T H E S I S

ON

"THE ECONOMY AND ADVISABILITY OF OPERATING A COMBINED POWER AND EXHAUST HEATING PLANT AT THE OREGON AGRICULTURAL COLLEGE".

Submitted to the faculty

of the

O R E G O N   A G R I C U L T U R A L   C O L L E G E

for the degree of

BACHELOR OF SCIENCE

in

ELECTRICAL ENGINEERING

by

Redacted for privacy

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June 1, 1913.

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INTRODUCTION.

The question of whether to purchase power or to maintain an isolated plant is one which frequently confronts the engineer, and the problem is by no means easy of solution, as there are a number of factors which vary with individual cases and determine the economy and desirability of the isolated plant. Rather unusual conditions are encountered in connection with the lighting and heating of the Oregon Agricultural College. For instance, the peak of the load occurs in the afternoon, between 3 and 7 P.M. while there is practically no peak in the morning. In addition, the load fluctuates greatly from day to day and there is but a light power load during the summer and no demand at all for heat. Notwithstanding the low rate of two cents per kilowatt hour paid by the college for power purchased from the Oregon Power Company, the question has arisen as to the advisability of operating a plant on the campus and using the exhaust steam for heating. The expense of operation, aside from fuel, the first cost and maintenance of a plant are not difficult to estimate, but the additional cost of fuel for the generation of power, the question of the utilization of all the exhaust steam and the practicability of operating a small plant to carry a load which is largely a heavy, fluctuating motor load with a low power factor are factors which would vitally affect the success of an isolated plant for the Oregon Agricultural College, and the principal difficulty in making this report is encountered in determining the importance of these factors. The determinations of operating expenses are necessarily approximate, and an effort has been made throughout to place any possible error on the debit side in order to make allowance for unforseen expenses which inevitably occur in connection with work of thid kind. This thesis is not intended to offer a design for a plant and the features properly belonging to design have been taken up only sufficiently to determine the cost of installing a plant and the character of equipment needed in order to find the fixed charges. It is the purpose of this thesis merely to determine the the advisability of installing a plant at the Oregon Agricultural College from the standpoints of economy and reliability of service.

PRESENT SYSTEM.

Heat for the college buildings is at present furnished by two plants, one of which, the old plant, uses wood for fuel, and is located on the North side of the campus,adjacent to the shops. The other plant is located on the extreme South of the campus and oil is burned in this plant. Its capacity is 400 B.H.P. and at present the plant is taxed to its full capacity when the demand for heat is greatest. The new plant furnishes heat for all the buildings on the South side of the campus, including the Armory, Science Hall, Gymnasium, Waldo Hall, Agricultural Buildings and Dairy Building. The vacuum return system is used in this plant, and the steam is supplied to the mains at a pressure of about 60 pounds gage.

The old plant is a low pressure plant using the gravity return system. The steam pressure is maintained at between 3 and 4 pounds gage in the mains and about 60 pounds gage in the boilers, steam being admitted to the mains through reducing valves. This plant furnishes heat to the Administration Building, Mechanical Hall, Shops, Bookstore and to the Mining Building. The vacuum return system is used for the Mining Building, and has been found to be very efficient. Steam is admitted to the main leading to the Mining Building at full boiler pressure of 60 pounds. The drawing of the steam mains of the old, or North heating plant shows the arrangement of the principal mains. They are all interconnected outside the plant to form a network. There are three boilers in the old plant of about 40 B.H.P. each. The boilers, however, are old and cannot be worked to their full capacity, a maximum pressure of only about 70 pounds being allowed. There is a header to which all boilers connect and four mains leading from the header, as follows; to the engine room, high pressure to the Mining Building, to Mechanical Hall through a reducing valve and to the shops through a reducing valve. The boiler feed and the vacuum pumps are located in a sump at the rear of the boiler room. The condensed steam from the gravity return portion of the system flows back to a receiver in the sump, from which it is returned to the boiler by a pump, the throttle of which is automatically controlled to maintain a constant level in the receiver.

REQUIREMENTS FOR A NEW PLANT.

The location of the new heating plant is very unsatisfactory, and an investigation has been made to determine the advisability of finding a better location upon which to construct the proposed combined power and heating plant. The principal trouble is the great distance of the plant from the buildings heated and the lack of insulating material on the mains, which are in tunnels lined with concrete. After a careful consideration of the matter, however, it has been decided to leave the new heating plant out of consideration entirely in connection with an exhaust steam heating project for the following reasons;

1. Because of the great distance between the buildings low pressure exhaust steam could not be used for heating all buildings from one plant unless the plant were located in some central part of the campus, which would be unsightly and altogether undesirable,

2. The new heating plant is so far away from the buildings it heats that exhaust from an engine in the plant could not be used to advantage. In addition, the mains, etc. are designed for high pressure steam and are consequently too small for use with low pressure steam. In order to use exhaust steam in the new system at all it would be necessary to completely reconstruct it, the expense of which would be prohibitive.

3. An approximate estimate of the exhaust steam which will be available has shown that there will be enough only to heat a part of the buildings and there would be no advantage in combining the two plants.

In view of the above reasons the remainder of this paper will be devoted to determining the capacity and type of plant most desirable for operation in connection with the old heating system on the North side of the campus, and the relative cost of power generated by it and that purchased at the present rate. In addition, it will be necessary to determine what portion of the heating load the exhaust from the plant will carry.

A consideration of the magnitude and nature of the load is necessary in order to make an estimate of the plant required. Plate 2 is a good illustration of the power load in the winter, when the lighting load is greatest. The data from which the curve was plotted was taken over a year ago, and the load has increased somewhat since that time, but a plant with a capacity of 150 K.W. will be sufficient for several years and allow one spare unit for emergencies. The peak load shown on the curve is slightly over 60 K.W. and occurs between 3:00 and 7:00 P.M. From 7:00 P.M. until midnight the load is fairly constamt at 30 K.W. after which it is lighter until the afternoon. The variation in load from day to day is considerable, and the load is very light on Sunday. At other times the load depends upon the work being done in the electrical laboratory, shops and planing mill. Plate 6 shows the characteristic power demand during the winter months. The maximum consumption for any one day in this month is 750 K. W.H. In the early fall and spring months the load is lighter, as shown by plate 3. In the summer the load is very light, as shown by plate 4. The load factor for the year is about 22%, which is very low for the economical operation of a power plant.

After a consideration of the load as illustrated above, it will be seen that for economical operation the plant should have one small unit with a sufficient capacity to carry the off peak load and be loaded to its capacity. The engine driving the generator should have a greater capacity in order to handle the sudden load when machines in the planing mill are started. These machines pull heavily on the system when being started, and the motors take large currents with low power factors when they are being started. A voltage regulator will be a necessity in order to maintain good service. For the generating units, a 50 and a 75 K.W. unit appear to be the most desirable from an operating point of view. The 75 K.W. unit would be of sufficient capacity to carry the peak load, during which time the smaller units could be shut down. The present plant is equipped with a 50 horsepower engine and a 35 K.W. generator, which would serve admirably to carry the off peak load. In addition, a unit of about 50 K.W. capacity should be installed for reserve. Then, in case the larger unit were out of service the two smaller units could carry the peak load together, and in case the 35 K.W, machine were out of service the 50 K.W. machine could be operated to carry the off peak load, and it would not be too large to carry the load uneconomically. The power factor curve on plate 2 shows that the power factor varies approximately in an inverse ratio to the load. When the peak load is on the power factor is very good, while at other times it is very low. This is caused by the large number of transformers on the campus which take magnetizing currents at a low power factor, and by induction motors running at light loads and it cannot be changed. This, however, is of no importance in connection with the operation of a plant, In addition to the above equipment outlined, it would be necessary to install at least 100 H.P. additional of boilers. No change need be made in the distributing system, as all the present equipment on the load side of the 11000/2200 volt transformers in use at present is owned and maintained by the college and is of ample capacity for a number of years at least. The system in use at present is a 2200 volt system with transformers at each building. The generator in the power house at present is a 2200 volt generator, and new generators should be of the same voltage.

EXHAUST STEAM AVAILABLE AND STEAM REQUIRED FOR HEATING.

A consideration of the load curves brings out an undesirable feature of the exhaust steam heating project. That is, that the peak load and the maximum demand for steam do not occur at the same time. The heaviest heating load comes in the morning, from 7:00 to 9:00 A.M. while during the peak load in the afternoon the demand for heat is light. However, with an exhaust heating plant the buildings could be kept warm all night, so that no extra heat would be required in the morning, and the only undesirable result would be some waste of heat during the peak load. The heat available and that needed for heating will be shown in subsequent calculations. In connection with this, the dormitories at once offer a very desirable exhaust heating load,as they require heating during long hours, and particularly while the peak load is on. However, the distance between the dormitories, and their distance from a desirable location eliminate the possibility of taking advantage of this. Also, as before stated, Waldo Hall is equipped with the vacuum return system.

As before mentioned, the power load has a definite peak occurring between 3:00 and 7:00 P.M. The heating load is practically constant throughout the day, except for a short time in the morning while the buildings are being warmed up. With heat on all night, as would be the case with an exhaust heating plant, the heating load would be practically constant throughout the day, and it will be considered constant in subsequent calculations. In comparing the heat required with that available from the exhaust, the time has been divided into two periods, one from 3:00 to 7:00 P.M. and the other including the remainder of the 24 hours. An inspection of the load curves, together with some allowance for increase of load since the curves were taken, shows that the load during the 4 hours peak is on an average 75 K.W. duringthe winter months when the load is greatest, and about 25 K.W. for the remainder of the day. The following computations show the amount of heat available from the exhaust and that required for heating for the two periods into which the day has been divided. This has been worked out for conditions during the most severe weather in the winter, when the power load is greatest and the demand for heat is greatest. It will be shown later how this applies to conditions at all other times.

The heat required for the buildings was determined in the following way: the condensed steam from the system is returned to the receiver and pumped back into the boiler by a reciprocating steam pump. A counter was attached to the pump and the strokes counted for several days in February 1913. The volume of water evaporated was then determined from these measurements, the average being determined for several days. This was 75000 pounds of water per day. The heating plant is operated 11 hours per day, and the pressure is maintained at an average of 70 pounds absolute. After passing through the reducing valves the steam is superheated, but the total heat of the steam remains the same. The total heat of steam at a pressure of 70 pounds absolute is 1180 B.T.U. per pound.

$$\text{Then} \quad \frac{75000 \times 4 \times 1180}{11} = 32,200,000$$

B.T.U. or the heat required for a period of four hours.

The heat available from the exhaust of an engine carrying a load of 75 K.W. will now be found for a period of four hours, which covers the peak load. The steam at present has a quality of 99% at the engine, and the calculations will be made for an absolute pressure of 70 pounds, the same as is carried at present. The total heat of steam at 70 pounds absolute and 99% quality = 1180 B.T.U. After being exhausted into the heating system at a pressure of 20 pounds absolute the steam is of 92% quality and the total heat is 1090 B.T.U. per pound. 1180–1090 = 90 B.T.U. per pound of steam which would be converted into work by an engine operating on the ideal Rankine cycle. The ordinary engine has an efficiency of about 40% of the Rankine cycle. Therefore, .4 x 90 = 36 B.T.U. converted into work per pound of steam.

75 K.W. = 100 H.H. An overall efficiency of 70% for a generating unit is a fair allowance, anf the calculations will be based on an efficiency of 70%. 100/.7=140 = I.H.P. of an engine carrying the peak load. 2545 B.T.U. = 1 horse power hour.

$\frac{140 \times 2545}{36}$ = 9900 pounds of steam required per hour for an engine carrying the peak load, and 4 x 9900 = 39600 pounds for the period of four hours. The heat per pound of exhaust steam = 1090 as determined before. 39600 x 1090 = 43,200,000 B.T.U. = heat of exhaust foe the period of peak load. This is about 4/3 the amount required for heating, showing that there is an excess of exhaust steam during this time which would probably be wasted. The excess, however, would probably not be so great as indicated,as the peak is not constant during the four hours, and 75 K,W, is a rather liberal allowance for the peak load, It might also be possible to reduce the live steam supplied just before the peak so that more of the exhaust could be utilized to heat up the radiators again.

The load during the remainder of the day is practically constant at about 25 K.W.

$$\frac{25}{.7 \times .75} = 49 = \text{I.H.P. of an engine}$$

carrying the off peak load.

$$\frac{49 \times 2535}{36} = 3465 \text{ pounds of steam con-}$$

sumed per hour. 1090 x 3465 = 3,780,000 B.T.U. available from the exhaust.

$$\frac{75000 \times 1180}{11} = 8,000,000 \text{ B.T.U. per hour}$$

required for heating. This shows that the exhaust steam is about 1/2 that required for heating during the off peak period. Actually, however, it would amount to somewhat more than 1/2, as steam would be on the buildings all night with a plant running, thus reducing the apparent steam consumption during the day.

COST OF POWER.

The data on power consumption as regards the characteristic daily load has been taken from the curve on plate 2, showing the characteristic load through the afternoon. This was taken in December, a month when the power load is heaviest, because of the power required for lighting late in the afternoon. The loads for the winter months of December, January and February are similar to this, and in the spring months and in November the load is less, as is shown by the monthly cost of power. An important point in connection with these calculations is that the power and heating loads undergo similar variations throughout the year. This is shown graphically by the diagram on plate 7. The solid lines indicate the monthly power consumption and are derived from the monthly power bills paid by the college during 1912. The dotted lines indicate the consumption of wood for heating and are derived from measurements taken of the wood burned. Consequently, the ratios of the heat required and that available from the exhaust as determined above may be considered to hold throughout the year, and the operating problem is the same for each day, except, of course in the summer, when no heating is done. The constant conditions are, that during the peak load the exhaust steam is slightly in excess of that required for heating, and during the remainder of the day it is 1/2 that required. On Sunday, as a rule, no heat is required, and the power consumption is very light, as shown on the curves. The figures given above have been worked out for the severest conditions, as the plant must be designed to operate under the maximum lighting and heating loads. During the time when the exhaust steam is insufficient, live steam must be admitted to the mains through reducing valves as is done at present. As the heat is used for 11 hours per day the exhaust during the 4 hours of the peak load will carry 4/11 or 35% of the total heating. The above figures show that the exhaust will carry 1/2 of the heating load for the remainder of the day, but consideration must be made for the fact that with an engine exhausting into the mains all night this heat would not be wasted, as the buildings would be kept warm all night, thus eliminating the heavy firing at present necessary for the first 2 hours in the morning. In view of this fact, the exhaust may be considered as capable of carrying at least 2/3 of the heating load for the remainder of the day. 7/11 x 2/3 = 40% additional of the heating load carried by the exhaust during the off peak period. 40 + 35 = 75% of the total heating which is carried by the exhaust. The yearly cost of power will now be estimated and the expense will be credited with 3/4 of the cost of heating at present in order to find the net cost for comparison with the cost as purchased from the Oregon Power Co,

Measurements taken of the fuel burned in the heating plant show that the consumption is as fol-ows: October, 30 cords; November, December, January and February, 50 cords each; March, April and May 35 cords each. This makes a total of 335 cords per year, which at a cost of $3.75 per cord amounts to $1256.00 per year.

The following is a computation of the cost of fuel per K.W.H. of power generated, based on the measurements of condensed steam in connection with comparison between heat required and that available from exhaust steam. The total heat of steam at 70 pounds gage pressure = 1180 B.T.U. The steam consumption at the time measurements were taken was 75000 pounds per day, and the average fuel consumption was 2.5 cords per day. 75000 x 1180 = 86,500,000 B.T.U. per day. (2.5 x 3.75)/86.5 = $0.108 = cost of heat per million B.T.U. With a new and more economical installation this cost would be reduced somewhat, but as no data is available on a new set of boilers these figures will be used in estimating the cost of power. As shown above, 9900 pounds of steam at a pressure of 70 pounds absolute are required to run a generating set 1 hour while carrying a load of 75 K.W. and exhausting into the heating mains at a back pressure of 20 pounds absolute. 9900 x 1180 = 11,675,000 B.T.U. = heat content of the steam consumed. 11.675 x .108 = $1.26 = cost of fuel for producing the steam. 1.26/75 = $0;0168 = cost of fuel per K.W.H. of power.

Cost per K.W.H. not satisfactorily computed.

The expense of running a plant may be classified under three main divisions; they are; fuel and water; labor and supplies; interest on the investment, depreciation and repairs. The cost of fuel has already been determined. The following estimate of the cost of a plant, interest. and depreciation, etc. has been gr based upon data from a paper by A.E, Hibner, entitled "The cost of Industrial Power" which was read before the A.I.E.E. in 1911. The following estimate is for an installation of 100 K,W. capacity designed to supplement the present installation.

Engines, generators, switchboard & wiring	$5500.00
Extra boilers & steam fitting............	3500.00
Addition to building and foundations......	2000.00
Total investment....................	$11000.00

The fixed charges on the installation are as follows:

Interest at 6%........................	$660.00
Depreciation on engines & generators at 3%.....................	165.00
" " on boilers at 4.5%.......	157.00
" " on building and foundations at .5%....................	10.00
Total fixed charges per year........	$992.00

Bldgs

The estimated operating cost, exclusive of fuel is as follows;

Supplies, oil, etc..................	$100.00
Repairs.............................	200.00
3 engineers at $720.00..............	2160.00
Water...............................	100.00
Total...............................	$2560.00

The cost of power for the year 1912 was as follows;

January......$200.01

February..... 284.92

March........ 250.02

April.........225.84

May...........236.72

June..........168.76

July.......... 74.28

August..... ..130.80

September..... 98.64

October.......193.96

November......321.52

December......333.96

Total.......$2520.43

This represents a power consumption of 126000 K.W.H.

126000 x .0168 = $2117.00 * cost of fuel.

Then the total cost of power per year is;

Fuel...............................$2117.00

Fixed charges...................... 992,00

Operating cost.....................2560.00

Total 5669.00

To this must be credited 3/4 of the cost of fuel which is used for heating alone, and the wages of one fireman who is employed at present.

Cost of fuel for heating = $1256.00. — why not 2117.00

1256 x .75 = 942.00.

Fireman..... 650.00

1592.00 = total credit.

$5669.00 -$1592.00 = $3077.00 = net cost of power for the year. $3077.00/126000 = $0.0244 = cost per K.W.H. This shows that a plant operated by the college could not produce power as cheaply as it is purchased at present at 2 cents per K.W.H. Of course, with an increased load the cost per K.W.H. would be reduced somewhat as the overhead and operating charges remain the same and only the fuel cost increases.

In addition to the above. there are a number of less important factors connected with the operation of a plant, which have not been taken account of, but which should balance each other and not affect the final results as given above. One is that in the summer the boilers would be operating at a higher efficiency than in the colder weather, and the engines would be more efficient because they could be allowed to exhaust into the atmosphere instead of against the back pressure in the mains, under which conditions the calculations were made. The Mining Building heating has not been taken into consideration because of the practical impossibility of measuring the steam used. This load is very light, however, and is of small consequence. These considerations, if taken into account in the calculations, would tend to decrease the estimated cost of power somewhat. On the other hand, no allowance has been made for power required for exciting current for the alternators. This amounts to from 1.5 to 2.0 % of the total power generated. Also, no heat is required on Sunday, as a rule, and the exhaust would be wasted. These factors operate to increase the estimated cost of power and it is believed that the several factors should neutralize one another.

In addition to the economical aspect of the problem there is still the question of the reliability of service. It is not probable that the service from an isolated plant would be so reliable as that furnished by the Oregon Power Company. The heavy motor load which is also very fluctuating, makes the problem of regulation a serious one,

On the other hand, a plant would be of some value in connection with the engineering laboratory, and there will probably be laboratory equipment purchased which would serve for use in the power plant.

In view of the foregoing facts, it is the conclusion of the authors that an isolated plant for the Oregon Agricultural College would be uneconomical and undesirable, at least until the load has greatly increased.

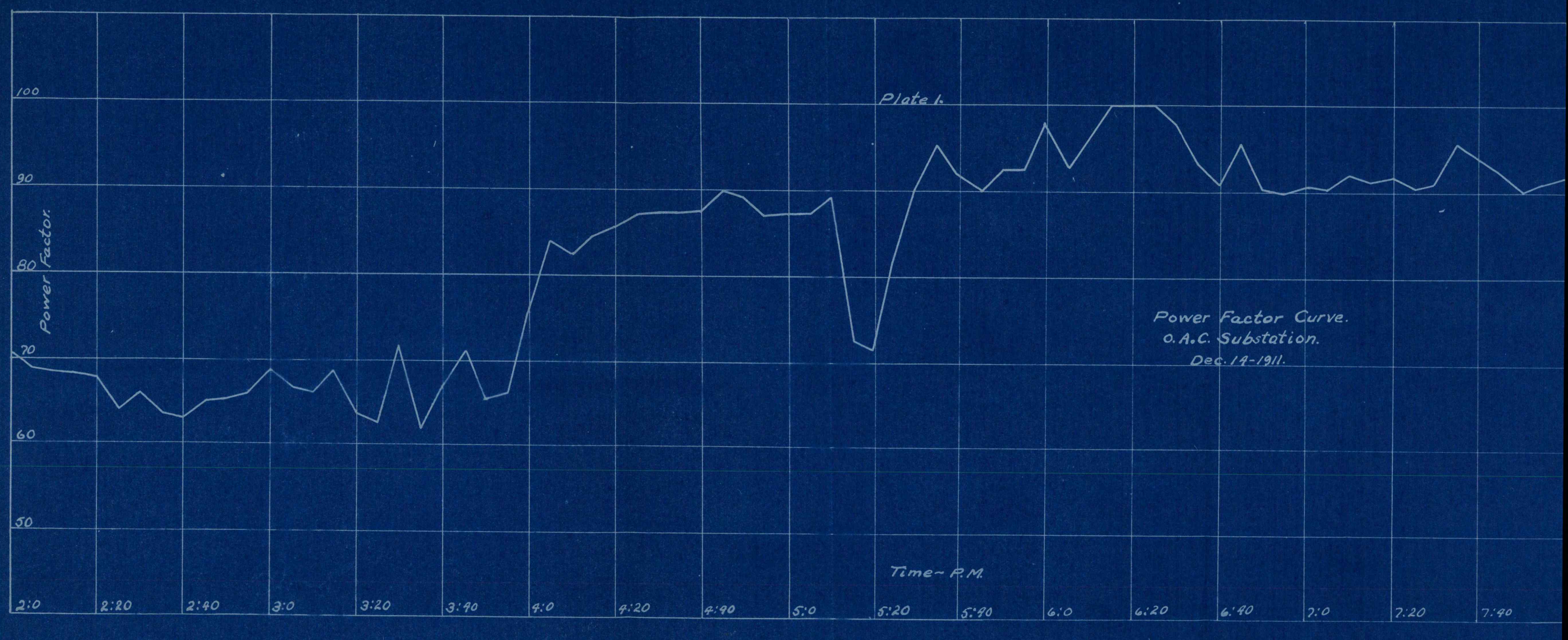


Plate I.
Power Factor Curve.
O.A.C. Substation.
Dec. 14-1911.
Power Factor.
100
90
80
70
60
50
Time ~ P.M.
2:0
2:20
2:40
3:0
3:20
3:40
4:0
4:20
4:40
5:0
5:20
5:40
6:0
6:20
6:40
7:0
7:20
7:40

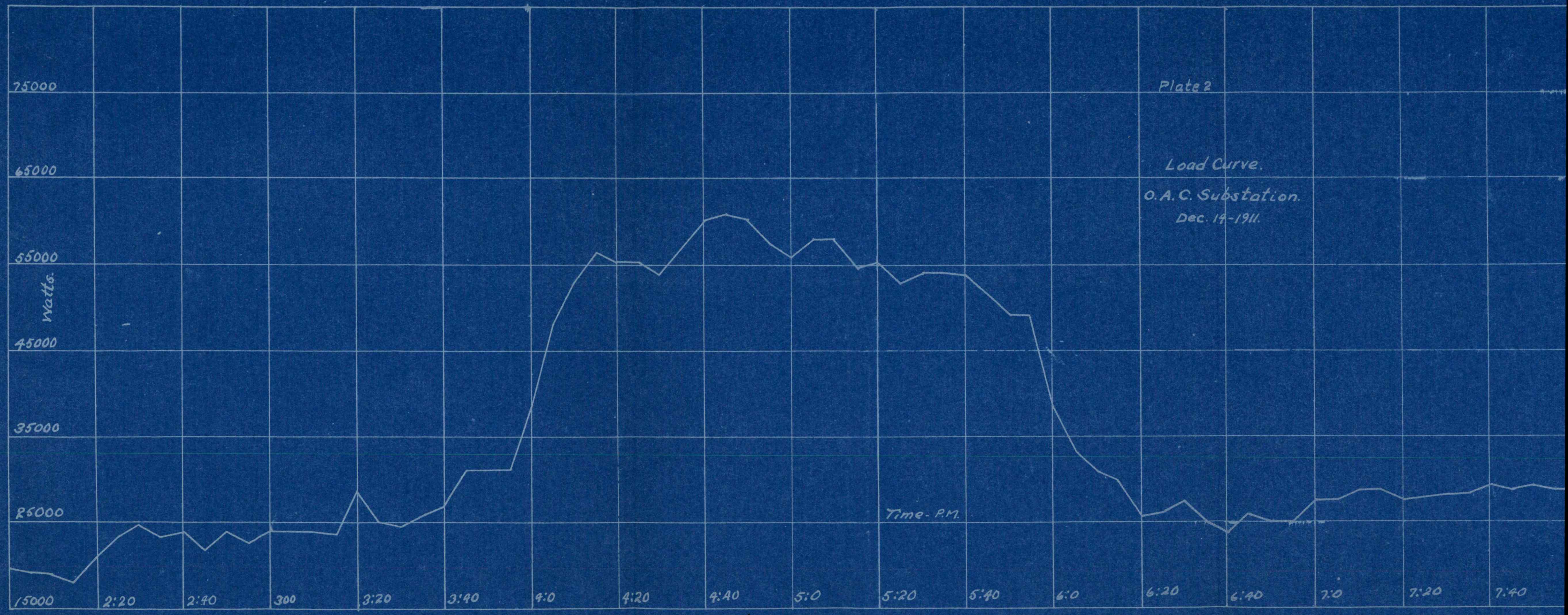
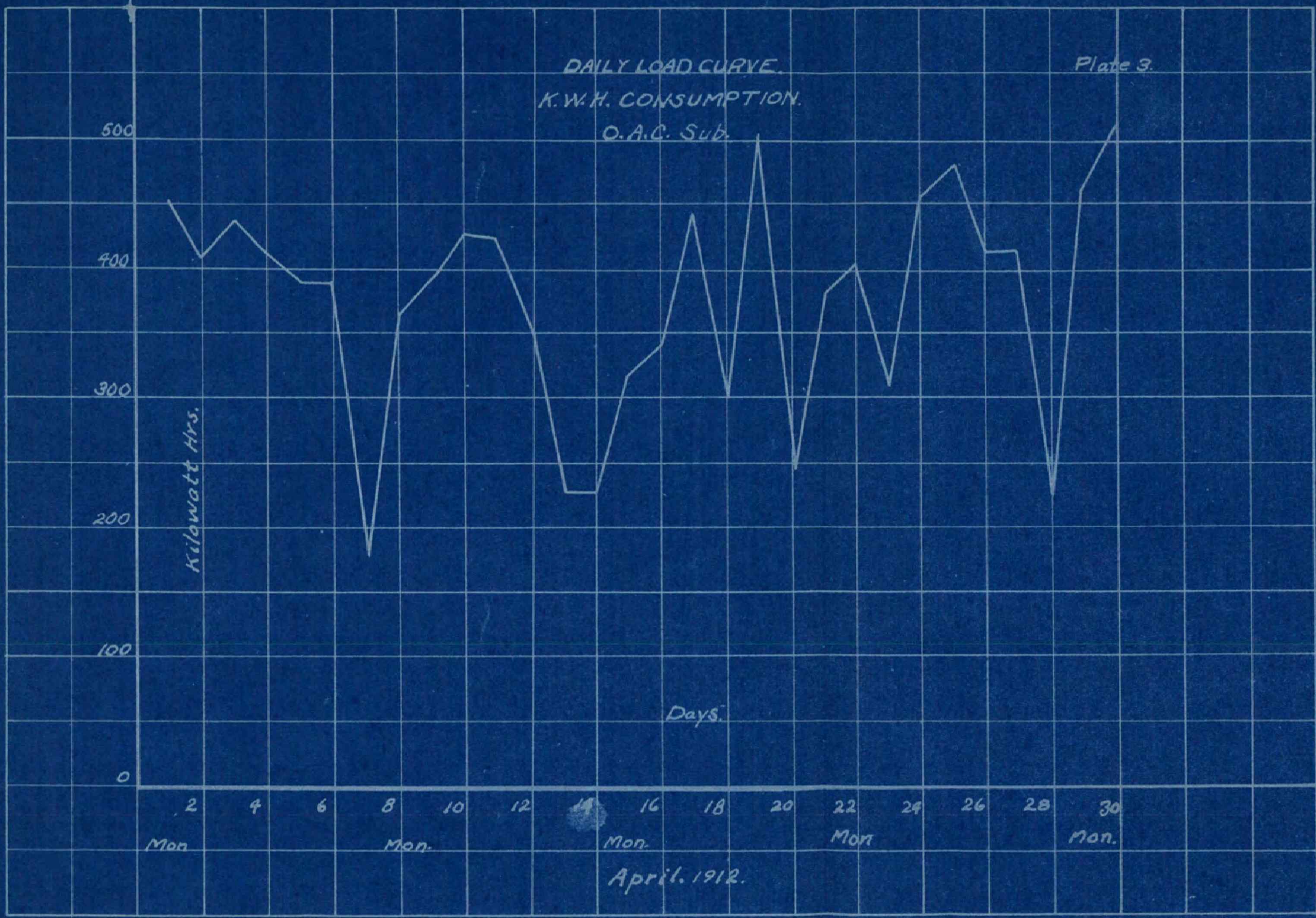


Plate 2
Load Curve.
O. A. C. Substation.
Dec. 14-1911.
Watts.
75000
65000
55000
45000
35000
25000
15000
Time - P.M.
2:20
2:40
300
3:20
3:40
4:0
4:20
4:40
5:0
5:20
5:40
6:0
6:20
6:40
7:0
7:20
7:40



DAILY LOAD CURVE.
K.W.H. CONSUMPTION.
O.A.C. Sub.
Plate 3.
500
400
300
200
100
0
Kilowatt Hrs.
Days.
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
Mon
Mon.
Mon.
Mon
Mon.
April. 1912.

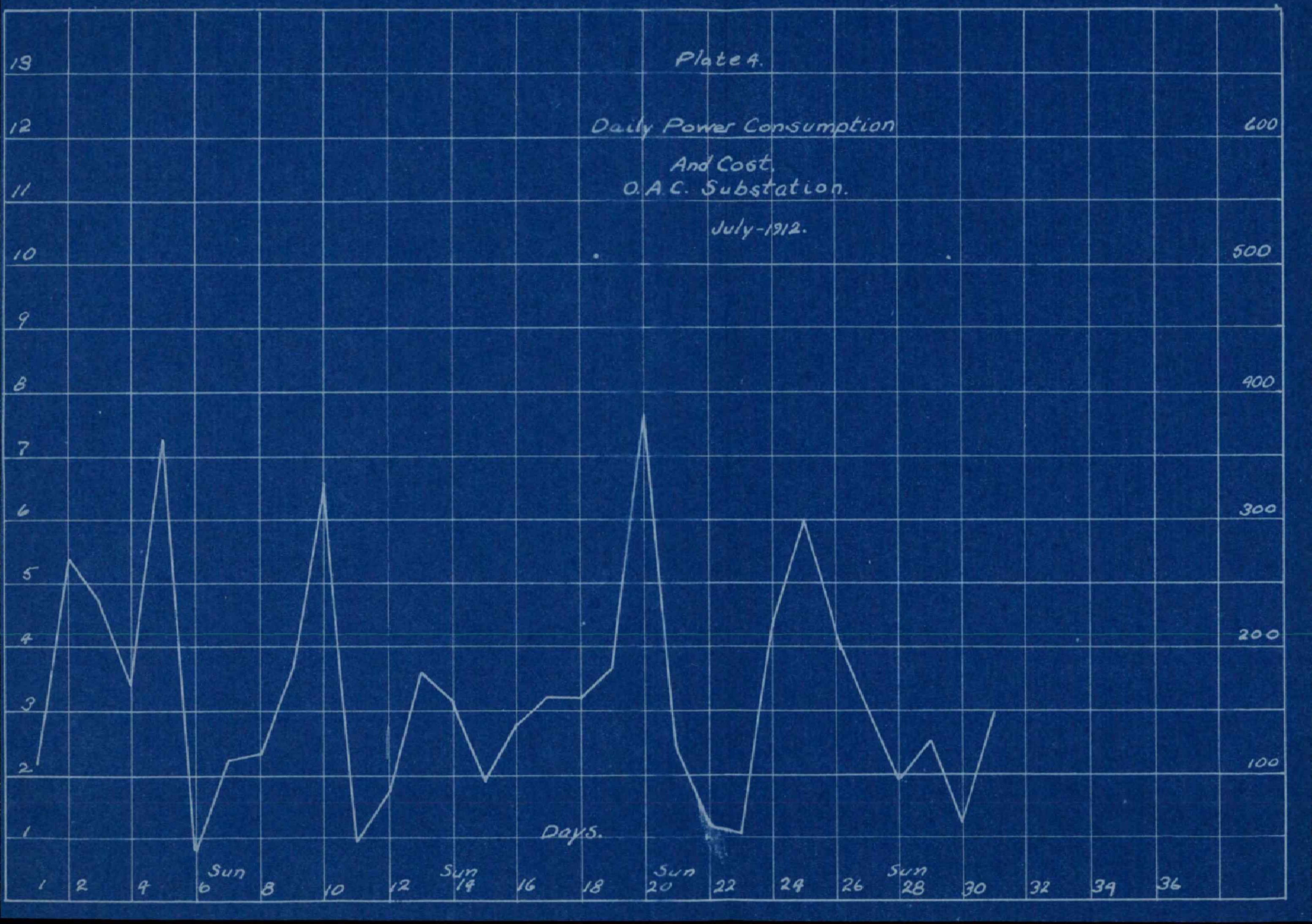
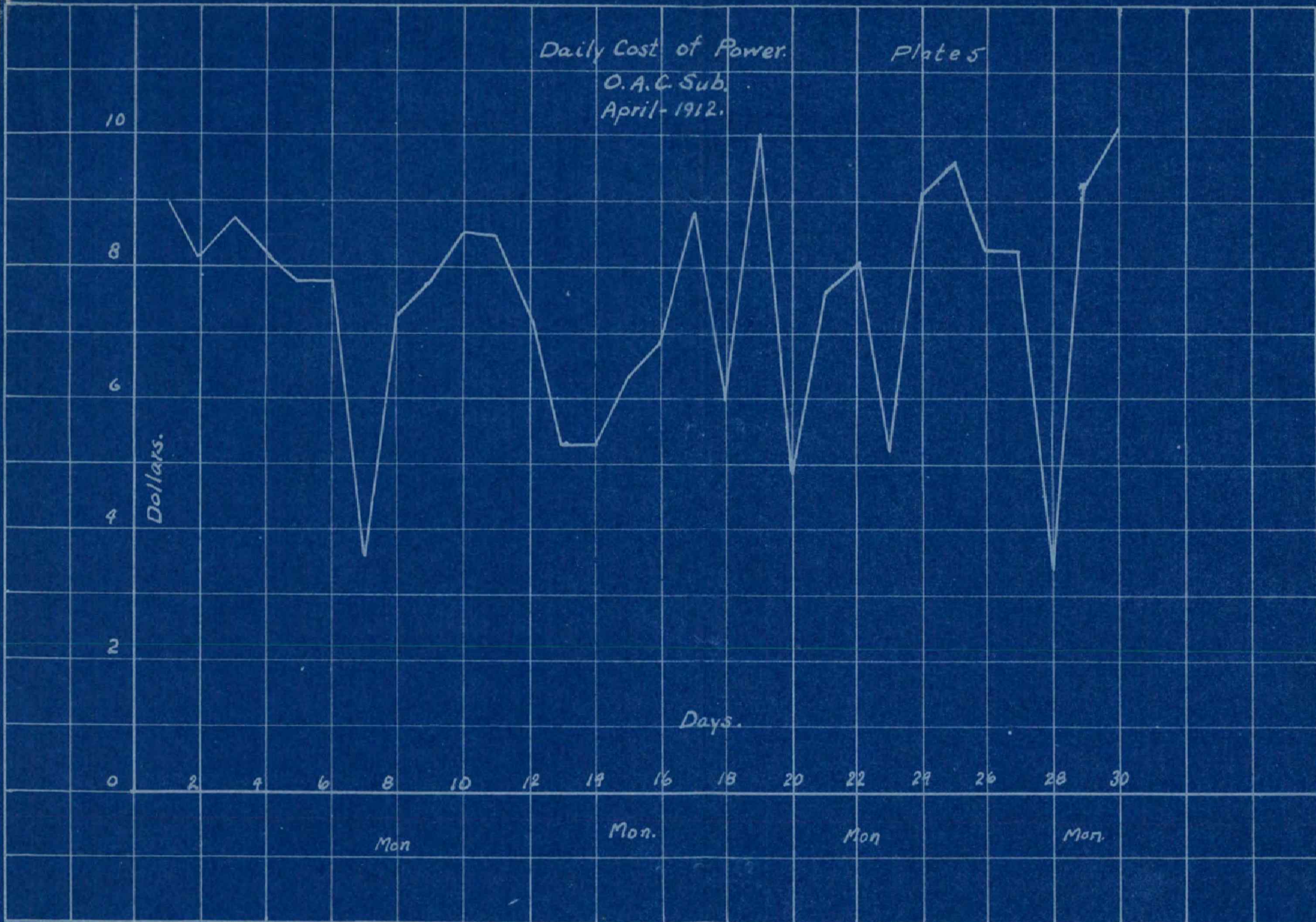


Plate 4.
Daily Power Consumption
And Cost.
O.A.C. Substation.
July-1912.
Days.
Sun
Sun
Sun
Sun
1
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
13
12
11
10
9
8
7
6
5
4
3
2
1
600
500
400
300
200
100


Daily Cost of Power.
O. A. C. Sub.
April - 1912.
Plate 5
Dollars.
10
8
6
4
2
0
Days.
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
Mon
Mon.
Mon
Mon.

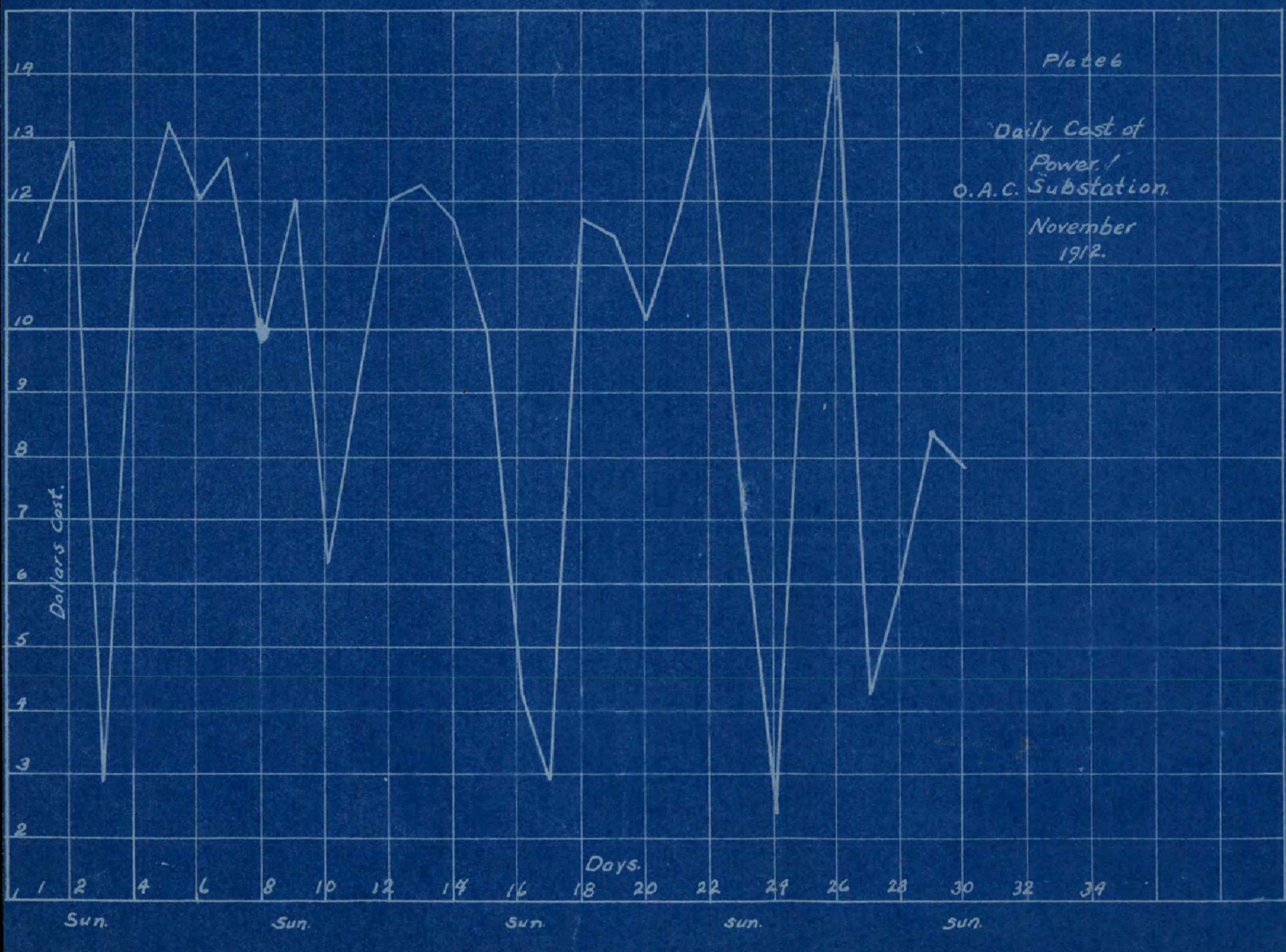


Plate 6
Daily Cost of
Power.
O. A. C. Substation.
November
1912.
Dollars Cost.
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Days.
1
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
Sun.
Sun.
Sun.
Sun.
Sun.

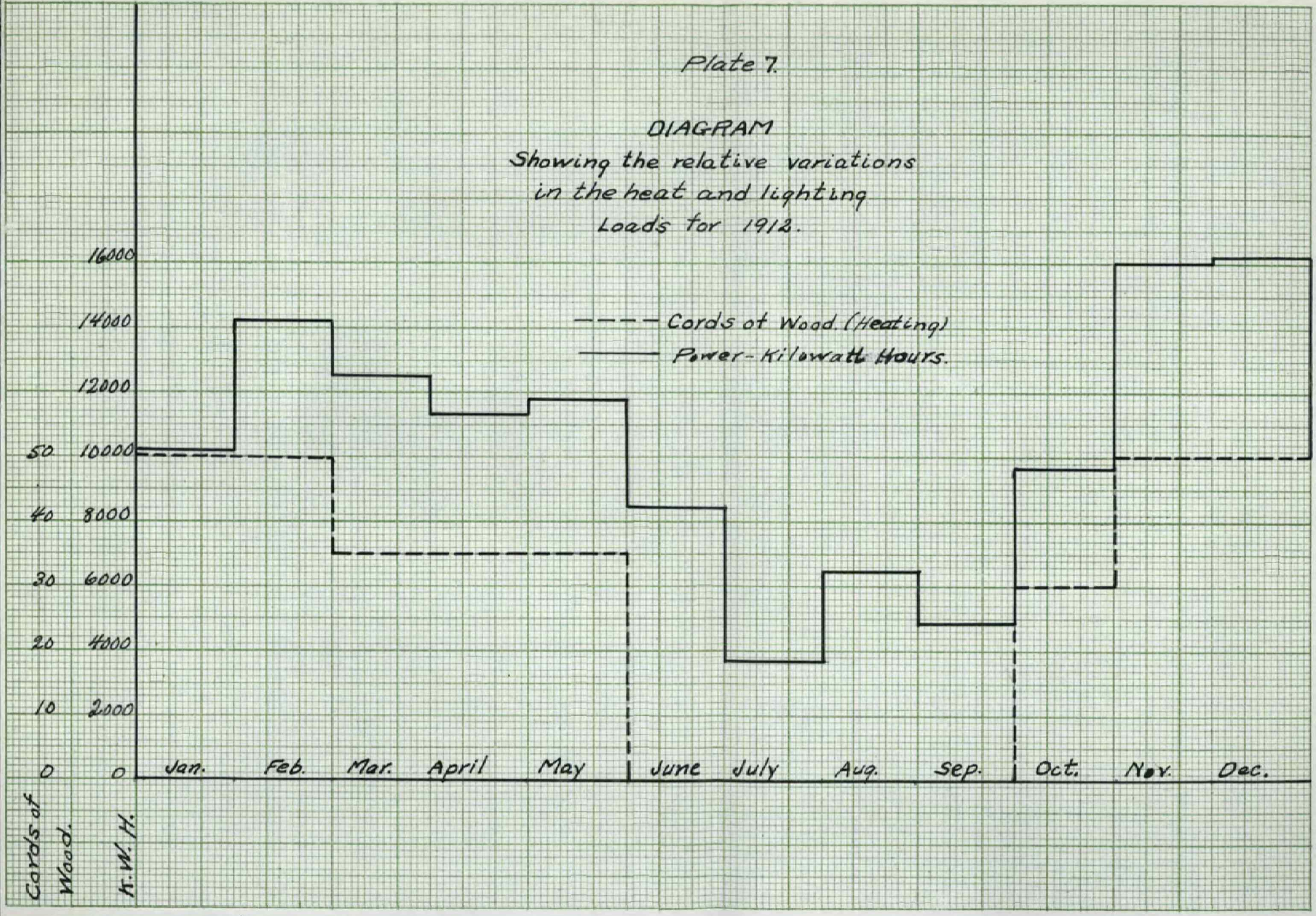
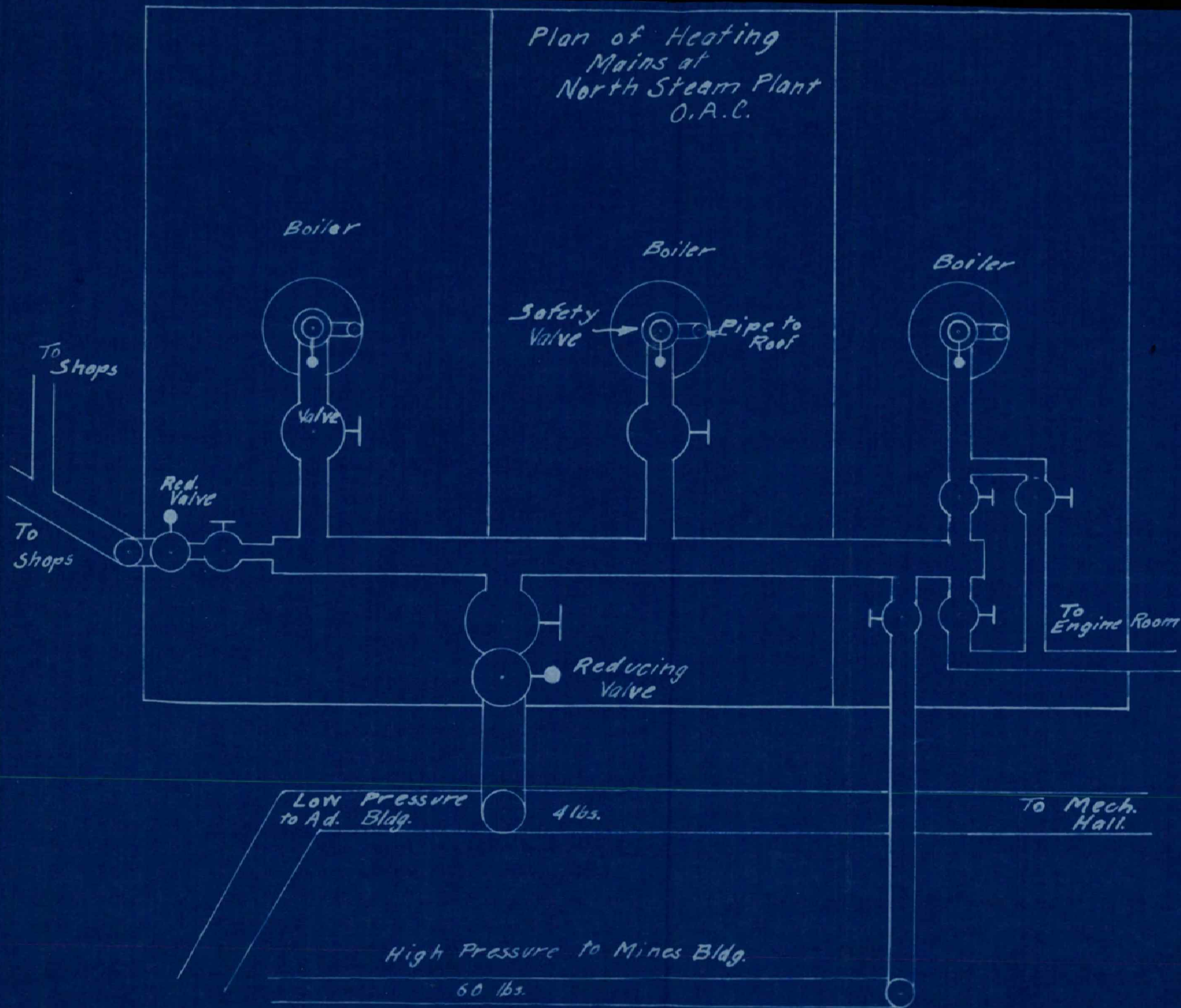


Plate 7.
DIAGRAM
Showing the relative variations
in the heat and lighting
Loads for 1912.
Cords of Wood. (Heating)
Power - Kilowatt Hours.
16000
14000
12000
50 10000
40 8000
30 6000
20 4000
10 2000
0 0
Jan. Feb. Mar. April May June July Aug. Sep. Oct. Nov. Dec.
Cords of Wood.
K.W.H.


Plan of Heating
Mains at
North Steam Plant
O.A.C.
Boiler
Boiler
Boiler
Safety
Valve
Pipe to
Roof
Valve
To
Shops
To
Shops
Red.
Valve
Reducing
Valve
To
Engine Room
Low Pressure
to Ad. Bldg.
4 lbs.
To Mech.
Hall.
High Pressure to Mines Bldg.
60 lbs.