the loss from covered pipe, the conditions of temperature difference, etc., being the same in both cases.

The efficiency of the insulation was calculated under two different conditions:- (1) The efficiency was calculated for the unit as a whole--that is, from the time the steam leaves the heating plant in the high-pressure feeder main, until it returns to the heating plant in the high-pressure trap discharge line. In this case the heat loss per pound of condensate returned, will be the difference in heat content of the steam in the line and the water that is collected. (2) The efficiency was then calculated, neglecting the effect produced by the high-pressure return line--that is, from heating plant to trap. In this case, the radiation loss per pound of condensate will be equal to the latent heat of the steam in the line, as the condensate will be delivered to the high-pressure return line at a temperature corresponding to the pressure in the steam line.

4. METHOD OF PERFORMANCE. The test in general consisted in supplying steam to the high-pressure feeder line being tested, and collecting and weighing the water condensed and returned through the trap discharge line. The pressure on the line was maintained constant through a pressure-reducing valve. Each of



BARE-PIPE LOSS CURVE

Data From Johns-Manville Inc.

FIGURE 1

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the two lines was tested seperately.

Readings were taken to determine the boiler pressure, the quality of the steam leaving the boiler, pressure on the line being tested, temperature of the condensate returned, temperature in each manhole on the line, temperature of the ground 30 ft. away from the conduit, and the temperature of the outside air.

When steam passes through a pressure-reducing valve, the change is a constant heat content change. This law of thermodynamics was made use of to determine the heat content of the steam in the feeder line being tested; the quality and the boiler pressure being known.

The total number of sq. ft. of pipe surface was calculated from the length of the line and the sizes of the mains (see plot plan in Appendix). Knowing the temperature of the steam in the main and the temperature of the ground, the temperature difference was calculated. From a chart furnished by Johns-Mansville Inc. (see Fig. 1) the B.t.u. loss in still air per sq. ft. of exterior pipe area per deg. Fahr. temperature difference per hour, was obtained. From these, the heat loss per hour from the equivalent bare surface in still air, was calculated. Knowing the equivalent heat loss in still air and the actual heat loss in the line, the efficiency was calculated as shown on page 4.

5. DATA AND CALCULATIONS. (See next page).

DATA FOR STRONG HALL LINE

Date of test---------------------------------May 8, 1927

Weather--------------------------------------Clear

Duration of test-----------------------------4 Hrs.

Average temperature outdoors-----------------65 deg. Fahr.

Average temperature of ground 30 ft. from
conduit--------------------------------------58 deg. Fahr.

Average temperature in manholes--------------137.6 deg. Fahr.

Average boiler pressure, gauge---------------150#

Average steam pressure on line, gauge--------35#

Average steam temperature on line------------281 deg. Fahr.

Average quality of steam leaving boiler------97.6%

Average quality at Reese Hall----------------90.1%

Average quality at Strong Hall---------------98.7%

Total weight of condensate-------------------682#

Total weight of condensate per hour----------170.5#

Average temperature of condensate------------189 deg. Fahr.

Heat content of steam (from Mollier chart)----1176 B.t.u.

Latent heat of 1 lb. of steam at 35# pres.----927 B.t.u.

Difference in temperature between steam
in pipe and surrounding earth----------------223 deg. Fahr.

Total area of insulated pipe-----------------4914.6 sq. ft.

Total area of bare pipe in manholes----------155.1 sq. ft.

Linear ft. of high-pressure return main, 2 in. 1285.7 ft.

" " " " " " " $1\frac{1}{2}$ " 1832 ft.

CALCULATIONS FOR STRONG HALL LINE

Calculation of total heat loss

Total heat loss per lb. of steam condensed in high pressure line = 1176-(189-32) = 1019 B.t.u.

Total B.t.u. loss per hour = 170.5x1019 = 173,739.5 B.t.u.

Calculation of heat loss per hr. for equivalent bare surface in still air

223

Temperature difference--------------------233 deg. Fahr.

B.t.u. loss per sq. ft. per hr. per deg. difference in temperature = 2.8 B.t.u. (see Fig. 1)

Total B.t.u. loss in still air = 223x2.8x4914.6

= 3,068,676.2 B.t.u.

Temperature difference between manholes and ground

= 137.6-58 = 79.6 deg. Fahr.

Heat loss per sq. ft. per hr. by bare surface in manholes per deg. difference in temperature = 2.06 B.t.u.

Total heat loss per hr. by bare surface in manholes

= 79.6x2.06x155.1 = 25,436.4 B.t.u.

Net loss per hour from insulated surfaces under test

= 173,739.5-25,436.4 = 148,303.1 B.t.u.

Efficiency of unit as a whole $= \frac{3,068,676.2-173,739.5}{3,068,676.2} = 94.33\%$

Efficiency of unit considering heat loss in manholes

$$= \frac{3,068,676.2-148,303.1}{3,068,676.2} = 95.16\%$$

Efficiency from heating plant to traps

Heat loss per lb. of condensate = 1176-(281-32) = 927 B.t.u.

Total heat loss per hour = 927x170.5 = 158,053.5 B.t.u.

CALCULATIONS FOR STRONG HALL LINE (Continued)

Efficiency of unit as a whole $=\frac{3,068,676.2-158,053.5}{3,068,676.2}=94.85\%$

Net loss per hr. from insulated surfaces under test

$=158,053.5-25,436.4=133,617.1$ B.t.u.

Efficiency considering the effect of manholes

$$=\frac{3,068,676.2-133,617.1}{3,068,676.2}=95.63\%$$

B.t.u. loss per hr. per sq. ft. of pipe surface per deg. difference in temperature $=\frac{173,739.5}{4914.6\text{x}223}=0.159$ B.t.u

DATA FOR HOME ECONOMICS LINE

Date of test-----------------------------------May 9, 1927

Weather--Clear

Duration of test-------------------------------5 Hrs.

Average temperature outdoors-------------------65 deg. Fahr.

Average temperature of ground 30 ft. from
conduit--58 deg. Fahr.

Average temperature in manholes----------------113.5 deg. Fahr.

Average boiler pressure, gauge-----------------150#

Average steam pressure on line, gauge----------25#

Average temperature of steam on line-----------277 deg. Fahr.

Average quality of steam leaving boiler--------97.6%

Total weight of condensate---------------------336#

Weight of condensate per hour------------------67.2#

Average temperature of condensate--------------167 deg. Fahr.

Heat content of steam (from Mollier chart)-----1176 B.t.u.

Latent heat of 1 lb. of steam at 25 lbs.
pressure---------------------------------------932 B.t.u. – 936

Difference in temperature between steam in
pipe and surrounding earth---------------------219 deg. Fahr.

Total area of insulated pipe-------------------3710.1 sq. ft.

Total area of bare pipe in manholes------------147.9 sq. ft.

Linear feet of high-pressure return main, 2 in.1788.4 ft.

CALCULATIONS FOR HOME ECONOMICS LINE

Calculation of total heat loss

Total heat loss per lb. of steam condensed in high-pressure line = 1176-(167-32) = 1041 B.t.u.

Total B.t.u. loss per hr. = 1041x67.2 = 69,955.2 B.t.u.

Calculation of heat loss per hr. for equivalent bare surface in still air

Temperature difference----------------------219 deg. Fahr.

B.t.u. loss per sq. ft. per hr. per deg. difference in temperature = 2.75 B.t.u. (see Fig. 1)

Total B.t.u. loss in still air = 2.75x219x3710.1 = 2,234,407.7 B.t.u.

Temperature difference between manholes and ground = 113.5-58 = 55.5 deg. Fahr.

Heat loss per sq. ft. per hr. per deg. difference in temperature of manholes and ground = 1.95 B.t.u.

Total loss per hr. by bare surface in manhole = 55.5x1.95x147.9 = 16,006.5 B.t.u.

Net loss per hr. from insulated surfaces under test = 69,955.2-16,006.5 = 53,948.7 B.t.u.

Efficiency of unit as a whole $= \frac{2,234,407.7-69,955.2}{2,234,407.7} = 96.86\%$

Efficiency of unit considering heat loss in manholes

$$= \frac{2,234,407.7-53,948.7}{2,234,407.7} = 97.57\%$$

Efficiency from heating plant to traps

Heat loss per lb. of condensate = 1176-(277-32) = 932 B.t.u. 93[illegible]

Total heat loss per hr. = 932x67.2 = 62,630.4 B.t.u.

CALCULATIONS FOR HOME ECONOMICS LINE (Continued)

Efficiency of unit as a whole $= \frac{2,234,407.7-62,630.4}{2,234,407.7} = 97.19\%$

Net loss per hr. from insulated surfaces under test

$$= 62,630.4-16,006.5 = 46,623.9 \text{ B.t.u.}$$

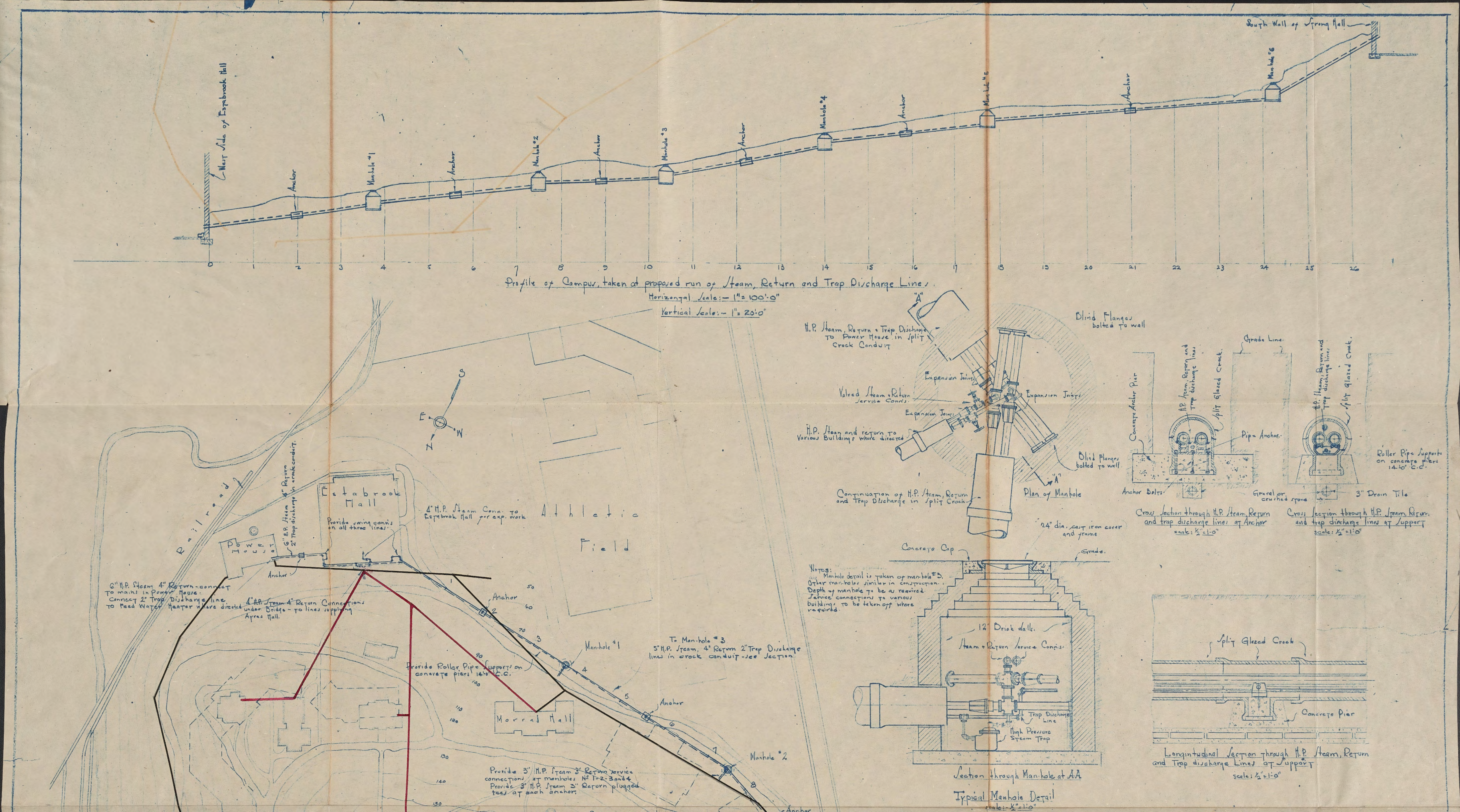
Efficiency considering the effect of manholes

$$= \frac{2,234,407.7-46,623.9}{2,234,407.7} = 97.91\%$$

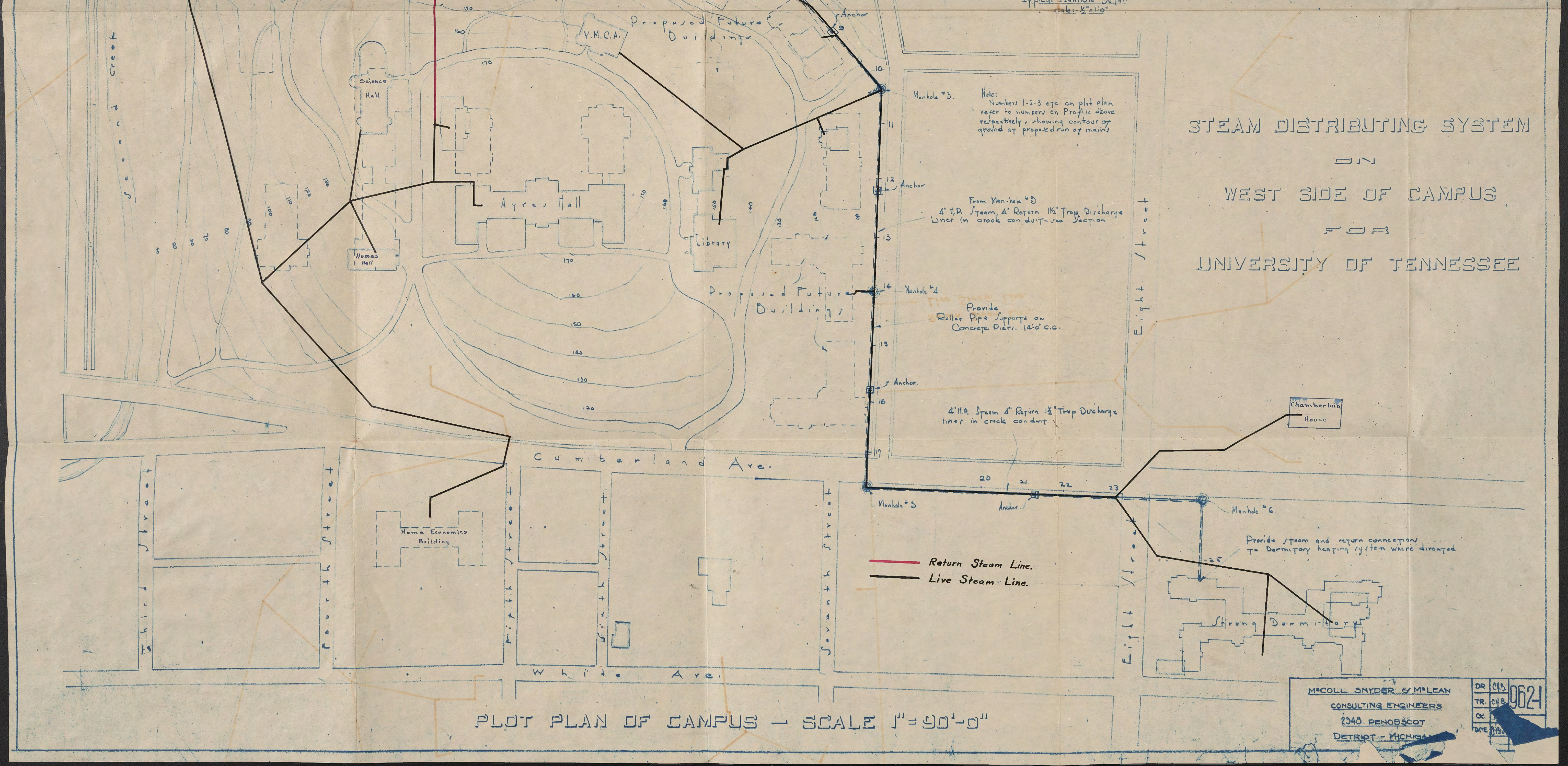
B.t.u. loss per hr. per sq. ft. of pipe surface per deg. difference in temperature $= \frac{69,955.2}{3710.1 \times 219} = 0.086$ B.t.u.

5. CONCLUSIONS. The foregoing results indicate an unusually high efficiency for this type of underground pipe insulation. However, considering the construction of the line, in which there is the high-pressure feeder main, the high-pressure return main, and the low-pressure return main, it is very probable that 50% of the radiated heat is carried away by the low-pressure return main.

A slightly higher efficiency was noted in the case of the Home Economics line. This can be explained by the fact that there is less leakage at manholes, and by the fact that in the case of this line, the insulation is sealed, thus preventing heat transfer from one manhole to the next.



South Wall of Strong Hall
West Side of Estabrook Hall
Anchor
Manhole #1
Manhole #2
Manhole #3
Manhole #4
Manhole #5
Manhole #6
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26
Profile of Campus, taken at proposed run of Steam, Return and Trap Discharge Lines.
Horizontal Scale:- 1"= 100'-0"
Vertical Scale:- 1"= 20'-0"
S
E
W
N
Railroad
Power House
Estabrook Hall
Athletic Field
Morrol Hall
6" H.P. Steam 4" Return 2" Trap discharge in crock conduit.
4" H.P. Steam Conn. to Estabrook Hall for exp. work
Provide swing conn's on all three lines.
Anchor
6" H.P. Steam 4" Return - connect to mains in Power House. Connect 2" Trap Discharge line to Feed Water Heater where directed.
4" H.P. Steam 4" Return Connections under Bridge - to lines supplying Ayres Hall.
To Man-hole #3
5" H.P. Steam, 4" Return 2" Trap Discharge lines in crock conduit - see Section
Provide Roller Pipe Supports on concrete piers 14'0" C.C.
Provide 3" H.P. Steam 3" Return service connections at manholes No 1-2-3 and 4
Provide 3" H.P. Steam 3" Return plugged tees at each anchor.
"A"
H.P. Steam, Return & Trap Discharge to Power House in Split Crock Conduit
Blind Flanges bolted to wall
Expansion Joints
Valved Steam & Return Service Conn's
Expansion Joints
H.P. Steam and return to Various Buildings where directed
Blind Flanges bolted to wall
Continuation of H.P. Steam, Return and Trap Discharge in Split Crock
Plan of Manhole
24" dia. cast iron cover and frame
Concrete Cap
Grade
Notes:
Manhole detail is taken of manhole #3. Other manholes similar in construction. Depth of manhole to be as required. Service connections to various buildings to be taken off where required.
12" Brick Walls.
Steam & Return Service Conn's.
Trap Discharge Line
High Pressure Steam Trap
Section through Manhole at A-A
Typical Manhole Detail
Grade Line
Concrete Anchor Pier
H.P. Steam, Return and trap discharge lines
Split Glazed Crock
Pipe Anchor
Anchor Bolts
Gravel or crushed stone
H.P. Steam, Return and trap discharge lines
Split Glazed Crock
Roller Pipe Supports on concrete piers 14'0" C.C.
3" Drain Tile
Cross Section through H.P. Steam, Return and trap discharge lines at Anchor
scale: 1/2"=1'-0"
Cross Section through H.P. Steam, Return and trap discharge lines at Support
scale: 1/2"=1'-0"
Split Glazed Crock
Concrete Pier
Longitudinal Section through H.P. Steam, Return and Trap discharge Lines at Support
scale: 1/2"=1'-0"


STEAM DISTRIBUTING SYSTEM
ON
WEST SIDE OF CAMPUS
FOR
UNIVERSITY OF TENNESSEE
Note:
Numbers 1-2-3 etc on plot plan refer to numbers on Profile above respectively, showing contour of ground at proposed run of mains
Manhole #3.
Anchor
From Man-hole #3
4" H.P. Steam, 4" Return 1½" Trap Discharge Lines in creek conduit - see Section
Manhole #4
Provide Roller Pipe Supports on Concrete Piers. 14'0" C.C.
4" H.P. Steam 4" Return 1½" Trap Discharge lines in creek conduit
Manhole #5
Manhole #6
Provide steam and return connection to Dormitory heating system where directed
Proposed Future Buildings
Proposed Future Buildings
V.M.C.A.
Science Hall
Ayres Hall
Library
Homes Hall
Home Economics Building
Chamberlain House
Strong Dormitory
Second Creek
Cumberland Ave.
White Ave.
Third Street
Fourth Street
Fifth Street
Sixth Street
Seventh Street
Eight Street
Eight Street
Return Steam Line.
Live Steam Line.
PLOT PLAN OF CAMPUS - SCALE 1" = 90'-0"
McCOLL SNYDER & McLEAN
CONSULTING ENGINEERS
2348. PENOBSCOT
DETROIT - MICHIGAN
DR.
TR. C.H.B.
CK.
DATE
962-1

CHAPTER II

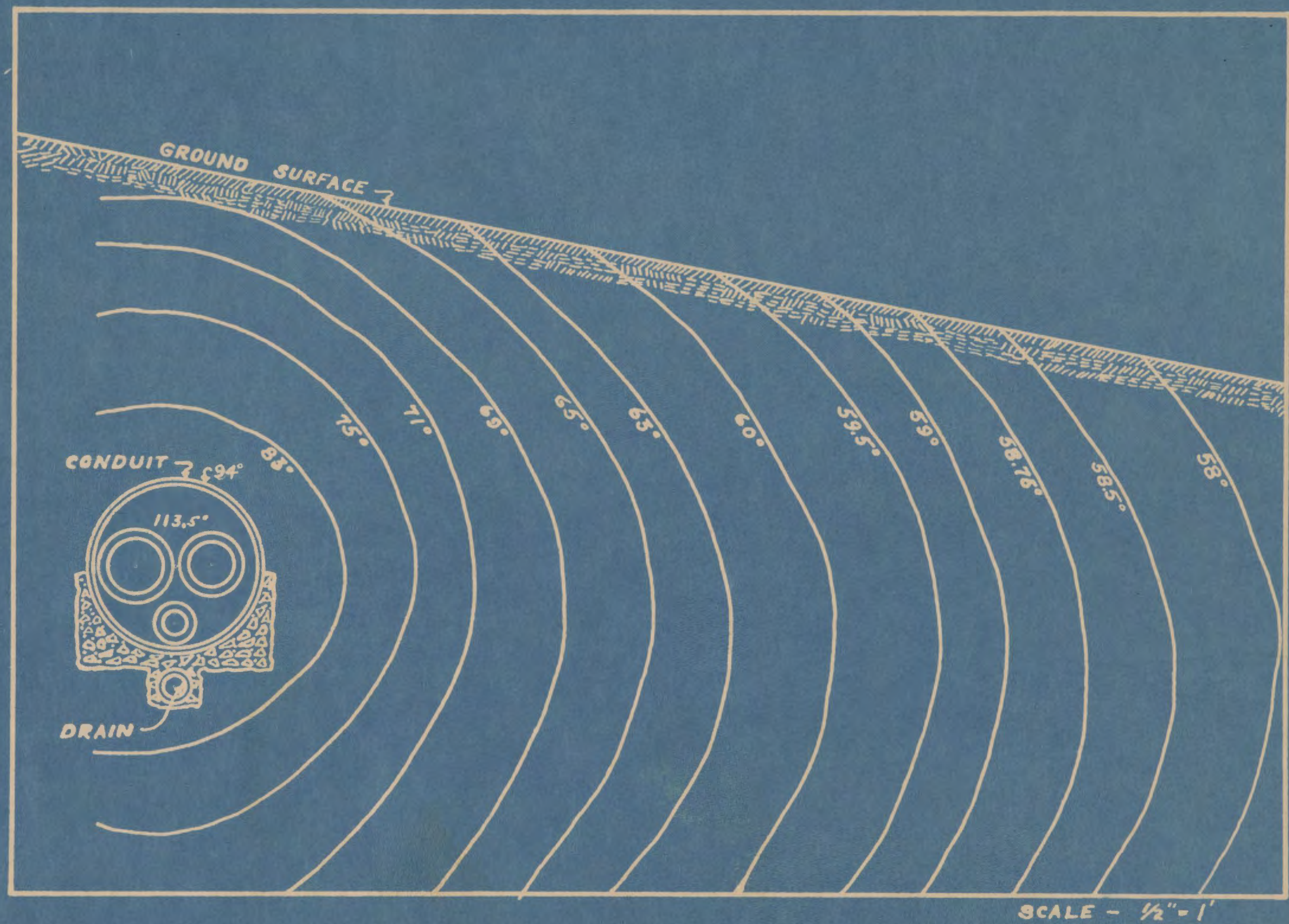
ISO-TEMPERATURE CURVES AROUND CONDUIT

1. STATEMENT OF PURPOSE. It is interesting to know just how the heat is radiated around a conduit carrying a steam main, and it was with this in mind that iso-temperature curves were drawn.

2. METHOD OF PERFORMANCE. To find out something of this condition, a number of pipes were driven vertically into the ground to different depths. And in order to find how far away from the conduit heat was being radiated, these pipes were driven at intervals of one foot, in a direction perpendicular to the pipe line, until a distance was reached where the ground temperature was constant. The temperature was taken at the bottom of each pipe on different days with varying weather conditions, and the average taken as the temperature for that point. By plotting these points and connecting points of equal temperature, iso-temperature curves were obtained (see Fig. 2). It was interesting to note that the widest variation in temperature for any one point was two deg. Fahr.

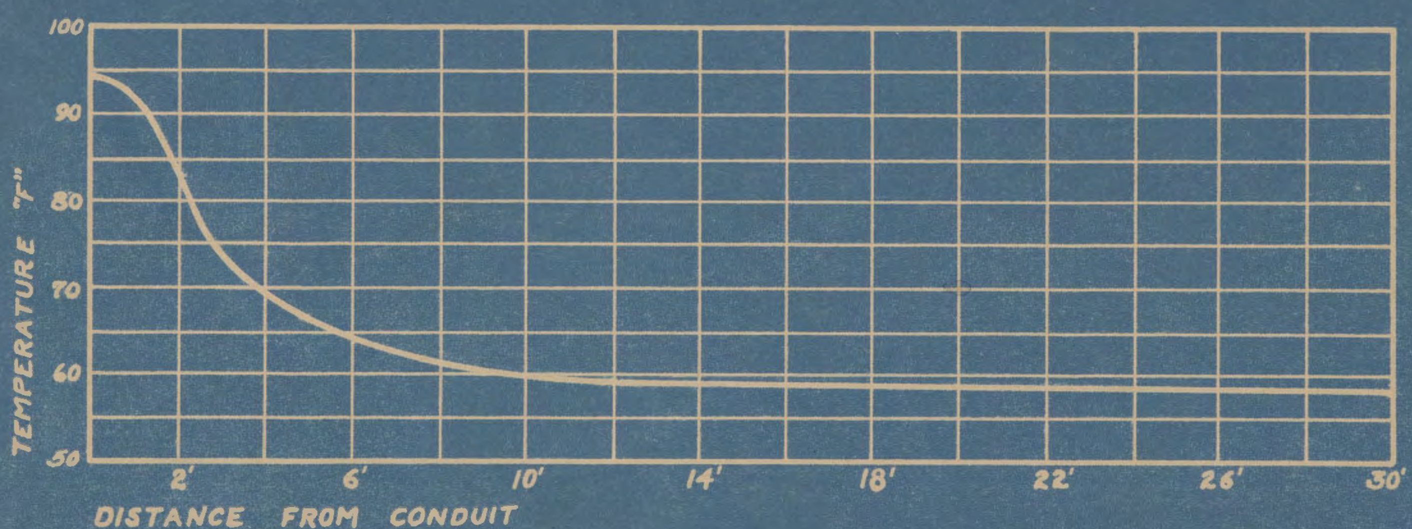
A curve showing how the temperature drops as the distance from the pipe line increases is shown in Fig. 3. This curve was drawn from temperature taken at a constant depth.

A place on the line to the new Home Economics Building about 40 ft. east of manhole "F", was selected as the location for the test (see plan of campus in Appendix). This location was selected because of convenience in driving pipes at this point, and because it seemed to be a representative location along the



ISO-TEMPERATURE CURVES IN GROUND
AROUND CONDUIT

Figure 2



CURVE FROM GROUND TEMPERATURE TESTS

FIGURE 3

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pipe line.

3. CONCLUSION. From the curves plotted it was noted that the temperature around the conduit became constant at a distance of 11 ft. from the conduit. Fig. 2 showed that the heat traveled better in a horizontal direction than in a vertical one. This, however, may have been influenced somewhat by the geological formation of the ground.

It is frequently possible to note that snow is melted from above the conduit during winter. The temperature at the average depth, which is four feet, is sufficiently high to cause this snow to melt. Freezing of the ground would hardly be probable under the weather conditions of this section, and snow will always melt above the conduit.

CHAPTER III

HEATING LOAD SUPPLIED BY CENTRAL HEATING PLANT

1. STATEMENT OF PURPOSE. At present the total heating load supplied by the central heating plant is not known, and it is the purpose of this phase of the thesis investigation to make a systematic determination of this heating load. In those buildings where the number of sq. ft. of radiating surface was not known, it was necessary to secure such data, either from specifications for the heating equipment for the building, or where this was not available, it was necessary to measure each radiator in the building being tested, and from tables furnished by the American Radiator Co., determine the radiating surface.

2. GENERAL SURVEY. Upon investigation, the heating surface

for the following buildings was found:-

Ayers Hall	10,633	sq.	ft.	
Barbara Blount Hall	2,500	"	"	
Carrick Hall	1,500	"	"	
Estabrook Hall	9,000	"	"	
Humes Hall	1,258	"	"	
Library	2,027	"	"	
Morrill Hall	4,258	"	"	
Reese Hall	797	"	"	
Science Hall	4,410	"	"	
South College	1,825	"	"	
Y. M. C. A.	1,509	"	"	
Total	39,717	"	"	39,717 sq.ft.

Buildings where radiating surface was measured are:-

Ayers House	767	sq.	ft.	
Bleecher Rooms	447	"	"	
Chamberlain Dormitory	1,214	"	"	
Green House	712	"	"	
Gymnasium	1,795	"	"	
Home Economics Bldg.	4,558	"	"	
Infirmary	639	"	"	
Jefferson Hall	3,336	"	"	
New Strong Hall	5,235	"	"	
Power Plant	2,240	"	"	
Strong Hall	2,340	"	"	
Turner House	496	"	"	
Total	23,779	"	"	23,779 sq.ft.
Total Heating Load				63,496 sq.ft.

In addition to heating the buildings, hot water is supplied to the dormitories, Gymnasium, Morrill Hall, Home Economics Building, Infirmary, Estabrook Hall, and Y. M. C. A. It is estimated that 75 H. P. in WATER heating load is carried by the central heating plant.

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by American Radiator Co.

Heating and Ventilating

by Leo Holdredge

APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

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