I N V E S T I G A T I O N   A N D   D E S I G N
O F   A   P O R T A B L E
E V A P O R A T I V E   C O O L E R

Thesis by

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In Partial Fulfillment of the Requirements

For the Degree of

Industrial Designer

California Institute of Technology

Pasadena, California

1949

ACKNOWLEDGMENTS

Gratitude is expressed to the people who, directly and indirectly, gave assistance and encouragement with the development of this thesis:

The instructors of the Industrial Design Section who very patiently concerned themselves with the progress of this work and offered constructive criticism: Mr. J. Paul Youtz; Mr. David F. Welch (Chairman, Thesis Committee); Mr. Harry R. Greene; Mr. Salvatore Merendino; Mr. Beverly W. Morant.

Dr. Donald S. Clark and Dr. Peter R. Kyropoulos for their helpful suggestions and assistance.

The manufacturers of air conditioning units, motors, blowers and fans for their prompt response to requests for reference material and information.

Figure 1 - FULL SCALE MODEL

ABSTRACT: The purpose of this thesis is the investigation and design of a portable evaporative cooler.

Preliminary investigation was made by a product survey through present evaporative cooler manufacturers. This survey indicated that the project was physically possible; that it had not as yet been solved in practice; that the manufacturers believed such a cooler would find a large market that they were not reaching, since its channels of distribution would be through appliance dealers, while their present channels were through specialists trained in installation. This divergence of channels of distribution had discouraged the development of such a product.

A tentative design was developed and all the appliance dealers in key cities were circularized with a description of the proposed unit. Their advice and comments were requested. From an analysis of their replies and from the advice of the manufacturers, the final design was developed.

The completed "FROST"* evaporative cooler is an aluminum container, 18 inches long, 8½ inches wide, and 12 inches high. It contains a 1/20 horsepower motor, which turns a single inlet squirrel-cage blower, 5¼ inches in diameter, 3 7/16 inches wide, at 1725 RPM, moving 268 CFM of air. The air passes through a venturi tube, which aspirates the water on to a 4-inch thick wire filter, 9 3/4 inches wide,

*Trade name selected for this cooler.

5 3/4 inches high, where it is evaporated. The base of the cooler contains a separate pan which holds sufficient water for over $2\frac{1}{2}$ hours use. The filter, venturi, and blower scroll are removable by the user for cleaning.

The unit is made chiefly of aluminum to prevent rust, electrolysis of parts, and for ease of cleaning the filter. It is painted with light grey, metallic-type paint that has a slight greenish tint.

The motor, blower wheel, grills, and filter are standard parts to be purchased. The container, venturi, and water pan to be manufactured to specification.

The estimated manufacturer's cost is $11. The sales price is estimated to be $30. The estimated first-year sales are 14,000 units.

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SECTION I - INTRODUCTION

CONDITIONS FOR HUMAN COMFORT: Research into the general problem of air conditioning revealed that: Considerable work had already been done in determining at what wet-bulb and dry-bulb temperatures human beings feel most comfortable for more than three hours; the summer optimum was 71° F. effective temperature (which varies from 78° F. dry-bulb and 63° F. wet-bulb to 75° F. dry-bulb and 67° F. wet-bulb); and the relative humidity varies from 30% to 70%. (See Appendix - Figure 7).

While for shorter periods than three hours a human being is comfortable even though the effective temperature varies from 73° F. to 68° F.; the relative humidity may vary from 43% to 59%; and the temperature from 80° F. dry-bulb and 65° F. wet-bulb to 72° F. dry-bulb and 62.5° F. wet-bulb. (See Appendix - Figure 8).

The above represents ideal conditions for the average North American. Any appreciable cooling of the air, particularly if it is in motion, will be of some actual, and a great deal of psychological, benefit to the recipient.

PRINCIPLE OF EVAPORATIVE COOLING: Evaporative cooling is the oldest known form of changing the climate. When a light breeze blows on the hot, sweaty laborer he is cooled and refreshed. The passing air evaporates part of the moisture, which cools the air and the remaining moisture. All evaporative cooling units now on the market work on this principle.

The principle of evaporative cooling, in modern mechanical coolers, is the evaporation of water by the passage of air over the surface, or through a spray of water. The latent heat needed to evaporate the water is furnished by the passing atmosphere. The evaporated water is carried off in the form of water vapor by the atmosphere as increased humidity. The total heat of the passing air is not changed. The process is adiabatic. For each unit of heat the air gains, in latent form, from the increased water it carries, it loses exactly the same amount from its sensible temperature. The wet-bulb temperature remains constant. If the chamber is sufficiently large, the dry-bulb temperature of the outgoing air will be the same as the wet-bulb temperature of the entering air, and the amount of water evaporated will equal that needed to furnish the change from sensible to latent heat.

Example -

Initial Conditions: At "A" (Figure 2)

$B = 30$ ins. Hg

$T_d = 78^\circ$ F.

$T_w = 55^\circ$ F.

$r = .20$

$s = 28$ grains of vapor per pound of dry air

Final Conditions: At "B" (Figure 2)

$T_d = T_w = 55^\circ$ F.

$r = 1.0$

$s = 64$ grains of vapor per pound of dry air

Water Evaporated:

$s_2 - s_1 = 64 - 28 = 36$ grains of water per pound of air

The design of a spray chamber to produce this result is necessarily based on experience with like apparatus previously built.

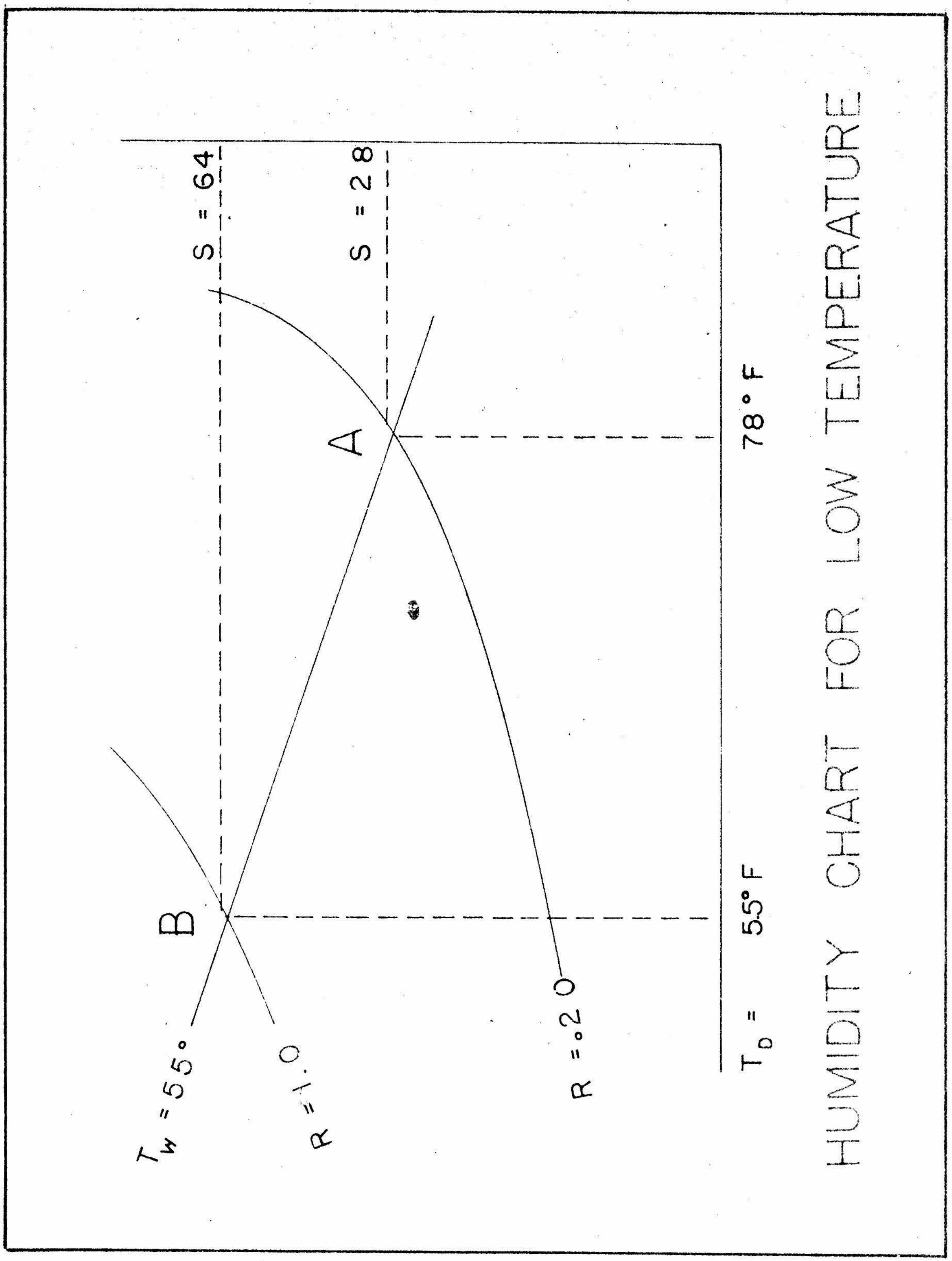
S = 64
S = 28
A
B
78° F
55° F
T_D =
T_W = 55°
R = 1.0
R = .20
HUMIDITY CHART FOR LOW TEMPERATURE

Figure 2

PROFESSIONAL OPINION: Thirty-four manufacturers of evaporative coolers were consulted, either by personal visits to their factories or by correspondence, in order to obtain their views on the proposed thesis problem. Many of these manufacturers made available their engineering and sales staffs to offer advice. They gave the following general opinions:

1. So far no manufacturer had produced a satisfactory portable evaporative cooler.
2. Such a unit was, in their opinion, a physical possibility.
3. A portable cooler would have high sales appeal.
4. Neither production nor sales of such units had been fully exploited, since being "off-the-shelf" sales items they were not of much importance to either the manufacturer or the local dealer. Such "off-the-shelf" sales normally would be made through electric appliance dealers. The present evaporative coolers were being sold through "jobbers" to trained specialists who could install and service them. These specialists were not interested in "pushing" the portable cooler with its smaller unit profit. Many such outlets had no suitable display space. The manufacturers had no contacts with electric appliance dealers who normally would sell the portable units.

SECTION II - MARKET SURVEY

LOCATION OF MARKET: The market for evaporative coolers is definitely limited to certain regions. An evaporative cooler that will give excellent results in the deserts of Southern California would be a "thorn in the flesh" in the Bayous of Louisiana or the Everglades of Florida.

Evaporative coolers are dependent for efficiency upon the local climate. A low wet-bulb temperature and a high dry-bulb temperature give the best results. A study of weather reports, consolidated in Figure 9, shows that the lowest average July wet-bulb temperature lies in the Mountain States and the Western Plain States. A study of the average summer temperatures (Figure 10) shows that the dry-bulb temperatures vary with the latitude; the elevation above sea level; and with proximity to large bodies of water.

A study of the relative humidity was made (Figures 11, 12, 13) and it was found that, although the relative humidity varies considerably during the day, in general the Rocky Mountain States and the Western Plain States consistently have a low relative humidity suitable for the use of evaporative coolers. By a study of all five charts, thirteen key cities in the Mountain and Western Plain states were chosen with representative wet- and dry-bulb temperatures and with various average summer temperatures. These key cities were circularized with the expectation that areas having similar climatic conditions would react similarly.

CONSUMER SURVEY: The manufacturers' statement that as yet "no successful, portable evaporative cooler has been produced," together with personal experience in interviewing individuals on the subject, proved that the average prospective consumer had no idea as to what would be desirable in such a unit. It was, therefore, decided to include the consumer survey with the survey for market analysis.

A form letter was written describing the proposed FROST cooler, listing its sales advantages, and requesting information as to what would increase its sales appeal. It was believed that the prospective retailer, an electric appliance dealer, being in close contact with the prospective customer and knowing his preferences in similar goods, was the best available source of obtaining consumer preference.

MARKET ANALYSIS: All of the electric appliance dealers in the thirteen key cities were circularized, except that of Los Angeles, where about one-fifth of the dealers were circularized. On the following pages the chosen climatic conditions and the results of the survey are tabulated.

1. <u>Albuquerque, New Mexico</u> - 23 dealers - 17.4% responded.

The choice of color was equally divided among grey, green, and white. They believed that $40 was a satisfactory sales price and that 74 units could be sold during the coming summer. Albuquerque has a population of 35,449. The climatic averages are as follows:

July Temperature	76.7° F.
Maximum Temperature	104° F.
July Wet-bulb Temperature	60° F.
Annual Rainfall	8.4 inches

The surrounding area, with a similar climate, has a population of 250,000. The sales expectation for the area is therefore:

(250,000 ÷ 35,449 x 74) 518 units.

2. <u>Atchison, Kansas</u> - 5 dealers - 0% responded.

This city has a population of 12,684. The climatic averages are as follows:

July Temperature	78.3° F.
Maximum Temperature	108° F.
July Wet-bulb Temperature	68° F.
Annual Railfall	34.58 inches

The surrounding area, with a similar climate, has a population of 4,000,000. The sales expectation for the area is unknown.

3. Austin, Texas - 28 dealers - 10.9% responded.

Choice of color was equally divided between grey and green. They indicated that \$45 was a satisfactory sales price and that they could sell 62 units this coming summer. Austin has a population of 87,930. The climatic averages are as follows:

July Temperature	83.9° F.
Maximum Temperature	109° F.
July Wet-bulb Temperature	70° F.
Annual Rainfall	34.43 inches

The surrounding area with a climate similar to that of Austin has a population of 3,200,000. The sales expectation for the area is therefore: (3,200,000 ÷ 87,930 x 62) 2,254 units.

4. Tulsa, Oklahoma - 39 dealers - 10.3% responded.

Choice of color was 75% for grey; 25% green. They believed that \$42.36 was a satisfactory sales price and that among them they could sell 300 units. The climatic averages are as follows:

July Temperature	82.8° F.
Maximum Temperature	115° F.
July Wet-bulb Temperature	70° F.
Annual Rainfall	38.38 inches

Tulsa has a population of 142,157 and its climate is similar to that of the surrounding area which has a population of 2,336,434. For this area the sales expectation is therefore:

(2,336,434 ÷ 142,157 x 300) 4,936 units.

5. Boise, Idaho - 11 dealers - 9.1% responded.

They offered no comment as to color, but believed that $40 was a satisfactory sales price, and that 20 units could be sold this coming summer. Boise has a population of 26,130. The climatic averages are as follows:

July Temperature	74.2° F.
Maximum Temperature	121° F.
July Wet-bulb Temperature	56° F.
Annual Rainfall	12.47 inches

The population of the surrounding area having a climate similar to that of Boise is 924,000. The sales expectation for the area is therefore:

(924,000 ÷ 26,130 x 20) 711 units.

6. Butte, Montana - 7 dealers - 42.9% responded.

The color choice was 50% blue; 50% green. They believed that $45 was a satisfactory sales price and that they could sell 50 units. Butte has a population of 37,081. The climatic averages are as follows:

July Temperature	64.8° F.
Maximum Temperature	100° F.
July Wet-bulb Temperature	55° F.
Annual Rainfall	13.51 inches

The climate of the surrounding area is similar to that of Butte and has a population of 809,000. The sales expectation for this area is therefore: (809,000 ÷ 37,081 x 20) 456 units.

7. <u>Tuscon, Arizona</u> - 32 dealers - 18.7% responded. The color choice was 80% grey; 20% blue. They believed that $36.54 was a satisfactory sales price and that they could sell 212 units in that section. Tuscon has a population of 36,818. The climatic averages are as follows:

July Temperature	85.1° F.
Maximum Temperature	111° F.
July Wet-bulb Temperature	65° F.
Annual Rainfall	11.16 inches

The climate of Tuscon is similar to that of the surrounding area which has a population of 750,000. The sales expectation for the area is therefore: (750,000 ÷ 36,818 x 212) 4,297 units.

8. <u>Santa Fe, New Mexico</u> - 9 dealers - 33.3% responded. The color choice was 66.7% green; 33.3% blue. They believed that $40 was a satisfactory sales price

and that they could sell 6 units. Santa Fe has a population of 20,325. The climatic averages are as follows:

July Temperature	68.9° F.
Maximum Temperature	97° F.
July Wet-bulb Temperature	63° F.
Annual Rainfall	14.19 inches

The surrounding area has a climate similar to that of Santa Fe and has a population of 250,000. The sales expectation for that area is therefore: (250,000 ÷ 20,325 x 6) 75 units.

9. <u>Reno, Nevada</u> - 27 dealers - 11.1% responded.

The color choice was 50% bronze; 25% green; 25% grey. They believed that $52.50 was a satisfactory price, and that together they could sell 100 units. Reno has a population of 21,317. The climatic averages are as follows:

July Temperature	71° F.
Maximum Temperature	106° F.
July Wet-bulb Temperature	53° F.
Annual Rainfall	7.73 inches

The surrounding area with a climate similar to that of Reno has a population of 110,000. The sales expectation for the area is therefore: (110,000 ÷ 21,317 x 100) 524 units.

10. Needles, California - 4 dealers - 0% responded.

The population of Needles is 3,624. The climatic averages are as follows:

July Temperature	93.2° F.
Maximum Temperature	125° F.
July Wet-bulb Temperature	63° F.
Annual Rainfall	4.62 inches

The surrounding area with a climate similar to that of Needles has a population of 50,000. The sales expectation for this area is unknown.

11. Bakersfield, California - 32 dealers - 0% responded.

The population of Bakersfield is 29,252. Climatic averages are as follows:

July Temperature	83.5° F.
Maximum Temperature	118° F.
July Wet-bulb Temperature	60° F.
Annual Rainfall	6.12 inches

The surrounding area with a population of 240,000 has a climate similar to that of Bakersfield. The sales expectation for the area is unknown.

12. Sacramento, California - 42 dealers - 11.9% responded.

Color choice was 43% green; 29% blue; 14% grey; and 14% bronze. They considered $40 as a satisfactory sales price, and believed that 47 units could be sold during the coming summer. Sacramento has a population of 105,958. The climatic averages are as follows:

July Temperature	73.9° F.
Maximum Temperature	111° F.
July Wet-bulb Temperature	61° F.
Annual Rainfall	15.88 inches

The area surrounding Sacramento has a similar climate and a population of 530,000. The sales expectation for the area is therefore: (530,000 ÷ 105,958 x 47) 236 units.

13. Los Angeles, California - 62 dealers - 8.1% responded. Approximately one-fifth of the total dealers were circularized. Choice of color was 37½% grey; 37½% green; 25% bronze. A price of $42.90 was considered satisfactory, and a total of 11 units could be sold. Los Angeles has a population of 1,504,277. Climatic averages are:

July Temperature	70.5° F.
Maximum Temperature	109° F.
July Wet-bulb Temperature	64° F.
Annual Rainfall	14.76 inches

The surrounding area with a climate similar to that of Los Angeles has a population of 3,250,000. The sales expectation for the area is therefore: (3,250,000 ÷ 1,504,000 x 5 x 11) 119 units.

Summary:

AREA	UNITS
Albuquerque, New Mexico	518
Atchison, Kansas	Unknown
Austin, Texas	2,254
Tulsa, Oklahoma	4,936
Boise, Idaho	711
Butte, Montana	456
Tuscon, Arizona	4,297
Santa Fe, New Mexico	75
Reno, Nevada	524
Needles, California	Unknown
Bakersfield, California	Unknown
Sacramento, California	236
Los Angeles, California	119
TOTAL	14,126

In total, 321 dealers were circularized throughout the general area where evaporative cooling is effective. Of that number, 11.21% responded. The 321 dealers serve 859,381 of the 16,699,434 people living in the general area, or 5.15% of the population. The dealers who did respond (11.21%) estimated that they could sell 892 units. The sales expectation is therefore (892 ÷ .0515) 17,320 units. More credence is placed in the former computations, since they are based on local conditions and also local prejudices.

There are 5,019 retail appliance dealers in the area in which evaporative coolers can be used to advantage.* Of this number, 321 were circularized, and those who answered believed that 892 units could be sold through their stores this coming summer.

$5019/321 = x/892 \qquad x = 13,947$

This computation confirms the first estimation which was based on the population ratio. It is expected, therefore, that 14,000 units could be sold during the coming year of production.

The percentages for color choice from those dealers replying were:

Green	34.8%
Grey	32.6%
Ice Blue	17.4%
Bronze	13.0%
White	2.2%

However, when the color recommendations are weighted by the number the dealer estimated were salable in his area, the following percentages were obtained:

Grey	71.3%
Bronze	11.7%
Green	9.5%
Ice Blue	2.9%
White	2.6%

* U.S. Census (1940) Retail Dealers - Bureau of Census Department of Labor, Washington, D. C.

No price-color relationship was evident; no regional-color relationship was evident.

Dealers' estimates of the proper sales price varied from $20 to $65. There was definite indication of a "buyer's market" by comments, such as "as low as possible," and "$40 or less." The recommendations were as follows:

74.3%	$40
11.4%	$55
5.7%	$50
2.8%	$65
2.8%	$30
2.8%	$20

However, when the sales price recommended is weighted by the number the dealers estimated were salable in the area, the following percentages were obtained:

33.4%	$50
31.1%	$40
22.2%	$30
11.1%	$65
1.3%	$20

Of the dealers who responded, 62.2% were of the opinion that the FROST evaporative cooler would be an item that would sell in their stores; 16.2% were doubtful--they stated that they would "have to see it first"; 21.6% did not believe it would fit in with their present line of merchandise.

CONCLUSIONS: It was decided that:

1. A ready market for 14,000 FROST coolers was available.
2. The electric appliance dealers would be willing sales outlets.
3. The cooler should be painted a metalic-type, light grey with a slight greenish tint.
4. The sales price of the unit could be set between $40 and $50 or less if possible.

SECTION III - DESIGN

ADVICE FROM MANUFACTURERS: Communications with thirty-four manufacturers brought out six basic problems that would have to be overcome if a satisfactory portable unit were to be produced. They are:

1. The present "installed" units depend upon the movement of large quantities of partially chilled air. A smaller, "portable" unit would be handicapped because of lack of space for a large air movement device and a large evaporative surface.
2. Pumps for the recirculation of water cause trouble in all units. Some manufacturers avoid the use of pumps by attaching a city water inlet to a trough at the top of the aspen pad. This requires the user to adjust the flow of water manually, so that after flowing down the pad and furnishing all the water needed for evaporation, only a small trickle is left which is allowed to waste. The chief difficulty is that every time the humidity changes, the valve has to be re-adjusted; otherwise part of the filter is dry or part of the water is wasted.
3. Difficulty of keeping the unit clean. In addition to the dust and dirt that the wet

filters pick up from the air, scale from the evaporated water clogs the filters; slime from bacteria that thrive in the warm, wet aspen pad clog the filter and make the air smell musty. As the filter clogs, the static pressure mounts until either the fan will not move the air or the moving air blows holes in the aspen filter, so that the air by-passes the wet part of the filter and no evaporative cooling takes place.

4. Most units are noisy because of poor construction or high fan-tip speed, and therefore must be placed as far from the user as possible.
5. The fan motor, which is normally placed in the wet air stream, often fails because of condensation of water within the motor.
6. Air must be exhausted from the room equal to that added or the accumulated moisture makes the room sweat and the atmosphere becomes similar to that of a "Turkish bath."

IDEAL FACTORS: Working from the advice of the manufacturers, it was decided that the ideal unit should:

1. Evaporate as much water as possible
2. Have a non-clogging, easily cleanable filter
3. Eliminate a water recirculating pump
4. Produce a sufficient air movement to be sensible

IDEAL FACTORS (Continued):

5. Use an air movement device which will operate against high static pressure
6. Reduce noise caused by fan and faulty construction
7. Protect the fan motor from moisture
8. Automatically exhaust the air

PROPOSED SCOPE OF THE DESIGN: The FROST cooler is designed to cool one room; being portable and relatively inexpensive, it is expected that it will compete in the electric fan market rather than in the high-cost, permanently installed evaporative cooler unit market. The basic idea of the unit is that it can be used in the kitchen during the day; in the dining-living room during the evening; and in the bedroom at night. It is an attempt to provide the low-salaried family with an air conditioning unit within the limit of the family budget. Such families usually live in one of the thousands of newly (and sometimes poorly) constructed so-called "G-I" homes. Many such homes are in hot, flat developments with little or no planting to protect them from the sun, and the tempering breeze is blocked by four identical, adjacent houses. A unit such as planned will not only find a large and waiting market, but also will be a positive contribution to the betterment of the living conditions of thousands of our citizens.

DETERMINATION OF CAPACITY:

Heat to be Removed: In the "G-I" home, the average room is 10 feet by 12 feet (a generous estimate) with an 8-foot ceiling. This contains 960 cubic feet of air. The average gain of heat (dependent on the type of walls and insulation) through the walls, ceiling, and floor is estimated to be:

GAIN IN HEAT OF AVERAGE RESIDENCE

Type of Surface	Average in Sq.Ft.	Average Coefficient	BTU/hr/degree of Temperature Gradient
Outside Wall	200	.3	60
Inside Wall Ceiling-Floor	440	.16	70
Window	22	1.00	22
		TOTAL	152

Figure 3

Considering the standard at which evaporative cooling units are usually rated, 100° F. dry-bulb - 70° F. wet-bulb, the comfort (effective temperature) is 75° F. Therefore, the unit must change from sensible heat to latent heat, 152 x 25 or 3800 BTU per hour.

The average occupant-produced heat of 400 BTU per hour per person for the average family of 3.5 persons equals 1400 BTU per hour. The unit should be designed, therefore, to reduce the sensible temperature by 5200 BTU per hour.

Water Evaporation Necessary: The latent heat of vaporization is expressed by the following equation:

$$h = 1092 - 0.55\ t$$

Where "t" is the dry-bulb temperature in degrees F.:

$$t = 100$$

$$h = 1037 \text{ BTU per pound of water evaporated}$$

It will, therefore, take 5200 ÷ 1037 or 5.014 pounds of water evaporated each hour to produce the desired cooling.

Air Movement Necessary: Reading from the standard "Psychrometric Chart":

One pound of dry air at $100^{\circ}\ F_d - 70^{\circ}\ F_w$ contains 62 grains of water.

One pound of dry air at $70^{\circ}\ F_d - 70^{\circ}\ F_w$ contains 100 grains of water.

This is a gain of 48 grains of water per pound of dry air.

However, most evaporative coolers now on the market are only 65% efficient. Until the FROST cooler has been made and tested, it may be assumed that it will have a similar efficiency. Therefore, one pound of dry air will absorb only 65% of 48 grains of water or 31.2 grains.

5.014 pounds of water = 35,098 grains

(1 pound = 7,000 grains)

It will, therefore, require 35,098 ÷ 31.2 or 1125 pounds of air ($100^{\circ}\ F_d - 70^{\circ}\ F_w$) per hour to evaporate the 5.014 pounds of water. This rate of evaporation will produce the needed 5200 BTU of cooling.

At 100° F_d - 70° F_w, one pound of dry air occupies 14.3 cubic feet; therefore, it will be necessary to pass (14.3 x 1125) 16,087.5 cubic feet of air an hour through the cooler, or 268 CFM.

Evaporative Surface Needed: The equation for the evaporation of water from a surface of water exposed to an air stream is expressed as follows:(2)

$$M = (0.031 + 0.035\ W)\ (P_s - P_d) \times (P_o + P_i)$$

Assuming a velocity of 11.3 feet per second, substituting and solving, the area required is 22.7 square feet. (See Appendix, page 43).

In addition to the evaporation of water from the surface, there will be an appreciable evaporation from water in droplet form. The size of these droplets as they are "scrubbed" through a porous evaporative surface is not predictable, and could only be determined by experiment, working backward, from tests which measure the amount of water evaporated, to the average size that the droplets must have been. Such an experiment is beyond the scope of this work. It will, therefore, be assumed that the 22.7 square feet of evaporative surface computed above is the maximum needed, and that the additional droplet evaporation which will occur will increase the efficiency of the unit.

(2) International Critical Tables of Numerical Data for Physics, Chemistry, and Technology, Vol. 5, p. 59.

Recapitulation: In order to cool the average 10 x 12 foot room, the unit change of 5200 BTU per hour from sensible heat to latent heat is necessary. This will require the evaporation of 5.014 pounds of water and the movement of 16,087.5 cubic feet of air through the unit over an evaporative surface of 22.7 square feet. The ambient temperature is assumed to be $100^\circ\ F_d - 70^\circ\ F_w$, which is the usual assumption in the trade in rating evaporative coolers.

STUDY OF MEANS AVAILABLE:

Air Movement Devices: Two general types of air movement devices were found suitable to move the quantity of air needed:

1. The 4-bladed pressure fan
2. The squirrel-cage type blower

Each has advantages and each has disadvantages. Each requires radically different design. Both types are considered.

The cost of the fan blade is one-third more than that of the blower wheel. The fan will move more free air per horsepower applied than the blower; but as the static pressure increases, the amount of air moved decreases more rapidly for the fan than for the blower. This is important, since as water is evaporated, leaving scale on the filter, the static pressure rises rapidly. This will necessitate a larger filter for the fan than for the blower in order to produce an equal initial volume of air; and the amount of air delivered will decrease much more rapidly upon the formation of scale for the fan than for the blower.

The blower requires two-thirds of the space that a fan capable of moving an equivalent amount of air would occupy. This is important, since the unit to be portable must be small. Air movement for the fan is axial with the fan and motor. The fan motor, therefore, must be placed in the air stream with the resultant risk of condensation of moisture in the motor; while for the blower, the air stream departs at right angles to the blower-motor axis, thus the blower motor can be kep clear of the wet air stream.

Figure 14 shows the general operating characteristics of both fan and blower as determined by the American Society of Heating and Ventilating Engineers jointly with the National Association of Fan Manufacturers.

<u>Evaporative Surfaces (Filters)</u>: According to present practice in the field, it requires two and one-half pounds of aspen fibre, spread evenly over 1,000 square inches of inlet to cool 1,000 cubic feet of air per minute. Accordingly, to cool the required 268 cubic feet of air per minute, it would require 268/1000 x $2\frac{1}{2}$, or 2/3 pound of aspen fibre spread over 268 square inches of opening. The

static pressure drop through such a filter is .09 inches of water with a face velocity of 144 feet per minute. Higher velocities blow holes in the filter.

The trade has experimented extensively with other forms of matted filters. At present, tests(3) are being made with glass wool that has been etched with hydrofluoric acid. It has greater tensile strength and is easier to clean than aspen fibre, but it does not properly "wet" thus the moisture stays in droplets instead of forming a film. It is less efficient as an evaporative surface than aspen fibre.

Since size is extremely important in order to make the FROST cooler portable, other types of evaporative media were investigated; because, with higher face velocities, the filter could be made smaller. A commercial-type wire filter was found which permitted face velocities of over 700 feet per minute. The alternating flat and crimped wire cloth (20 meshes to the inch of .03 diameter wire) offers 40 linear feet of wire per cubic inch or .1 square foot of evaporative surface. The 22.7 square feet of surface required to evaporate the needed water will require 227 cubic inches of screen filter. A four-inch thickness will permit an evaporative outlet of 56.75 square inches.

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(3) The Utility Corporation, Los Angeles, California.

Water Recirculating Devices: Several methods for recirculating the unevaporated water were considered. The most common in present practice is a separate motor, which either pumps the water back to the top of the system or whirls the water into a spray in the air stream. One manufacturer uses a "V" belt running from the fan motor to an idler in the water reservoir which keeps a spray of water in the air stream. Some manufacturers, as mentioned before, connect the upper reservoir to the city water supply which requires manual adjustment of the flow. No system now in use is completely satisfactory for the reason that motors, in the water, fail because of condensation or scale; the life of a "V" belt, running in and out of water, is short; and manually adjusted systems need constant attention.

To avoid these difficulties, the idea of aspirating the water into the air stream was conceived. If a constriction is placed in the air flow and the reservoir is kept at the outlet pressure, the resulting difference in head is sufficient to aspirate the water into the air stream. The formulae for such aspiration is as follows:

$$Q = C\ A_2 \sqrt{\frac{1}{1 - (d_2/d_1)^4}} \times \sqrt{2\ gh}$$

The idea of using part of the fan energy, through the air stream, to lift the water from the reservoir into the air stream was found to be practical. Experiment showed that a fine spray of one-sixteenth inch (approximate) droplets was formed.

FINAL DESIGN: After a careful consideration of all of the advantages and disadvantages enumerated above, it was decided the ideal factors and the required capacity could be best achieved by using:

1. A squirrel-cage blower
2. A water reservoir
3. A venturi device for aspirating the water into the air stream
4. The air stream to scatter the water over a wire cloth filter
5. The evaporation of water from the filter by the passing air stream

A schematic diagram of such a unit is shown on the following page (Figure 4).

<u>Blower</u>: A commercial-type blower[4] has suitable characteristics. The wheel has a diameter of 5 1/4 inches; a width of 3 7/16 inches; and when turned at 1725 RPM will produce air movement as shown in Figure 5 on page 31.

(4) S 52331 - The Burden Company, Los Angeles, California

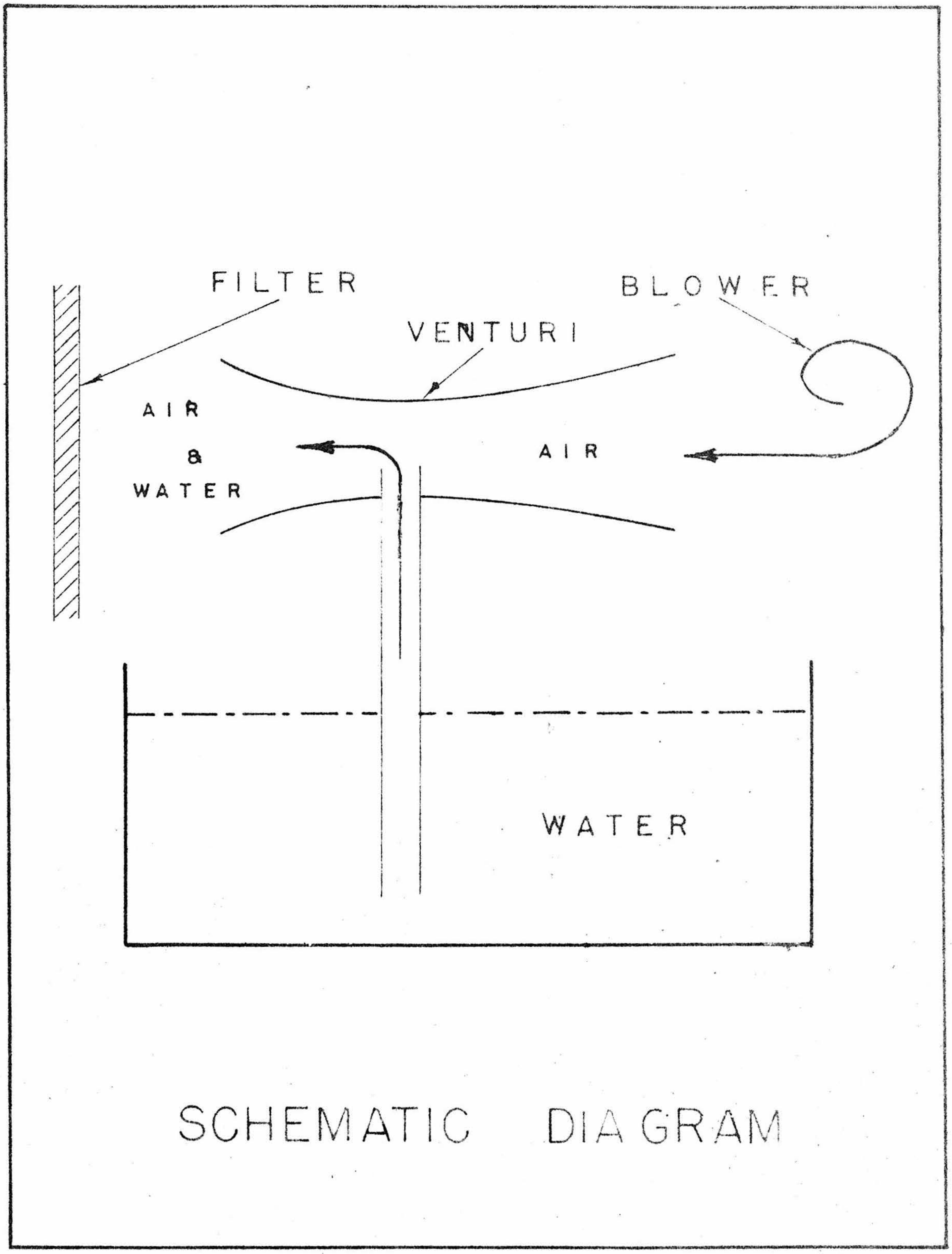

FILTER
BLOWER
VENTURI
AIR
&
WATER
AIR
WATER
SCHEMATIC DIAGRAM

Figure 4

CHARACTERISTICS OF BLOWER

Static Pressure inches of water	CFM	H.P.
0.0	343	.057
.1	326	.050
.2	297	.042
.4	224	.034

Figure 5

At .25 inches of water (the static pressure through the clean filter) the wheel will produce a flow of 268 CFM requiring .040 H.P. The present cost of this wheel in 5 to 25 thousand lots is sixty-eight cents.

Scroll and Venturi: To simplify construction, to reduce manufacturing costs, and to increase the rigidity of the unit, the venturi is built into the throat of the blower. The venturi is to maintain the same vertical height throughout. The reduction to the throat is to be gained by constricting the vertical sides.

Filter: The water will be evaporated from a commercial-type, crimped wire cloth filter,(5) 9 3/4" x 5 3/4" x 4" thick. The static pressure drop through the filter is .25 inches of water.

---

(5) Farr Company, Los Angeles, California.

Motor: The motor requires .04 horsepower to produce the needed 268 CFM against the static pressure of the filter. A 1/20 horsepower induction motor (of standard make), shaded pole, 60 cycles, 115 volts is used to provide sufficient capacity for motor overload.

Container: Top and Bottom - Sixteen-gauge aluminum, identical shallow drawn. The top to be perforated for the inlet grill, parted and hinged to make a service door.

Overall Dimensions: 18" x 8½" x 1"

Sides: The top and bottom to be separated by an 18-gauge aluminum "wrap-around," crimp sealed at the center of the motor end, and perforated for the outlet grill.

Overall Dimensions: 11" x 8½" x 18"

Motor Support: Fourteen-gauge aluminum, 8½" x 12", carrying motor support bracket, cut away to permit the passage of the blower scroll throat, with a power break tab on the sides, bottom, and scroll opening to permit joining to the bottom, sides, and scroll.

Water Reservoir: Drawn or folded aluminum pan, 10½" x 8 13/32" x 4" deep, which will hold 353 cubic inches of water (1.52 gallons), a quantity sufficient to last for over two and one-half hours. The top edge is to be rolled in. The pan is to be spot-welded to the sides and end.

CONCLUSIONS: The unit described will have the eight ideal factors expressed on pages 20 and 21.

1. Because it evaporates the water both from a sufficiently large surface film and from the droplets as they are "scrubbed" through the wire screen, it will evaporate as much water as possible.
2. The filter is of crimped aluminum wire screen. Soaking in a solution of warm washing soda will remove the scale; and the crimps in the screen will provide open ports for the passage of air; therefore, the unit will have a non-clogging, easily cleanable filter.
3. The use of a venturi to aspirate the water onto the filter eliminates the use of a water pump.
4. Since the unit is designed to operate at window sill height and has a surplus capacity in its motor, it will produce a sufficient air movement to be sensible.
5. A squirrel-cage blower is the most satisfactory air movement device because of its small size and high static pressure ability.
6. The blower and venturi are enclosed in a scroll inside of a closed case. The motor and blower do not turn at excessive speeds. The fan noise will not be audible.

CONCLUSIONS (Continued):

7. The fan motor is so placed as to be out of the air stream and is protected from moisture.

8. The unit is designed to be placed on the sill of an open window. It does not fill the average window. The cool air blown into the room strikes the opposite wall and drops to the floor--by virtue of its being heavier than the warm air in the room--recrosses the room along the floor and passes from the room through the window opening alongside of the unit; and still being cooler than the outside air, it falls away from the unit towards the ground. The air intake being at the top of the unit has a constant supply of dry, outside air. The unit is designed to automatically exhaust the air.

APPENDIX

PRODUCT SURVEY:

	Manufacturer	Address
1.	Acme Blower & Pipe Co., Inc.	5419 Tweedy Blvd. Los Angeles, Calif.
2.	Air-Fan Engineering Company	833 S. San Pedro Los Angeles, Calif.
3.	Air-Perme-Ator Mfg. Company	Preakness Avenue Paterson, N. J.
4.	Alumalloyn Engineering Co.	1058 N. St. Andrews Los Angeles, Calif.
5.	American Metal Products Co.	Fort Worth, Texas
6.	American Moistening Company	260 W. Exchange St. Providence, R. I.
7.	American Society of Heating and Ventilating Engineers	51 Madison Avenue New York, New York
8.	Arrow Sheet Metal Works	2708 West 7th St. Los Angeles, Calif.
9.	Atlas Heating & Ventilating Company, Ltd.	557 - 4th Street San Francisco, Calif.
10.	Bahnson Company, The	1001 S. Marshall St. Winston-Salem, N. C.
11.	Burden Company	1000 N. Orange Drive Los Angeles, Calif.
12.	Coleman's Sheet Metal Works	1350 Margo Street Los Angeles, Calif.
13.	Curtis Refrigerating Machine Company	1989 Kienlen Avenue St. Louis, Missouri
14.	Electrical Merchandising	68 Post Street San Francisco, Calif.
15.	Electrical Merchandising	330 W. 42d Street New York, New York

16.	English and Lauer, Inc.	1978 S. Los Angeles Los Angeles, Calif.
17.	Farr Company	2615 Southwest Drive Los Angeles, Calif.
18.	General American Transportation Corporation	10 East 49th Street New York, New York
19.	General Electric Company Air Conditioning Dept.	Bloomfield, N. J.
20.	Great National Air Conditioning Corp.	324 Oklahoma Bldg. Oklahoma City, Okla.
21.	Hieatt Engineering Company	2508 West 6th Street Los Angeles, Calif.
22.	Industrial Blow Pipe & Sheet Metal Company	6218 S. Central Ave. Los Angeles, Calif.
23.	International Sales Company	2045 Evans Avenue San Francisco, Calif.
24.	Johnson Fan & Blower Corp.	1319 W. Lake Street Chicago, Illinois
25.	Jones Manufacturing Company	4028 N. Barnes St. Oklahoma City, Okla.
26.	Marl Coil Company	6735 Manchester St. St. Louis, Missouri
27.	Morey, Dan	814 S. Robertson Blvd. Los Angeles, Calif.
28.	Palmer Manufacturing Corp.	Phoenix, Arizona
29.	Payne Furnace Company	336 N. Foothill Road Beverly Hills, Calif.
30.	Peerless Mfg. Company	Dallas, Texas
31.	Pryne & Co., Inc.	140 N. Towne Avenue Pomona, Calif.
32.	Queen Stove Works, Inc.	Alberta Lea, Minnesota
33.	Rapids Products Co., Inc.	Cedar Rapids, Iowa

34.	Refrigeration Economics Co.	1231 Tuscarawas St. Canton, Ohio
35.	Rheem Manufacturing Company	4361 Firestone Blvd. South Gate, Calif.
36.	Robinson, Hugh & Sons	1130 E. 108th St. Los Angeles, Calif.
37.	Rodman Engineering Company	Kenmore, New Jersey
38.	Southwest Manufacturing Co.	1214 W. Madison St. Phoenix, Arizona
39.	Spraying Systems Company	3201 Randolph Street Bellwood, Illinois
40.	Spraying Systems Company	4022 W. Lake Street Chicago, Illinois
41.	Supreme Electric Products Co.	194 Vassar Street Rochester, New York
42.	Trane Company, The	La Crosse, Wisconsin
43.	Utility Appliance Corp.	4851 S. Alameda St. Los Angeles, Calif.
44.	Wagner Electric Corp.	1240 S. Hope Street Los Angeles, Calif.
45.	Western Engineering and Manufacturing Company	1726 E. Washington Los Angeles, Calif.
46.	Western Thermal Equipment Co.	1701 W. Slauson Ave. Los Angeles, Calif.
47.	Worthington Pump and Machinery Company	426 Worthington Ave. Harrison, New Jersey

Several of the manufacturers were particularly helpful in their constructive criticism of the problem, spending much of their time in a thorough analysis and offering valuable advice. Listed below are some of the more pertinent excerpts from their correspondence:

1. R. N. Bowman, Assistant Manager
   Rheem Manufacturing Company
   South Gate, California

"Items of a portable nature are classed as 'off-the-shelf' items and are sold through appliance and hardware stores."

2. H. W. Ribble
   Rapids Products Company
   Cedar Rapids, Iowa

"We suggest that you dwell on the importance of keeping the evaporative cooler clean. This seems to be one of the major problems and one that has been neglected..."

3. Dan Morey
   Evaporative Cooler Supplies
   Los Angeles, California

"It takes about 2½ pounds of Aspen fibre spread over 1,000 square inches of opening to properly humidify and cool 1,000 cubic feet of air per minute...the air has to be exhausted as it is cooled, otherwise the humidity will build up in a room and give a 'Turkish bath' effect."

"The walls and contents of an ordinary room will absorb a considerable amount of moisture to keep down the humidity, but any sustained exposure will lead to difficulties."

4. John C. Mueller, Director of Research
   Payne Furnace Company
   Beverly Hills, California

"We have found that usina a 1½ inch thickness of wet excelsior, packed at average density, the static pressure drop through the pad is about 0.1 inch water column at a velocity through the pad of 200 feet per minute."

The physiological sensation produced by a domestic-type cooler is due, not only to the temperature reduction, but also to the feeling of air movement."

5. Don R. Groth, Sales Manager
   Great National Air Conditioning Corp.
   Oklahoma City, Oklahoma

"You have picked a problem which has been give considerable thought by manufacturers of evaporative coolers... We know that there is a definite need for a portable evaporative cooler air conditioner, but we have not, as yet, been successful in designing one which can be sold to the public and still be actually portable."

CONSUMER SURVEY:

There were 321 appliance dealers circularized, and of that number the 47 dealers listed below responded with valuable advice on the color, price range, dealer discount, and channels of distribution. They felt that the "FROST" cooler would find a ready market.

	Name	Address
1.	A & A Appliance Company	Tulsa, Oklahoma
2.	A. B. Hollywood Electric Service	Hollywood, Calif.
3.	A-1 Appliance & Radio Co.	Los Angeles, Calif.

4.	Albuquerque Lighting Fixture Company	Albuquerque, N. Mex.
5.	Andersen's Department Store	Huntington Park, Calif.
6.	Anerson's Electric City	Beverly Hills, Calif.
7.	Aoki Music Company	Sacramento, Calif.
8.	Appliance Distributor Co.	Tuscon, Arizona
9.	Austin Goodyear Co., Inc.	Austin, Texas
10.	Ayres & Hall Hardware Co.	Los Angeles, Calif.
11.	Becky Furniture & Appliance Company	Butte, Montana
12.	Beverly Hills Electric Co.	Beverly Hills, Calif.
13.	Blue Line Electric Co.	Los Angeles, Calif.
14.	Brenner Brothers	Los Angeles, Calif.
15.	Brewster Electric & Hobby Shop	Tulsa, Oklahoma
16.	Butte Bottlers' Supply Company, Inc.	Butte, Montana
17.	California Electric Co.	Los Angeles, Calif.
18.	Capital Tire & Appliance Co.	Santa Fe, New Mex.
19.	Carmichael Appliance Co.	Carmichael, Calif.
20.	Central Texas Appliance Co.	Austin, Texas
21.	City Electric Company	Winnemucca, Nevada
22.	Clark & Company	Sacramento, Calif.
23.	Davis Brothers Furniture Co.	Tulsa, Oklahoma
24.	Dolan's	Sacramento, Calif.
25.	Electrical Appliance Distributors, Inc.	Boise, Idaho
26.	Fruitridge Hardware & Appliance Company	Sacramento, Calif.

27.	G & H Electric Appliance Co.	Tuscon, Arizona
28.	George Steele & Co.	Butte, Montana
29.	Hagginwood Appliance Store	Sacramento, Calif.
30.	Home Supply Company	Albuquerque, N. Mex.
31.	L. H. Chant Electric Co.	Albuquerque, N. Mex.
32.	Maxeiner's Store	Lovelock, Nevada
33.	May's Music Co., Inc.	Albuquerque, N. Mex.
34.	Maytag Appliance Co.	Austin, Texas
35.	Mitchell Hardware & Appliance Store	Tulsa, Oklahoma
36.	Monitor Home Appliance, Inc.	Butte, Montana
37.	Nevada Machinery & Electric Company	Reno, Nevada
38.	Rah's Radio & Home Appliance Company	Tuscon, Arizona
39.	Repair All Shop, The	Tuscon, Arizona
40.	Sav-On Furniture Co.	Tuscon, Arizona
41.	Sherman Clay & Company	Sacramento, Calif.
42.	Singer Sewing Machine Co.	Santa Fe, New Mex.
43.	Spry Appliance Company	Tuscon, Arizona
44.	Summers Sales Company	Albuquerque, N. Mex.
45.	Swartz Hardware Company	Sacramento, Calif.
46.	Universal Electrical Contracting Company	Santa Fe, N. Mex.
47.	Wood-Davis Hardware Company	Santa Fe, N. Mex.

COMPUTATIONS:

Determination of Evaporative Surface Needed: The evaporation of water from a surface exposed to an air stream is expressed by the following equation:(6)

$$M = (0.031 + 0.035\ W)\ (P_s - P_d) \times P_o \div P_i$$

M = kg, M^{-2}, hr^{-1}

W = air velocity in meters per second (.5 to 4 m ÷ sec.)

P_o = 760 mm Hg

P_i = barometric pressure

P_s = saturation pressure at temperature of surface

P_d = saturation pressure at dew point

Range of formulae 20° - 70° C.

Assuming standard conditions of 100° F_d - 70° F_w, 760 mm Hg, it is desired to evaporate 5.014 pounds of water each hour in an air stream of 268 CFM. "W" is expressed in velocity. The 268 CFM can be obtained at various velocities dependent on the size of the opening through which the air is passed. An arbitrary opening size is chosen that will give a velocity of 11.3 feet per second.

M = (5.014 pounds of water) 2.276 kg

M^{-2} to be determined

$hr^{-1} = 1/1 = 1$

W = 268 CFM = 11.3 ft/sec = 3.444 m/sec (velocity is variable with the design)

(6) International Critical Tables of Numerical Data for Physics, Chemistry, and Technology, Vol. 5, p. 59.

$P_i = 760$ Hg

$P_s = .363$ lb/sq. in. $= 18.82$ mm Hg

$P_d = .206$ lb/sq. in. $= 10.67$ mm Hg

Substituting:

$$\frac{2.276}{M^{-2}} = (0.031 + 0.035 \times 3.444)(18.82 - 10.67)\frac{1}{1}$$

$M^{-2} = 2.11$ sq. meters $= 22.7$ sq. ft.

See Figure 6 on page 45.

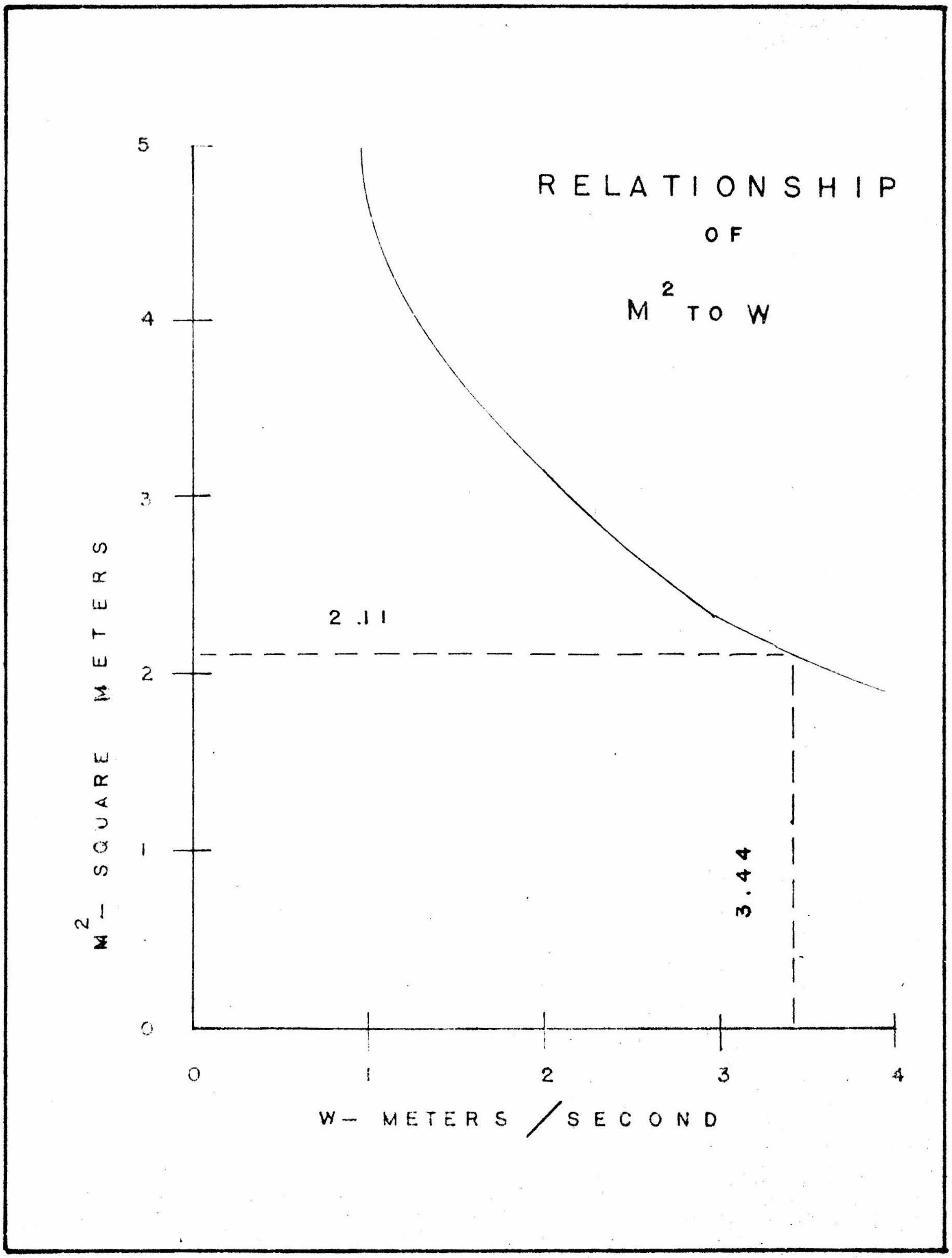

RELATIONSHIP
OF
M 2 TO W
2.11
3.44
M 2 - SQUARE METERS
W- METERS/SECOND
0
1
2
3
4
5

Figure 6

<u>Determination of the Venturi Throat</u>: The necessary lift to introduce water from the bottom of the water reservoir into the air stream is $7\frac{1}{2}$ inches or .625 feet of head (h_w). The formulae for translating a head of water into a head of air, which is the medium flowing through the venturi, is:

$$P = w_w\ h_w = w_a\ h_a$$

w_w = specific gravity of water = 1

h_w = head of water in feet = .625

w_a = specific gravity of air = .00129

h_a = head of air in feet

$$h_a = \frac{w_w\ h_w}{w_a} = \frac{1 \times .625}{.00129} = 485$$

The formulae for the performance of a venturi is:

$$h_2 - h_1 = \frac{1}{2g}\ (V_1{}^2 - V_2{}^2)$$

$$h_2 - h_1 = 485$$

$$\frac{1}{2g} = \frac{1}{64.4}$$

$$V_1 = \frac{Q}{A_1} = \frac{268}{60} \times \frac{144}{A_1}$$

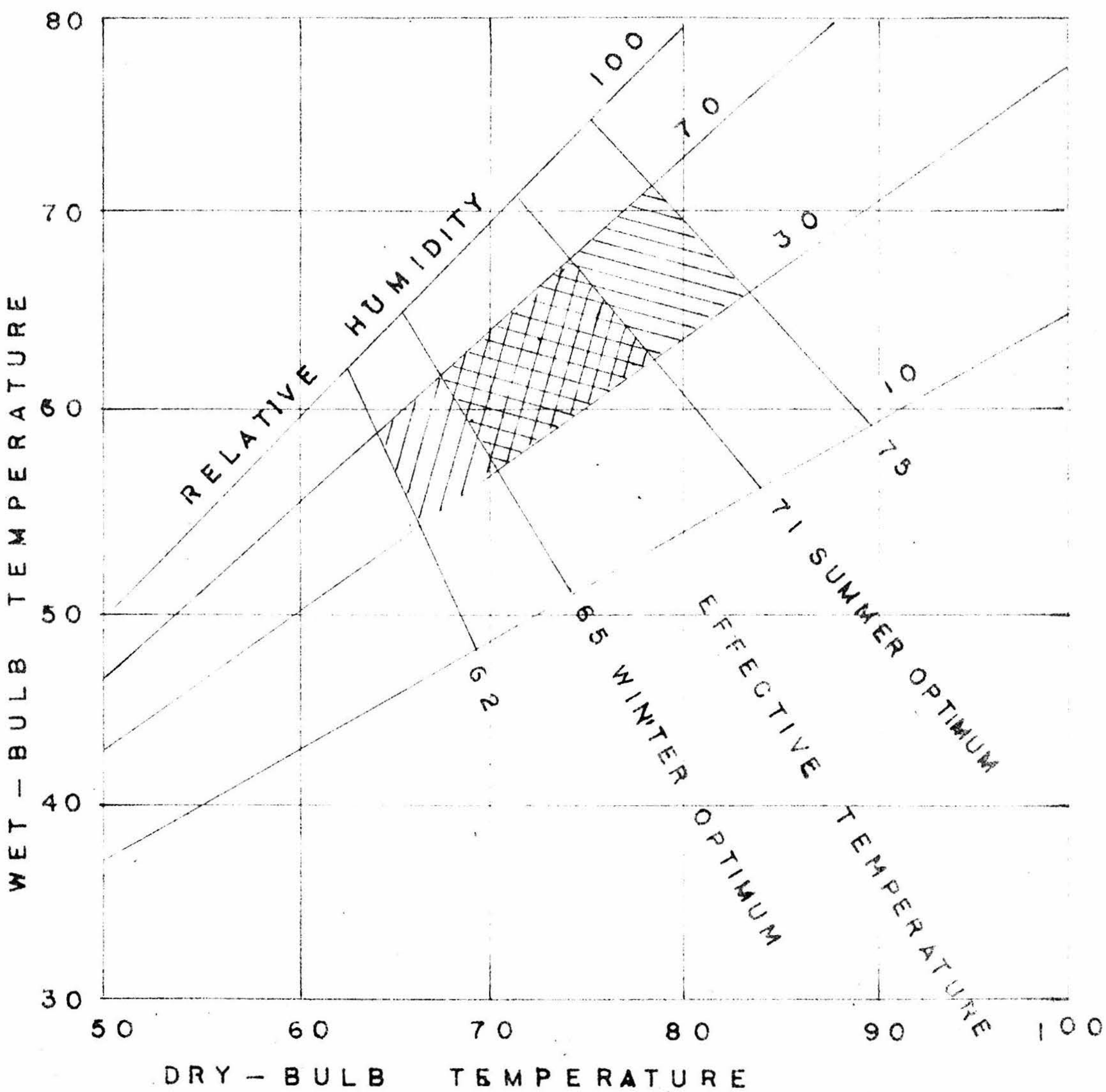
$$V_2 = \frac{Q}{A_2} = \frac{268}{60} \times \frac{144}{21} = 30.63$$

Substituting:

$$485 = \frac{1}{64.4} \quad (30.63)^2 - (\frac{268}{60} \times \frac{144}{A_1})^2$$

$$A_1 = 4.34 \text{ square inches}$$

Since the coefficient of the proposed venturi is not known, the area of the throat as found above is approximate and must be determined by experiment. However, since most venturi formulae use a coefficient of .97 - .99, the above approximation is considered to be sufficiently accurate for the purpose of this work.



ASHEV COMFORT CHART

FOR COTINUOUS OCCUPANCY
OF MORE THAN THREE HOURS

Figure 7

DESIRABLE TEMPERATURES FOR SHORT PERIOD OCCUPANCY

Outdoor Dry-bulb F.	Dry-bulb	Wet-bulb	Relative Humidity	Effective Temperature
95	80.0	65.0	43%	73
90	78.0	64.5	48%	72
85	76.5	64.0	50%	71
80	75.0	63.5	52%	70
75	73.5	63.0	55%	69
70	72.0	62.5	59%	68

Figure 8

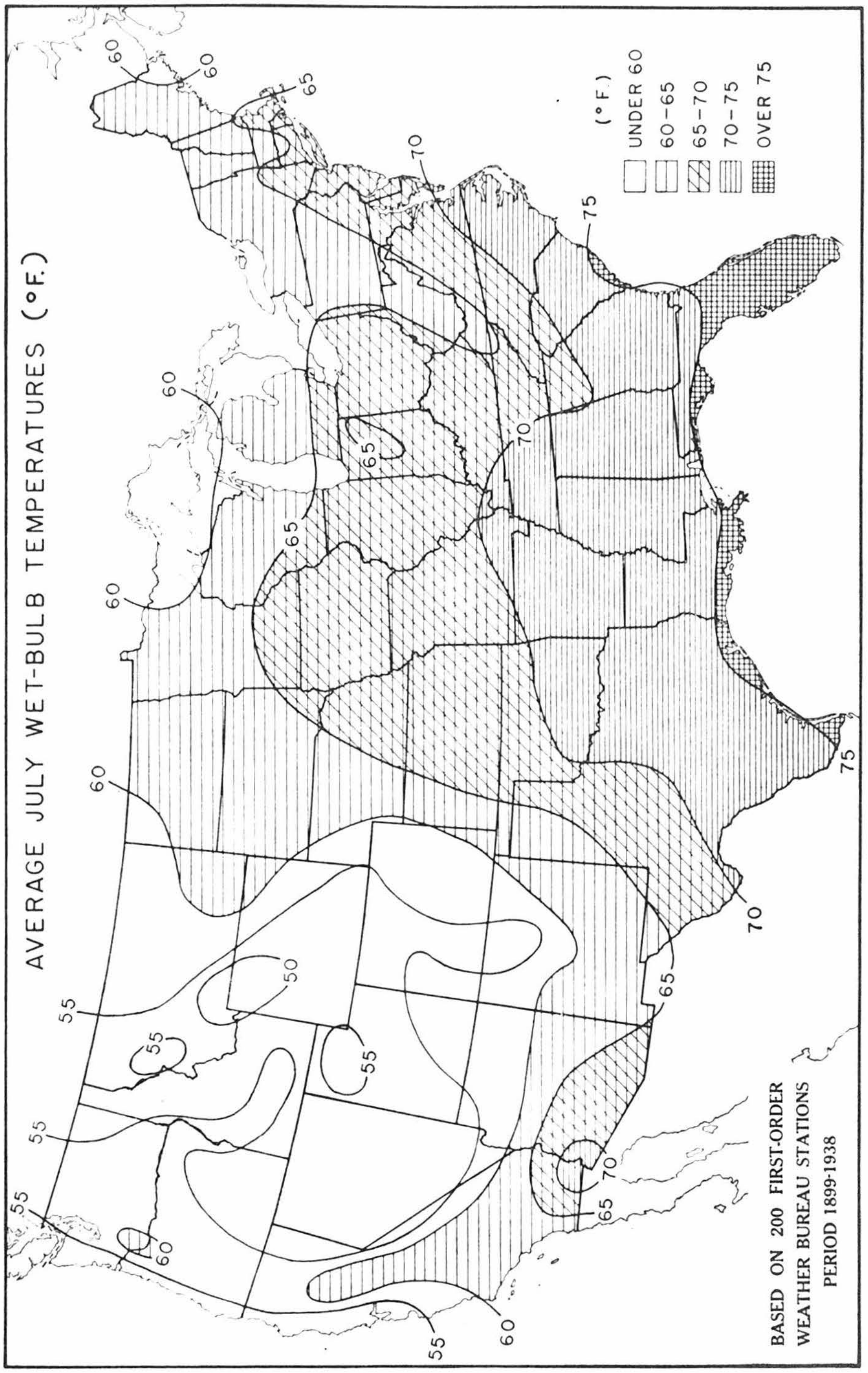

AVERAGE JULY WET-BULB TEMPERATURES (°F.)
(°F.)
UNDER 60
60-65
65-70
70-75
OVER 75
BASED ON 200 FIRST-ORDER
WEATHER BUREAU STATIONS
PERIOD 1899-1938

Figure 9

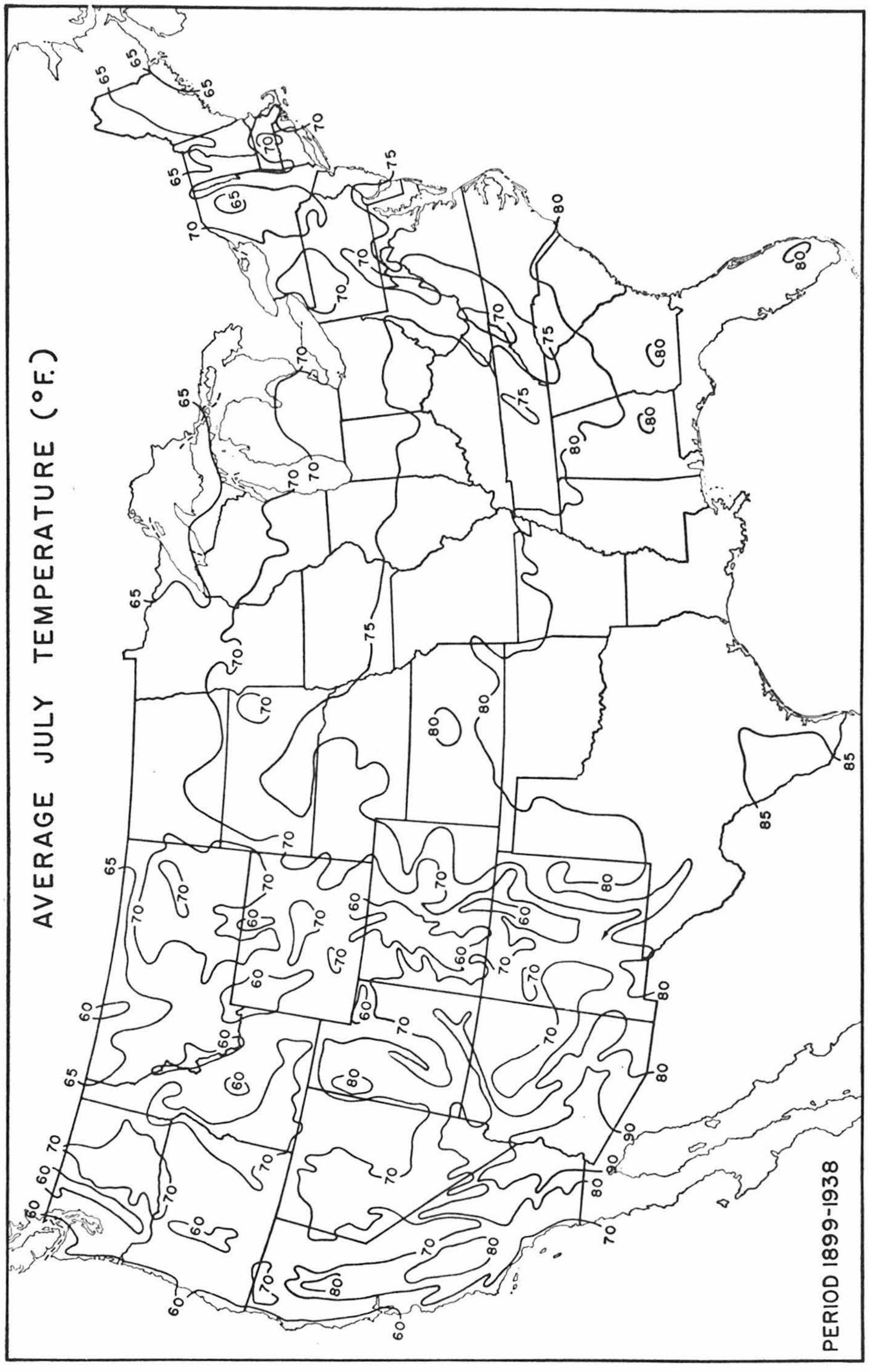


Figure 10

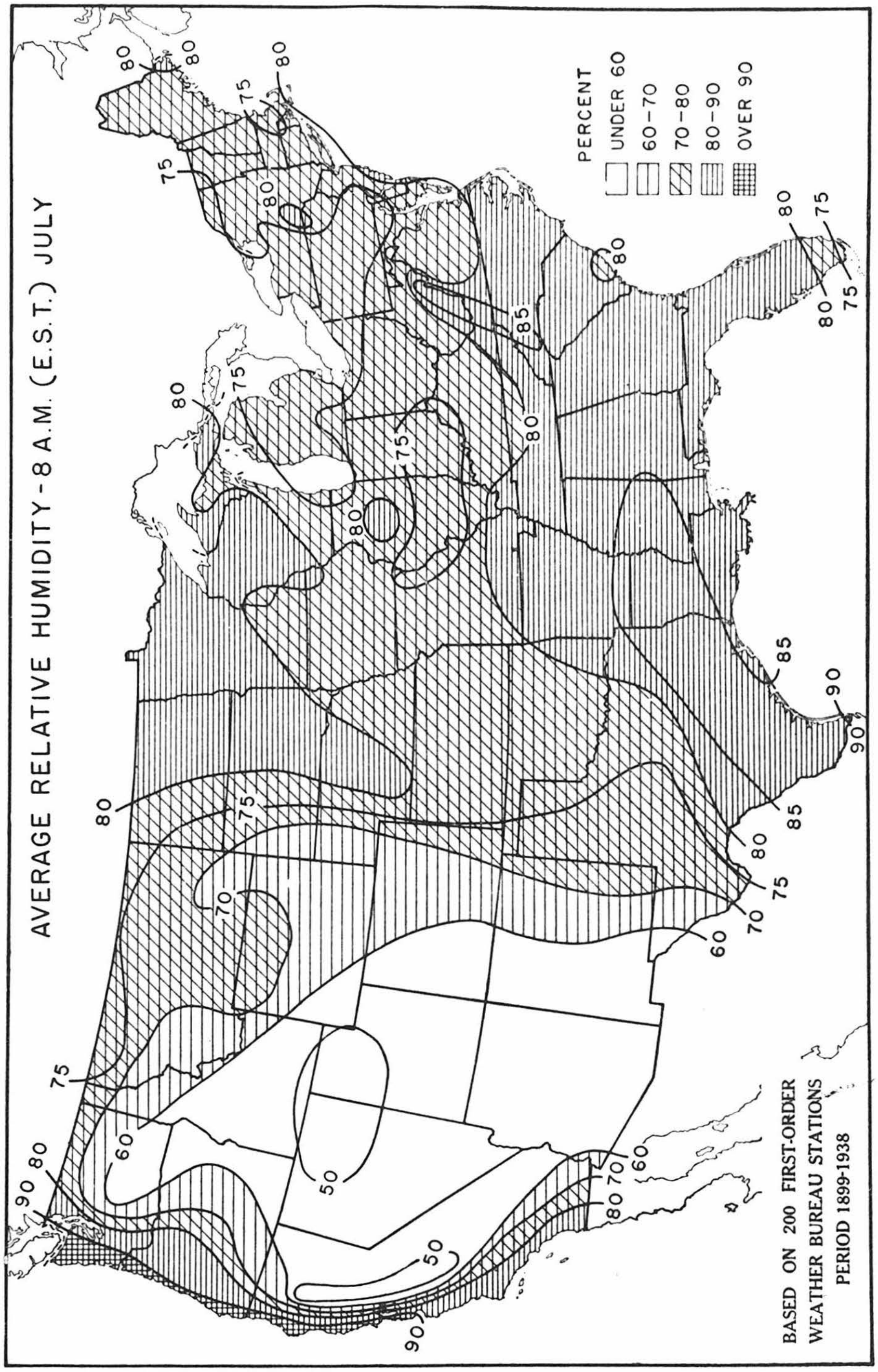

AVERAGE RELATIVE HUMIDITY - 8 A.M. (E.S.T.) JULY
PERCENT
UNDER 60
60-70
70-80
80-90
OVER 90
BASED ON 200 FIRST-ORDER
WEATHER BUREAU STATIONS
PERIOD 1899-1938

Figure 11

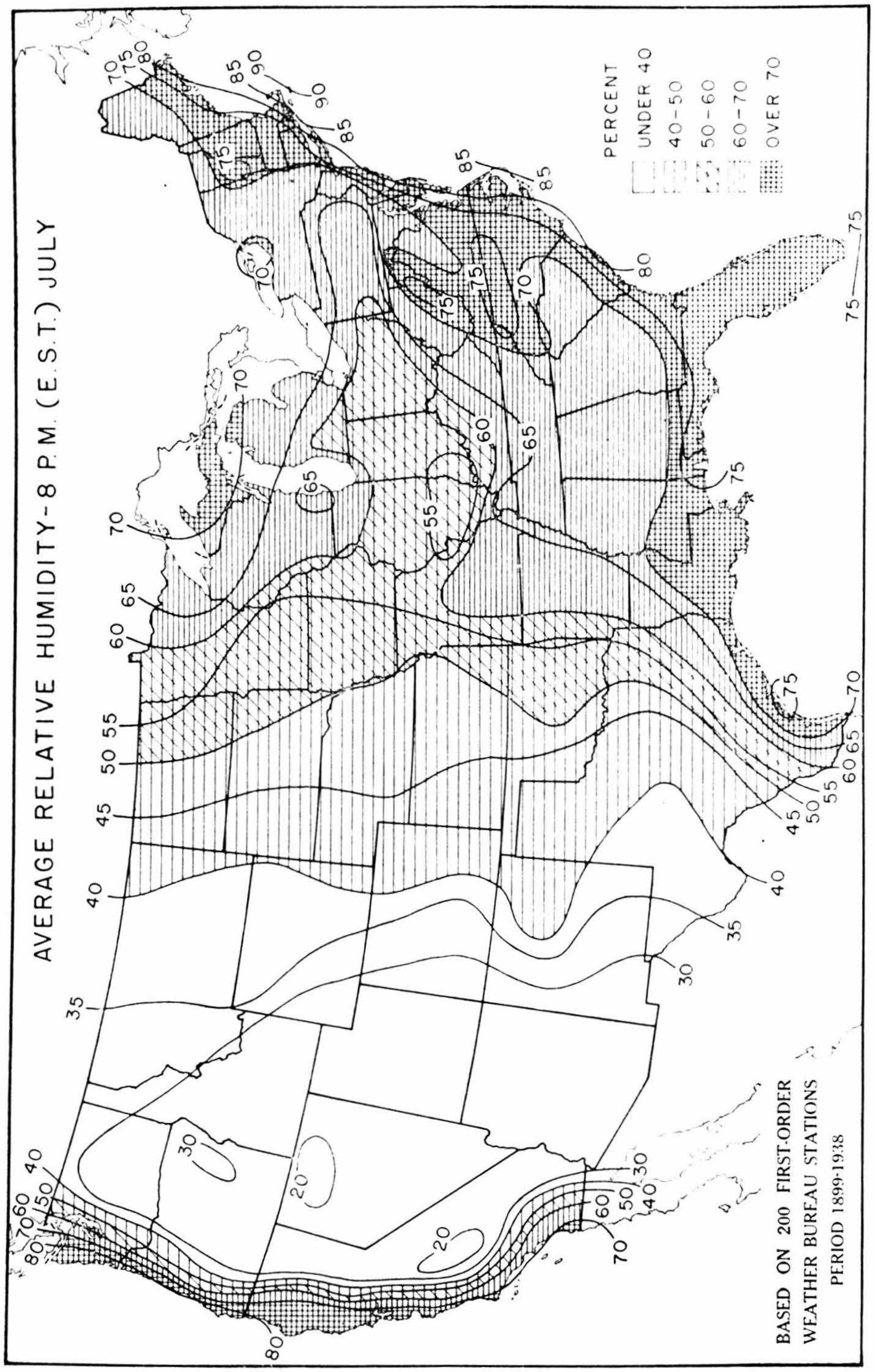

AVERAGE RELATIVE HUMIDITY - 8 P.M. (E.S.T.) JULY
PERCENT
UNDER 40
40-50
50-60
60-70
OVER 70
BASED ON 200 FIRST-ORDER
WEATHER BUREAU STATIONS
PERIOD 1899-1938

Figure 12

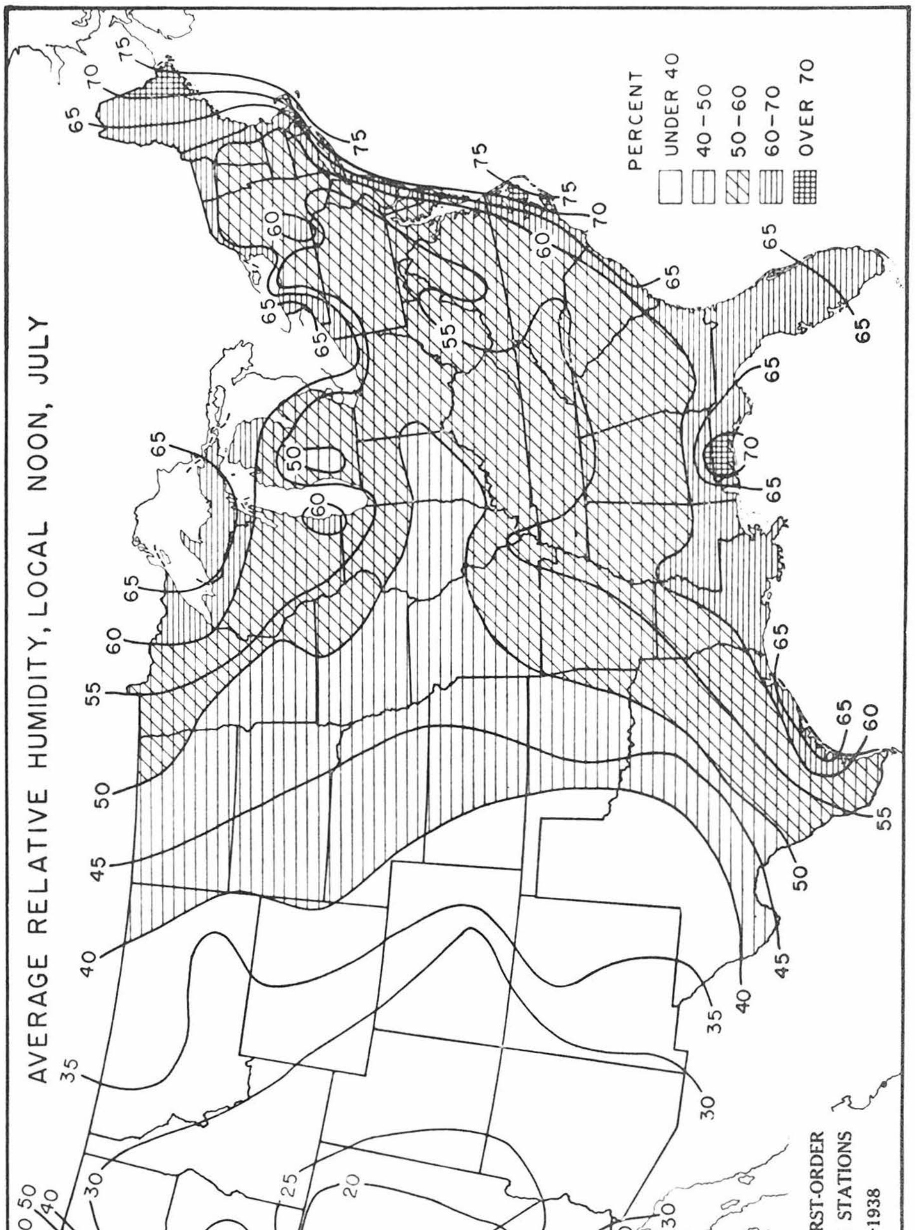

AVERAGE RELATIVE HUMIDITY, LOCAL NOON, JULY
PERCENT
UNDER 40
40-50
50-60
60-70
OVER 70
BASED ON 200 FIRST-ORDER
WEATHER BUREAU STATIONS
PERIOD 1899-1938

Figure 13

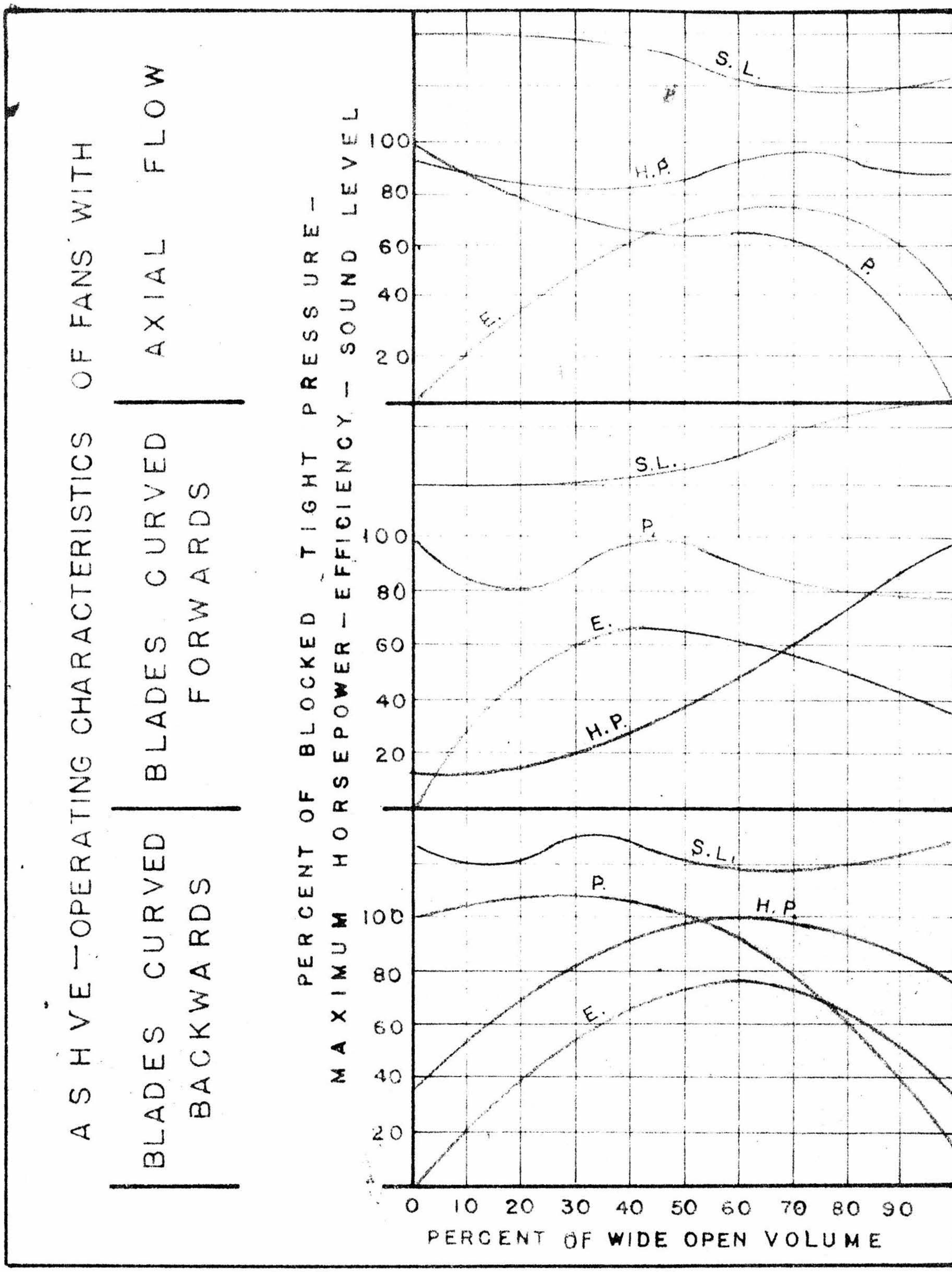

ASHVE — OPERATING CHARACTERISTICS OF FANS WITH
BLADES CURVED BACKWARDS
BLADES CURVED FORWARDS
AXIAL FLOW
PERCENT OF BLOCKED TIGHT PRESSURE —
MAXIMUM HORSEPOWER — EFFICIENCY — SOUND LEVEL
S.L.
H.P.
P.
E.
0 10 20 30 40 50 60 70 80 90
PERCENT OF WIDE OPEN VOLUME

Figure 14

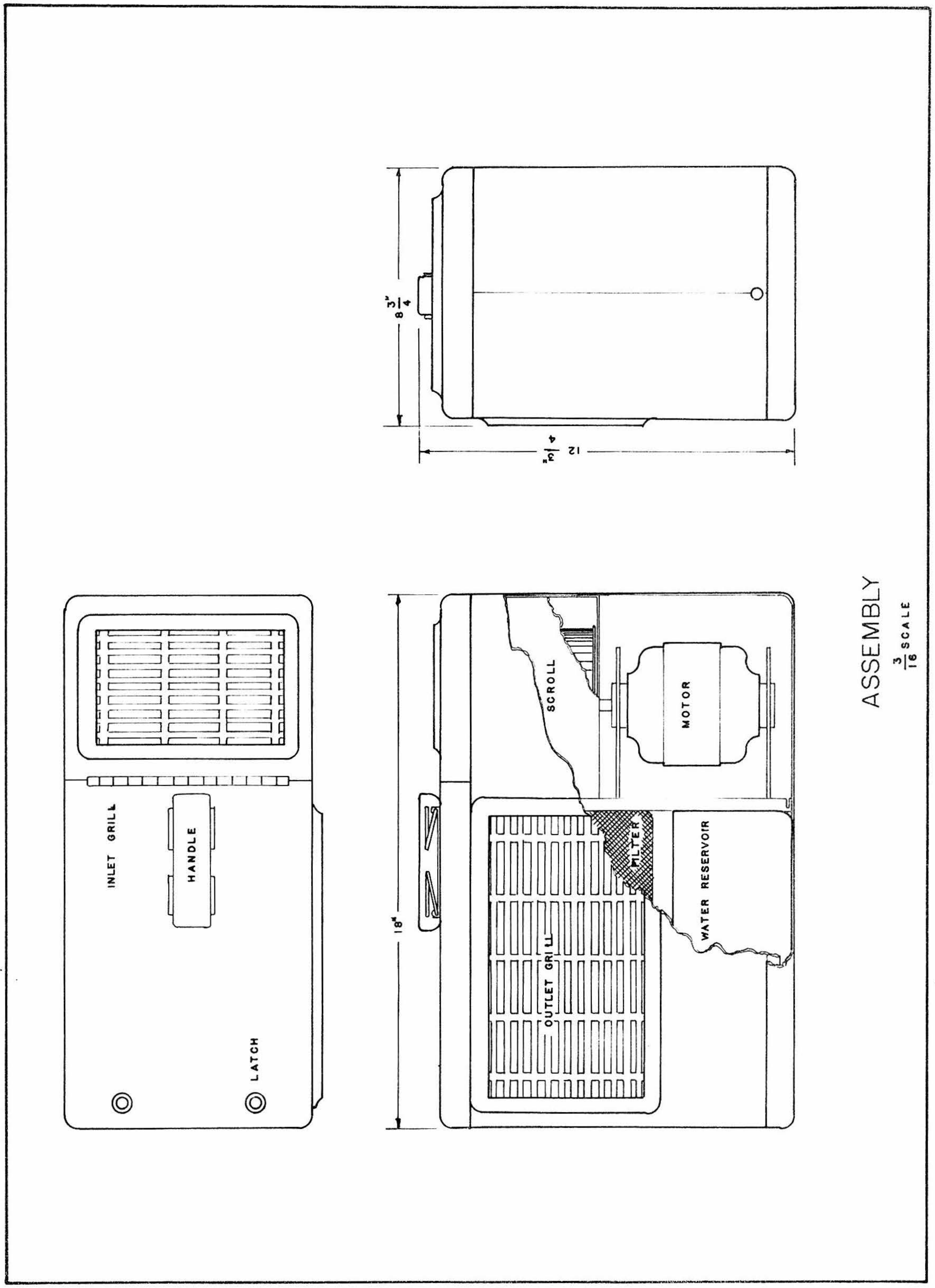

ASSEMBLY
3/16 SCALE
INLET GRILL
HANDLE
LATCH
SCROLL
MOTOR
FILTER
WATER RESERVOIR
OUTLET GRILL
18"
8 3/4"
12 3/4"

Figure 15

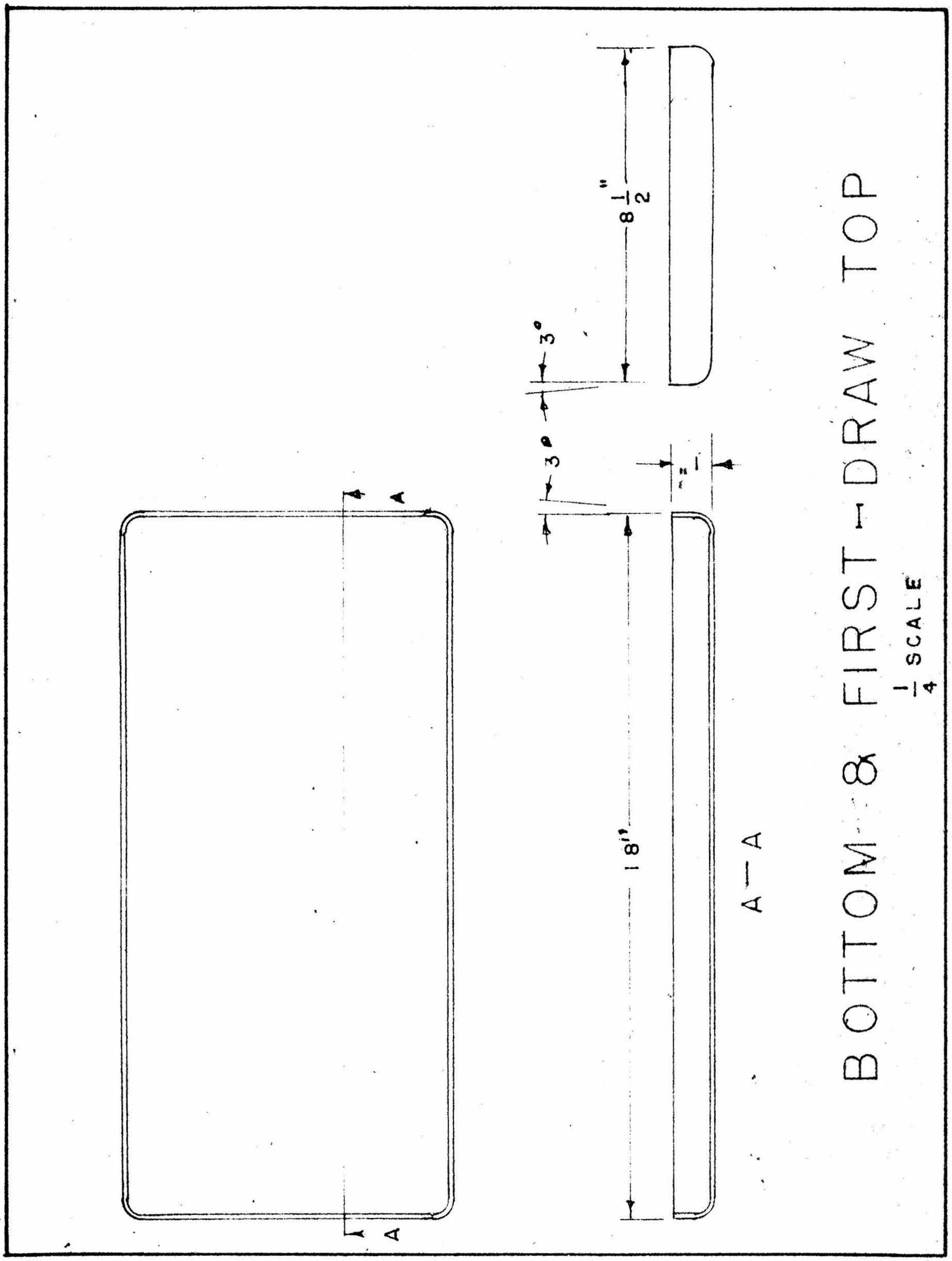


Figure 16

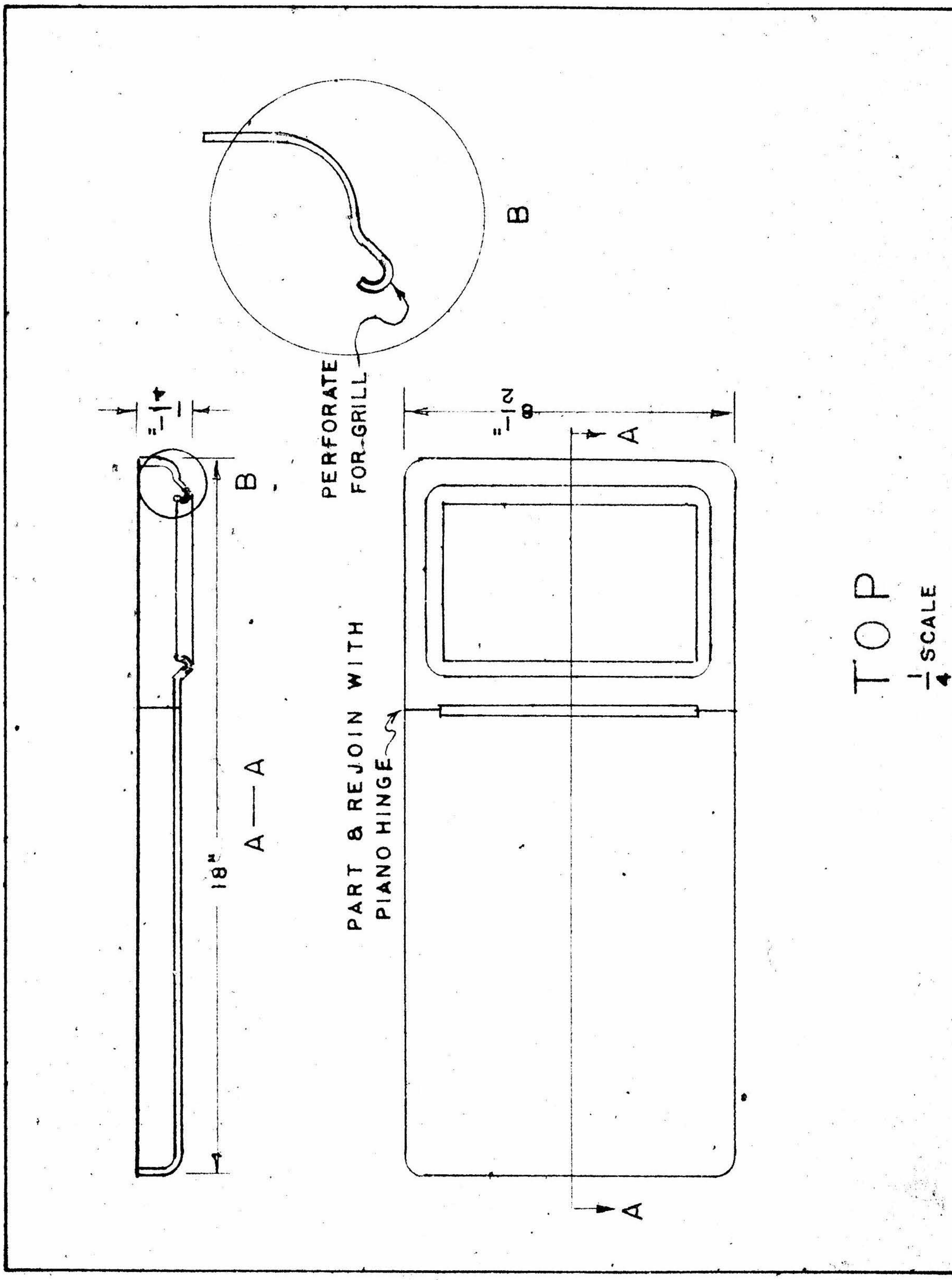

PERFORATE
FOR GRILL
B
A — A
18"
PART & REJOIN WITH
PIANO HINGE
A
TOP
1/4 SCALE

Figure 17

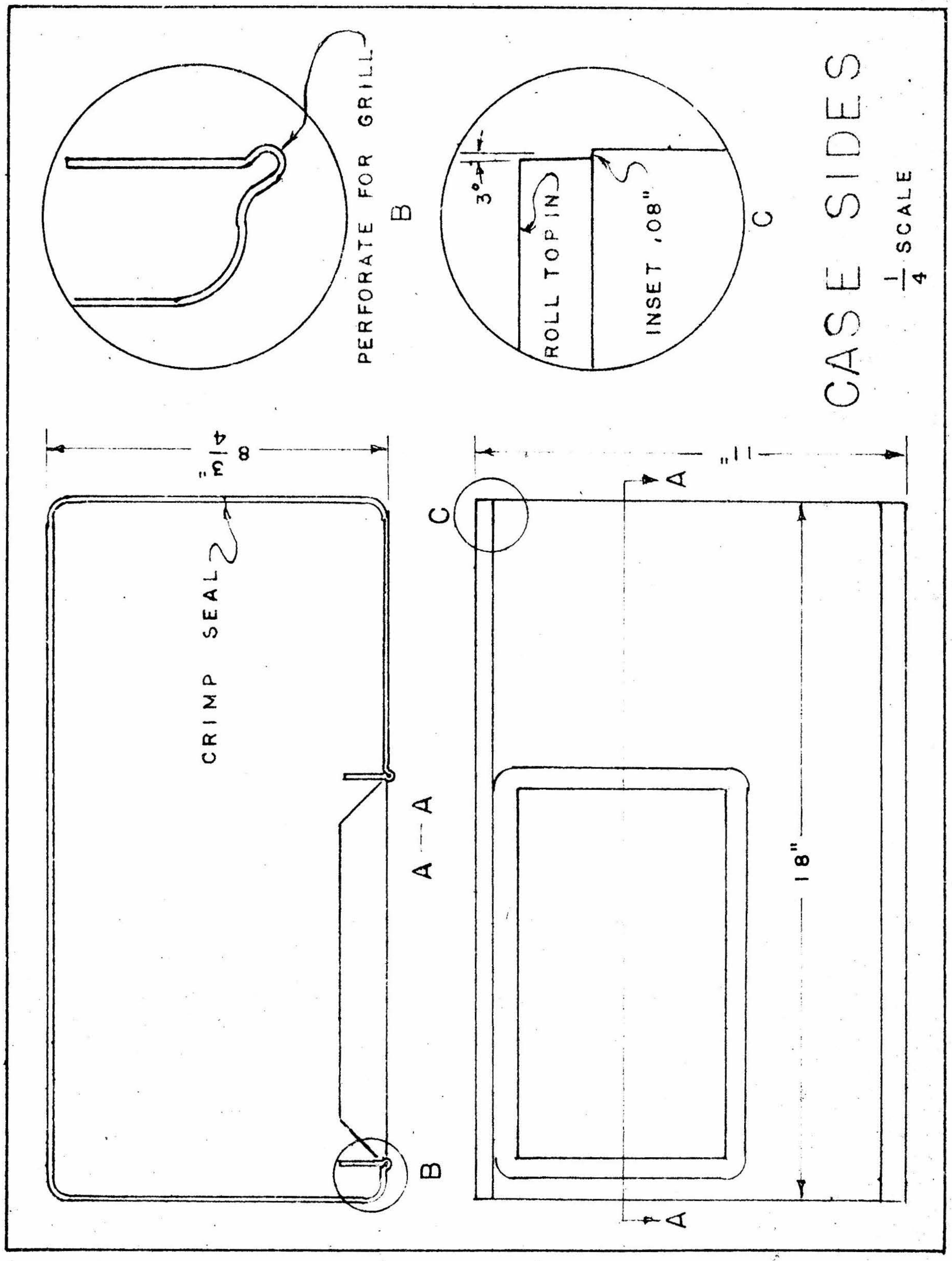

CASE SIDES
1/4 SCALE
PERFORATE FOR GRILL
B
ROLL TOP IN
INSET .08"
3°
C
CRIMP SEAL
8 3/4"
A — A
11"
18"
A
A
B
C

Figure 18

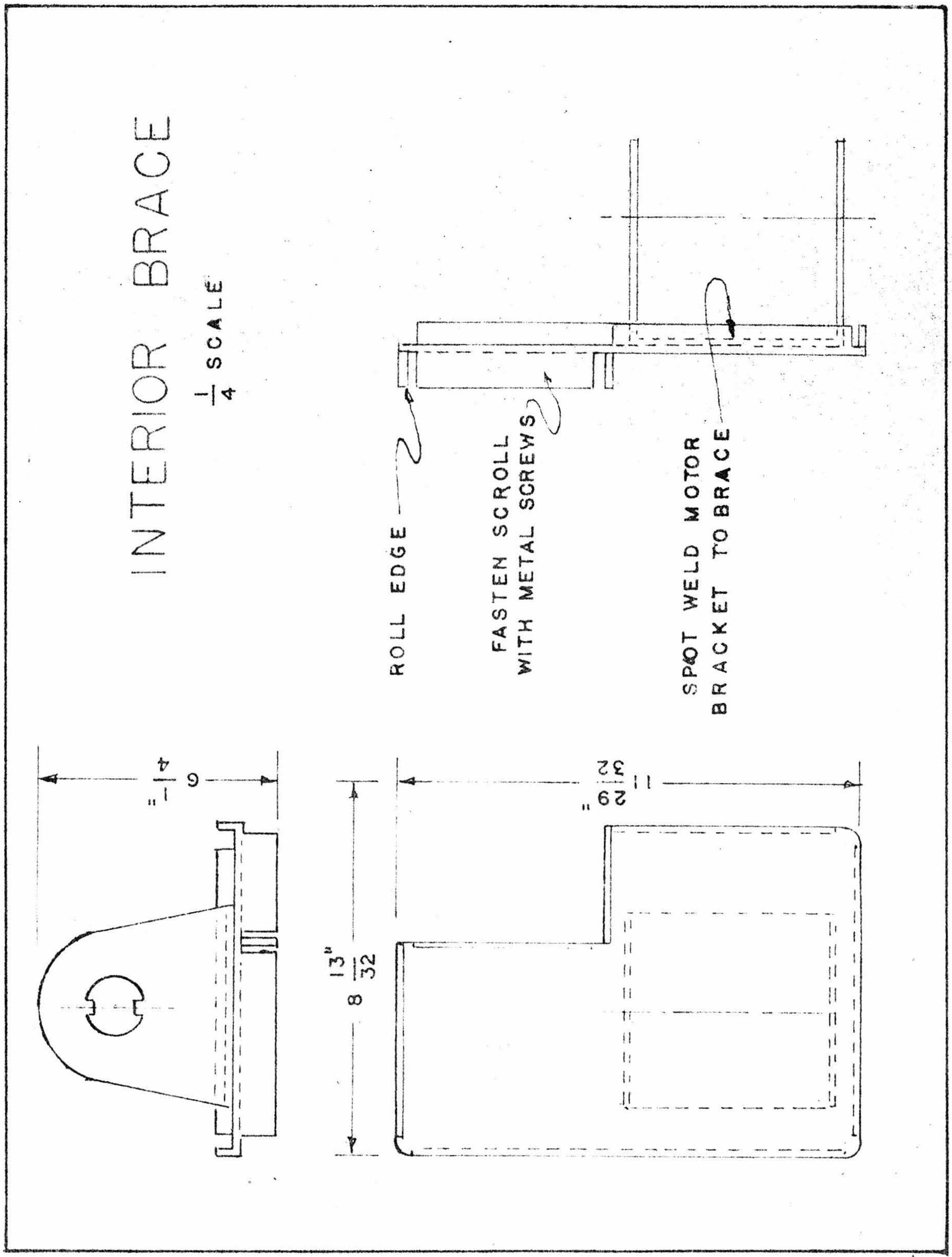

INTERIOR BRACE
1/4 SCALE
ROLL EDGE
FASTEN SCROLL
WITH METAL SCREWS
SPOT WELD MOTOR
BRACKET TO BRACE
6 1/4"
8 13/32"
11 29/32"

Figure 19

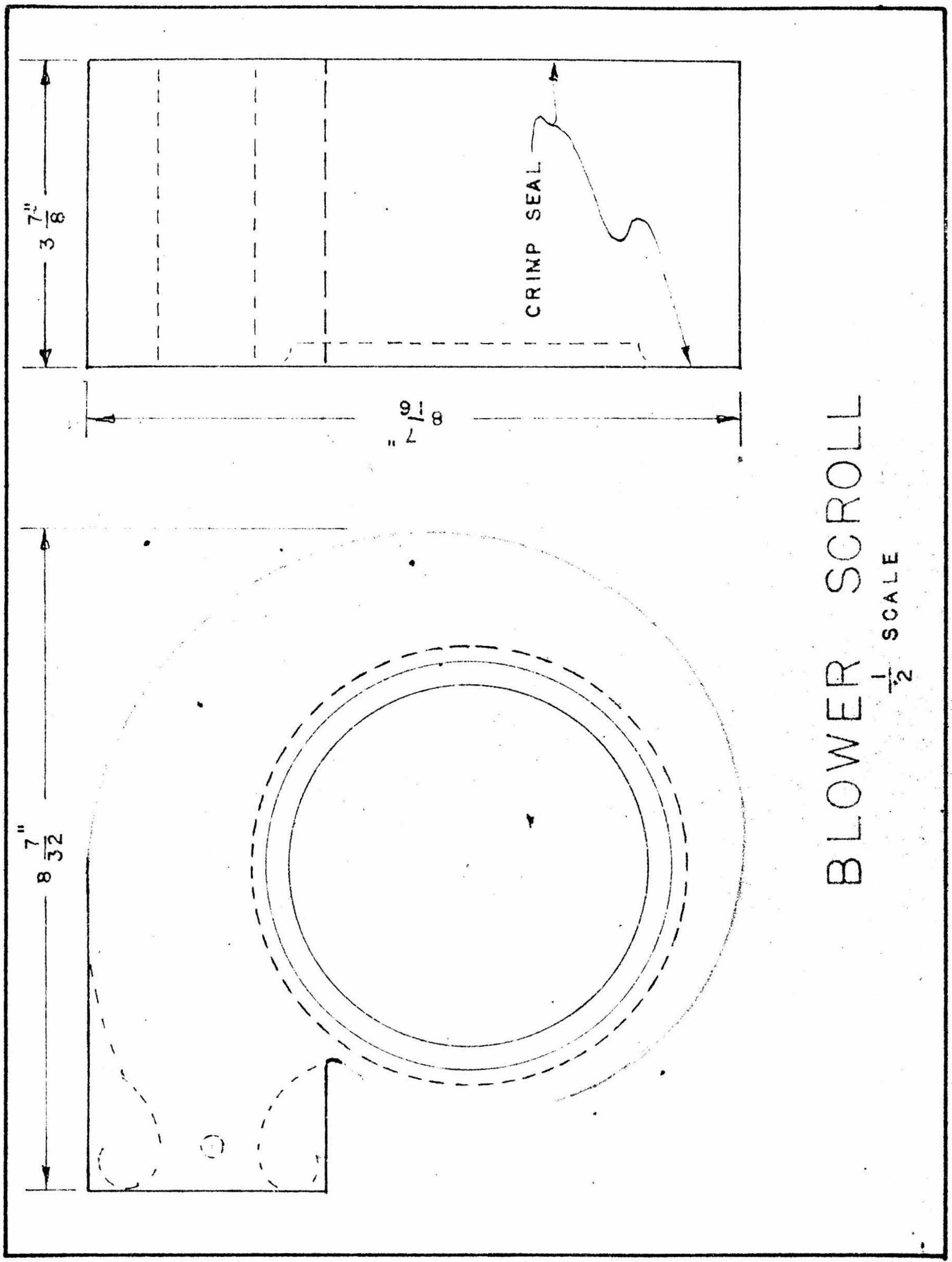


Figure 20

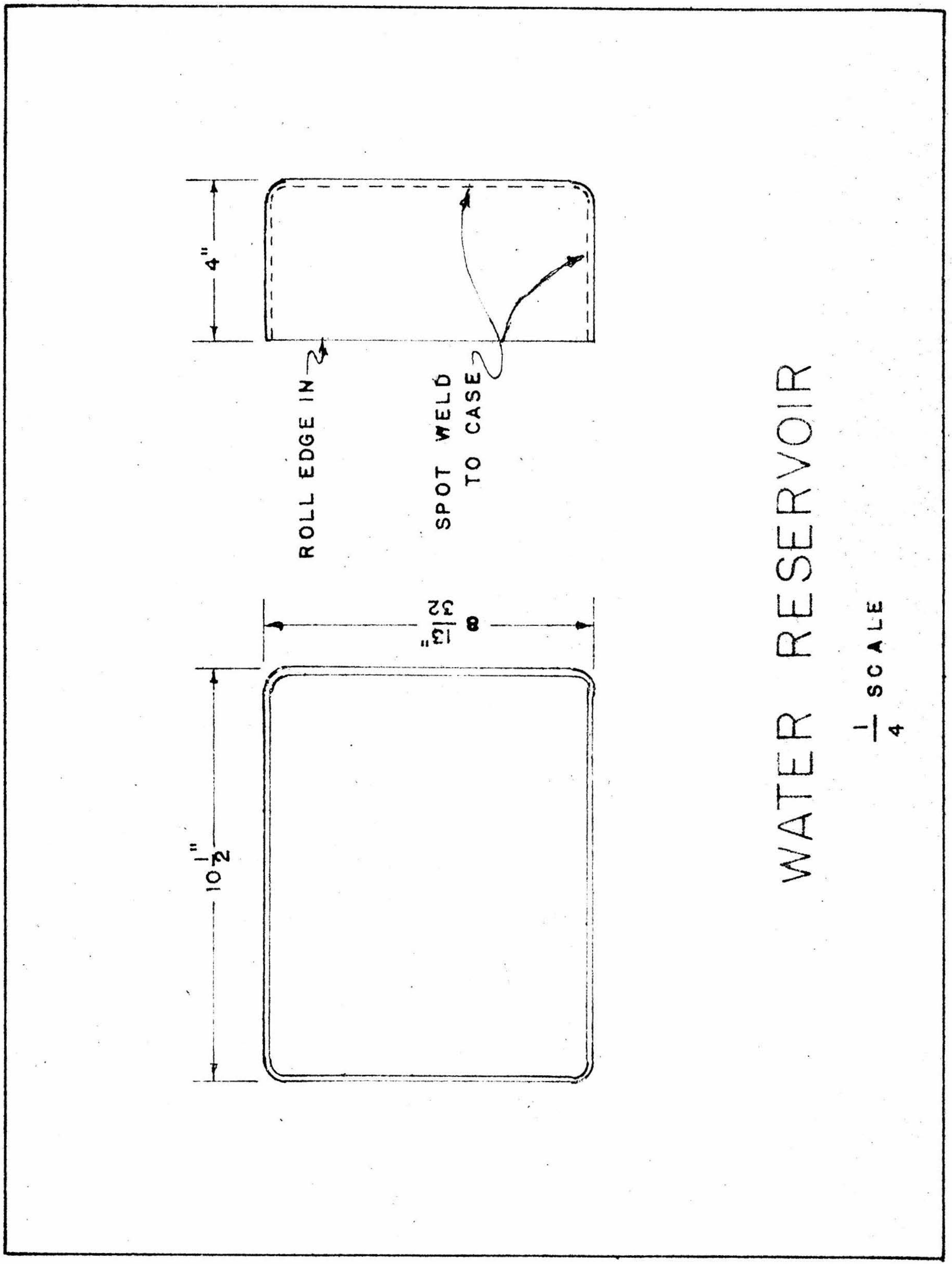

WATER RESERVOIR
1/4 SCALE
ROLL EDGE IN
SPOT WELD
TO CASE
4"
8 13/32"
10 1/2"

Figure 21

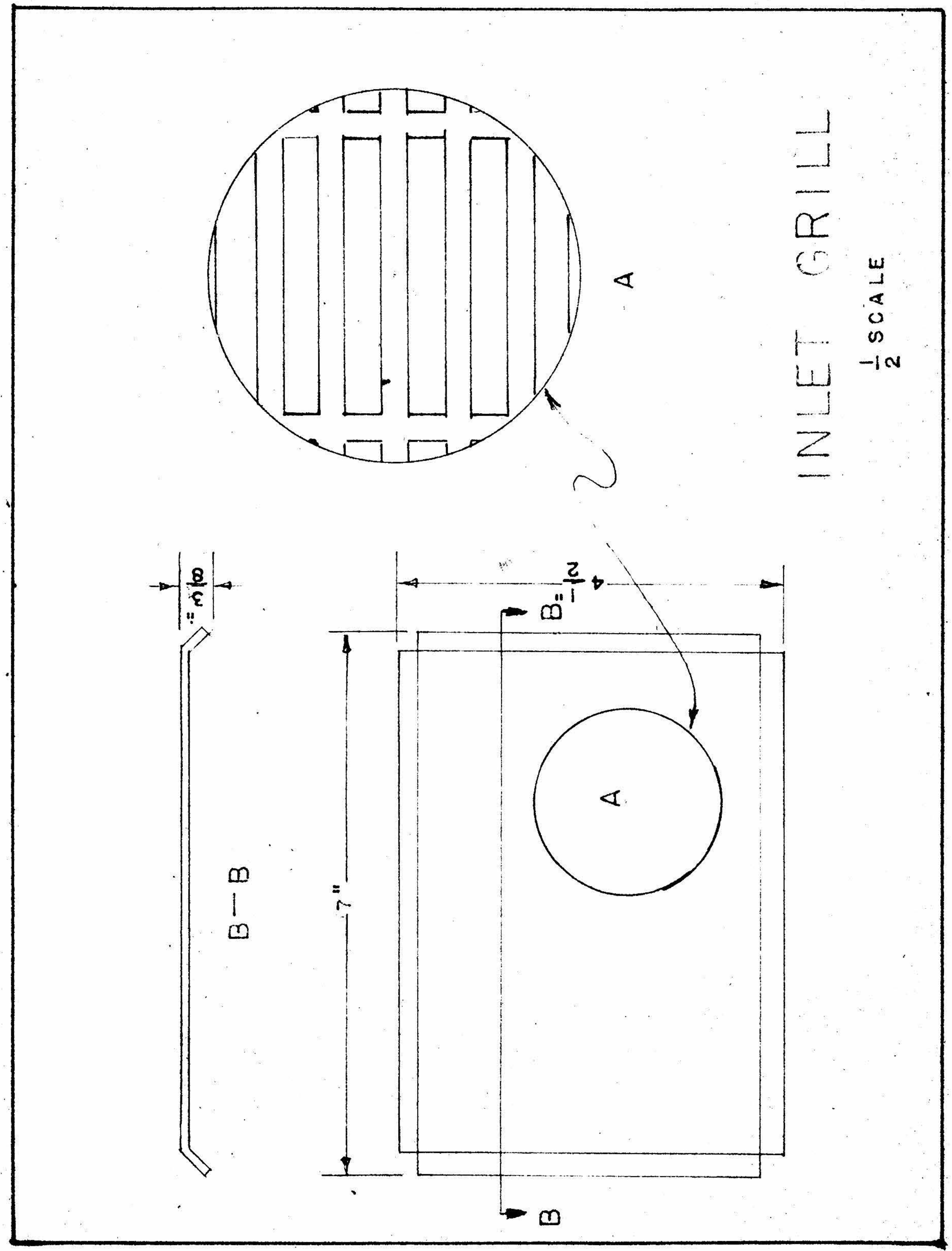


Figure 22

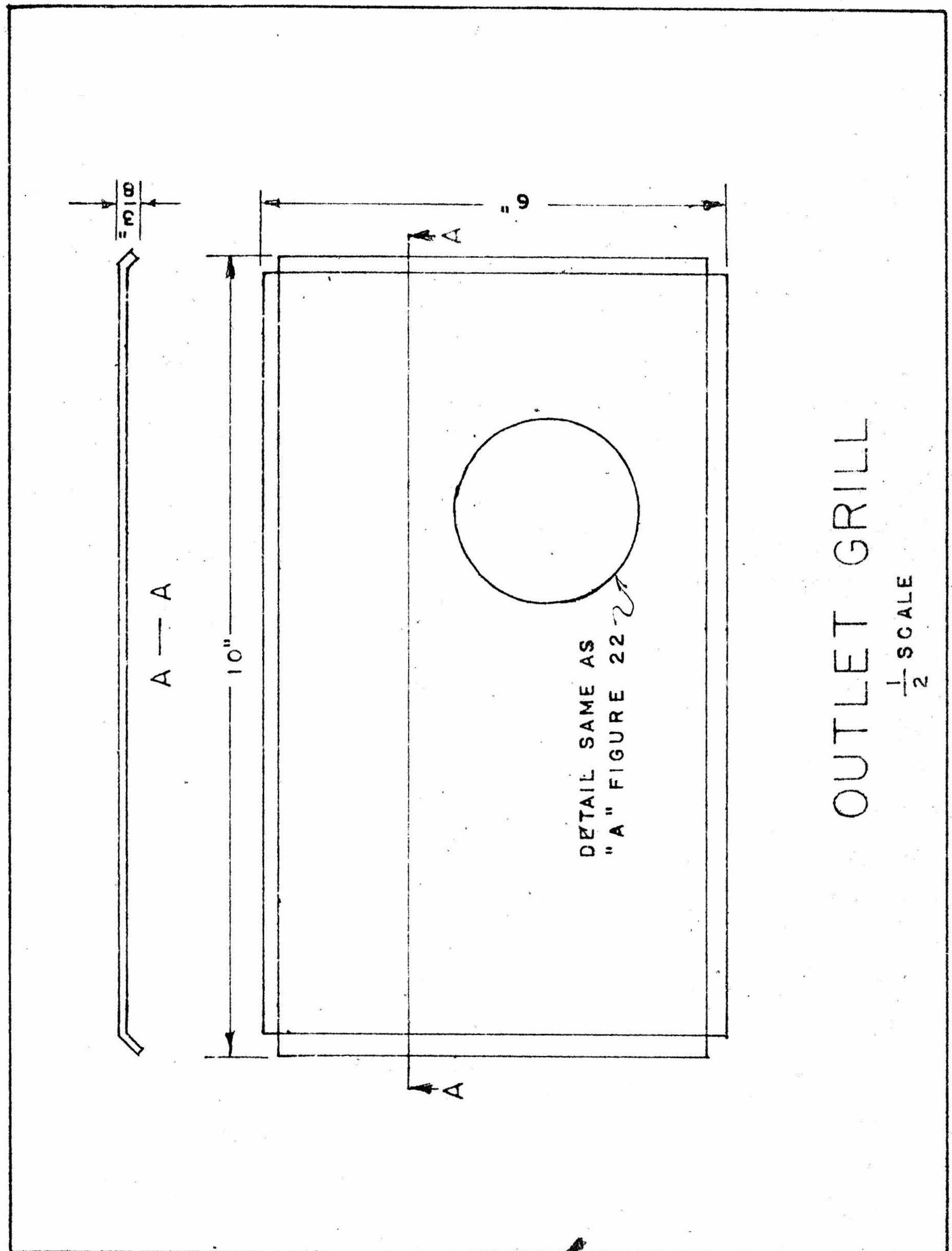


Figure 23

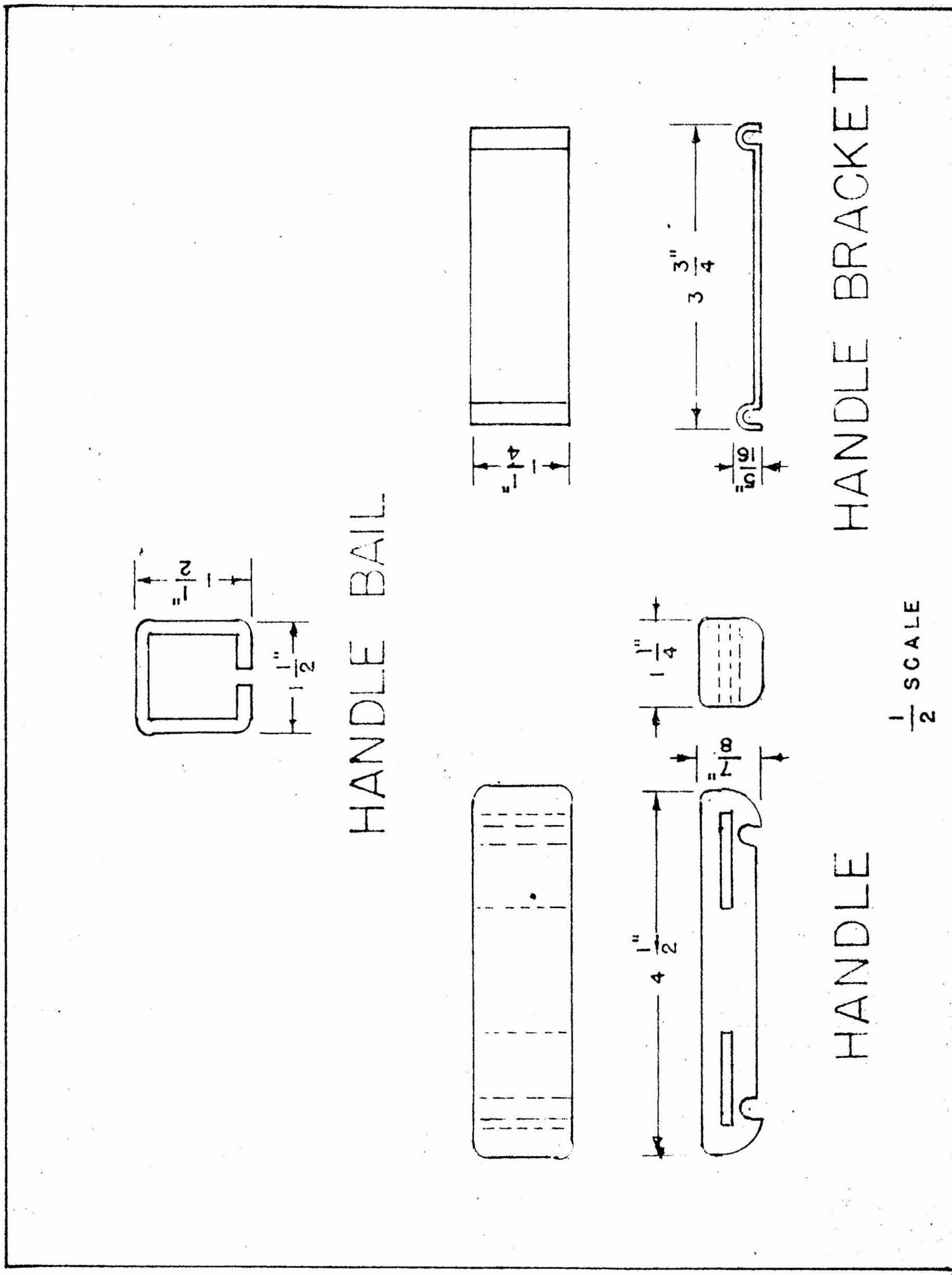

HANDLE BAIL
1/2"
1 1/2"
HANDLE BRACKET
1/4"
3 3/4"
5/16"
HANDLE
4 1/2"
7/8"
1 1/4"
1/2 SCALE

Figure 24

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