AN EFFICIENCY TEST OF A NATURAL DRAFT ELECTRICAL CONVECTOR

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TABLE OF CONTENTS

		Page
I	Introduction	1
II	Acknowledgements	2
III	General Survey	3
IV	Statement of Purpose	5
V	Theory	6
VI	Apparatus Used	10
VII	Procedure	11
VIII	Sample Calculation	15
IX	Conclusion	17
X	Bibliography	19
XI	Appendix - Data and Curves	20
XII	Approval Sheet	28

INTRODUCTION

The work of this thesis has been to test, for the Newton Calloway Company, a portable convection type electric heater for its efficiency as a convector, to compare the results with the results from other available tests, to correlate the findings and suggest any refinements that may seem practical.

ACKNOWLEDGEMENTS

The writer wishes to make acknowledgement of the use of an electric heater supplied by the Newton Calloway Company; the use of a meter loaned by the Tennessee Public Service Company; the assistance rendered by his instructors in general; and specifically of the services rendered by Professor F. L. Wilkinson who supervised the work herein described.

Heating by electricity dates back to the discovery of the carbon electrode, but very little was accomplished along this line until the latter part of the nineteenth century. Heating by the use of electricity has many applications in industrial processes, but until recently, house heating by this means has been impractical due to the high cost of electrical energy. Even now, only a few sections of the country have developed natural resources to the place where cheap electricity is available for this purpose.

Where waste power is available during the winter months, and fuels are expensive, house heating with electrical energy has gained much headway in the past few years. One power project in Idaho used for pumping water during summer months supplies power for heating at a reasonable rate during the winter. Many buildings along the west coast and in Florida are electrically heated.

Since the advent of the TVA, much interest has been aroused in this section in favor of electrical heating. Buildings in the town of Norris are equipped for electrical heating, and some new buildings in nearby towns are being constructed so that the heating system may easily be converted to the electrical type if, and when, cheap power becomes a reality.

Electrical house heating in this locality has been confined chiefly to the heating of small rooms such as the bathroom, by small portable heaters. This method of heating, in general, has been unsatisfactory because most of the units have been too

small for the service for which they have been used, and the buildings in which they have been used are not constructed to conserve the heat supplied. In addition to these objections, the heaters have been used on lighting circuits and the power consumed has been charged at the high rate charged for this service.

Very little material is available regarding small electric heaters, the cost of operation and their efficiencies. The cleanliness and convenience obtainable through the use of electricity for heating make its use very desirable. Electricity at one-half cent per kilowatt hour will compete favorably with coal at $9 per ton,* therefore in this region the electrical energy rate would have to be about 0.3 cent per kilowatt hour to compete with coal.

* Electric Heating of Residences - University of Washington Bulletin - - Loew.

STATEMENT OF PURPOSE

The purpose of this test is to determine the convection efficiency of the tested electric heater. Convection efficiency refers to the efficiency of a unit in transferring heat to the surrounding air by means of convection, and is the ratio of the heat transferred by convection to the total heat given off by the unit.

THEORY

Heat transfer takes place by conduction, convection and radiation.

Heat transfer that takes place due to the heat vibrations between molecules is called conduction. Materials of high density such as the metals have higher conductivities than the ones in which the molecules are more widely separated, such as cork, wood, and porous mineral products.

Radiation is the transfer of heat through transparent materials or space from a radiant body. Radiation takes place without raising the temperature of the medium through which it travels, but raises the temperature of the object by which it is finally absorbed.

Convection is the transfer of heat by the movement of air or fluid currents. It involves a mechanical movement of heat from one place to another and is supplemented by conduction, or radiation. Convection may also involve heat transfer by evaporation and condensation supplemented by conduction and radiation.

Heating with electric current is accomplished by causing current to flow through a suitable resistance. The value of the resistance is chosen so that when connected to a given circuit the proper current will flow through it for developing the required amount of heat. Joule's Law is used to determine the value of the resistance to be used for such purposes.

Assume a resistance element to have a resistance of R and carry a current I. Also assume the potential difference

between the terminals of the element to be E. Then the quantity of electricity flowing through the element in T seconds is

$$Q = It$$

When this quantity of electricity passes through the element the potential energy of the system is decreased by an amount W. Then

$$W = EQ$$
$$W = EIt$$
$$E = It \text{ Ohm's Law}$$

$$\text{Therefore } W = IRIt = I^2Rt$$

This is known as Joule's Law. If E is expressed in volts and I in amperes, W is given in Joule's. The power expended in heating the element is equal to the total energy expended divided by the time

$$P = W/t = I^2R$$

That is, the power expended in heating an element is equal to the product of the resistance and the square of the current flowing in it. From Ohm's Law $IR = E$ where E is the potential difference between the terminals of the resistance. Therefore

$$P = EI$$

If E is expressed in volts and I in amperes, then P will be expressed in watts. From the above discussion, it is evident that in any circuit carrying a steady current, the power absorbed is equal to the product of the current in the circuit and the potential difference between the circuit terminals. Introducing the element of time the energy expended may be given in watt hours. This is the unit used in testing the heater herein described.

1 Watt Hour = 3.142 B.t.u's

If a room is heated by radiation, the heat rays pass through the air and are absorbed by the objects upon which they fall. These objects in turn heat the surrounding air by conduction and convection. Radiated heat does not warm the air through which it passes. This accounts for the inability to secure proper heat distribution by the use of radiators, stoves and open fires, and produces the condition referred to as "Cold 70" which is an accumulation of the room heat in the upper part of the room, and a lack of heat near the floor, due to the absence of air currents.

Convectors give an even distribution of heat in the living zone of a room by setting up a natural circulation of air. Convectors properly designed and installed deliver heat quickly, evenly, noiselessly and where most needed. Convectors take in air near the floor level and the circulation through this type of heater takes place due to the difference in weight of the heated air in the convector and the weight of the outside air. The factors that influence the volume of air moved by the temperature difference alone are:

1. The amount of heat given off,
2. The vertical distance between inlet and outlet, and
3. The area of inlet and outlet openings

Therefore satisfactory convector operation requires that the heating element be of sufficient capacity; that the air path be sufficiently unrestricted to allow free circulation; and that the stack be of ample size and height. When air is moved through a stack it must have a draft sufficient to start and maintain the

flow of air. This involves static head which is the head required to overcome the frictional resistance and velocity head which is the head required to overcome the inertia of the air.

In order to find the convection efficiency of any unit heater, it is necessary to take readings from which calculations may be made of the heat given off to the air passing through the unit; the quantity of air heated during the test; and the input to the unit.

APPARATUS USED

The heater tested consists of a resistance heating element around which glycerine is allowed to circulate. The glycerine absorbs heat from the heating element and by convection and conduction, transfers the heat to the metal plates surrounding it. These plates in turn transfer the heat to the air, chiefly by convection. A thermostat cuts off the current, when the glycerine reaches a predetermined temperature , to prevent boiling. This unit is contained in a suitable sheet metal cabinet.

A rotating standard watthour meter was used in measuring the power input to the heater. On a 110 volt line supplying up to 5 amperes of current, the meter is integrating up to 8 1/3 watthours.

An anemometer was used to measure the velocities of air flow through the heater. A rotor of the anemometer propelled by air currents is connected by a system of gearing to an indicator which gives readings of velocities in feet.

Mercurial thermometers were used in taking temperature readings.

To find the humidity of the air entering the heater, a sling psychrometer was used. It consists of two mercurial thermometers in a frame that can be rapidly rotated in the air, and around the bulb of one thermometer is an absorbent material to be saturated with water when used. The other is to be dry.

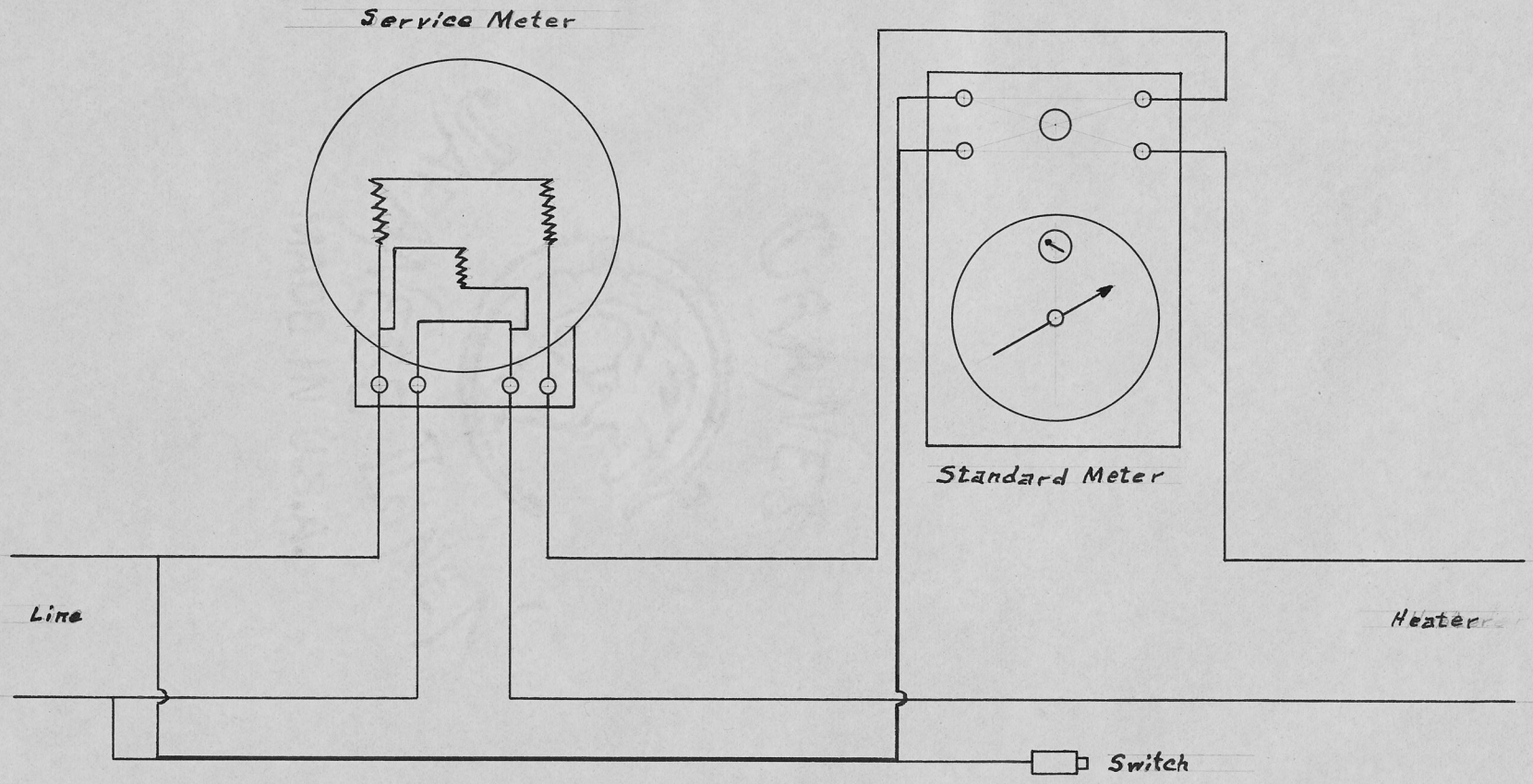
Other equipment consisted of necessary wiring and connections for setting up the heater and testing equipment.

After setting up the equipment according to the wiring diagram (Fig. 1) it was found that velocities through the outlet grille were so low that they could not be successfully measured. To increase the outlet velocities, the outlet grilles were closed and the top of the heater cabinet was removed. This change reduced the outlet area and increased the stack height of the unit from 16 3/16 inches to 21 1/4". Both changes tend to increase the outlet velocity of the air passing through the unit. The top opening was then divided into five parts of equal area, and temperature and velocity readings were taken near the center of each area. The averages of these readings were taken as the averages of temperature and velocity for the entire area. Readings were taken at 15 minute intervals of the wet and dry bulb temperatures of the inlet air, the dry bulb temperatures of the outlet air, and the velocities of the outlet air. The power input and times the thermostat cut off were recorded for a period of one hour for each test. From these data, the convection efficiency of the unit was calculated. Figure 2 shows a sketch of the heater and the location of thermometers during the test.

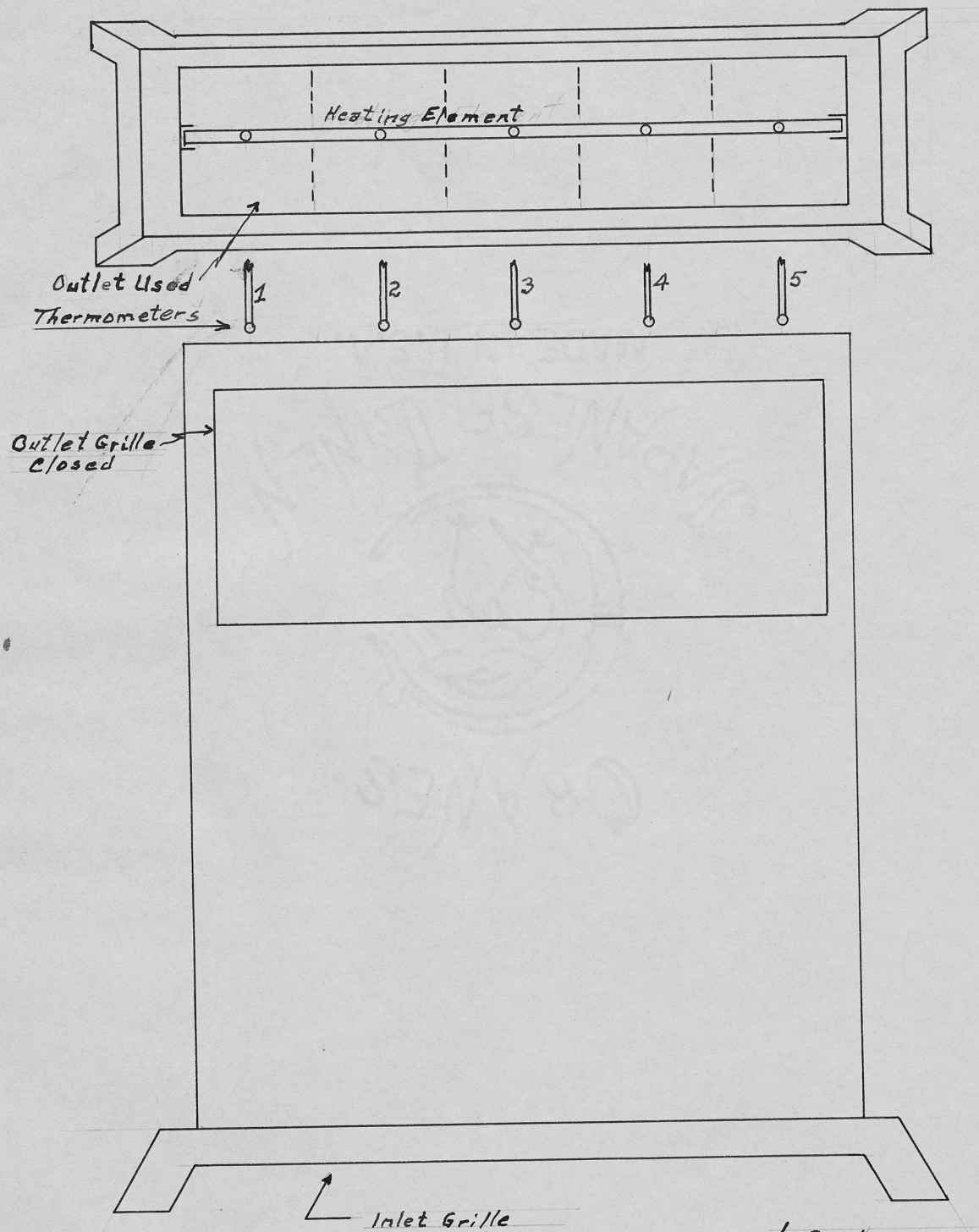
The chief sources of error consist of the inexact methods of measurment and of the assumption that the average temperature and velocity of air through the unit is the same as the average of several specific temperature and velocity readings taken during the test. To minimize the possibility of error several readings were taken at points distributed over the outlet area.

The efficiency of an electric heater is 100%, or all

the energy is converted into heat, therefore the heat energy not transferred by convection is dissipated t hrough radiation.



Wiring Diagram — Figure Number 1



¼ Scale

Sketch of Heater and Location of Thermometers

Figure 2

SAMPLE CALCULATION

Area of outlet used = $2\frac{1}{2}$" x $16\frac{3}{4}$" = 43.75 sq. in.

Effective area of outlet grille of heater

Small circular holes = 3078

Area = 3078 x $(3/32 \times 1/2)^2$ x 3.1416 = 23.45 sq. in.

Large octagonal holes 9-32" effective diameter

Area = 603 x $(9/32 \times 1/2)^2$ x 3.1416 = 37.45 sq. in.

Total area of outlet grille = 23.45 sq. in plus 37.45 sq.in.
= 60.9 sq. in.

Heat transfer surface = (2 x $16\frac{1}{2}$ x $20\frac{1}{4}$)/144
= 4.64

% of humidity was found from the wet and dry bulb temperatures using the psychrometric chart.

Average velocity of air outlet = the sum of the individual velocities divided by the number of velocities.

Cu. ft. of air heated equals the average velocity in feet per minute x the outlet area in square feet x the duration of the test in minutes.

Initial heat content of the air - from Goodenough's table of mixtures of air and saturated vapor, by interpolation, one pound of air, 45% humidity of 82 degrees F. contains 31.91 B.t.u's.

Final heat content - from tables, one pound of air, 7.5% humidity at 146 degrees F. contains 49.43 B.t.u's.

Volume in cubic feet per pound of air - from tables, by interpolation = 15.61 cu.ft.

Air heated in pounds = total volume divided by the volume of one pound of air = 705.14 divided by 15.61 = 45.17

Output in B.t.u's = heat added per pound of air heated times pounds of air heated = (49.43 - 31.01) 45.17 = 832.03

Input in B.t.u's = 343.83 x 3.142 = 1173.11

% efficiency = output over input = 832.03/1173.11 = 70.92

The average convection efficiency indicated by the five tests is 68.16%. Allowing the possibility of an error in test three, which varied considerably from the other four tests, would indicate a convection efficiency of approximately 70% for the unit. This is about 6% lower than the average convection efficiency of a group of heaters tested as a thesis by W. H. Moody at this school in 1934, and about 20% lower than the highest efficiency obtained in his tests. The efficiencies of the heaters tested by Moody are as follows:

Test No.	1	2	3	4	5	6	7
% efficiency	55.6	55	70	71.5	74	79.5	79.5
Test No.	8	9	10	11			
% efficiency	83	86.4	87	90.2			

These heaters were strip heaters, copper fin heaters or a combination of the two. The high convection efficiencies of tests 7 to 11 are due to insulation of the cabinet housing against radiation.

The introduction of glycerine into the heater under test adds another heat transfer medium to the system and probably accounts for a part of the loss in convection efficiency. The unit has 4.64 sq. ft. of transfer surface in contact with the air. The sheet metal cabinet inclosing the heating unit was warmed considerably, and was a source of

CONCLUSION - (Continued)

heat loss through radiation, and also represents a heat loss through convection to the air outside the heater. Therefore the convection efficiency of the unit in heating the air in the room is somewhat greater than the value indicated by the test. Insulating the cabinet would reduce this loss but would increase the manufacturing cost of the heater.

BIBLIOGRAPHY

Steam Tables-Properties of Air and Saturated Vapor --Goodenough

Textbook of Physics --Spinney

Thesis--Performance Characteristics of Several Types of Natural Draft Electrical Heaters --W. H. Moody

Handbook of Refrigeration --Woolrich

Air Conditioning for Comfort --Lewis

Electric Heating of Residences--University of Washington Bulletin --Loew

American Society of Heating and Ventilating Guide

APPENDIX

Test Number 1

					Average	Totals
Time Minutes	15	15	15	15		60
Temp. inlet air dry bulb	82	82	82	82		
Temp. inlet air wet bulb	67	67	67	67		
1. Temp. outlet air dry bulb*	142	140	141	140	140.75	
2. Temp. outlet air dry bulb*	148	144	148	150	147.50	
3. Temp. outlet air dry bulb*	146	146	144	146	145.50	
4. Temp. outlet air dry bulb*	155	156	157	158	156.50	
5. Temp. outlet air dry bulb*	139	138	140	144	140.25	
Average of Total Outlet Temperature Readings					146.00	
1. Velocity Outlet Air	18	20	22	28	22.00	
2. Velocity Outlet Air	48	50	54	58	52.50	
3. Velocity Outlet Air	54	57	57	59	56.75	
4. Velocity Outlet Air	59	58	61	57	58.75	
5. Velocity Outlet Air	27	25	36	32	30.00	
Average of Total Outlet of Velocity Readings					44.00	
Power input-watts						343.83
Times Thermostat cuts off						19.

*Figures 1, 2, 3, 4 and 5 represent readings for the areas indicated in Figure No 2.

Test Number 2

					Average	Totals
Time-Minutes	15	15	15	15		60
Temp. inlet dry bulb	82	82	82	82	82	
Temp. inlet wet bulb	67	67	67	67	67	
1. Temp. outlet air dry bulb	142	142	142	142	142	
2. Temp. outlet air dry bulb	150	150	150	150	150	
3. Temp. outlet air dry bulb	147	146	148	147	147.0	
4. Temp. outlet air dry bulb	155	157	158	160	157.5	
5. Temp. outlet air dry bulb	138	144	144	146	143.0	
Average Total Outlet Temperature Readings					147.8	
1. Velocity Outlet Air	18	22	20	21	20.25	
2. Velocity Outlet Air	45	55	48	45	48.25	
3. Velocity Outlet Air	57	50	53	46	51.50	
4. Velocity Outlet Air	59	58	57	60	58.50	
5. Velocity Outlet Air	35	23	32	29	29.75	
Average of Total Outlet Velocity Readings					41.65	
Power input watts						340.92
Times Thermostat Cuts Off						22

Test Number 3

					Average	Totals
Time-Minutes	15	15	15	15		60
Temp. inlet air dry bulb	84	84	84	84	84	
Temp. inlet air wet bulb	68	68	68	68	68	
1. Temp. outlet air dry bulb	142	140	138	140	140.00	
2. Temp. outlet air dry bulb	150	150	148	146	148.50	
3. Temp. outlet air dry bulb	146	147	144	146	145.75	
4. Temp. outlet air dry bulb	157	154	156	155	155.50	
5. Temp. outlet air dry bulb	144	144	144	144	144.00	
Average of Total Outlet Temperature Readings					147.15	
1. Velocity outlet air	19	12	13	14	14.50	
2. Velocity outlet air	44	41	43	36	41.00	
3. Velocity outlet air	60	55	56	39	52.50	
4. Velocity outlet air	54	50	55	43	50.50	
5. Velocity outlet air	28	20	22	31	25.25	
Average of Total Outlet Velocity Readings					36.75	
Power input watts						329.33
Times Thermostat Cuts Off						18

Test Number 4

					Average	Totals
Time-Minutes	15	15	15	15		60
Temp. inlet air dry bulb	80	80	80	80	80	
Temp. inlet air wet bulb	70	70	70	70	70	
1. Temp. outlet air dry bulb	136	139	143	138	139.00	
2. Temp. outlet air dry bulb	156	158	159	154	156.75	
3. Temp. outlet air dry bulb	144	144	146	144	144.50	
4. Temp. outlet air dry bulb	150	150	150	146	149.00	
5. Temp. outlet air dry bulb	142	142	144	142	142.50	
Average of Total Outlet Temperature Readings					146.25	
1. Velocity outlet air	0	0	22	31	13.25	
2. Velocity outlet air	45	53	60	50	52.00	
3. Velocity outlet air	59	56	54	61	57.50	
4. Velocity outlet air	50	50	52	55	51.75	
5. Velocity outlet air	19	30	27	23	24.75	
Average of Total Outlet Velocity Readings					39.85	
Power input watts						345.48
Times thermostat cuts off						17

Test Number 5

					Average	Totals
Time-Minutes	15	15	15	15		60
Temp. inlet air dry bulb	83	83	83	83	83	
Temp. inlet air wet bulb	71	71	71	71	71	
1. Temp. outlet air dry bulb	144	144	142	145	143.75	
2. Temp. outlet air dry bulb	157	155	160	158	157.50	
3. Temp. outlet air dry bulb	145	144	142	143	143.50	
4. Temp. outlet air dry bulb	154	150	153	152	152.25	
5. Temp. outlet air dry bulb	148	146	144	145	145.75	
Average of Total Outlet Temperature Readings					148.45	
1. Velocity Outlet Air	14	22	26	22	21.00	
2. Velocity Outlet Air	45	50	52	43	47.50	
3. Velocity Outlet Air	58	57	63	55	58.25	
4. Velocity Outlet Air	47	53	53	58	52.75	
5. Velocity Outlet Air	31	30	37	22	30.00	
Average of Total Outlet Velocity Readings					41.90	
Power input watts						333.99
Times Thermostat Cuts Off						16

SUMMARY OF DATA AND CALCULATIONS

Test	1	2	3	4	5
Time-Minutes	60	60	60	60	60
Initial Temp. Dry Bulb	82	82	84	80	83
Initial Temp. Wet Bulb	67	67	68	70	71
% Humidity Initial	45	45	43.5	60	55
Final Temp. Dry Bulb	146	147.8	146.65	146.25	148.45
% Humidity	7.5	7.2	7.5	9	8.5
Velocity Outlet Air	44	41.65	36.75	39.85	41.90
Air Heated Cu. Ft.	705.4	667.48	588.96	638.64	671.49
Initial Heat Cont./lb. Air	31.01	31.01	31.87	33.31	34.21
Final Heat Cont./lb. Air	49.43	50.72	49.91	52.46	53.24
Volume Cu. Ft. Lb. Air	15.61	15.68	15.65	15.70	15.77
Air Heated Pounds	45.17	42.57	37.63	40.68	42.58
Times Thermostat Cuts Off	19	22	18	17	16
Input Watts	343.82	340.92	329.33	345.48	333.99
Input B.T.U.	1173.11	1163.22	1123.77	1178.78	1139.57
Output B. T. U.	832.03	838.05	678.85	779.02	810.30
% Efficiency	70.92	72.05	60.41	66.09	71.24

Convection Average Efficiency % - - - - - - 68.16

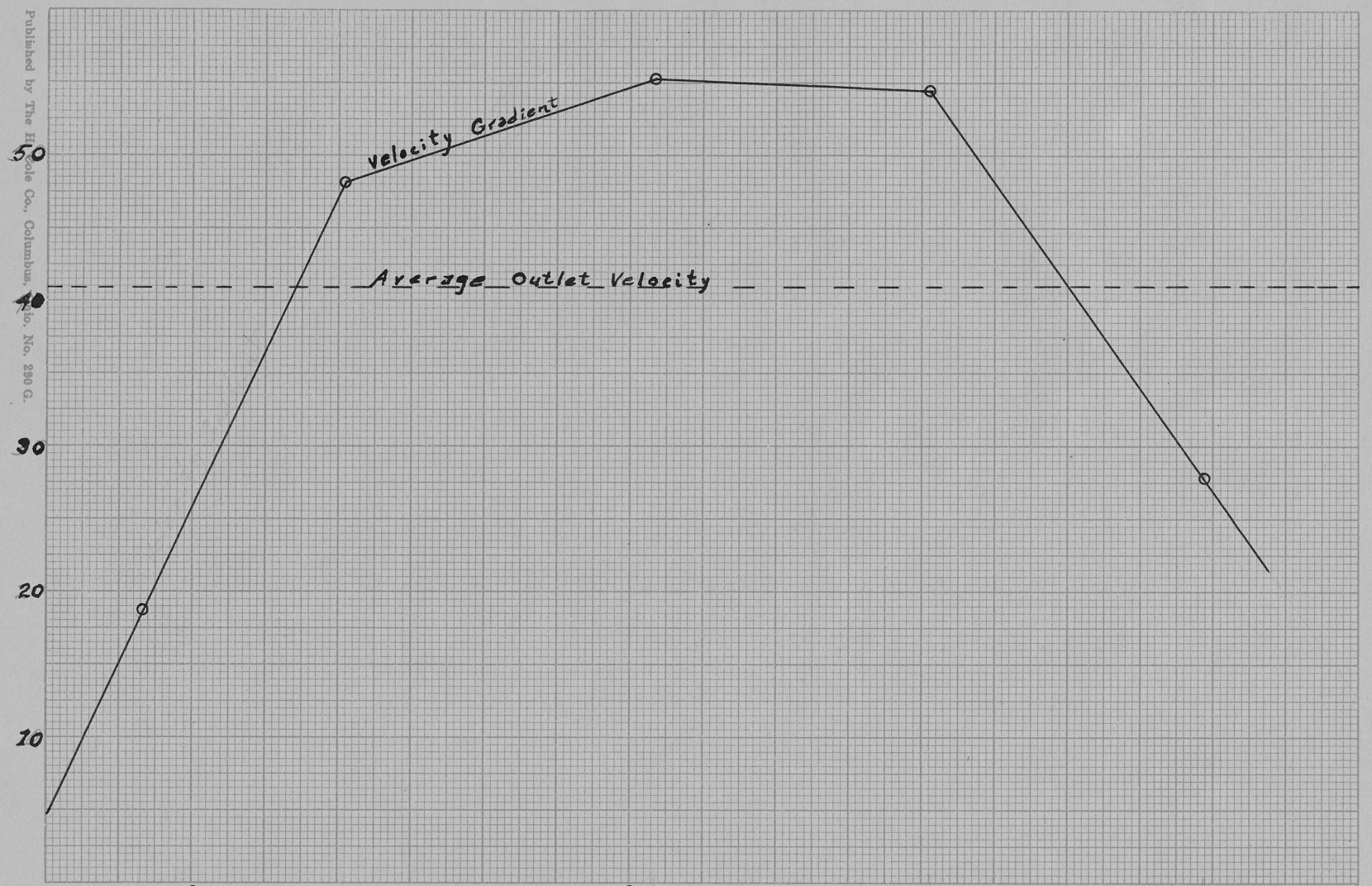


Figure 4

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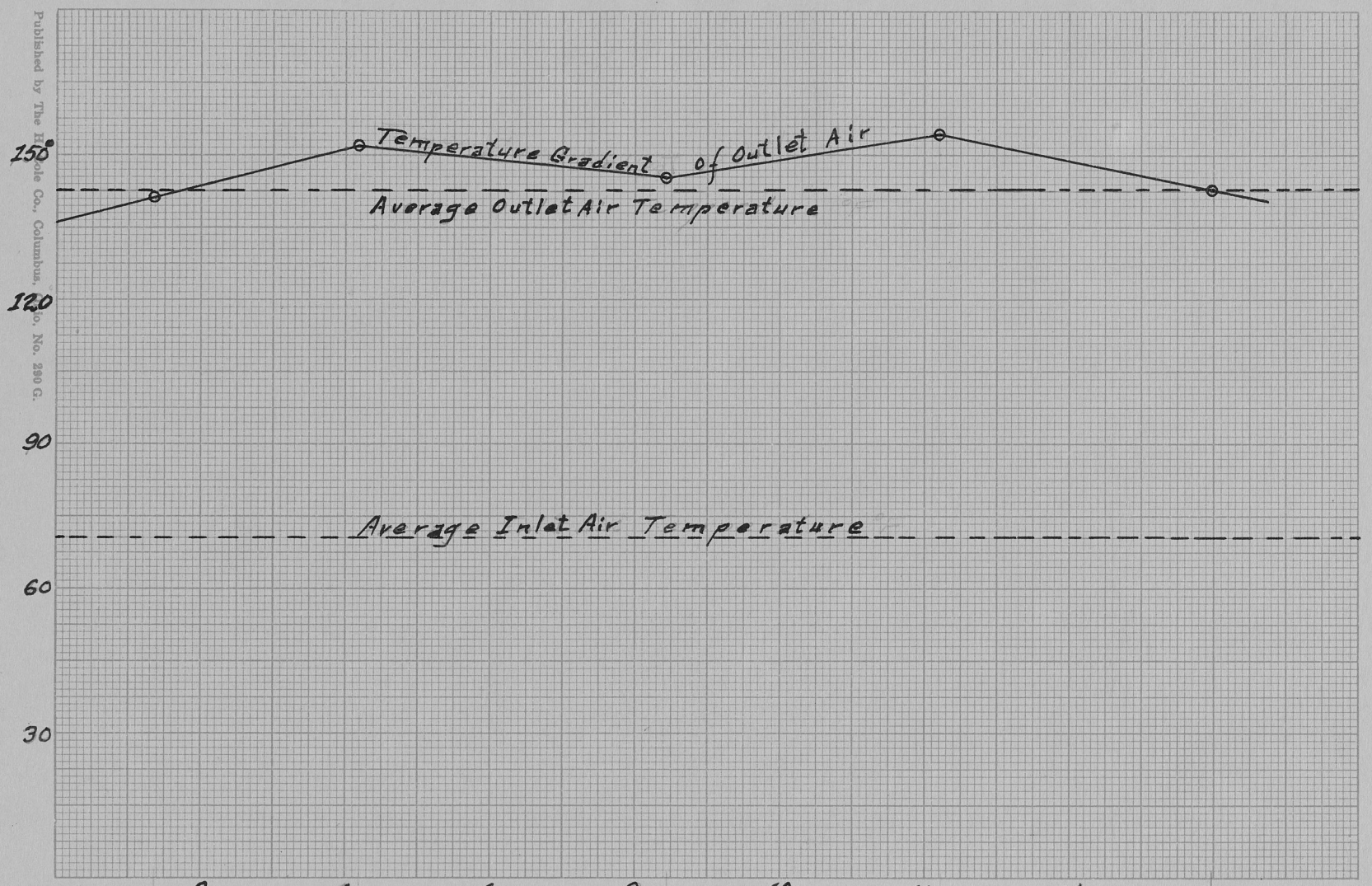

Figure 3

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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 it submitted.

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