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Clothing Branch Report No. 17

SPACER SYSTEMS FOR COOLING BY NATURAL CONVECTION  
INSIDE CLOTHING

by

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## FORWORD

This is the eighth report under contracts covering investigation of the principles of spacers suitable for use in hot weather clothing.

This report was prepared by Harris Research Laboratories under contract No. DA 19-129 QM 1328, Headquarters Quartermaster Research and Engineering Command, Quartermaster Research and Engineering Center, U. S. Army. The contract was initiated under Project No. 7-79-10-001A, and was administered under the direction of the Textile Clothing, and Footwear Division, Headquarters Quartermaster Research and Engineering Command, with Mr. J. H. Vanderbie and Mr. C. J. Monego acting as project leaders.

This material constitutes contract Report No. 4 for the quarter ending November 17, 1959, the final quarter of the contract, and is a summarizing review, as required by the contract.

SPACER SYSTEMS FOR HOT WEATHER CLOTHING

Contract No. DA 19-129-AM 1328  
Project No. 7-79-10-001A  
OI 9067

HARRIS RESEARCH LABORATORIES, INC.  
6220 Kansas Avenue, N. E.  
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Quarterly Report No. 4  
Period Ending November 17, 1959  
Spacer Report No. 8

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SUMMARY

The amount of air movement which can be obtained by natural convection depends on the difference in density between the air in the environment and saturated air at skin temperature. This means that there is a range of combinations of vapor pressure and temperature for which there will be little or no movement, but with air temperatures as much as 5°C (9°F) below body temperature, and vapor pressure differences of 25 mm, sufficient movement is obtained to give 150/Kg cal m<sup>2</sup> hr of cooling.

Channel size or clearance is the most critical clothing design factor in securing cooling. Clearances of two inches are as effective as no cover at all, (or even somewhat better, with a relatively long chimney); one inch is nearly as good, but with the channel reduced to half an inch clearance there is considerable loss of cooling. Increase of channel length lowers the average rate of cooling, but gain from greater length exceeds the loss in effectiveness of the upper parts of the channel. Extra length is much more effective in channels with one inch clearance than in half inch channels.

Laboratory tests of motion of the "body" inside the spacer show a decrease of cooling, compared with undisturbed natural convection, or a small gain, when a flexible diaphragm is used to make the motion produce flow in and out instead of merely mixing the air inside the spacer.

## I. PHYSICAL FACTORS IN COOLING BY NATURAL CONVECTION

### 1. Air movement-density differences:

Cooling the body by means of air inside the clothing depends on two conditions, one, the capacity of the air to take up heat, either directly or by evaporating water, the other, the movement of air over the surface to be cooled. The cause of air movement in cooling the body by natural convection is difference of density between the air in contact with the skin and the air in the general environment. The density of air is decreased both by raising its temperature and by increasing its water vapor content. Figure 1 shows the density of air for a range of temperatures and relative humidities. It should be noted that the lower densities are at the upper end of this chart.

For environments up to skin temperature, both factors combine to make the air next to the skin rise, like the warm air in a chimney. Air at temperatures above skin temperature can be cooled by evaporation at the skin surface, and will flow downwards, if the vapor pressure in the warm environment is lower than the saturation vapor pressure at skin temperature. Fortunately, in natural environments temperatures above body temperature are usually correlated with low humidity. The line on the chart marked SL, for saturation limit, indicates the condition of temperature and relative humidity corresponding to saturation at 95°F (35°C) a relatively high skin temperature. Any atmosphere with relative humidity or vapor pressure greater than this line would warm the skin by condensation of water instead of cooling by evaporation.

To compare the relative contribution of changes in water content or changes in temperature on the density it is helpful to think in terms of vapor pressure rather than relative humidity. Figure 2 covers the same range as Figure 1, but in terms of vapor pressure. The vapor pressure in air cannot rise above the saturation vapor pressure for any given temperature, and the saturation limit for a given skin temperature, such as 35°C, is a vertical line of constant vapor pressure on this chart.

The exact relation is

$$D = D_0 \frac{273}{T} \frac{B - .378e}{760}$$

where D = density of air-water vapor mixture

$D_0$  = density of dry air at 273°K, 760 mm

T = absolute (Kelvin) temperature

B = barometric pressure in mm Hg

e = partial pressure of water vapor in mm Hg

This relation derives from the gas laws and the lower molecular weight of water vapor than the average molecular weight of the gases in dry air. From this one sees that at any barometric pressure and temperature, a given change in  $e$  always produces the same effect on density, while the effect of a change of  $1^{\circ}\text{C}$  in temperature varies slowly, from  $1/293$  at  $20^{\circ}\text{C}$  ( $68^{\circ}\text{F}$ ) to  $1/313$  at  $40^{\circ}\text{C}$  ( $104^{\circ}\text{F}$ ).

However, to compare the practical effect of changes in each variable we need to consider the range of changes usually available. In the tests reported here this was some 25 mm in vapor pressure, and some  $9^{\circ}\text{F}$  ( $5^{\circ}\text{C}$ ) in temperature. This gives 1.2 percent change in density due to moisture, and 1.6 percent due to temperature, indicating that the two factors are each significant in influence on density and hence on rate of air flow.

All of the tests have been on the low temperature side, but there is no reason to suppose that anything except symmetrical results with descending air streams would be obtained for corresponding temperature differences above body temperature, if the vapor pressure is below saturation at skin temperature, so that evaporative cooling can go on. An analogous case is the downward current of air along a pitcher of ice water.

It is important to note that there is a set of conditions at which the saturated air at body temperature can have the same density as the environment, so that there will be no air movement. This will bring a stop to cooling, once the air has become saturated. The conditions for no air movement corresponding to  $35^{\circ}\text{C}$  skin temperature are found along the line of constant density, shown in Figures 1 and 2. Moreover, since a certain draft due to density difference will be required to move air in any volume against the frictional losses in the channel, there must be a zone, rather than a line, of conditions of relatively stagnant air at densities near saturation at skin temperature, for which natural convection movement and cooling will be very low. Unfortunately, such environments are not uncommon, so that clothing design permitting voluntary forced ventilation will be a valuable addition to providing space for natural convection.

## 2. Air movement - chimney effect:

The chimney draft arises from the difference in pressure between the column of gas in the chimney and a column of equal height in the general atmosphere. The vertical distances and temperature differences, are very small in clothing in comparison with chimneys for heating systems, or the drafts available for natural ventilation in buildings. Nevertheless, the results of the tests do show definite signs of chimney effect within clothing, in comparisons ranging from 7 to 33 inches vertical height. Calculation of the chimney draft per foot vertical distance, for the density differences involved in clothing, are on the order of only a few thousandths of an inch water gage.

### 3. Friction effects:

The size of channel available in clothing is smaller than those for which friction tables are available in the Heating and Air Conditioning Guide (1). The effect of channel size, and of some types of obstruction by porous, space maintaining materials which might be used in spacer assemblies, has been examined experimentally, in terms of effect on evaporative cooling and direct heat losses.

### 4. Type of Flow:

Monego has used the schlieren technique to show the manner in which warm air layers flow along a hot surface, with or without a nearby spacer wall (2). Depending upon the temperature difference and the distance to the spacer wall, an upward current develops along the spacer wall, until with increased intensity the whole space is filled with a rising current. Similar relations probably hold for the convection currents in the present test, although the temperature differences are smaller than those required to produce refractive index effects in the schlieren tests.

The schlieren tests confirm the inference from low Reynold's number, that the flow in these natural convection systems will normally be laminar. From the test results, some inferences can be made regarding mixing and diffusion through the column, and the effect of motion of the evaporative surface within the channel.

## II. EXPERIMENTAL METHOD

Details of the experimental method have been discussed in the quarterly progress reports (3, 4, 5, 6, 7, 8, 9,) so that only the general outline of method is given here. Further points specific to particular experimental findings are indicated in presenting the results. Two general types of test systems have been used, one on the scale of an arm or a leg, the other, torso-scale.

Arm-scale system: One, two, or three aluminum cylinders each three inches in diameter, seven inches high, are used in vertical arrangement. Heat is supplied and measured electrically; temperature is held constant near 33°C, with a range of about 0.5°C. Average surface temperature of each cylinder is measured by a resistance wire grid. Evaporative loss is measured by weighing the whole system, or each segment.

Torso size system: One or two aluminum drums, 10 inches in diameter, 16.5 or 33 inches total height, are covered with 3 or 6 strips of wet fabric from which evaporation can be measured by weighing. The fabric strips are each 5 inch high, and are held in snug contact with the torso by an elastic insert and a zipper

fastener. The surface temperature of each strip is measured by a resistance wire grid, and each strip is backed with a water impermeable film so that no water is left behind on the torso, when the strip is removed for weighing. Each corresponding section of the torso is separately heated by an electric circuit controlled by a temperature regulator attached to that section. The maximum range between sections is within  $1.2^{\circ}$ , in dry tests, and the range from on to off is  $0.5^{\circ}\text{C}$ .

Spacer channels: In all tests, the spacer channel was established by a concentric cylinder of thin (0.020 inch) plastic, open at each end and free of obstructions (unless otherwise specified). The ends are at the same level as the ends of the test cylinders. The space inside the channel is specified as the difference in radius, that is, the space or gap between cooling surface and the inner edge of the outer assembly.

Natural convection conditions: The tests were carried out in chambers which were shielded from drafts but connected with the general environment of the room. Air movement in these chambers is at a practical minimum, comparable to telephone booth conditions. Indeed, the chamber for the torso-scale tests has about the dimensions of a phone booth. The arm-scale tests were in a smaller chamber, in which, with no spacer present, the nearest approach to a wall was six inches, with the distances to other walls 8 or 9 inches.

### III. EXPERIMENTAL FINDINGS

#### 1. Effect of temperature difference:

Tests with a dry system indicate the effect of temperature differences alone. Using three cells of the arm-scale system, in a stack with 21 inches vertical height, the total heat loss from the bare system is proportional to the temperature difference between environment and surface, as shown in Figure 3.

With a spacer present, confining the flow near the surface which is being cooled, the over-all cooling is also proportional to the temperature difference, but the rate of cooling per degree difference is less, as shown in Table I, which gives the total cooling for an environment at  $28^{\circ}\text{C}$ .

Table I shows results for two sizes of spacer, with open or closed ends, and the effect of partial obstruction by very light tubing one inch in diameter, such as might be used for maintaining the separation.

The losses from individual segments, as shown in Table II show

that the upper segments lose less heat, in terms of the temperature difference to the general environment. The data in Table II show that there is a blanketing of the upper segments by warm air from the lower segment, even with no cover. With a one inch spacer, the cooling effect is reduced on all segments, even the lower one where the fresh air enters. This suggests that even within seven inches vertical distance there is some blanketing of the upper part by warm air from below.

## 2. Effect of vapor pressure difference:

The temperature of the moist skin from which evaporation went on in these tests varied somewhat with the rate of evaporation, but a representative figure is close to 34°C, corresponding to 40 mm vapor pressure. This is a convenient rounded figure for design purposes and discussion. In the detailed analysis of the results, the exact temperatures and vapor pressures for each segment were used. The vapor pressure in the general environment was determined by a ventilated wet bulb measurement.

Figure 4 shows the effect of differences in vapor pressure in the air on total evaporative cooling from the three arm-scale segments arranged in one vertical stack, with no cover and with 2, 1, and 0.5 inches gap to the spacer wall. The results with no cover are highest, and are taken as defining the environmental limit of evaporative cooling under natural convection conditions, by drawing a straight line to zero difference. This assumes that rate of air movement will be the same throughout the range, whereas in fact the air movement will be less, at a given temperature difference, the higher the vapor pressure in the air. Because of lesser air movement, observations at higher vapor pressures in the air, or smaller differences from the vapor pressure of the skin, are likely to fall below the indicated environmental limit line.

With narrower channel, the rate of evaporative cooling falls off progressively. For the wider channels, two inches or one inch between skin and wall, the evaporative cooling seems relatively independent of vapor pressure difference, suggesting that the spacer system itself is the main limiting factor. The narrowest channel examined, with 0.5 inch gap, sets an even more severe limit, which appears to drop more rapidly than the others, as the vapor pressure in air increases, or the vapor pressure difference decreases.

One can understand how the channel can set the limit, and the more severely the smaller the channel, when one recalls that with no spacer every element of surface has a direct diffusion path to the general environment, even though the upper portions may be blanketed by air rising from below. With an impermeable wall creating a channel, however, there is no direct diffusion path through the blanketing layer, which will tend to become saturated.

Hence, with channels the major effect of difference between skin and outside air will be observed in the first segment with which the fresh air comes in contact, and this effective surface will be smaller, the narrower the channel or the smaller the vapor pressure difference. The results with the smallest channel appear to show this double limitation.

In the balance of the discussion, results are presented in terms of evaporative rate,  $\text{Kg cal/m}^2 \text{ hr mm}$ , that is the evaporative cooling divided by the difference in vapor pressure. The range of vapor pressure differences is between 20 and 30 mm from that of the skin, that is, 20 to 10 mm vapor pressure in the air. The average and typical condition of the tests is approximately 15 mm vapor pressure in the air, 25 mm difference of vapor pressure from the skin.

3. Relative amount of cooling by evaporation and by other means;

Comparison of the total energy supply to (and loss from) the three cell arm-scale system with the evaporative loss is shown in Figure 5. This indicates that with no cover, or with spacer gaps of 2 or 1 inch, the evaporative cooling is six fold or more larger than all other cooling mechanisms. This result is obtained even though the area for evaporation is limited to the sides of the cylinders, while the top and bottom ends contributed to the loss by other routes.

It is instructive to compare this with the heat capacity of moist air in the range of temperatures and moisture contents involved, and with the possibilities of heat loss by radiation. The Heating, Ventilating and Air Conditioning Guide (1) gives the enthalpy or heat content of moist air, in terms of one pound of dry air and associated water vapor, from which one can calculate heat for the skin condition, saturation at  $34^\circ\text{C}$  ( $93^\circ\text{F}$ ) and a typical air condition at 15 mm water vapor pressure and  $28^\circ\text{C}$  ( $82^\circ\text{F}$ ). Since the saturation vapor pressure at  $82^\circ\text{F}$  is 28 mm, one multiplies the vapor enthalpy by  $15/28$  to get that of the vapor in the mixture:

Temperature		Enthalpy, Btu/lb dry air			
$^\circ\text{C}$	$^\circ\text{F}$	Dry air	Saturated Vapor	Factor	Vapor in Mixture
34	93	22.3	37.9		37.9
28	82	19.7	26.2	15/28	14.0
Differences		2.6			23.9
Ratio		1		to	9.2

This indicates that the observed ratio of 1 to 6 or 1 to 7 falls short of the possible preponderance of evaporative cooling which is 1 to 9.2. In part this is because of the additional non-evaporative loss from the ends, and in part it represents a failure to reach saturation.

The loss by radiation from the skin to the surroundings depends on the fourth power of the temperature differences, and on the relative areas of surfaces at different temperatures "seen" by the emitting surface. The largest surface in the field of view is the inner surface of the spacer wall, which is certain to be nearer the skin temperature than the more remote surfaces in view at the ends, or with no cover. Calculation indicates that the radiation loss with no cover can be the largest part of the observed non-evaporative loss, but that this is substantially reduced as the inside of the spacer shell warms toward skin temperature.

Because the evaporative heat loss is so much larger than all the other heat losses, and because evaporation is the chief means of cooling in warm environments, all the further results are based on evaporative loss alone.

#### 4. Effect of chimney height and contribution of successive segments:

Comparisons of vertical stacks on one, two, or three cells, in the arm-scale system, with 7, 14, or 21 inches total height, show that there is a definite chimney effect even in this range. Figure 6 shows the evaporative rate from the first (lowest) cell in the stack. The amounts evaporated from this cell increase with stack height indicating increased flow past it. However, the rate for the upper cells decreases, with increasing stack height, as shown in Figure 7, which shows the progression in a stack of three sections, for a range of spacer gaps and no cover at all. While the smaller rates of the upper sections produce a smaller average rate for the system as a whole, nevertheless the increase of area for evaporation exceeds the loss of effectiveness per unit area, so the longer channels are well worth having, unless the channel is too narrow. In addition, the problem of clothing design is made easier with longer channels, especially if protective closing devices are required at the ends.

Tests on the torso-scale system in which the evaporation could be compared in six zones covering 35 inches of chimney height are shown in Figure 8. With the exception of the central zones, zone 3 and zone 4, there is a steady progression from larger evaporative rates for the first zones to smaller evaporative rates for the last zones, for all the tests inside spacer systems. The reversal of order for zones 3 and 4 is small scale, compared with the general progression, and probably arises from a difference in structure of the cells at the mid point, where there is a partition dividing the

upper and lower groups of three.

#### 5. Effect of spacer gap:

The results with the torso-scale system show that with enough chimney effect there can be more cooling by natural convection in a spacer system than with no cover at all. This is suggested by the maximums of cooling rate for several of the zones at 2 inches spacer gap, as shown in Figure 8. The averages for the system as a whole, in Table III, show that the whole cylinder is losing more heat by evaporative cooling with a spacer channel 2 inches wide than with one 4 inches wide, or with no cover at all.

It should be noted that this result is obtained under natural convection conditions with the minimum of air movement in the environment. With any wind or motion of a man with respect to the air, the condition with no spacer cover would be expected to favor evaporation from the skin or from damp clothing.

Figure 9 brings together all the data on different spacer gaps and different chimney heights, for both arm-scale and torso-scale systems. This shows that with the longer channels, there is a decrease in average effect, which is more than made up, however, by the greater total evaporating area. This compensation is more complete for the larger clearances. However, there is not much to gain, and may even be a loss, in using spacer channels wider than 2 inches clearance; at one inch clearance there is some loss of effect, and at 0.5 inch clearance, even more loss of evaporative rate, especially for the longer channels.

A comparison of half inch channel width with one inch width, in terms of the combined effect of average rate and length, is shown in Table IV. This table shows that the half inch clearance falls off in effectiveness more rapidly than the one inch clearance, as the length of channel increases.

This suggests that channels in clothing certainly should not have less than 0.5 inch clearance, and that one inch clearance would be a practical compromise.

#### 6. Effect of obstruction:

Space maintaining structures of some kind will be required in practical clothing. In addition, there will be obstructions due to closures at the ends of the channel. Openings and channels should be arranged so as not to be closed off by belts, at the shoulders, or by the pack. A load bearing spacer under the pack may be desirable, even if it is relatively high in obstruction to air passage.

A few tests of the obstructing effect on natural convection have been made, using the arm-scale system. Table I shows the effect on dry heat loss of closing the ends of the channel, or of "fitting" it with 10 vertical tubes, each about one inch in diameter.

With the torso-scale system, a test of corrugated, nominal 3/8 inch leno weave "Trilok" spacer fabric in a channel 16.5 inches high reduced the evaporation by nearly half, from 6.69 to 3.47 Kg cal/m<sup>2</sup> hr mm, comparing half inch clear gap with the same gap containing the "Trilok" fabric.

#### 7. Effect of motion inside the spacer:

In all of the tests discussed so far, there has been no motion of the system as a whole nor any relative motion of the evaporating surface with respect to the spacer shell. With fairly heavy protective clothing outside the spacer channel, the motion of the man with respect to air, or wind effects, can be expected to have only small or no influence by direct penetration of the system. Clothing design allowing for wind scoops may, however, be desirable.

Inside the spacer assembly, however, there can be two kinds of relative motions between the body and the spacer: those from breathing, and the motions involved in walking and moving the arms. These can cause the clothing to swing back and forth, stirring the air inside.

Laboratory tests simulating relative motion of the body inside the spacer shell have been made with the arm-scale system, using two sections, with 14 inches in vertical height. The motion was back and forth, a simple harmonic motion produced by a track and a crank of variable radius. Change of radius changed the amplitude, and a change of rate of rotation, the frequency of the motion. The frequencies can be compared with 120 paces (60 steps or whole cycles) per minute, a common rate of marching. For simplicity, the different combinations available are compared in terms of inches linear motion per minute. The combinations examined are shown in Table V. Combinations up to the highest were tried with no cover, but the trials of spacer systems were limited to 0.5 inch average gap, in which only the 0.5 inch radius crank could be used, and 1.5 inch average gap, in which the 1 inch crank radius could also be used.

With no cover, the results for motions above 110 inches per minute show more evaporation with more motion. At the lower rates of motion, increase of amplitude is more effective than increase of frequency, at a given linear distance per minute. The averages for the whole system for the whole range are shown in

Figure 10 and individual test data for the separate cells, in the range of motion used with the spacer assemblies, in Figure 11. Figure 11 shows that parallel effects are seen for upper and lower cells.

Figure 11 and the corresponding data in Figure 10 also show that at low rates of motion, the evaporation from the moving system is actually less than with no motion. This is seen for the lowest amplitude, at the two lower frequencies. While increase of frequency produces an increase in evaporation, both are below the rate with no motion. Further increase of frequency at this same amplitude does increase evaporation still further, to values above those for no motion.

This inhibiting effect of low amounts of motion for the exposed cylinder is probably connected with the results obtained for motion within a spacer. No increase in evaporation was obtained, even with increase in amplitude, as shown in Figure 12 by the results for 0.5 and 1.0 inch crank radius in the 1.5 inch spacer. The 0.5 inch amplitude at two frequencies in the 0.5 gap spacer, also showed no increase in evaporation. The results with the 1.5 inch spacer are particularly significant, since with it there was no increase at 190 inches per minute, a rate and extent of motion which did show an increase with no cover.

One possible explanation of this failure to increase evaporation by this type of motion may be the disturbance of the upward moving convection layers, reducing the density difference which makes the warm air layers tend to rise. Whatever the explanation, the laboratory tests do not show any advantage from this type of motion inside spacers.

#### 8. Motion with air flow:

The relative motion produced by moving back and forth inside the spacer does not change the volume of the system and therefore has no pumping action to create air flow or increase the exchange with the environment.

A means of increasing air flow and exchange with the environment which might be used in clothing is to divide the inclosed space into at least two parts, by a flexible diaphragm set at right angles to the line of motion. A diagram of such an arrangement is shown in Figure 13. By this arrangement the volume is increased on one side and decreased on the other, in each half cycle of motion, so that exchange with the environment is increased by this tidal flow.

The effect of this tidal flow on evaporation is small, but favorable, as shown in Table VI, which is based on one section, 7 inches high. Increases in evaporation on the order of 10 percent are obtained over the rate with motion but without a diaphragm. This increase approximately compensates for the decrease

from conditions with no motion, which is observed without the diaphragm.

To use such a system in clothing would require some connection between the outer shell and underwear or other garments close to the skin. This would be a special problem in clothing design and maintenance.

9. Other types of motion to produce air flow:

No other types of relative motion have been examined experimentally, but some possibilities can be discussed. One is tidal, in and out motion of air between the body and the spacer shell, caused by breathing. Whether the change of volume of the chest and abdomen corresponding to breathing will cause a corresponding change inside the spacer depends on whether the spacer shell is supported on the body at several points and expands and contracts with breathing, or whether it is independently supported, for example, by being hung from the shoulders. If the shell around the torso can be independent of breathing motions, there will be changes of volume in it.

Another possibility is to have the whole clothing structure supported by some elastic or springy mechanism, so that it will bounce up and down out of phase with the body motions in walking. If the upward motion of the body on each stride came at the time the clothing was tending to stand still, or continue downward from the previous stride, there could be a pumping action which would increase exchange by flow in and out. This would be a rather novel type of clothing, and would be hard to combine with the equipment which a soldier must carry.

The possibility of valves of some kind to change the flow of air from in and out to flow in one direction does not seem compatible with the small pressure differences involved in natural convection.

Clothing design with a loose panel, such as a flap under the sleeve, something like a "Dolman sleeve", which might be voluntarily used to force air in and out, may be a desirable feature, as a supplement to natural convection in the environments in which flow due to density differences is small.

#### DISCUSSION

The effect of spacing on vertical convection, for a non-evaporative system, has been studied by Wing and Monego (10) using a guarded hot plate thermal transmission test system. The heat loss was measured from a central square, 10 inches on edge, in the center of a square guard plate which was 20 by 20 inches in outside dimensions. The hot plate was at 96°F, and the

environment at 85°F, conditions similar to those of the present report. Vertical channels were made by spacing fabric of low permeability at distances away from the vertical heated surface, from 1/8 to 3 1/4 inches. An actual decrease of heat loss was observed, for the narrowest spacings, 1/8 and 1/4 inch, with steady rise from this low point to the largest spacings. The minimum in heat loss at 1/4 inch spacing indicates that too narrow a channel, by impeding air motion, can increase the insulation and overcome any advantage of convection.

The results of Wing and Monego reinforce the recommendation that spacings as wide as possible, up to 2 inches, be used, certainly larger than 0.5 inch, with 1 inch a practical level.

#### ACKNOWLEDGMENT

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ERRATUM

In Report No. 2 of this contract, Textile Engineering Laboratory Report No. 258, "Net Direct heat loss in spacer systems with simultaneous evaporation", in Figure 6, the values of vapor pressure difference between environment and skin, (Ps-Pa) are wrong. Correct values are:

<u>Spacer Gap</u> inches	<u>Vapor Pressure Difference</u> mm Hg
0.5	22.0
1.0	23.8
2.0	25.1
Free	22.3

The conclusion drawn, that the vapor pressure differences were similar, and are not the main cause of differences in evaporation, remains correct.

TABLE I. HEAT LOSS RATES, WITH NO EVAPORATION

<u>Cover over the cylinders</u>	Rate at 28°C air <u>temperature</u> Kg cal/m <sup>2</sup> hr	<u>Relative rate</u> %
None	46	100
2" annular space, open at ends	40	87
1" annular space, open at ends	40	87
2" annular space, closed at ends	30	65
1" annular space, closed at ends	27	59
1" annular space, with 10 vertical tubes of hair foundation tubing, open ends	30	65

Notes: Vertical arrangement of 3 cylinders, each 3" diam., 7" high,  
minimum air movement.

TABLE II.

DRY HEAT LOSS PER DEGREE TEMPERATURE DIFFERENCE FROM THE  
GENERAL ENVIRONMENT, AS INFLUENCED BY LOCATION AND COVER

	<u>Bottom</u>	<u>Middle</u>	<u>Top</u>
No cover, Kg cal/m <sup>2</sup> hr °C	8.3	5.0	6.3
1" space, open ends, Kg cal/m <sup>2</sup> hr °C	6.9	2.9	3.5
Loss with spacer as fraction of loss with no cover	83%	58%	56%

Note: Bottom and top segment losses are calculated for area of side plus one end; middle segment for side only. One side = .0425 m<sup>2</sup>; one end = .0045 m<sup>2</sup>.

TABLE III. EFFECT OF SPACER CLEARANCE ON EVAPORATION FROM TORSO SIZE TEST CELL.

The test cell is 10 inches in diameter, 33 inches high.

<u>Spacer Gap</u> inches	<u>Evaporation rate</u> Kg cal/m <sup>2</sup> hr mm
0.5	4.68
1.0	6.70
2.0	7.62
4.0	6.48
no cover	7.10

TABLE IV. COMBINED EFFECT OF LENGTH OF CHANNEL AND AVERAGE RATE OF COOLING, FOR CHANNELS 0.5 OR 1.0 INCH WIDE

The combined effect for the whole length is shown by the product (evaporation rate) x (inches length). The efficiency is shown in terms of the rate for 7 inch length, times the actual length, as 100 per cent.

<u>Length</u>	<u>Width</u>	<u>Product</u> (Kg cal/m <sup>2</sup> hr) x in		<u>Efficiency</u> %	
		0.5"	1.0"	0.5"	1.0"
<b>Arm-scale</b>					
7		61	66	100	100
14		120	123	99	93
21		128	162	70	82
<b>Torso-scale</b>					
16.5		110	---	78	---
33		155	222	54	71

TABLE V. COMBINATIONS OF MOTIONS

Radius, inches:	0.5	1.0	2.0
Range, inches:	1.0	2.0	4.0
<hr/>			
RPM	Inches per minute		
25.4	51	102	203
47.6	95	190	380
84.7	170	340	680

TABLE VI. RELATIVE EFFECT ON EVAPORATION OF  
MOTION WITH OR WITHOUT A DIAPHRAGM.

Evaporation is expressed as per cent of the rate with no motion, in each system. One cell, 7 inches high, is used, with 1.5 inches average clearance from the spacer wall.

Rate of motion, in/min:	0	51	95	102	190
Relative evaporative rate, per cent					
without diaphragm:	100	92	94	105	97
with diaphragm:	100	100	100	120	106

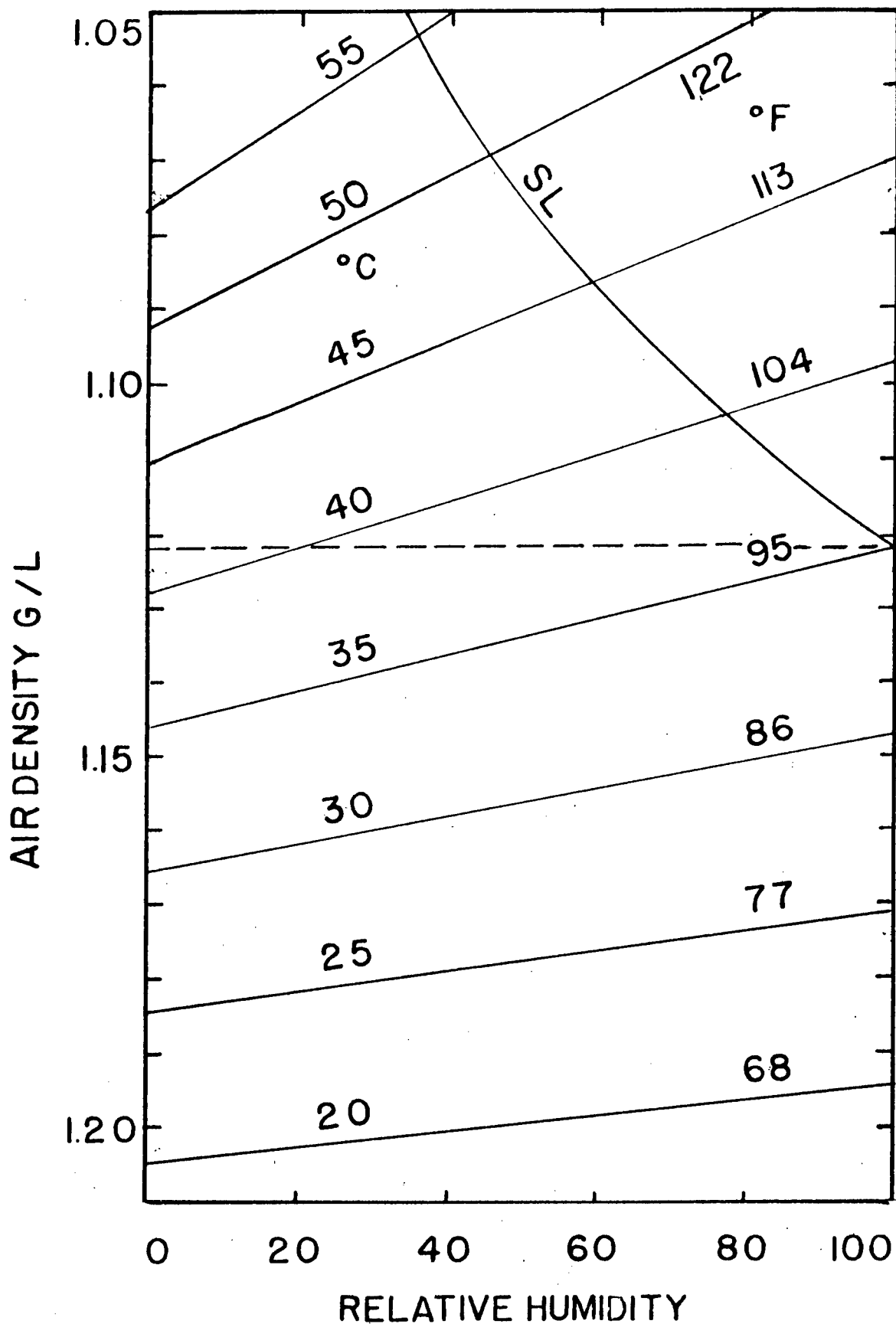


Fig. 1. Density of moist air at indicated temperatures and relative humidities. The curve marked SL shows saturation limit at vapor pressure equal to that at 35°C skin temperature.

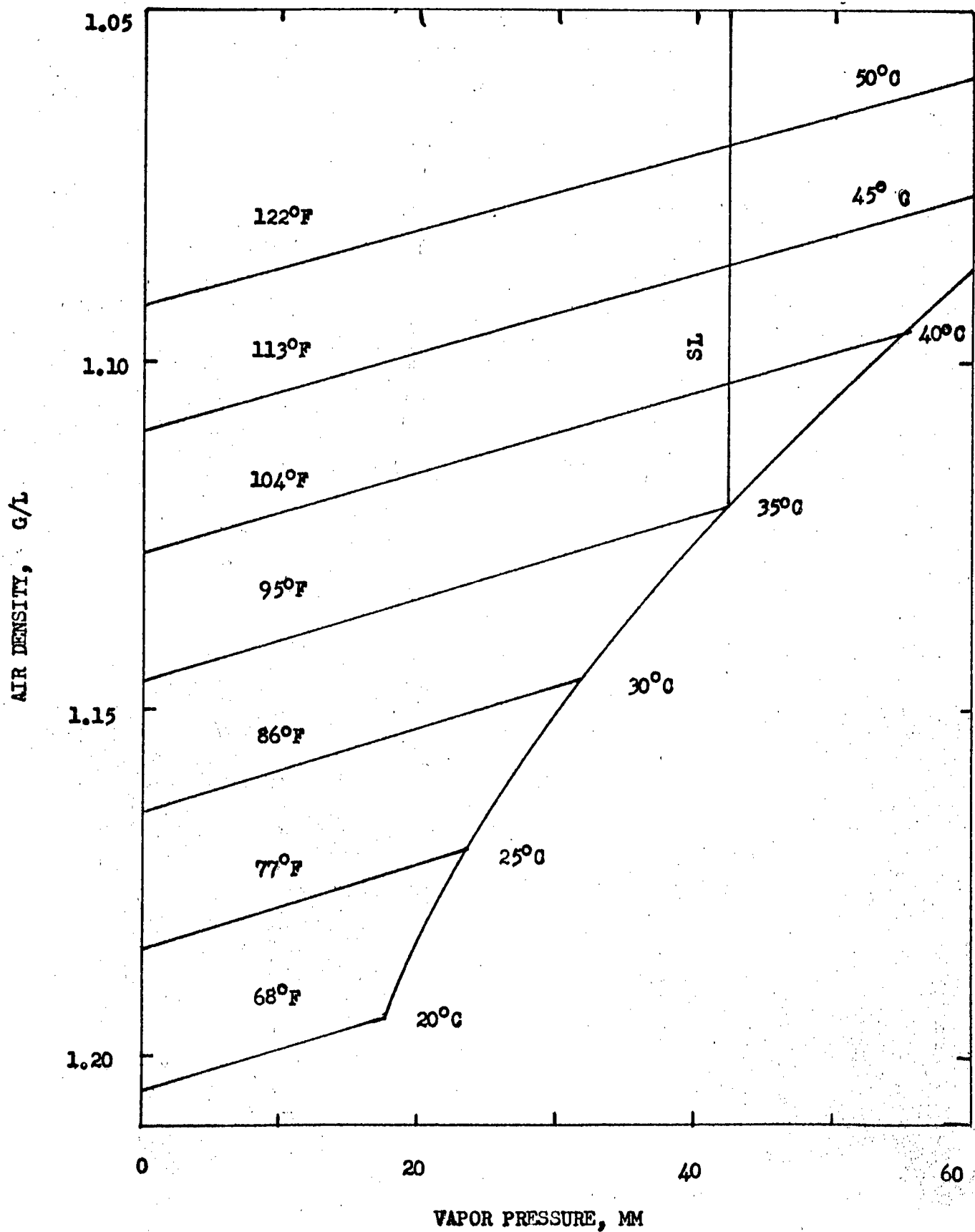


Fig.2. Density of moist air in terms of vapor pressure and temperature. The curve on the right indicates saturation vapor pressure at increasing temperatures; the vertical line from 35°C indicates saturation at this skin temperature.

TOTAL HEAT LOSS, Kg cal/ m<sup>2</sup> hr.

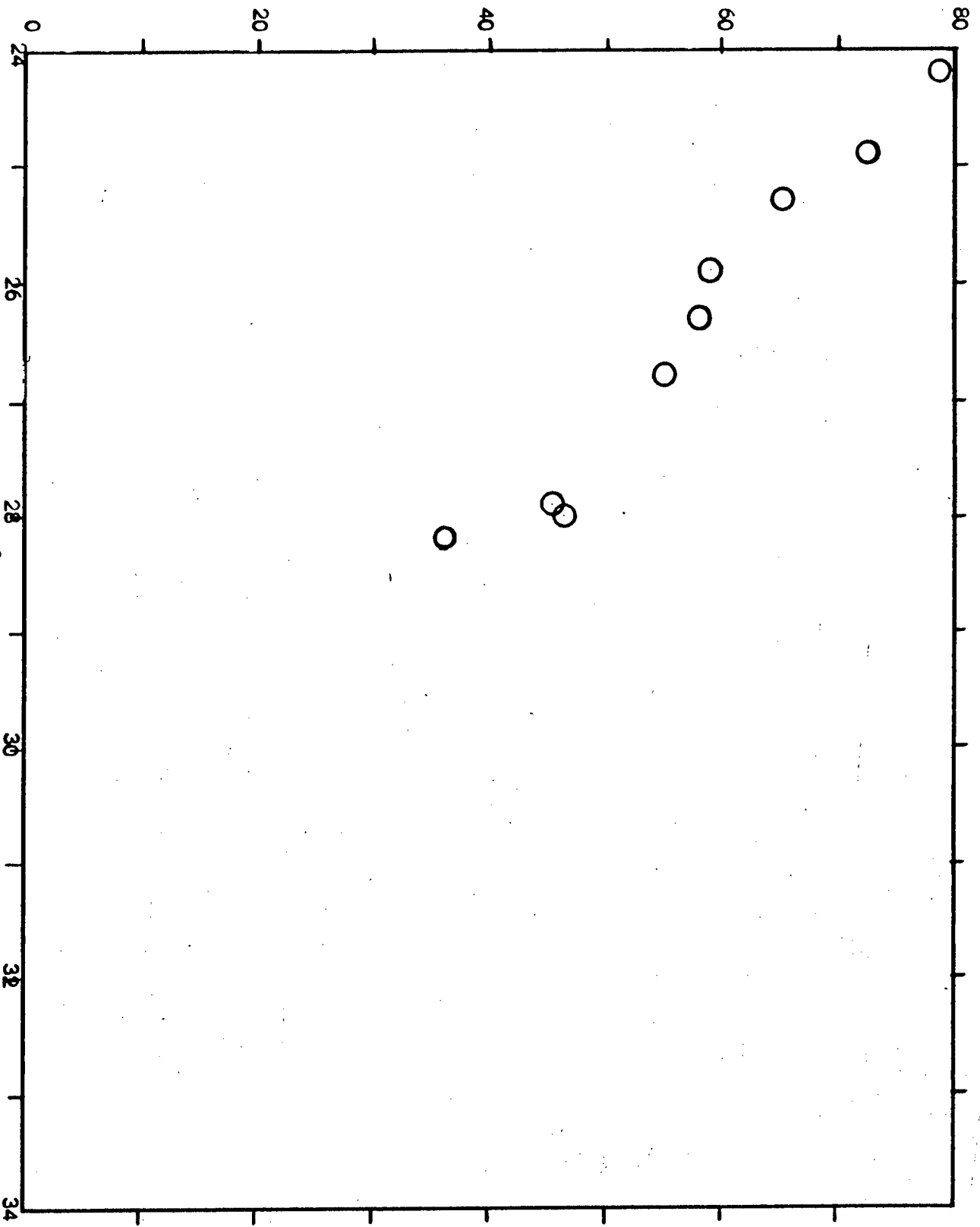
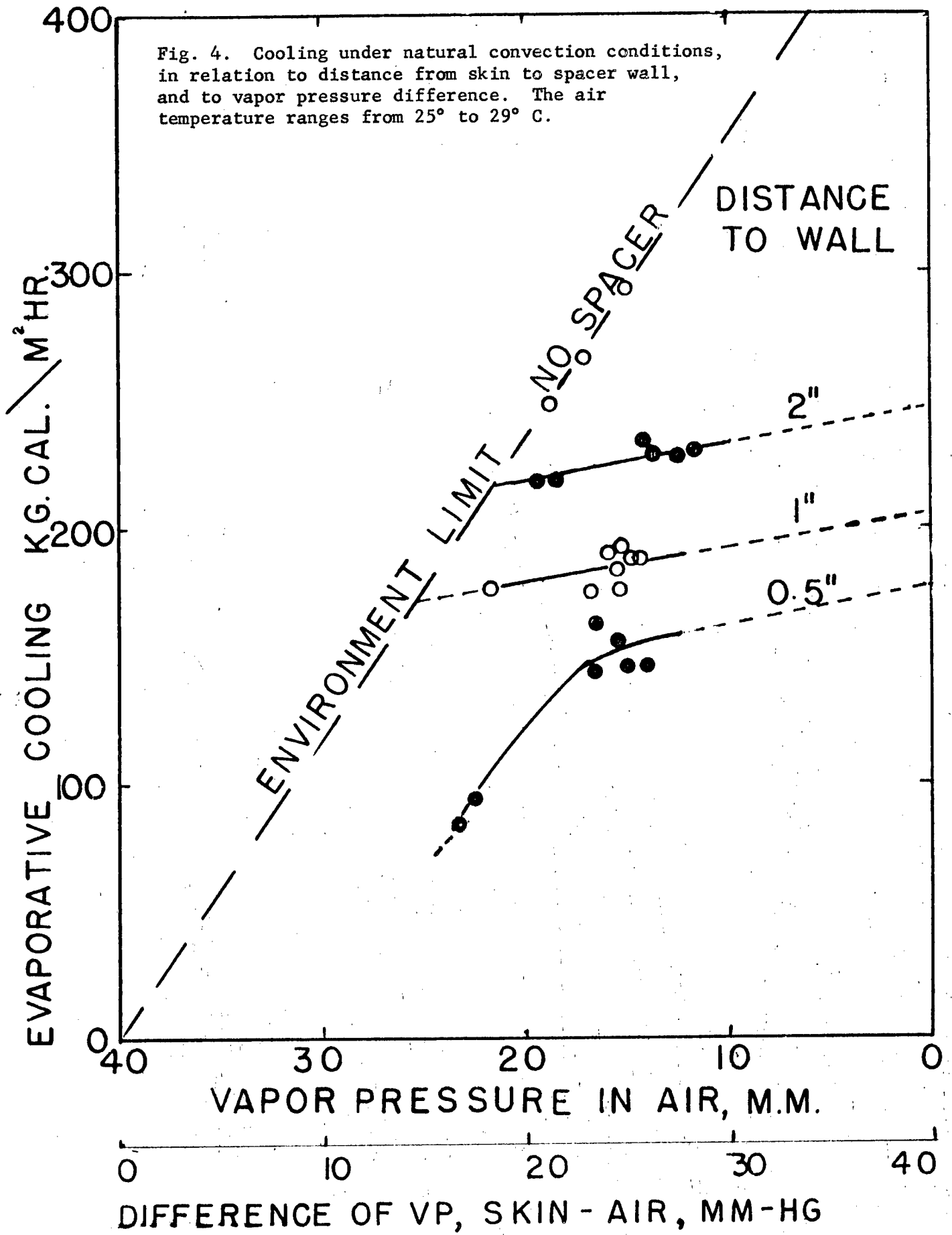


Fig. 3.

Heat loss from whole system, no cover.

Fig. 4. Cooling under natural convection conditions, in relation to distance from skin to spacer wall, and to vapor pressure difference. The air temperature ranges from 25° to 29° C.



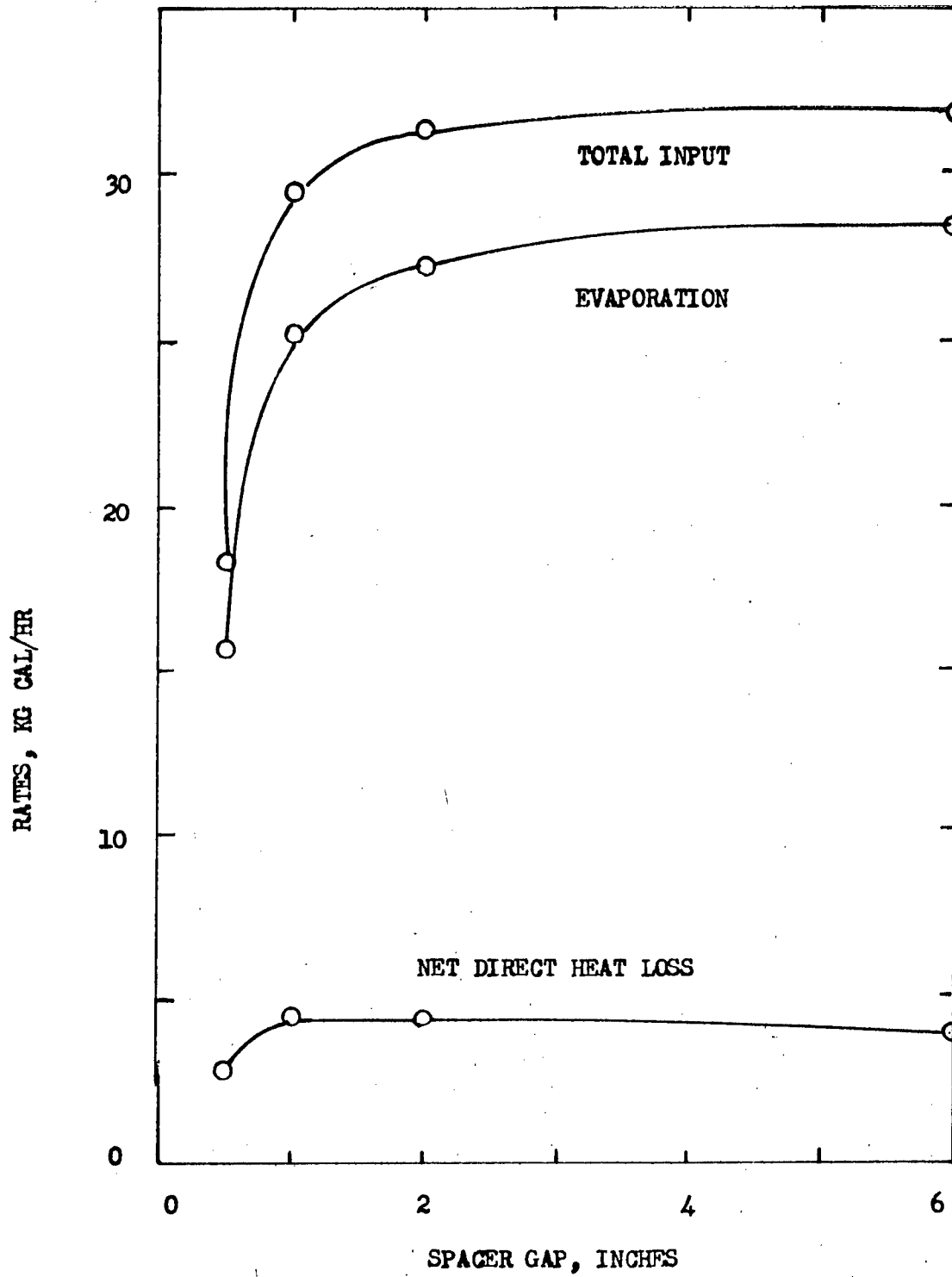


Fig. 5. Energy rates for system as a whole, without calculation to unit area.

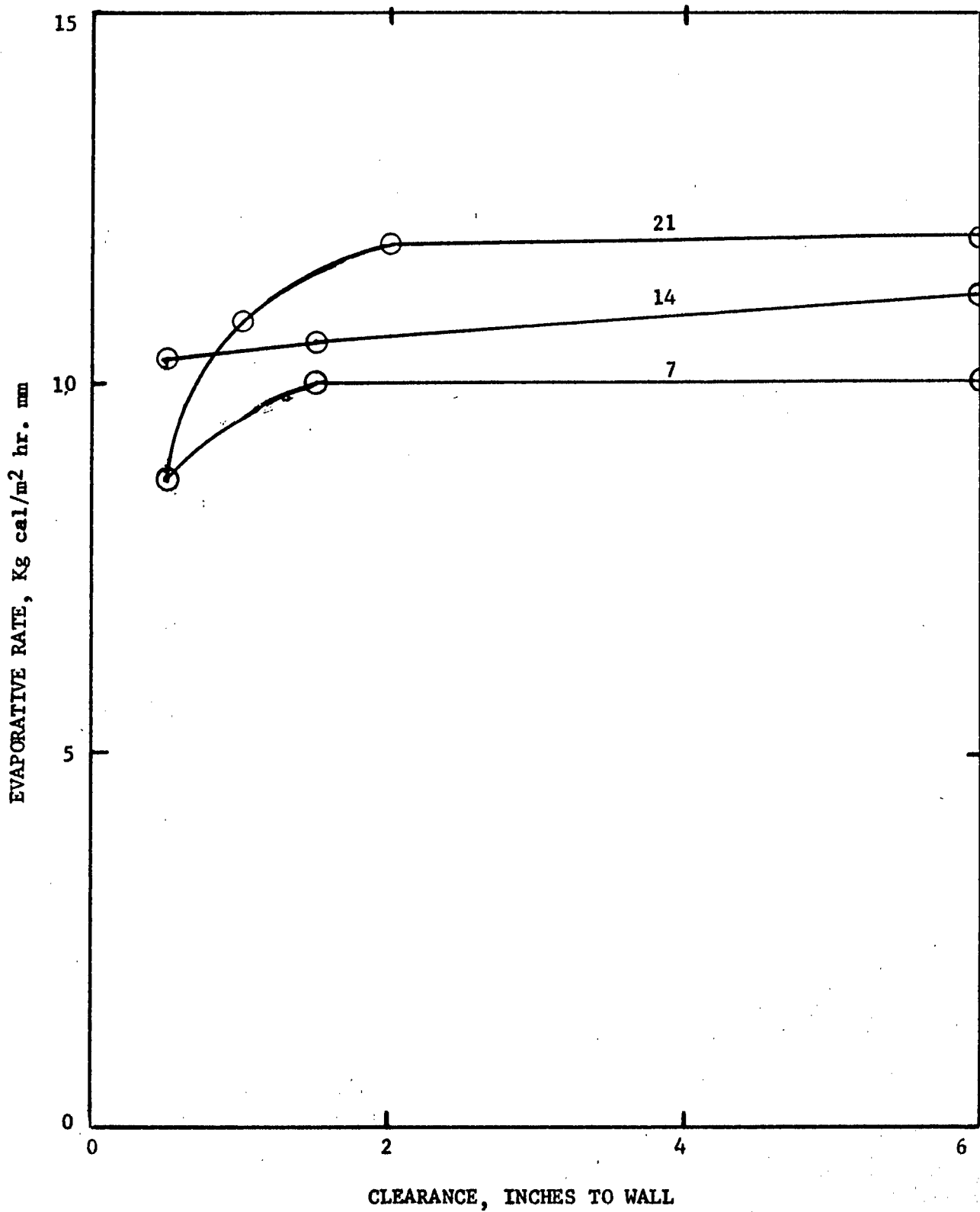


Fig. 6. Chimney effect as shown by evaporation from first segment in stack, for stacks 21, 14, or 7 inches high.

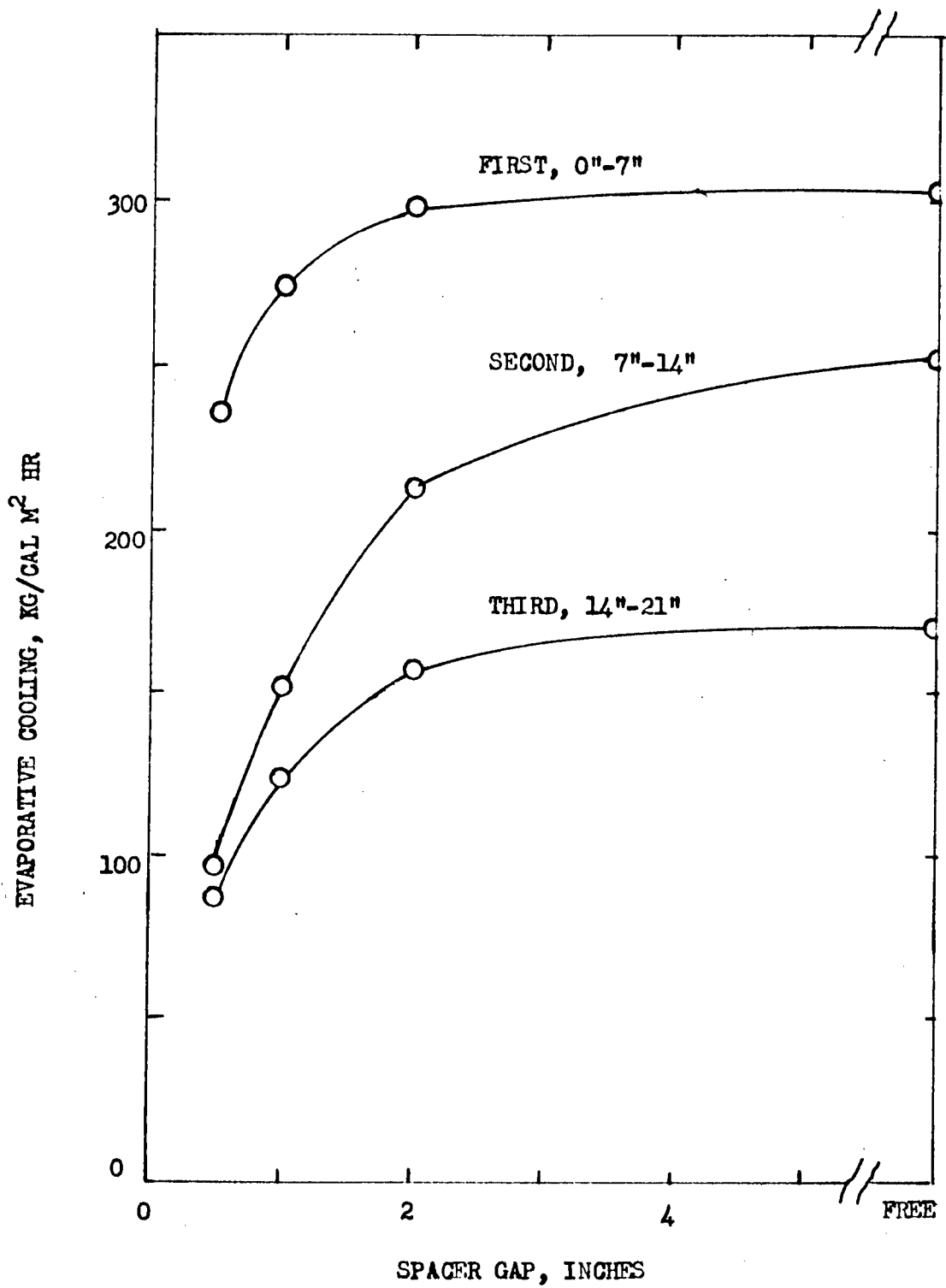


Fig. 7. Evaporative cooling from three sections of vertical stack, showing that the upper sections are less effective than the lowest or first section, which is exposed to fresh air.

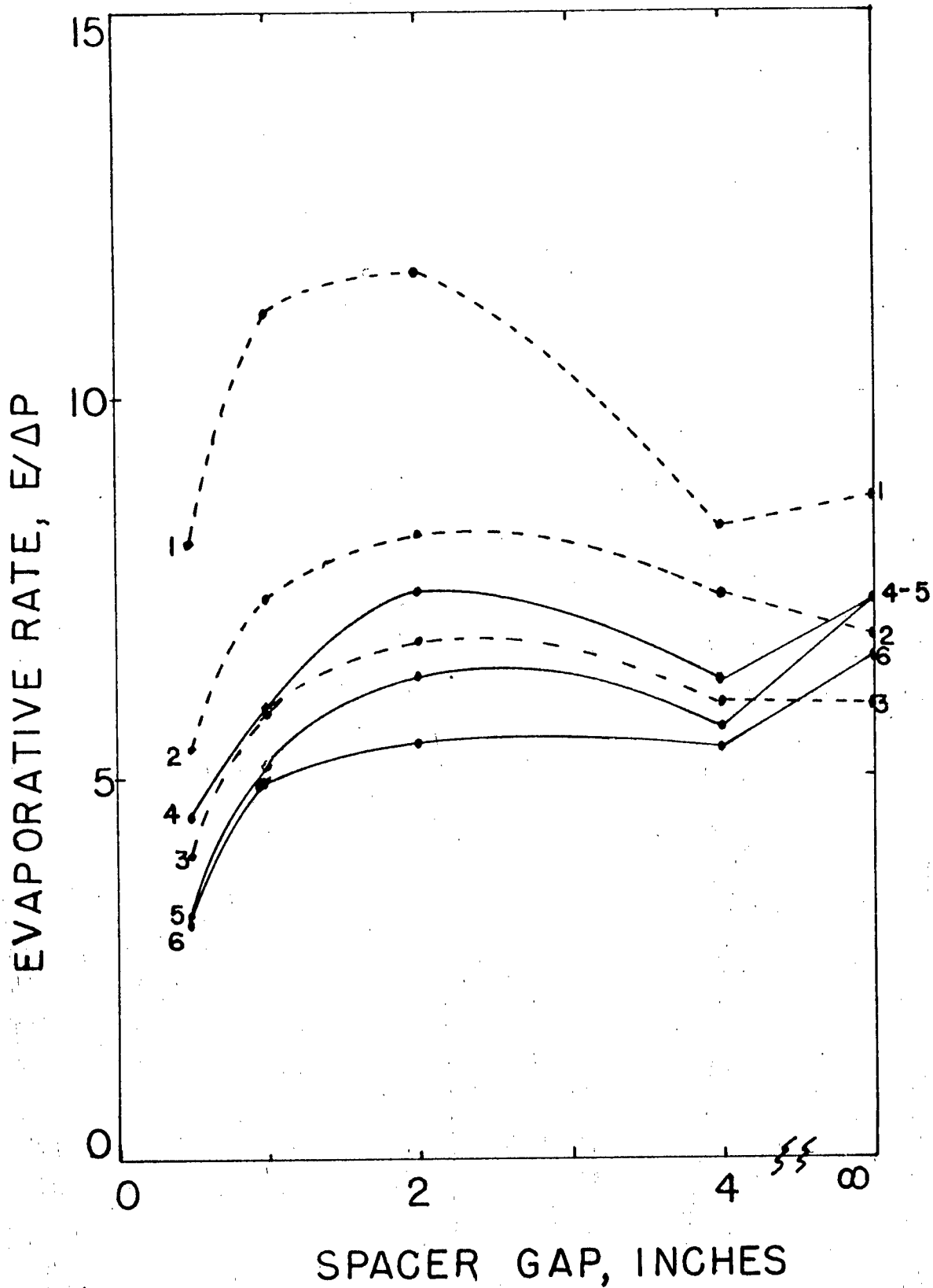


Fig. 8.

Evaporative rate for each section in column of 6, total height 33 inches. The sections are numbered from 1 at the bottom to 6 at the top of the column, which is the reverse of the general order of evaporative rate. Data at right margin are for free exposure, no spacer, "infinite" gap.

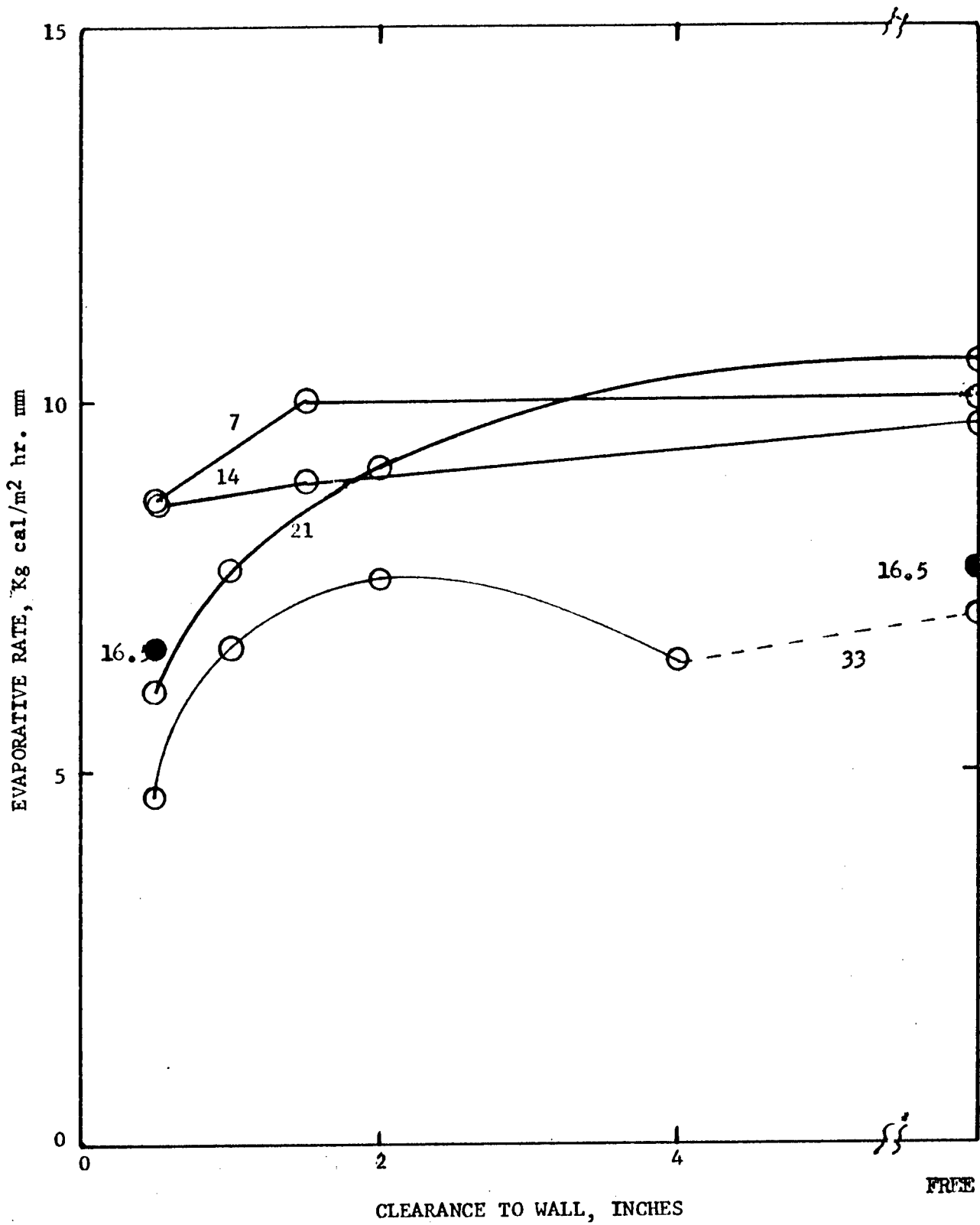
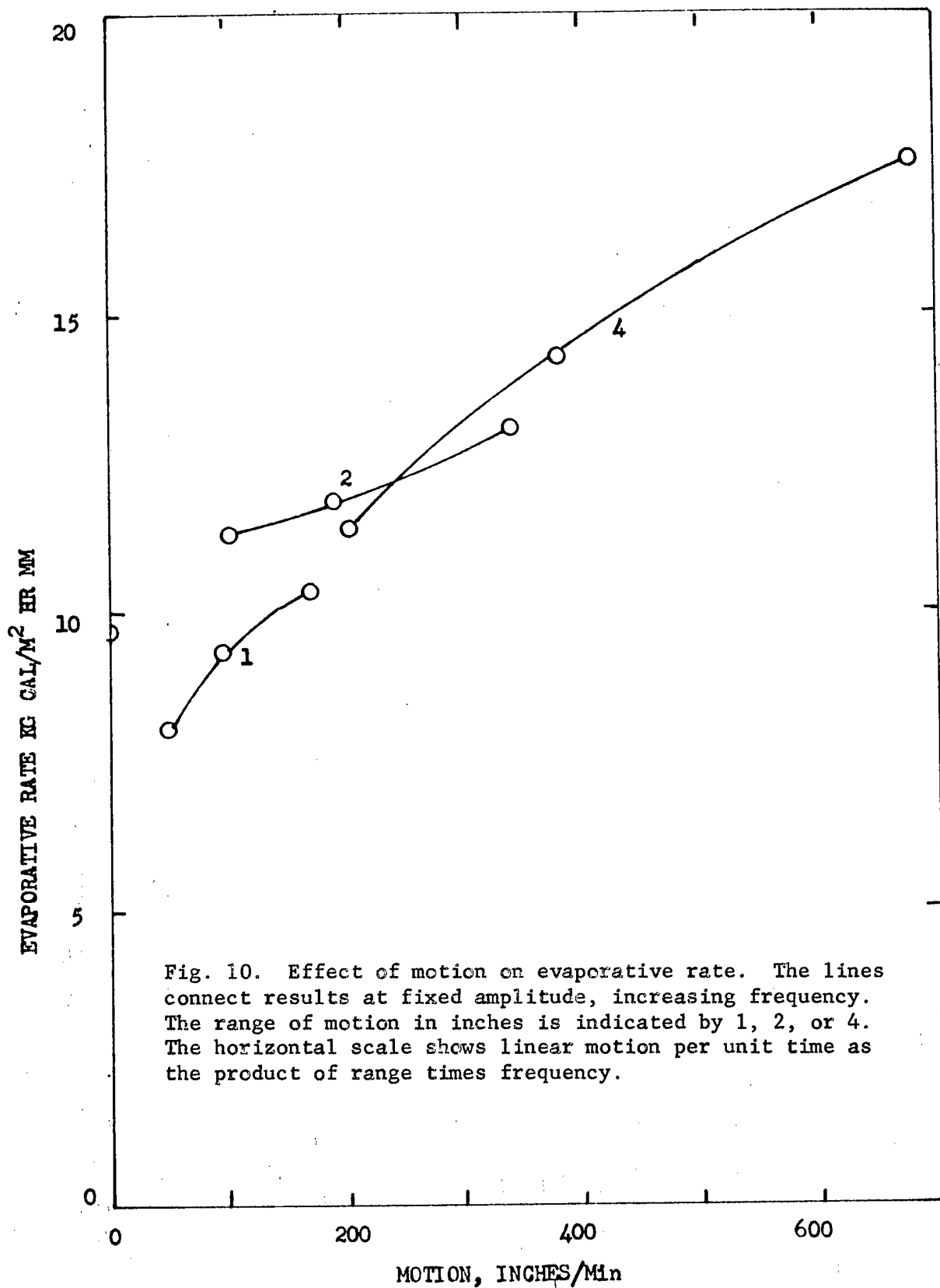


Fig. 9. Average rate of evaporation from whole assembly, for stacks 7, 14 or 21 inches high, 3 inches in diameter, or 16.5 or 33 inches high, 10 inches in diameter. (Data for 16.5 inches is shown by solid circles.)



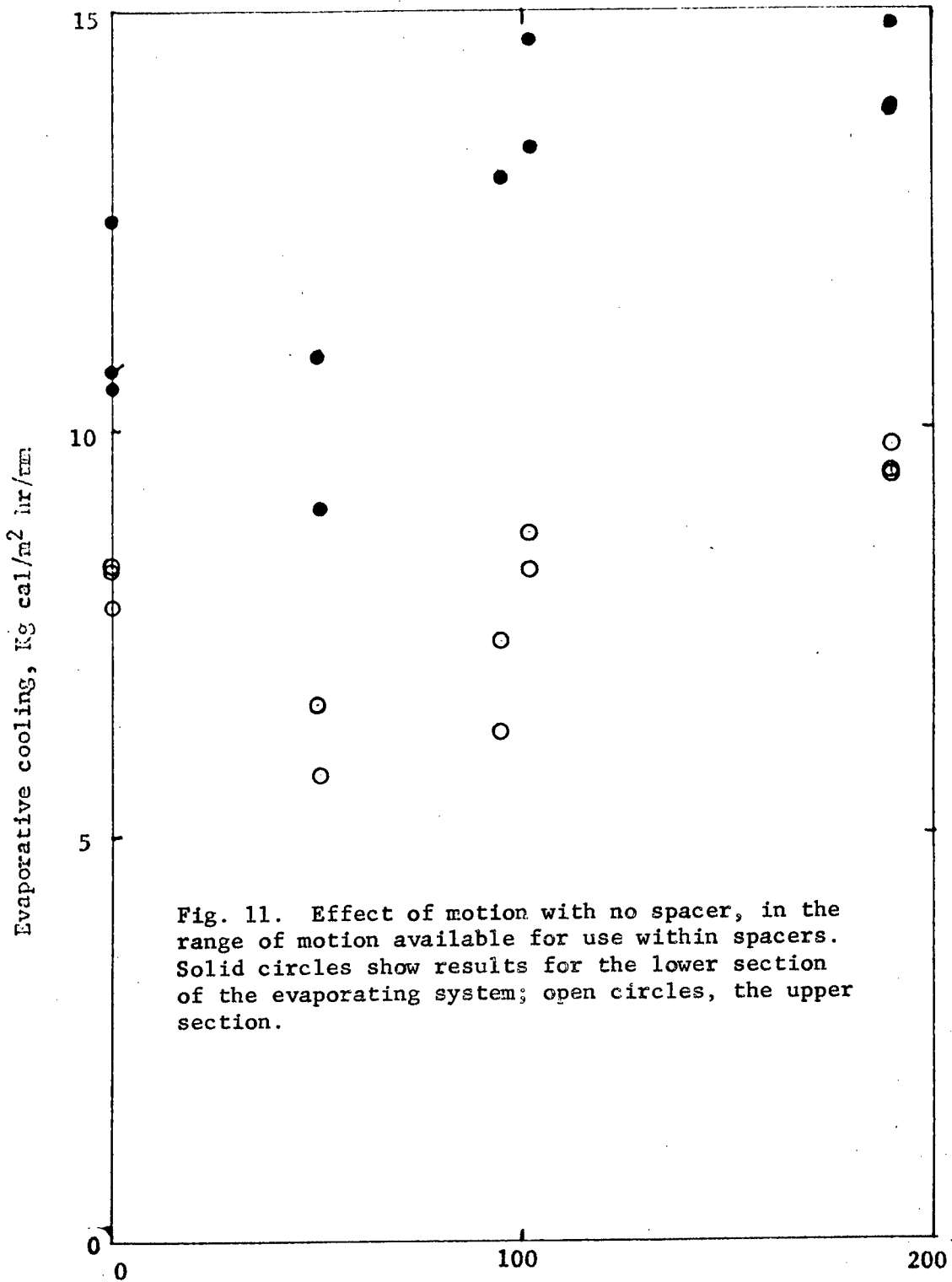


Fig. 11. Effect of motion with no spacer, in the range of motion available for use within spacers. Solid circles show results for the lower section of the evaporating system; open circles, the upper section.

Motion in inches per minute

No spacer, 6 inches to wall

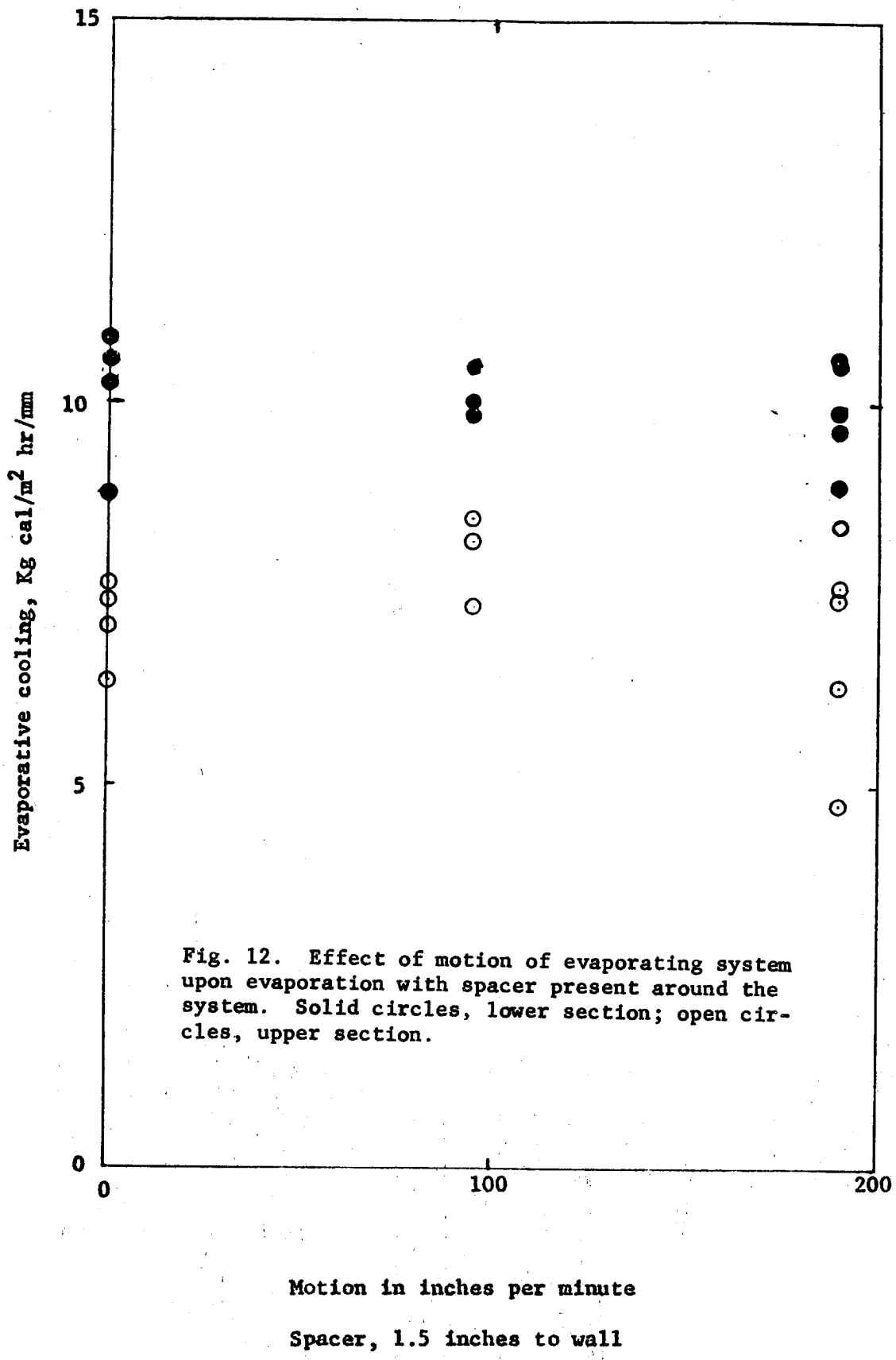


Fig. 12. Effect of motion of evaporating system upon evaporation with spacer present around the system. Solid circles, lower section; open circles, upper section.

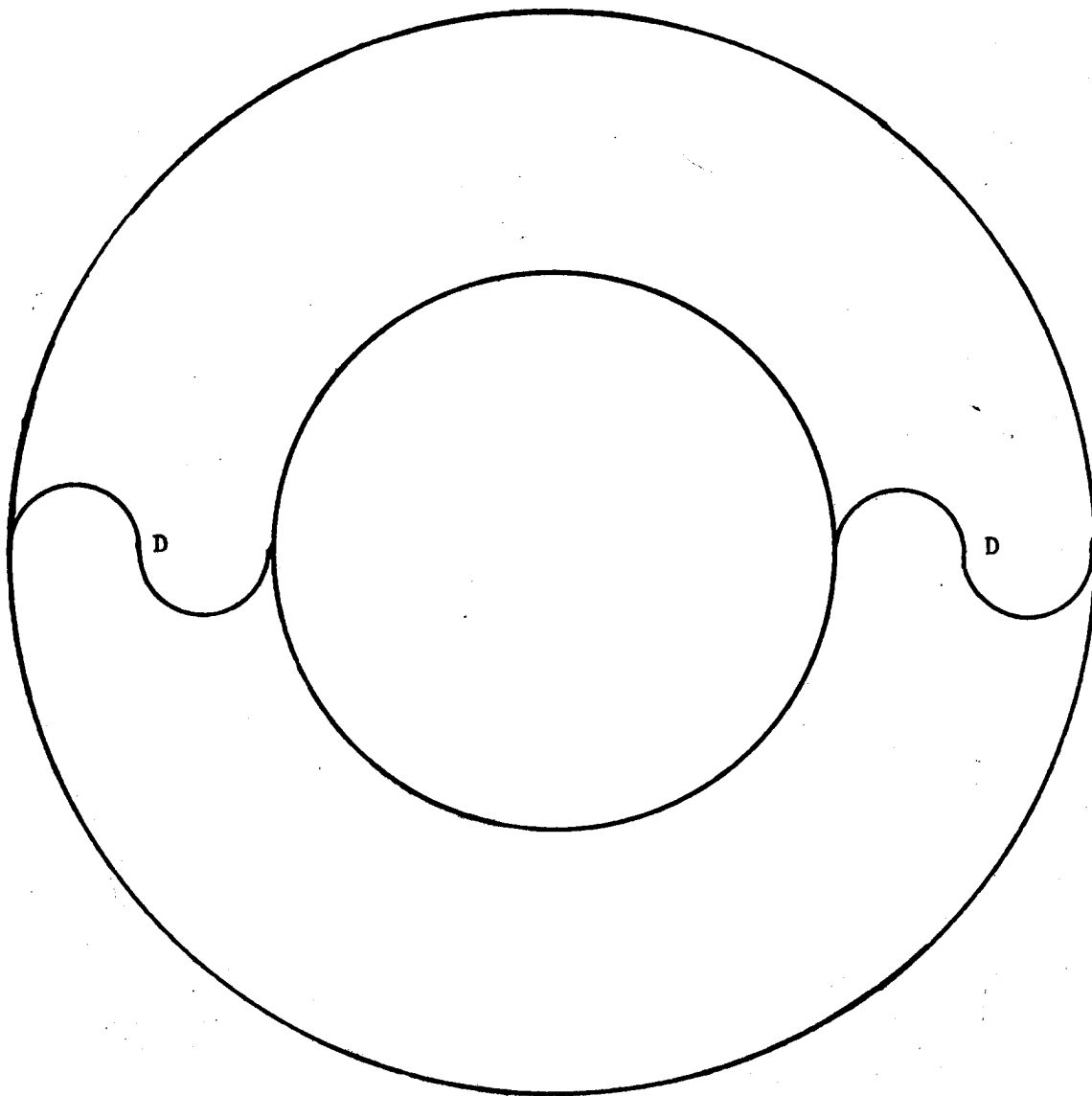


Fig. 13. Arrangement of flexible diaphragm, D, between inner evaporating cylinder and outer spacer wall. The diaphragm is located at right angles to the line of motion.

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SPACER SYSTEMS FOR COOLING BY NATURAL CONVECTION INSIDE  
CLOTHING - Lyman Fourn.

Report No. 4, June 1960, 24 pp, 13 illus, 6 tables (Contract DA 19-129-  
-QR 1328) Project 7-79-10-001A. Unclassified report.

Air movement by natural convection depends on the difference in density between the air in the environment and saturated air at skin temperature. There is a range of combinations of vapor pressure and temperature for which there will be little or no movement, but with air temperatures 5°C (9°F) below skin temperature, and vapor pressure differences of 25 mm, sufficient movement is obtained to give 150/Kg cal/m<sup>2</sup>-hr of cooling. Channel size is the most critical clothing design factor in securing cooling. Clearances of two inches are as effective as no cover at all, but with the channel reduced to half an inch clearance there is considerable loss of cooling. Increase of channel length lowers the average rate of cooling, but gain from greater length exceeds the loss in effectiveness. Extra length is much more effective in channels with one inch clearance than in half inch channels. Laboratory tests of motion of the "body" inside the spacer show a decrease of cooling, compared with undisturbed natural convection, or a small gain, when a flexible diaphragm is used to make the motion produce flow in and out.

- UNCLASSIFIED
1. Clothing, spacer
  2. Clothing, hot weather
  3. Convection, natural
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