ROGER ALLAN PARSONS

THESIS

REPORT

of

CHEMICAL ENGINEERING 400

or

SENIOR THESIS

Roger Allan Parsons
and
Evans Edward Boucher

6/9/33

12-4-51

FOREWORD

This report relates of the work done by Evans E. Boucher and Roger A. Parsons on their senior problem in fulfillment of the requirements of Chemical Engineering Course #460.

The principle problem taken up was the test run on a "Dailaire" furnace to determine whether or not a blower mount- in the top of a warm air furnace and drawing air through the furnace is more efficient than a blower mounted at the base of the furnace and pushing air through the furnace. This problem occupied most of our laboratory time. The work was carried on in the laboratories of the Dail Steel Products Company, located in Lansing, Michigan.

In addition to our main problem we worked out several practical problems that were brought to our attention. We analyzed a heating problem involving a drying kiln for drying hops. The analysis of this problem is enclosed in this report. In addition to these two problems we made several trips with Mr. Dail and his associates on inspections of installed forced air equipment. The practical knowledge gained on these trips is impossible to present in this report.

We wish to thank Mr. Dail for his assistance in setting up the necessary equipment and also for his timely advice on several important points.

R.A.P

E.E.B.

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Part I

BLOWER TEST

Introduction

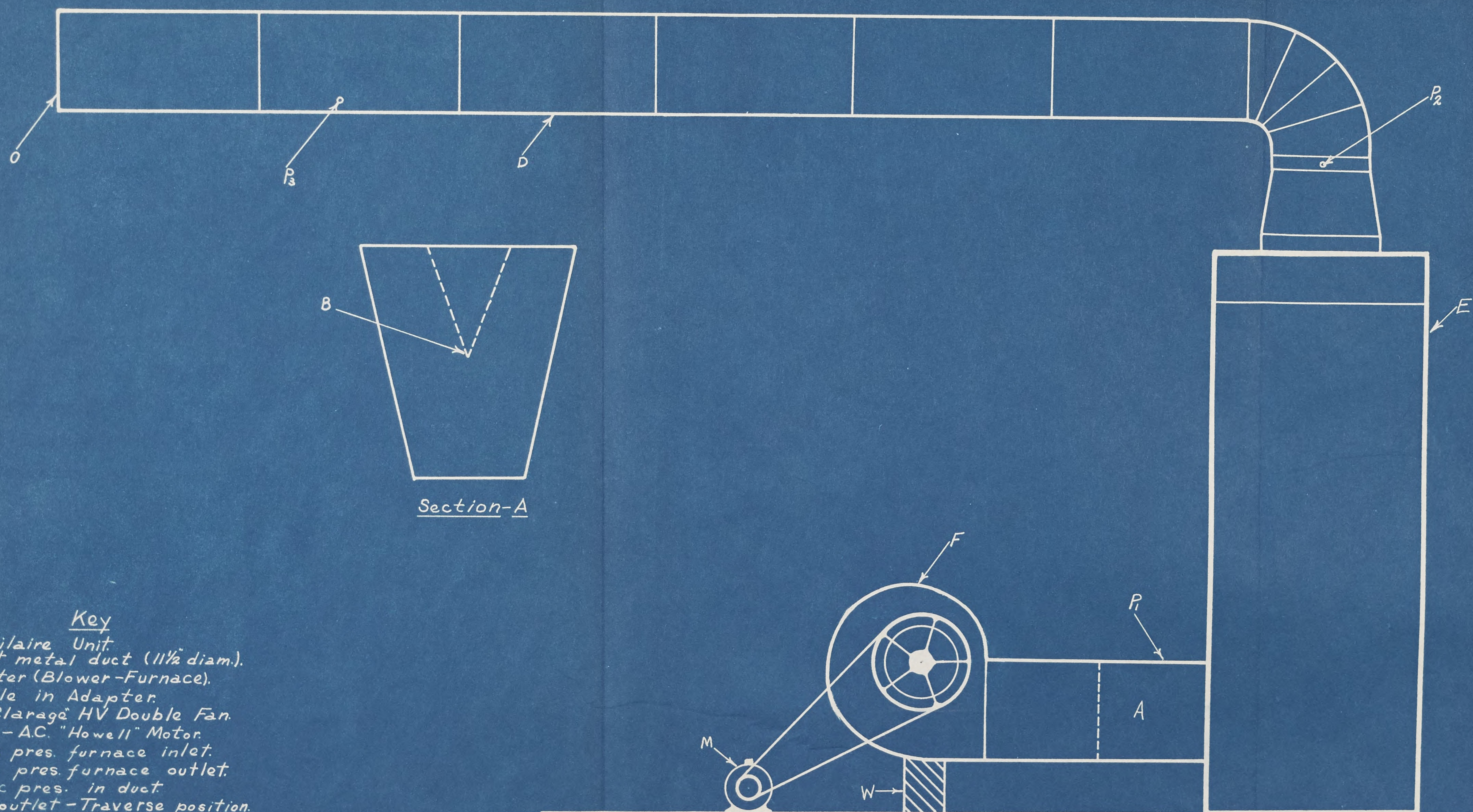
In keeping with the progress of the new air conditioning industry, the Dail Steel Products Company is making a furnace to be used in a forced air heating system. The blower used in connection with this furnace is not, however, simply placed in some convenient place at the bottom of the furnace. It is mounted in the top of the furnace. This practice is followed because it is believed that better air delivery can be obtained with the blower in this position than in any other position.

It is the purpose of this problem to determine the differences in air delivery of a furnace having a blower mounted in the top and the same furnace having the blower at the bottom.

Apparatus

In order that a true comparison might be obtained, all conditions which related to the performance of the test were maintained as nearly identical as possible. A #8 Dailaire furnace was used throughout the test. This furnace is of a size which is used in the average installation, and the inner part is well designed for a forced air system. The construction of the furnace is shown in the pictures. The air enters at each side of the furnace and is circulated around the combustion chamber and compartments containing the hot gaseous products of combustion.

A #7/8 Clarage fan was used throughout the test and was driven by the same constant speed electric motor. In all cases fig. 1



Key

E - #6 Dailaire Unit.
D - Sheet metal duct (11½" diam.).
A - Adapter (Blower-Furnace).
B - Baffle in Adapter.
F - # 7/8 "Clarage" HV Double Fan.
M - ¼ H.P. - A.C. "Howell" Motor.
P_1 - Static pres. furnace inlet.
P_2 - Static pres. furnace outlet.
P_3 - Static pres. in duct.
O - Duct outlet - Traverse position.
W - Wood support.

Date:- 5-12-33	Furnace Blower Test - Blower Pushing	Scale:- 1"=1'

E.E. Boucher

at least twice the area of the fan opening was available for inlet air to the fan.

The size, length, and position of the outlet duct remained the same for each part of the test. The duct was also in the same position in respect to the furnace, and the latter was in the same place in the room. There was at least eight feet of clearance between the end of the duct and the wall or the room.

The tests were all made with air at the same temperature. The same pulleys, revolution counter, stop watch and anemometer were used throughout, with one exception, for which correction was made.

The arrangement of the apparatus is illustrated in figure 1. Twelve feet (six sections) of 11' inch circular duct (D) were used at the outlet of the furnace. The fan (F) was driven by a constant speed motor (M). In the first two parts of the test, the air from the fan passed through the adapter (A) where it was divided equally by the baffle (B) before entering the furnace.

Procedure

The same method of procedure was followed in each part of the test. In order to obtain different fan speeds, and thus different air deliveries, five pulleys of different diameters were used, the speed in each case being constant for the same pulley. The speed was measured by means of a revolution counter and a stop watch.

The average of five readings of the anemometer taken at the end of the duct were used as a basis for determining the air delivery. The five positions of the anemometer were such as to cover the entire duct. One position of the instrument was at the center of the duct, and the other four positions were 90 degrees apart on the circumference.

Data and Results

The test is divided into three parts as follows:

(1) Determination of air delivery with the blower at the bottom of the furnace. (fig. 1)

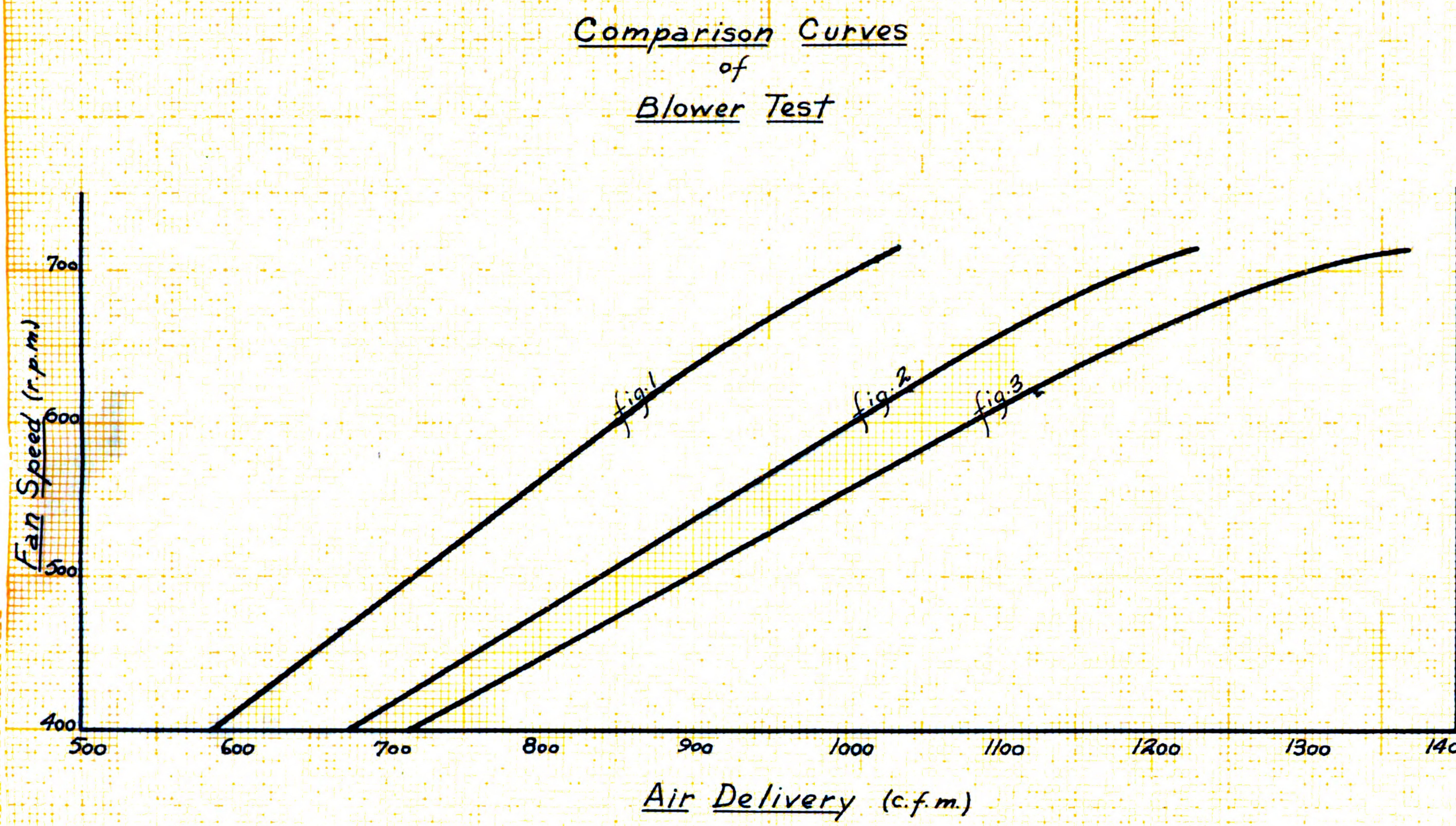
(2) Determination of air delivery with the blower mounted in the top of the furnace using the same inlet as in (1). (fig 2)

(3) Determination of air delivery with the blower mounted in the top using two side openings. (fig. 3) (In this part the back, or adapter inlet, was completely closed off, and in the first two parts the side openings were completely closed off.

The following table and accompanying curves contain the data as tabulated in the laboratory.

Comparison of Deliveries

Motor Pulley Size	Motor Speed (RPM)	Fan Shaft Speed	Fan Pulley Size	Cfm Air Delivery Part (1)	Part (2)	Part (3)	% Eff. of (2) over (1)	% Eff. of (3) over (1)
3"	1750	400	13"	581	673	715	15.8	23
3½"	1750	465	13"	680	772	827	13.5	22
4"	1750	543	13"	760	912	977	20.0	28
4½"	1750	620	13"	873	1040	1120	18.5	27.5
5¼"	1750	715	13"	1035	1230	1370	18.8	31.5
						Average =	17.3	26.4


Comparison Curves
of
Blower Test
Fan Speed (r.p.m.)
700
600
500
400
500
600
700
800
900
1000
1100
1200
1300
1400
Air Delivery (c.f.m.)
fig.1
fig.2
fig.3

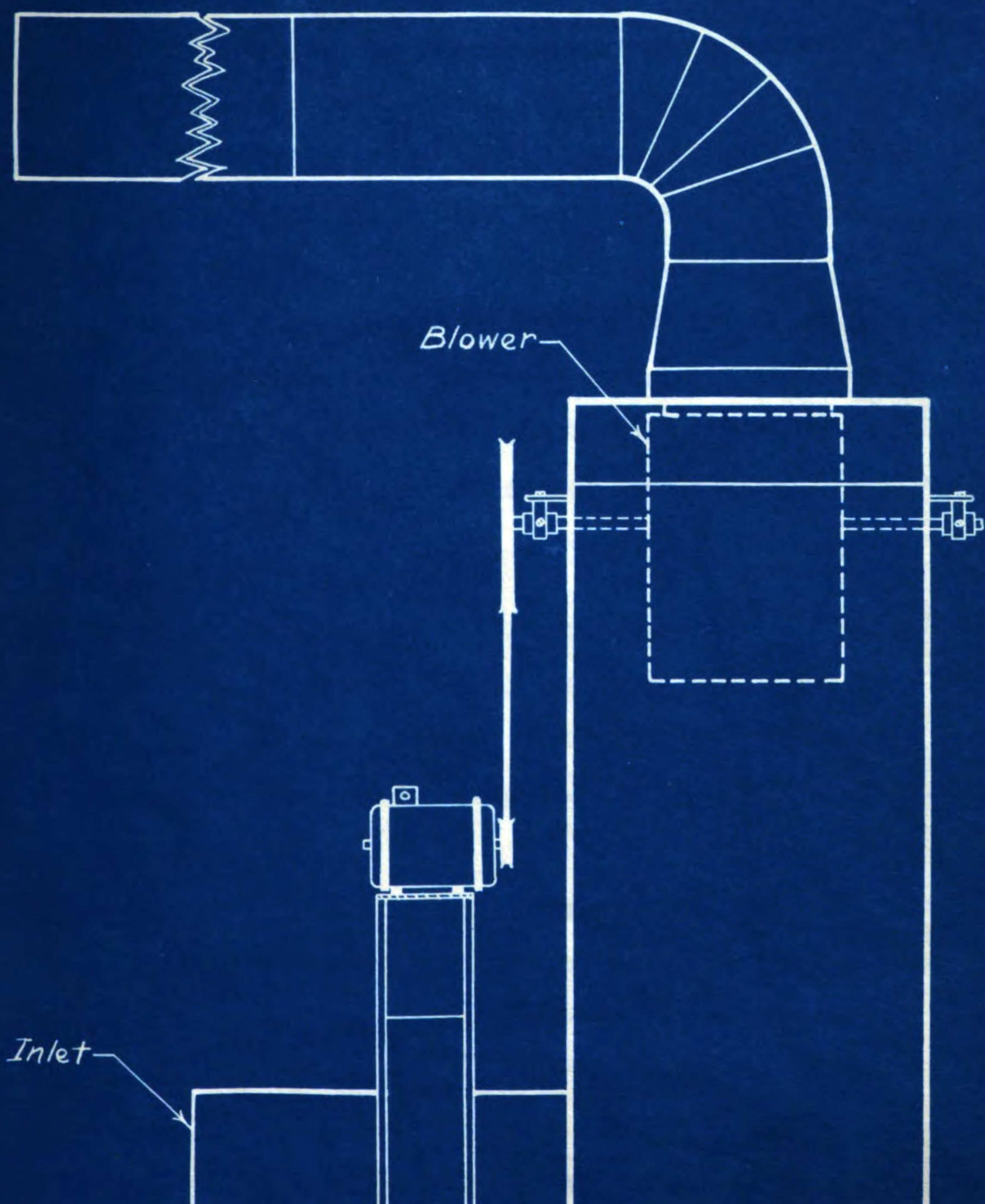
Effect of Air Temperature on Delivery

In connection with this test there was some doubt as to whether or not the blower would deliver more or less air at a temperature higher than that used in the test. This doubt had arisen because of the fact that in actual installations a blower at the bottom of a furnace is moving cold air while a blower in the top of a furnace is moving heated air. Thus, if the temperature of the air has any effect upon the delivery of the fan, a true comparison could not be obtained without applying a correction.

A separate test was run in order to clear up this point in question, the blower being mounted in the top of the furnace. The delivery was first measured with air at 76 F. The burner was then turned on and the temperature of the air increased to 140 F. The delivery at this temperature was found to be identical with that obtained with the air at 76 F. Therefore, we are safe in saying that the temperature of the air had no effect upon the delivery of the fan.

Effect of Friction on Delivery

Another interesting thing was observed in connection with this test. It was in regard to the friction losses in the system with the various setups. The static pressure at three different points in the system was taken for each setup, the same three points being used in each of the three cases. A simple inclined draft gage, calibrated to one-hundredth of an inch of water, was used in connection with a static tube. The three points at which the readings were taken are as follows: (fig. 1) P_1, the center *fig. 2*



Date:-5-14-33

Blower Exhausting

Scale:-1"=1'

on each side of the baffle in the boot opening; P_2, thirteen inches above the top of the furnace; P_3, three feet from the end of the outlet duct.

The difference between the static pressures at points P_1 and P_2 is the friction loss through the furnace, and the difference between readings P_2 and P_3 is the friction loss in the duct. The interesting thing to be observed as a result of these readings is the fact that the friction loss through the furnace was approximately the same for each setup, at the same fan speed. It may therefore be concluded that any difference in air delivery among the three setups was not due to difference in friction.

Discussion of Results

The question then is, what does cause the difference in air delivery in the different blower arrangements? Upon observation of the data, or curves plotted from the data, it appears that the differences are due entirely to the turbulence of the air in the furnace.

In part (1) (fig.1) with the blower at the bottom, the air is forced straight ahead against the inside of the furnace. Eddies are then set up, because the air must change its direction to go to the top of the furnace and out the ducts, but is held back by more air being forced in against it. The air already in the furnace must be displaced, however, and so it is squeezed out by the incoming air. This condition does not produce a uniform flow from the blower, but it sets up a back pressure or damper effect which prevents the fan from delivering as much as

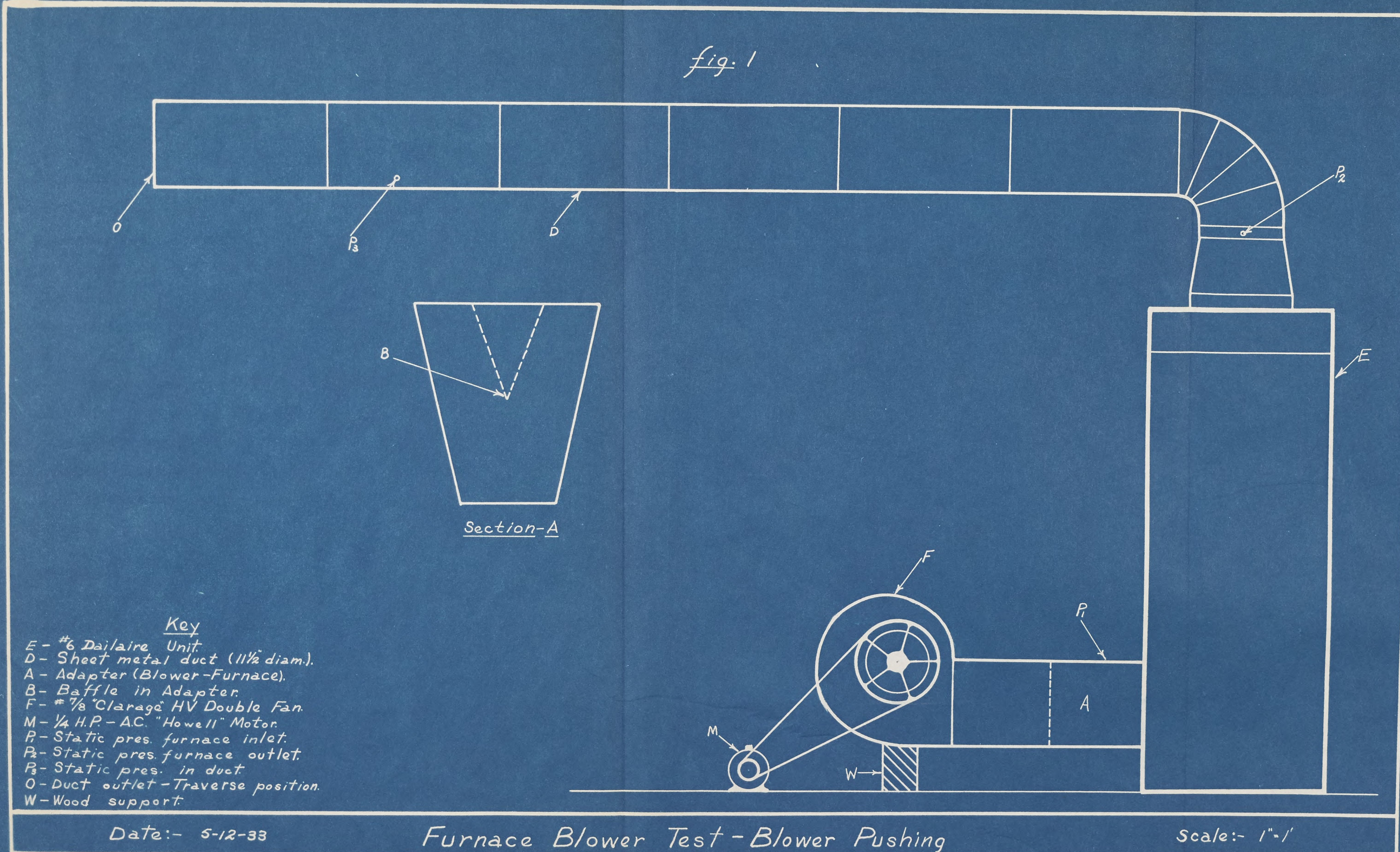


fig. 1
O
P3
D
P2
B
E
Section-A
F
P1
A
M
W
Key
E - #6 Dailaire Unit.
D - Sheet metal duct (11½" diam.).
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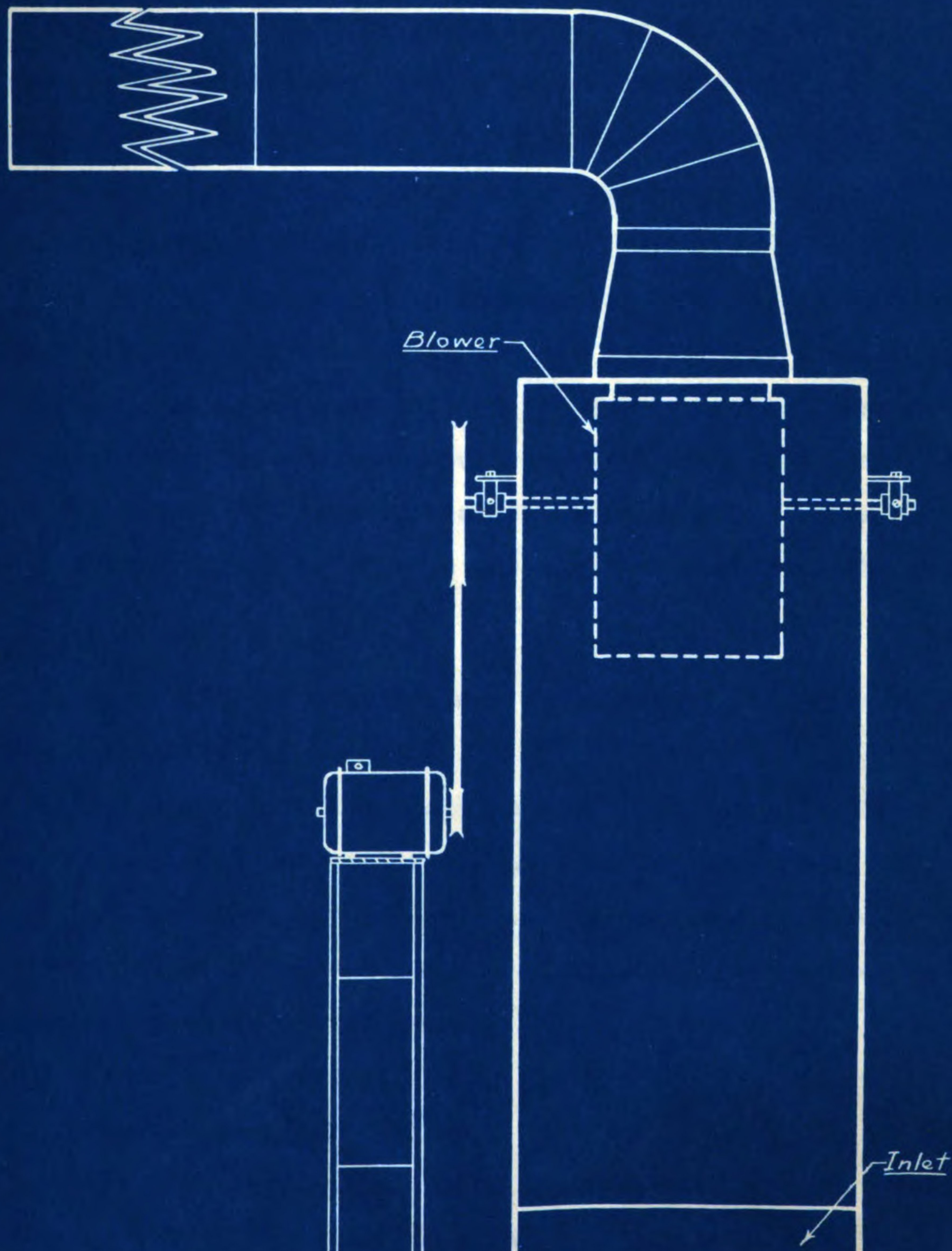
M - ¼ H.P. - A.C. "Howell" Motor.
P1 - Static pres. furnace inlet.
P2 - Static pres. furnace outlet.
P3 - Static pres. in duct.
O - Duct outlet - Traverse position.
W - Wood support.
Date:- 5-12-33
Furnace Blower Test - Blower Pushing
Scale:- 1"=1'
E.E. Boucher

fig. 3



Date:- 5-15-33 | Blower Exhausting | Scale:- 1" = 1' it should. That is, some of the air is forced out the blower through the same opening it entered.

In part (2) (fig.2) with the blower at the top and the air entering through the same opening as in part (1), the air is not forced against the inside of the furnace, but is drawn up through it, thus eliminating a large amount of the eddies and turbulence which were present in part (1).

The best air delivery was obtained in part (3) (fig.3) in which the blower was mounted in the top and air was admitted through an opening on each side of the furnace. This arrangement results in the minimum amount of turbulence or damper effect. The reason for this is that the side openings allow a steady stream of air to flow up through the furnace to the fan.

<u>Conclusion</u>

In reviewing the observations made in this test, the following statements may be made:

1. Maximum air delivery may be obtained with a blower mounted in the top of a furnace having an inlet on each side.

2. An increased air delivery may be obtained by placing a blower on top of a furnace instead of at the bottom, other conditions being equal or the same.

3. The air delivery of a #7/8 Clarage fan is independent of the temperature of the air.

4. Friction loss in a furnace is independent of the motion of the air, other things being equal.

Form 257-G

Sheet No. 1

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

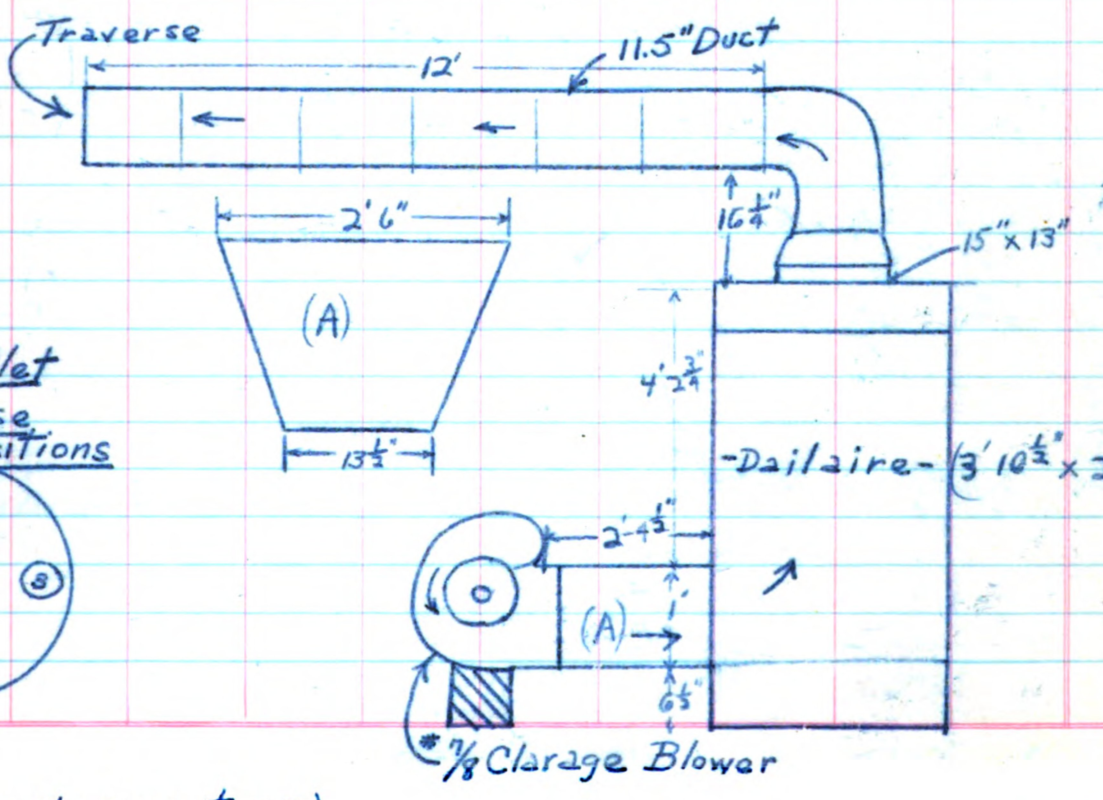
Running Log of Blower Setup — Pushing (Volume Delivery vs. Speed)

Observers { R. A. Parsons, E. E. Boucher

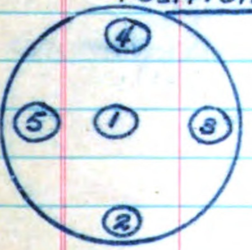
Date 4/30/33, 193

No.	Pulley Diam. (inches)	Fan Speed (r.p.m.)	Traverse Anenometer Readings (lin.ft./min) — Position 1	2	3	4	5	Aver.	Volume Factor	Volume (c.f.m.)
1	5 1/4	715	1530	1380	1400	1450	1380	1430	.723	1035
2	4 1/2	620	1280	1200	1175	1215	1200	1214	.723	878
3	4	543	1120	1040	1000	1060	1030	1050	.723	760
4	3 1/2	465	980	892	927	954	942	940	.723	680
5	3	400	828	760	795	826	815	804	.723	581
6										
7										
8										

Apparatus Setup



Duct Outlet Traverse Positions



Remarks:

No heat (Air at room temp.)

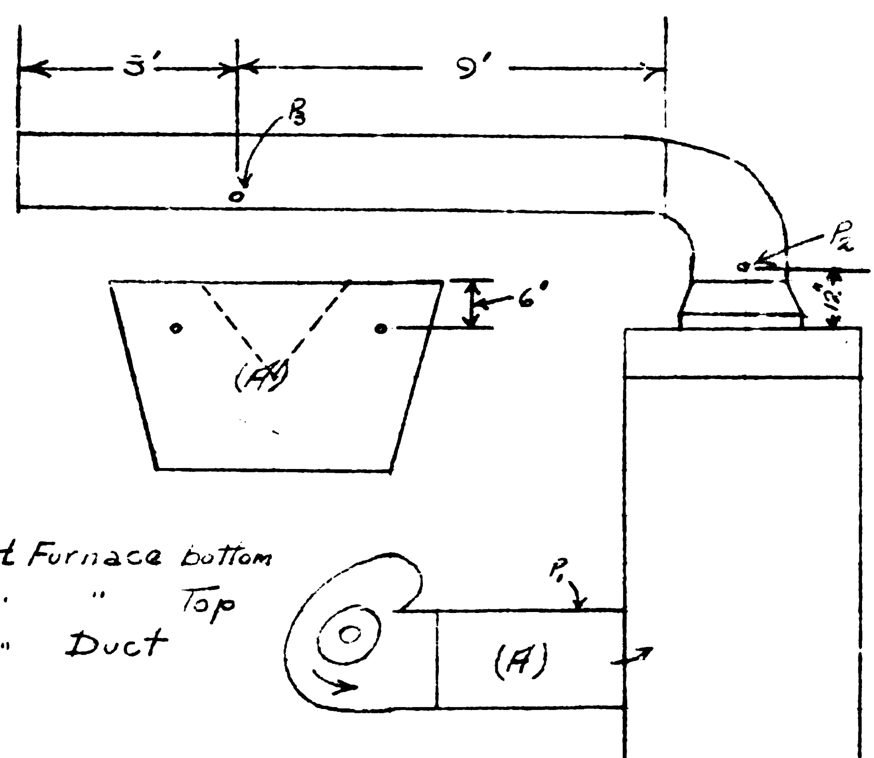
Form 257-G Sheet No. 2

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of Blower System Pushing (Pressure Losses)

Observers { E. E. Boucher, G. A. Parsons } Date May 2, 1933

No.	Pulley Diameter (inches)	Fan Speed RPM	Static Pres At Fan (In H_2O)	Static Pres in Duct (in. Water)	Static Pres at Furnace Top (in. Water)	Friction Loss Thru Furnace (in Water)	Friction Loss in Duct (in Water)	Friction Loss in System (in Water)
1	3	400	.065	.008	.037	.028	.029	.057
2	3½	465	.081	.010	.049	.032	.03[illegible]	.071
3	4	543	.110	.015	.066	.044	.051	.095
4	4½	620	.148	.020	.083	.065	.063	.125
5	5¼	715	.192	.027	.108	.084	.081	.165



21 P_1 – Static press. at Furnace bottom
22 P_2 – " " " Top
23 P_3 – " " " Duct

Remarks:

E. Boucher

Form 257-G Sheet No. 3

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of Blower System - Pulling
(A.) Regular Setup (opening in side)

Observers E. E. Boucher, R. A. Parsons

Date 5/8/33, 193

Traverse Anemometer Readings (Ft/Min) — Position

No.	Pulley Diam (Inches)	Fan Speed (RPM)	1	2	3	4	5	Aver.	Volume Factor	Volume (C.f.m.)	Anemometer Correction	Volume (c.f.m.)
1	5¼	715	1980	1850	1953	1920	1780	1901	.723	1370	✓	1370
2	4½	620	1640	1360	1600	1550	1425	1550	.723	1120	✓	1120
3	4	545	1622	1605	1622	1560	1532	1590	.723	—	.85	977
4	3½	465	1368	1341	1390	1360	1270	1346	.723	—	.85	827
5	3	400	1190	1160	1175	1207	1090	1164	.723	—	.85	715
6												
7												
8												
9												
10												
11	(B.) Boot Inlet											
12												
13												
14												
15	5¼	715	1810	1740	1672	1652	1620	1700	.723	1230	✓	1230
16	4½	620	1535	1462	1430	1412	1385	1445	.723	040	✓	1040
17	4	544	1520	1550	1480	1425	1454	1480	.723	—	.85	912
18	3½	465	1300	1290	1250	1210	1235	1255	.723	—	.85	772
19	3		1130	1100	1090	1065	1097	1096	.723	—	.85	673
20												
21			for Correction Factor (Anemometer)									
22	~~4½~~	~~620~~										
23												
24												
25												

for Correction Factor (Anemometer)

$$C.F. = \frac{1380}{1622} = .85$$

E. E. Boucher

Remarks: Beginning with 4" pulley a different anemometer was used. The factor to correct this with the first inst-

Form 257-G

Sheet No. 3a

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of Comparison of Heated - Cool Air

Observers Parsons, Boucher

Date 5/9, 1933

No.	Pulley Diam. (in.)	Fan Speed (r.p.m.)	Delivery Anemometer Traverse Readings (ft./min.) 1	2	3	4	5	Aver.	Volume Factor	Volume (c.f.m.)	Outlet Air Temperature (°F)
1	3½										Air at Room Temp (Cool) 76°
2	4	520	1510	1525	1460	1400	1470				
3	4½										
4											
5	3½										Heated Air 140°
6	4	520	1520	1505	1440	1400	1460				
7	4½										
8											

Static Pressures

No.	Pulley Diam. (in.)	Fan Speed (r.p.m.)	Static At Furnace Bottom (P_1)	Static In Duct (P_2)	Static loss thru System (in. H_2O)	outlet air Temp (°F)	Total in Duct	Total bottom Furnace	Total Top Furnace
9									
10									
11									
12									
13									
14	**Air At Room Temp.**								
15									
16	3½								
17	4	520	-.015	.02		76	.105	-.025	.21
18	4½								
19									
20	**Heated Air**								
21									
22	3½								
23	4								
24	4½								
25									

Remarks:

Form 257-G Sheet No. 4

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of Blower System - Pulling

Observers { E. E. Boucher, R. A. Parsons } Date 5/11/33, 193

No.	Pulley Diameter	Fan Speed RPM	Static Pres In Duct (In Water)	Static Pres At Furnace Top (In Water)	Static Pres At Furnace Entry (In Water)	Friction Loss Thru Furnace	Friction Loss In Duct	Friction Loss In System
1	3	400	.015	.035	-.035	.030	.020	.050
2	3 1/2	465	.020	.060	-.050	.030	.040	.070
3	4	543	.025	.075	-.070	.045	.050	.095
4	4 1/2	620	.030	.095	-.090	.055	.065	.120
5	5 1/4	715	.040	.120	-.120	.080	.080	.160
6								
7								
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25								

Remarks:

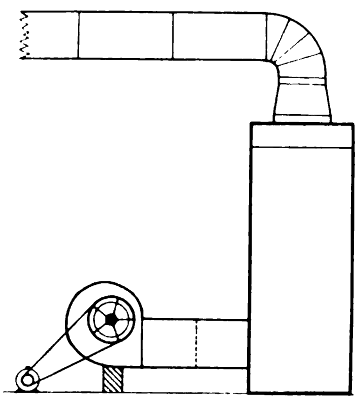
Dailaire

System of Heating and Air Conditioning

The following tests have been made on a No. 6 Dailaire unit to compare the relative merits of a fan placed in rear of heating plant, as is general common practice and the Dailaire method of placing blower in the top of casing above the heating plant - In all cases same size fan was used - The results are obviously in favor of the Dailaire system.

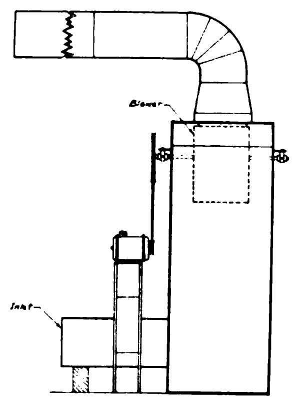
Table of Comparison

Motor Pulley Size	Motor Speed	Size Fan	Fan Shaft Speed	Fan Shaft Pulley	C.F.M. Air Delivery Set-Up No. 1	Set-Up No. 2	Set-Up No. 3	Percentage of Efficiency of No. 3 over No. 1.
3"	1750	7/8	400	12"	581	673	715	23%
3 1/2"	1750	7/8	465	12"	680	772	827	22%
4"	1750	7/8	543	12"	760	912	977	28%
4 1/2"	1750	7/8	620	12"	878	1040	1120	27.5%
5 1/4"	1750	7/8	715	12"	1035	1230	1370	31.5%
					E. E. Boucher — R. A. Parsons		Average	26.4%



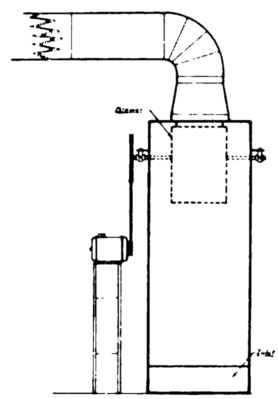
Set Up No. 1

This set up is with blower in Rear and pushing air into furnace casing which is general practice with other furnace manufacturers.



Set Up No. 2

This set up is with blower in top of furnace but taking air in at rear through same boot as in Set Up No. 1.



Set Up No. 3

This is standard Dailaire practice with blower in top and taking incoming air in at both sides of furnace at the bottom.

East Lansing, Michigan.
May 19th-1933.

Dail Steel Products Company,
Lansing, Michigan.

Gentlemen:--

Referring to the tests recently run on blowers in connection with your furnace, for the purpose of determining the relative efficiency of pushing the air through the furnace in comparison to pulling the air. We herewith submit charts and tables showing the results of the two methods, together with drawings showing location of blowers and air inlets. From the attached tables it is apparent that the same fan running at the same speed, will deliver an average of 26.4 percent more air when the fan is at the top of the furnace, and with air intakes on each side of furnace, which we understand is your standard practice, than when the fan is placed at the base of the furnace, as is customary practice with other manufacturers.

We believe this is accounted for by the fact, that pushing the air creates a turbulence, thus retarding the flow of air, while pulling the air results in an even distribution over every part of the furnace.

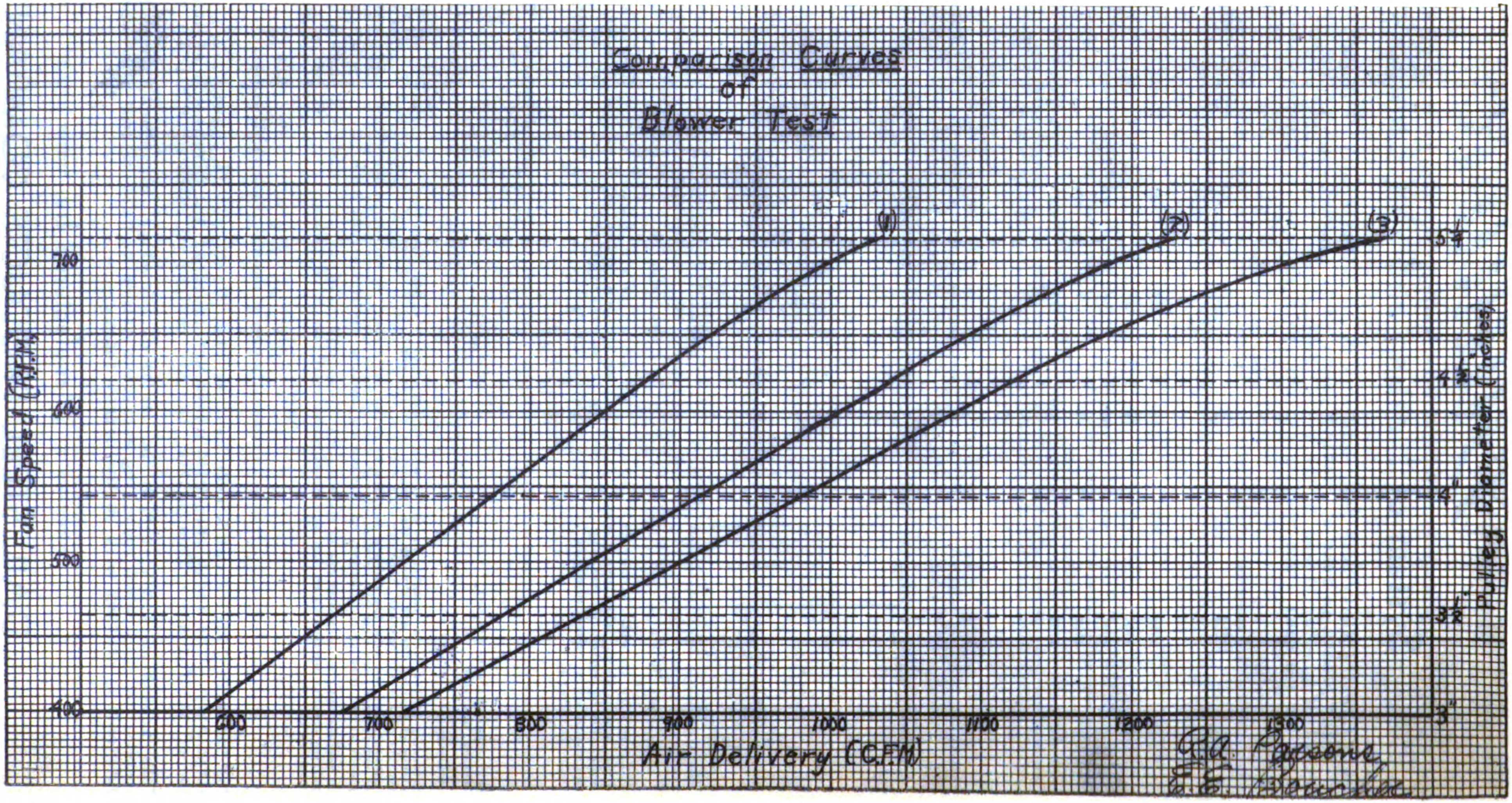
Signed James E. Boucher
Robert A. Parsons
Senior Engineering Students Michigan State College.

The Dailaire line is not a made over heating plant, but is engineered to give the greatest efficiency - The facts presented above are proof of the advantages of locating the fan in top of the furnace - Thus pulling the air instead of pushing it through the furnace.

This inovation together with the use of chrome alloy (stainless steel) in combustion chamber and increased radiating surface combines to make Dailaire the most effiɕient and outstanding heating unit on the market today.

Dailaire System of Heating and Air Conditioning

The following Graph shows the curves on tests as run on opposite side of this sheet, and shows a true comparative picture of the superior efficiency of pulling air through the heating plant in place of pushing it.



Part II

HOP DRYING

Introduction:

In our work with Mr. Dail we came in contact with a drying problem. Being Chemical Engineering students, we felt that we would benefit by analyzing the problem. It was a problem on the calculation of the heating load for a hop kiln at Yakima, Washington. In addition to the analysis of this problem we made a brief study of the harvesting and drying of hops, giving a discussion on some of the present types of hop kilns.

Harvesting and Drying of Hops

August and September are the hop harvesting months in California. The crop in the Sacramento Valley matures from one to two weeks earlier than in the coastal area. At harvest, the vines are pulled from the trellis and the cones are picked, either by hand or by machine. Picking two hundred pounds of cones by hand is a good day's work, although three to four hundred pounds are sometimes picked. Picking charges vary from 80 cents to $1.00 per 100 pounds.

Hop picking machines have been successfully used in some large yards. One machine with 40 men can harvest twelve to fifteen hundred bales (1 bale 180 to 200 pounds) per season (an average of 250,000 pounds), or the hops from about 150 acres. One machine will, therefore, replace from 225 to 250 hand pickers. When picked the contains from 65 to 75 per cent water. Drying to 10 to 14 per cent water is necessary to prevent spoilage during storage.

For drying, the cones are piled in a loose level pile (about 18 inches deep) on the drying floor. When the floor is filled the kiln is closed except for the ventilators and openings where cold air is admitted and the fire increased. The temperature beneath the drying floor is kept low at first, about 100 to 130 degrees; as the drying progresses the temperature is increased to 150 or 160 degrees Fahrenheit. The temperature is controlled somewhat by the firing, but more by regulating the admission of cold air and the ventilators at the top. A thermometer is suspended just under the drying floor.

Too high temperatures are certainly bad, for even if the hops are not scorched or scalded much of the volatile oils are driven off and certain changes are produced in the lupulin.

At a temperature not exceeding 160 Fahrenheit it requires from ten to eleven hours to dry an eighteen inch floor of hops. When the hops have been on the floor long enough for the heat from below to have gone through them, they are turned so as to get the more moist ones from the top onto the bottom next to the cloth. In a very short time after they are turned they will be ready to take off the kiln. When properly dried the bracts will be perfectly dry, but the stems of the cones will still be soft and pliable. Here is where the experience and skill of the drier comes in. Insufficiently dried hops are apt to mold or heat in the cooler and if highly dried the bracts break off and the lupulin falls out, seriously injuring the quality of the hops.

From the drying floor the hops are removed to the cooling room where they lose their heat and absorb some moisture from the air. The stems are usually not so dry as the other parts of the hop, and during the sweating process the moisture is equalized and the hops become tough and pliable. The best informed growers recognize that other important changes occur during the sweating process which materially affect the quality of the product. A finer and more pleasing aroma, as well as a better physical appearance, is developed during sweating, provided the process is carefully watched and the hops prevented from becoming too moist or heated. Under ordinary circumstances these two evils are avoided by loosening up the hops and turning them over with forks or by moving them to another part of the cooler. If taken in time, slack hops may be brought out in this way and practically freed from their sour, musty smell. If the hops in the cooler become too moist, their condition may be improved by dumping over them a car full or hot dry hops just from the kiln. Likewise hops that have become too dry in the cooler may be helped by mixing with them hops taken from the kiln a little before they are properly dry. Great care and good judgment are necessary for proper handling in the cooler, and more attention given to this phase of hop curing will certainly result in an improved quality of product.

It is the practice among some California growers to sulphur hops during the drying process, although unsulphured hops bring a premium of 2 to 3 cents per pound. Sulphuring aids in the drying process, bleaches the hops to the desired color, and assists in holding the quality of hops during storage, although in past hears some difficulty has arisen from the arsenical content of hops. For exporting to England, hops must not contain arsenic in excess of 0.01 grains per pound, or 1.4 parts per million. As it has been proven that most of the arsenic in hops is obtained from the use of impure sulfur, only sulfur free from arsenic should be used.

Quality

The following characteristics determine the quality and value of hops.

1. They should have a silky luster and be of a pale greenish-yellow or golden color, neither too green or too much bleached.

2. The cones should not be too large and are preferred of a conical shape, rather than cylindrical or spherical. The size depends on the locality where grown and to be considered in that light, but generally the smaller the hop the greater the proportion of lupulin. The cones should not be broken or the bracts standing open, as then the lupulin readily drops out and is lost.

3. They must be clean picked, free of leaves and stems, weeds, dirt or other foreign matter; free of discolored or moldy hops.

4. They should possess a fine strong aroma free of any moldy, musty or garlicky smell. New hops have the strongest

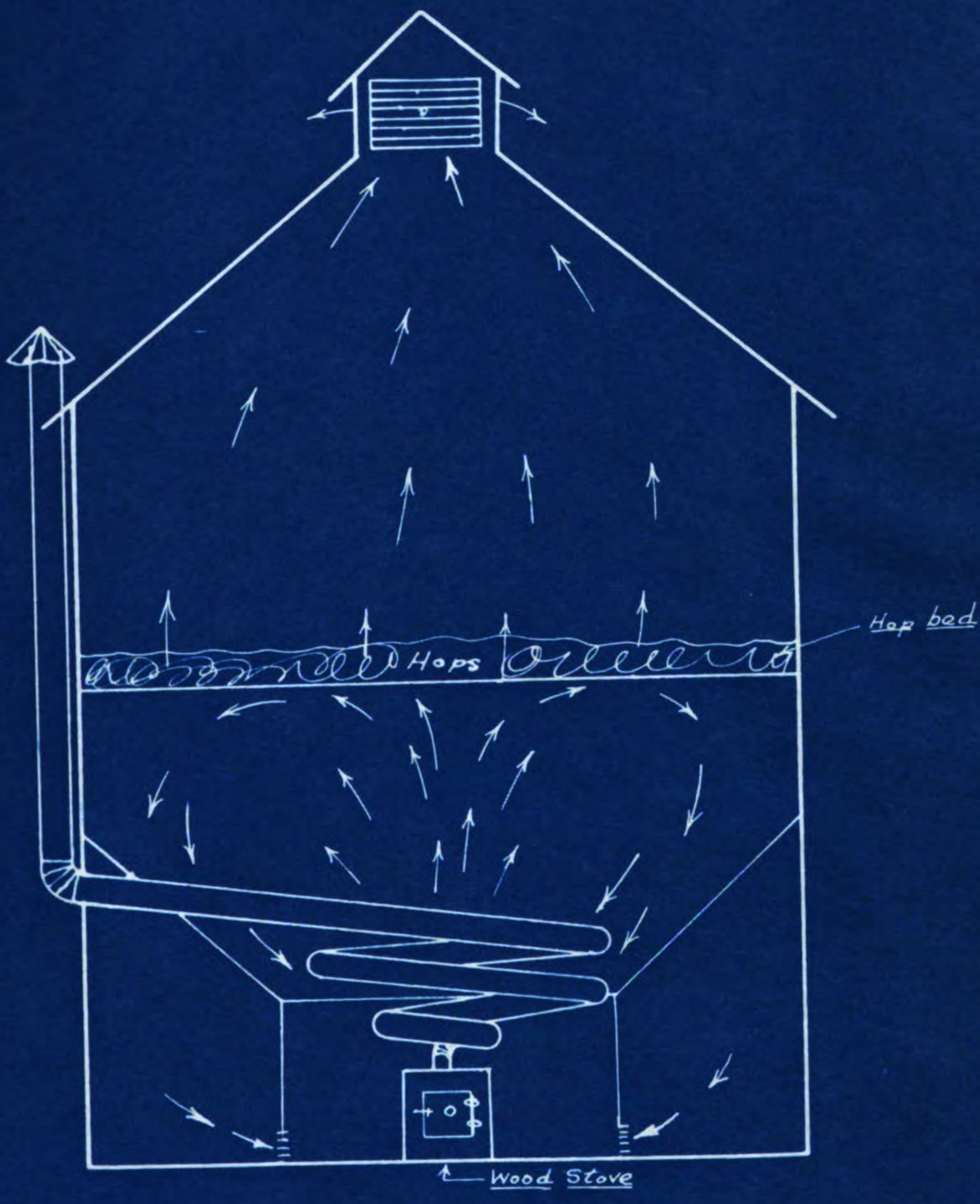
aroma; this declines with age and finally gives place to a cheesy smell in old hops.

5. A maximum lupulin content is desirable. Further, they should be neither slack dried nor high dried. They should not be broken by squeezing in the hand, but when firmly pressed in the hand they should adhero closely together at first and then slowly assume their original form.

Present types of kilns

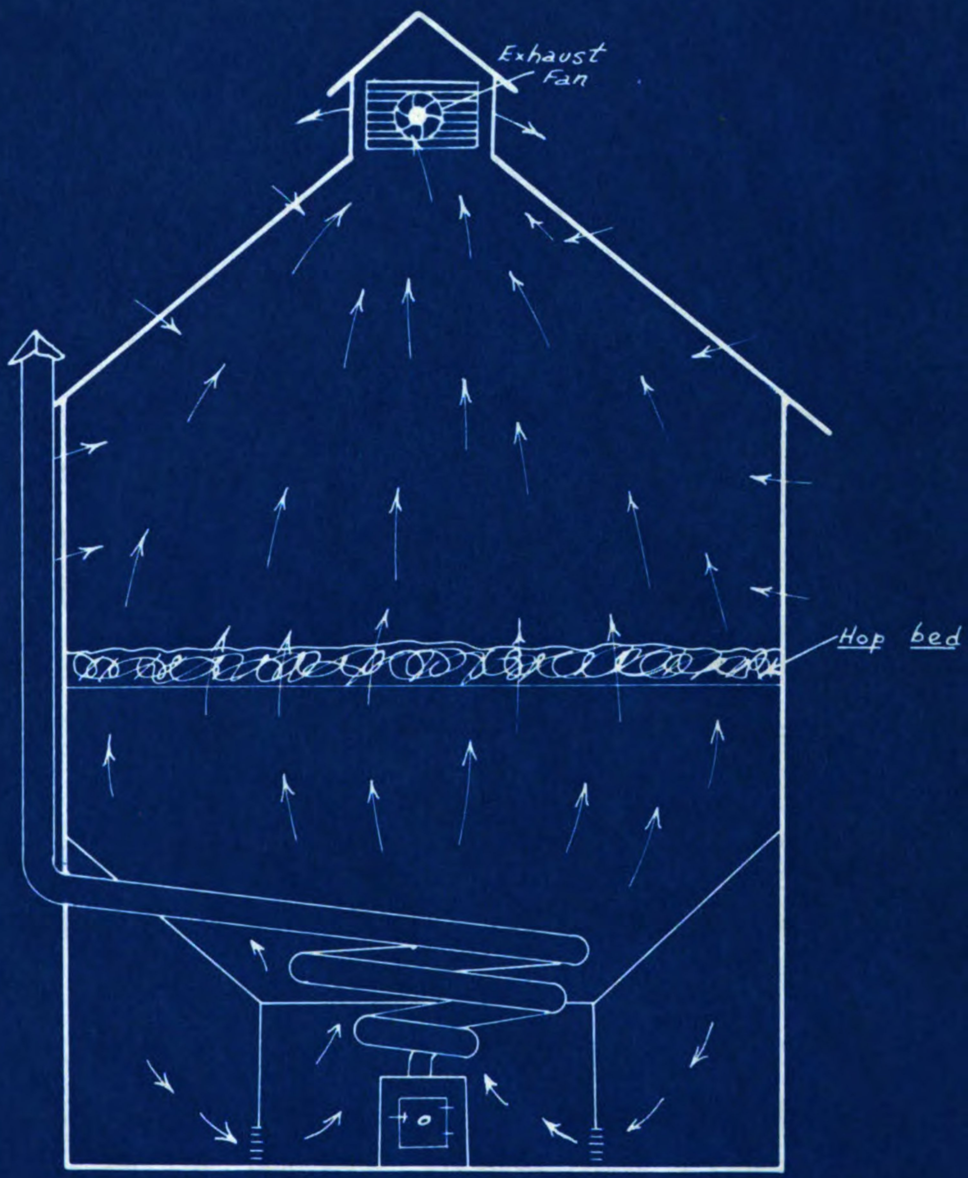
The kilns in use at the present time are built in a two story arrangement. A heating unit is placed on the ground floor and a drying area, composed of 2x4 rafters covered with coarse burlap, constitutes the upper floor. The roof goes to a peak, at which is placed an exhausting louver arrangement.

The oldest type (fig.1) is one in which a gravity heating stove (wood burning) is placed in the bottom and the warm air rises from this up to the hop bed. It requires a considerable length of time for the warm air to break through the hop bed, but when it does the drying is finished in a short time. Some of the more observing owners took advantage of this fact and placed fans in their structures to help create a pressure to force circulation through the hop bed. Figure 2 shows a fan installed in the top of the kiln and exhausting air from the structure. This arrangement proved to be quite practical. Its greatest fault was the creating of a vacuum above the hop bed which in turn caused a large amount of infiltration (as indicated by the arrows) which resulted in heat losses and dust.



(fig. 1)

E.E.B.



(fig. 2)

E.E.B.

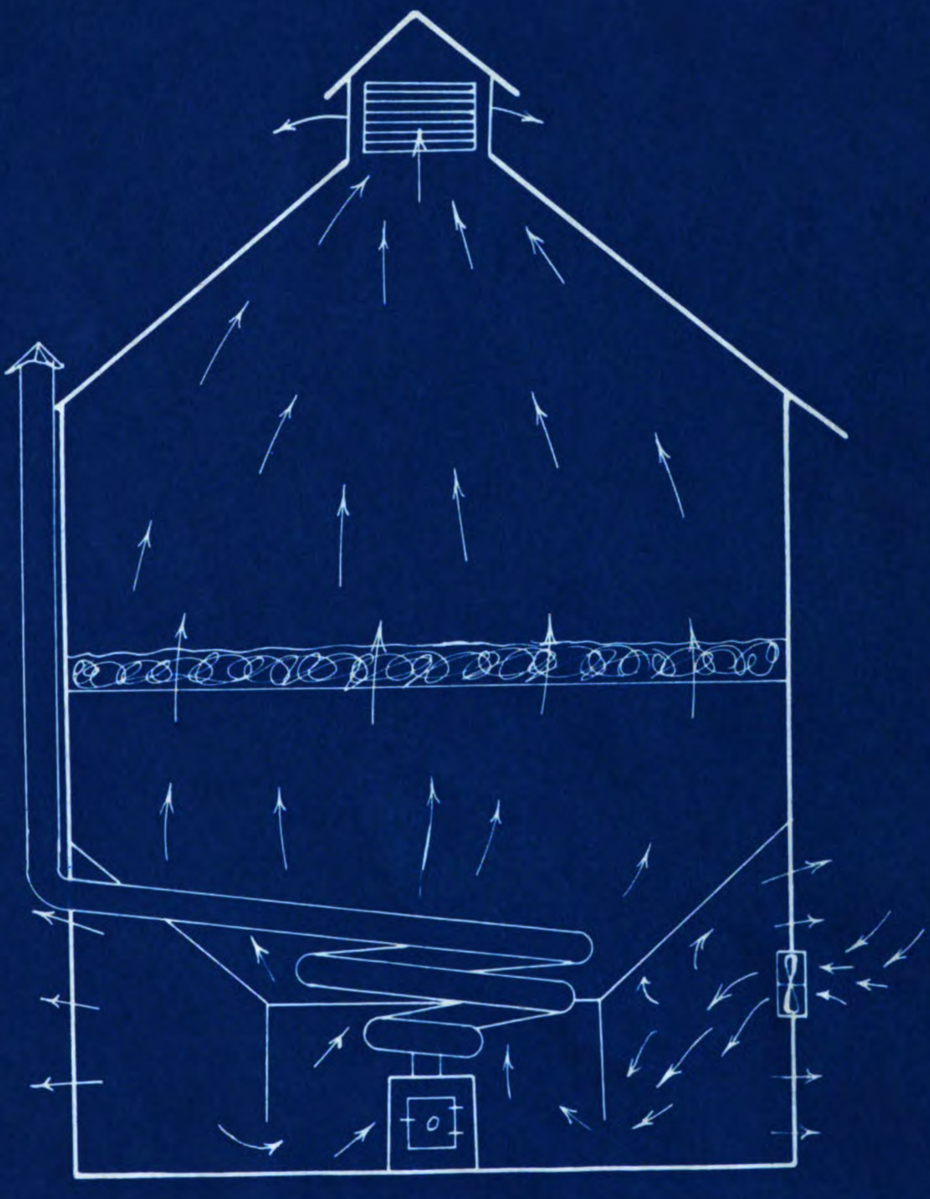
Figure 3 illustrates another type of auxiliary fan installation. The fan is mounted in the wall of the heater room and creates a large static pressure, which is transmitted by the heating ducts to the hop bed above. This arrangement also results in large losses due to the exfiltration from the heating room.

The inefficiency of these installations is largely due to the loose construction of the building and not so much to the type of heating system. The buildings, therefore, must be properly constructed in order to have much success with a forced air heating system.

The ideal equipment for drying hops, we then conclude, would consist of a fan installed in a building of fairly tight construction. This system would shorten the drying period considerably and also facilitate the control of the drying operation.

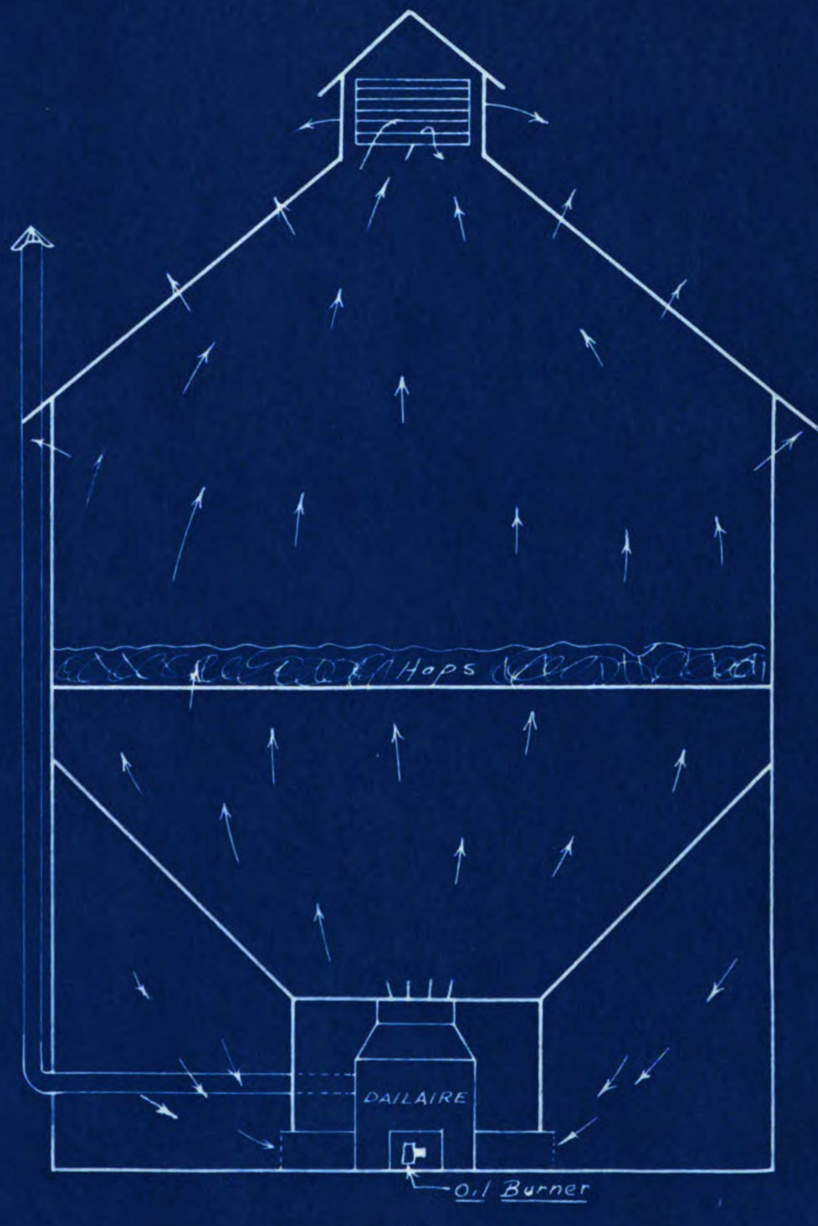
Figure 4 shows a Dailaire installation which is sealed from the furnace to the hop bed. In this case no warm air is lost through the walls below the hop bed and no air is drawn into the building above the hop bed. On the other hand, the air passing out of the top and through the walls above the hop bed is carrying part of the moisture in the hops along with it and thus no loss is incurred. This system thoroughly sealed throughout, with the exception of the exhaust louvers, would probably be even better.

Figure 5 illustrates a sealed forced warm air system



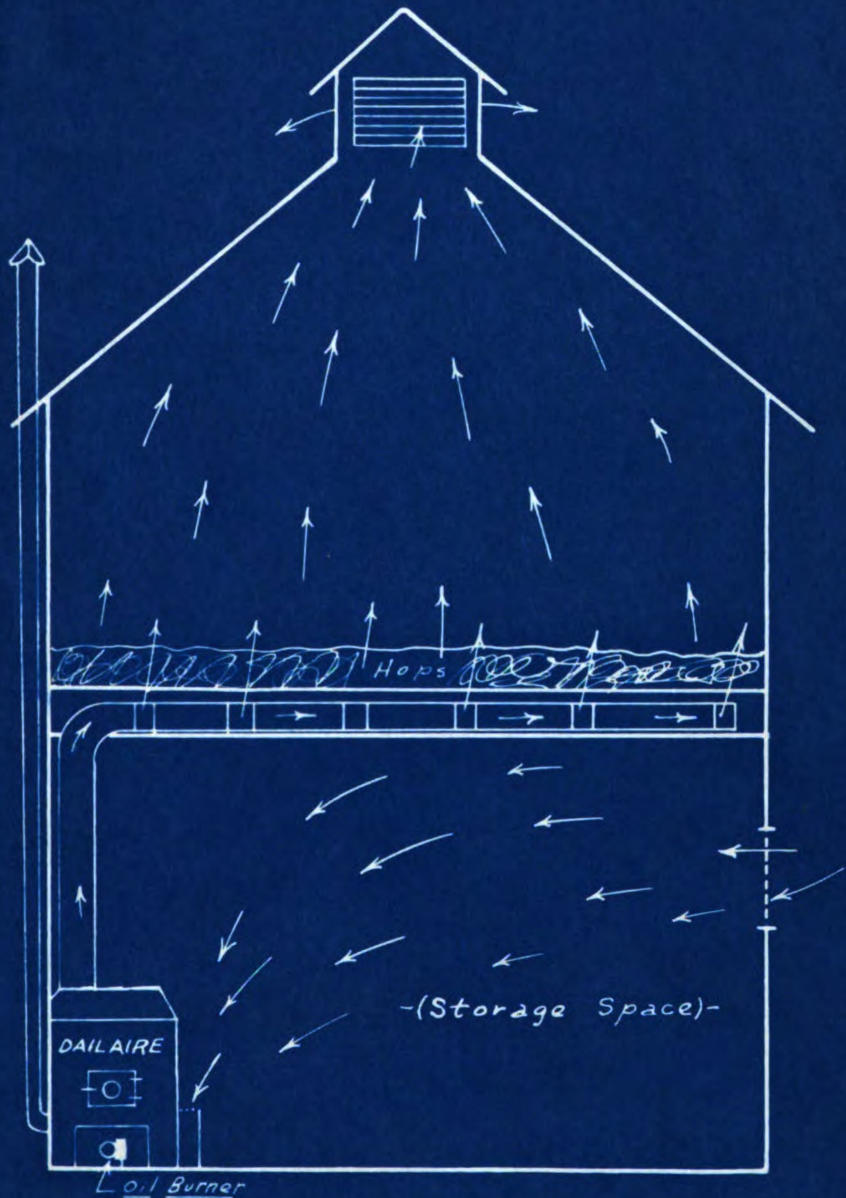
(fig. 3)

E.E.B.



(fig. 4)

Scale 1/8" = 1'
E.E.B.



(fig. 5)

E.E.B.

which is equipped with ducts and a plenum chamber below the hop bed. This arrangement makes possible much more room on the ground floor, which may be used for storage space.

Calculation of the Heating Load

The original problem involved was the calculation of the heating load on the heating unit, which was to replace an installation as shown in figure 1. The building is to be sealed, however, so that the wall leakages will be reduced to a minimum. The new heating unit is to be installed as illustrated in figure 5.

Data

The data was obtained by correspondence from Mr. Lawrence, who handles Dailaire equipment in Yakima, Washington. The necessary data for the problem is as follows:

1. Dimensions of drying floor *--------- 30'x 30'
2. Weight of hops ---- 5.55 lbs/sq ft at depth of 2 feet
3. Weight of water in hops ----- 75% of total weight
4. Hops to be dried to water content of 10% " "
5. Temperature of air at hop bed ---- 140 F.
6. Bonnet temperature of furnace ---- 150 F.
7. Outside temperature of air 60 F. at 60% relative hum.
8. Air delivery is to be 6,000 c.f.m. from furnace.

Calculations

1. Heat to evaporate water:

   30x30 = 900 sq. ft. (area of drying floor)

   .90x.75x5.55 = 3.75 lbs. water per sq. ft. area

   900x3.75 = 3,380 lbs. water to be removed per charge

   Sensible heat to water from 60 to 140 = 80 Btu/ lb.

   Latent heat of evaporation at 140 F. = 1014.4 Btu/ lb.

   Total heat required to evap. water = 1094.4 Btu/lb.

   3,380x1094.4 = 3,700,000 Btu total to evaporate

   (3750-3380)x(140-60) = 29,600 Btu sensible heat to moisture in hops which remains after drying

   3,700,000 + 29,600 = 3,729,600 Btu total required

2. Quantity of Air:

   Sensible heat to air from 60 to 140 =
   (temp. change)x(spec. heat)x(wt per cu. ft)
   (140-60) x (.2415) x (.077) lbs.

   80x.2415x.077 = 1.4876 Btu/cu ft.

   Sensible heat to water vapor in air at 60% rel. hum.

   (temp. change)x(spec. heat)x(wt per cu. ft)

   80 1x.000498 = .040 Btu/cu ft.

   1.4876 + .040 = 1.53 Btu per cu. ft.(carried by air)

   $\frac{3,729,600}{1.53}$ = 2,440,000 cu ft air required

3. Drying Period:

   Fan delivery = 6,000 cfm.

   6,000x60 = 360,000 cu ft per hour

   2,440,000 + 360,000 = 6.8 hours per batch

4. Relative Humidity of Exhaust Air:

Air at 140 F. will hold .00813 lbs. water per cu ft

Exhaust contains $\frac{3380}{2,440,000}$ = .001385 lbs/cu ft

$\frac{.001385}{.008130}$ = 17% rel. hum.

5. Volume of Air per Square foot of Floor:

$\text{Volume} = \frac{\text{Cfm}}{\text{Area}} = \frac{6000}{900}$ = 6.67 cfm per sq ft

6. Rating Table:

Cfm	Cfm/sq ft	Btu/hr req.	Period (hrs)
3000	3.33	275,000	13.5
4000	4.45	367,000	10.1
5000	5.56	459,000	8.1
6000	6.67	550,000	6.8
7000	7.78	642,000	5.8
8000	8.90	734,000	5.0

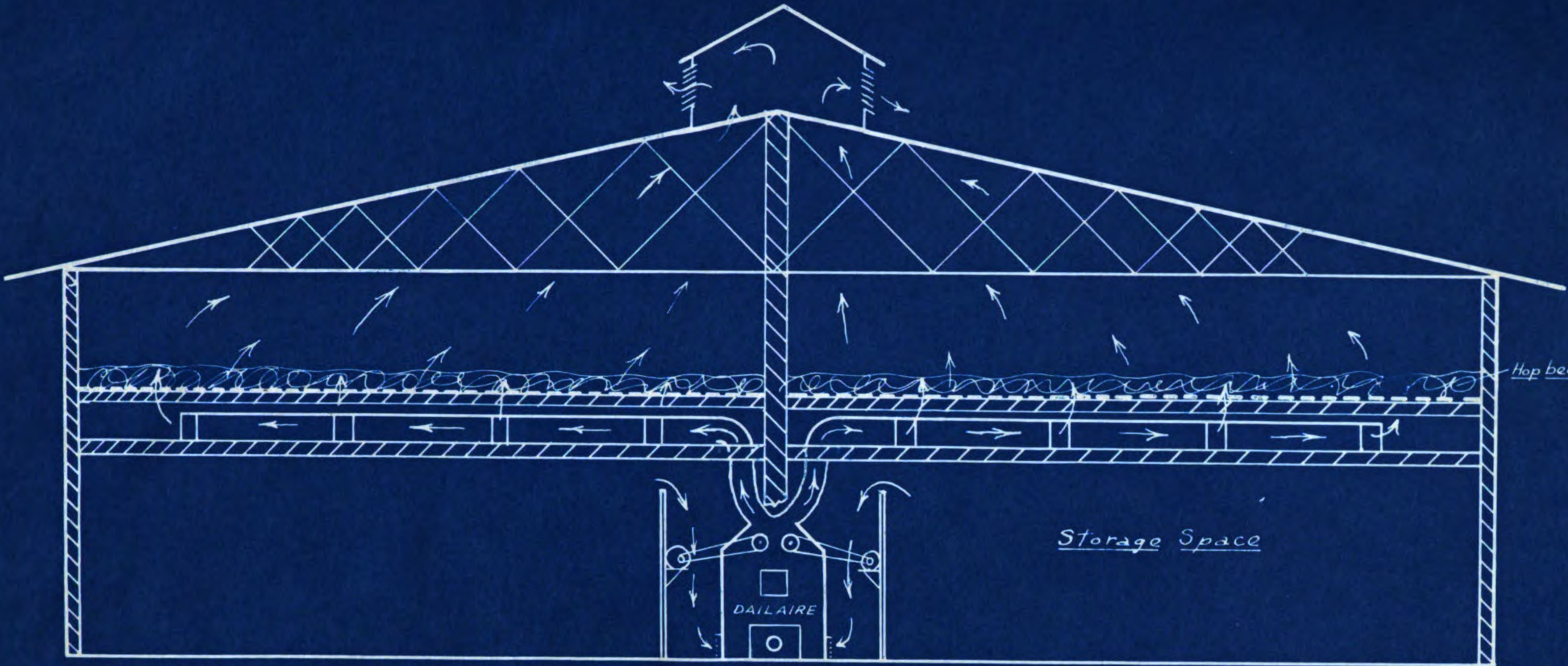
The above values will have to be corrected for each installation as the heat loss from the building must be figured into the total heating load. The table, however, indicates the general relationship between drying period and volume of air.

7. Rating Table for Proposed Lawrence Kiln:

The following table is based upon the kiln designed by Mr. Lawrence, the kiln having a drying area of 2592 square feet (2x36x36). The table shows the general relationship between drying perios and depth of the bed of hops.

'Lawrence'

HOP KILN



SECTION VIEW
SCALE: 1/8" = 1'

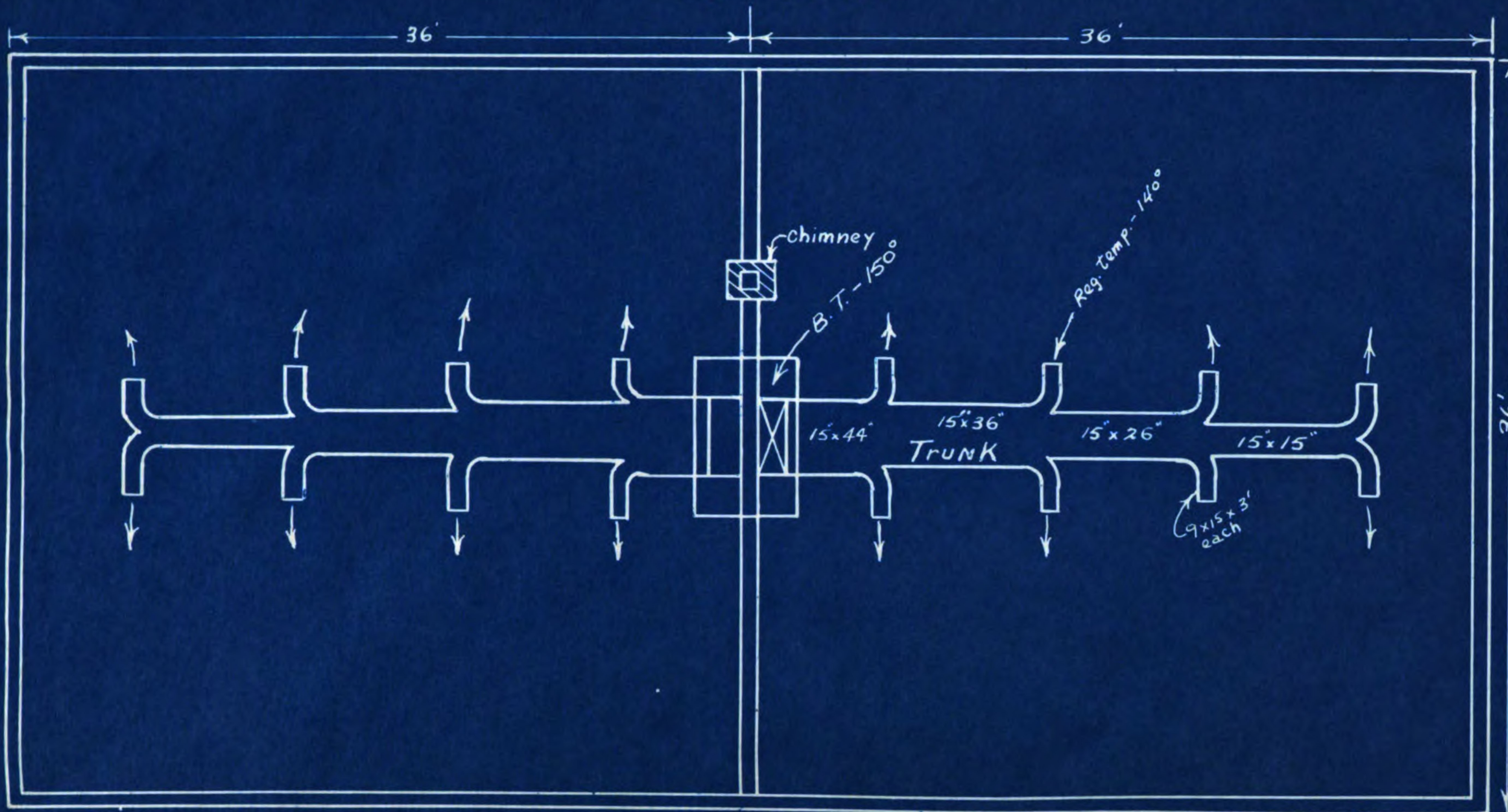
(fig. 6)

E.E.B.

Lawrence

HOP KILN

-DUCT PLAN-



(fig. 7)

Scale:- 1/8"=1'

Depth (ft)	Water to Remove (#)	Total Heat Req. (Btu)	Total Air Req. (Cf)	Period (Hours)
1	4,870	5,4[illegible],[illegible]	3,470,[illegible]	9.[illegible]
1½	7,300	8,0[illegible]7,000	5,[illegible],[illegible]	13.4
2	9,7[illegible]0	10,712,[illegible]	7,[illegible],[illegible]	18.4
3	14,[illegible]	1[illegible],1[illegible],[illegible]	1[illegible],[illegible],[illegible]	[illegible]
4	21,700	[illegible]1,540,000	14,000,000	[illegible].2
5	24,[illegible]	2[illegible],830,000	17,500,[illegible]	4[illegible].5
[illegible]	[illegible],[illegible]	3[illegible],310,000	21,100,[illegible]	58.5