

April 14, 1942.

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2,279,810

METHOD AND APPARATUS FOR EFFICIENTLY STERILIZING AIR IN DUCTS

Filed June 28, 1940

3 Sheets-Sheet 1

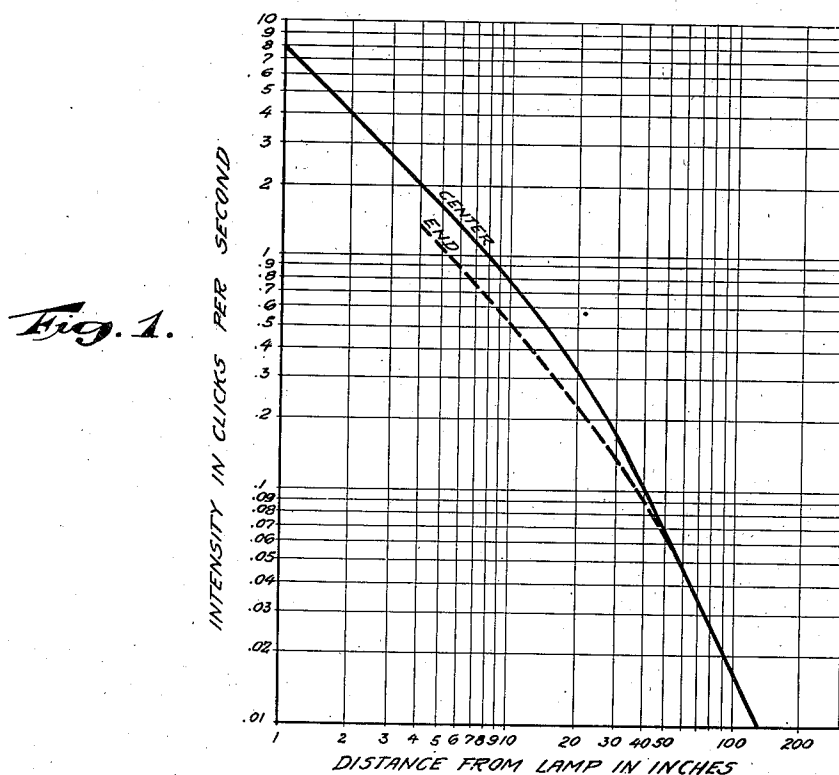
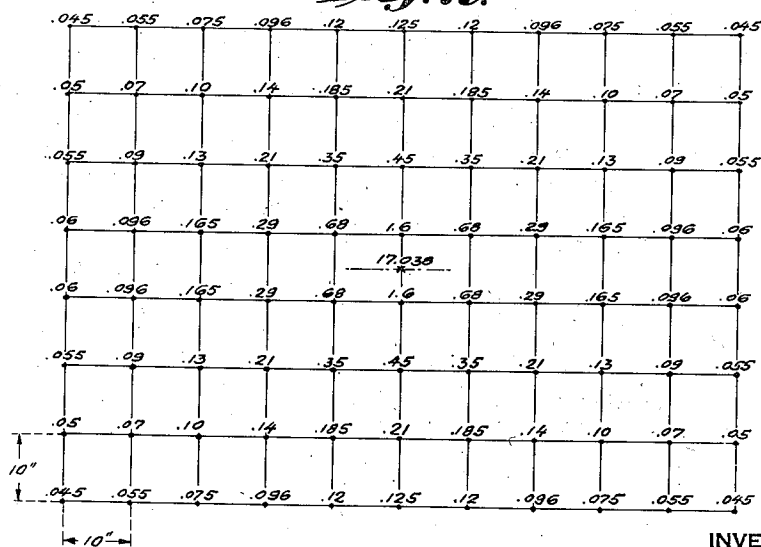


Fig. 2.



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Fig. 3.

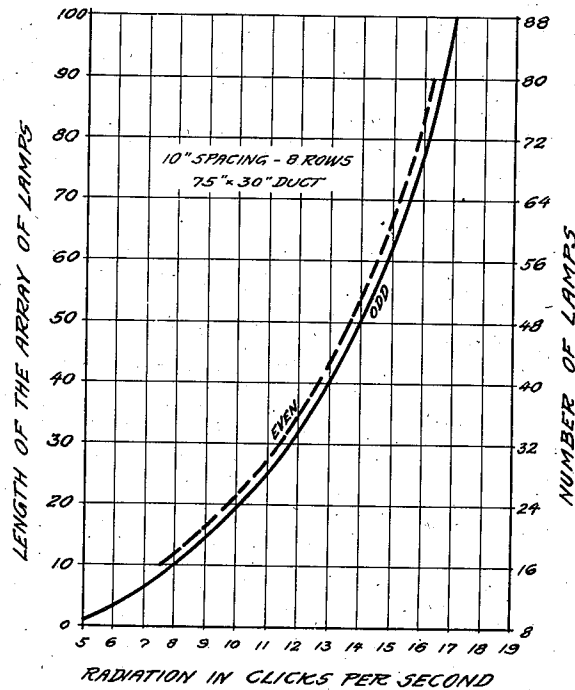
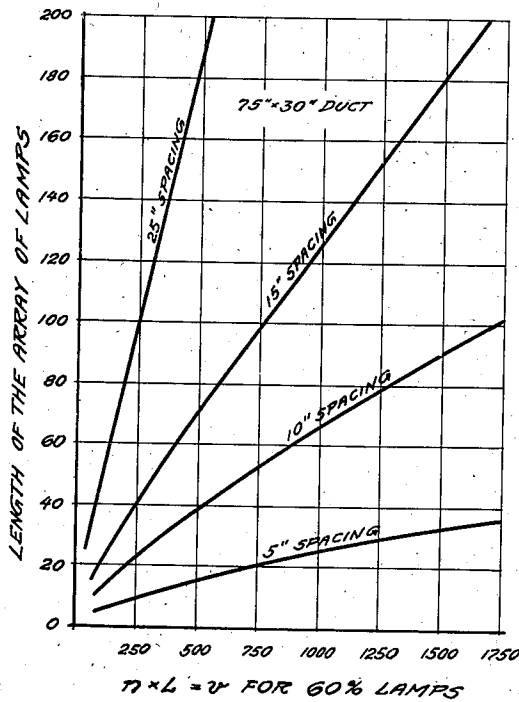


Fig. 4.

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Fig. 5.

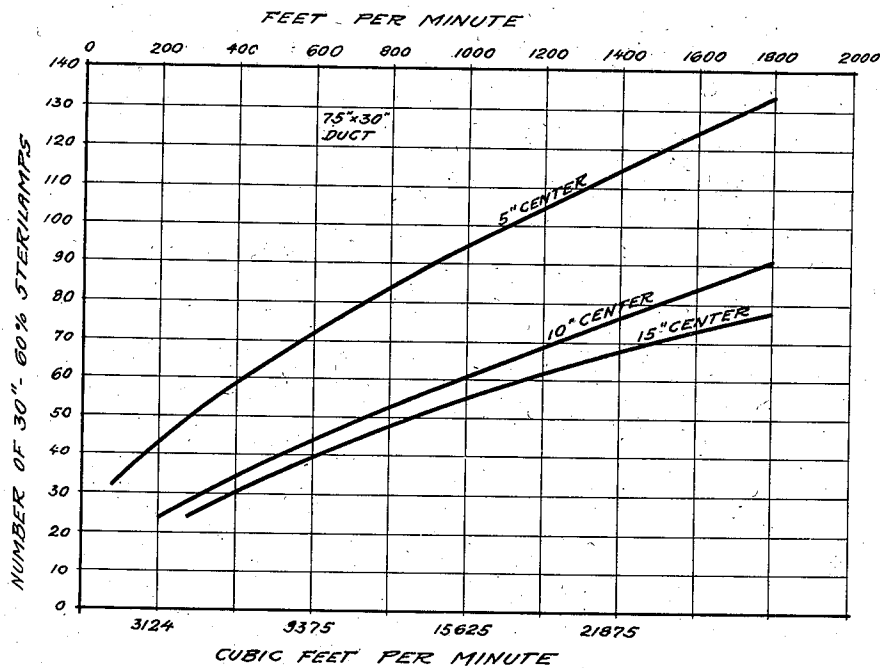


Fig. 6.

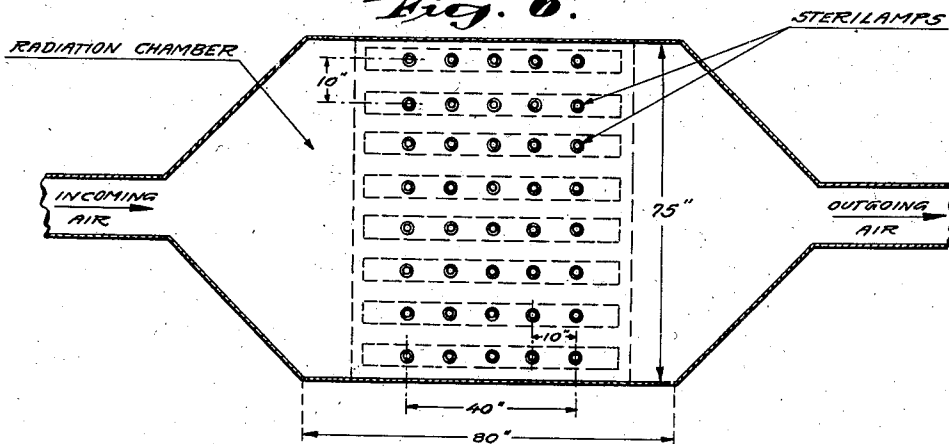
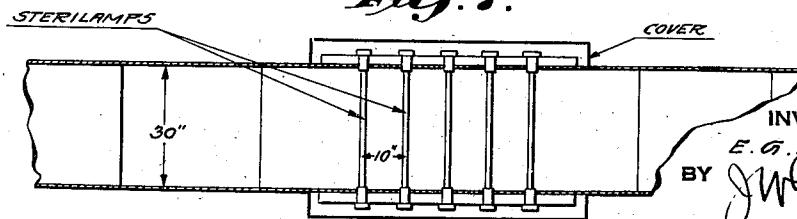


Fig. 7.



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METHOD AND APPARATUS FOR EFFICIENTLY STERILIZING AIR IN DUCTS

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Application June 28, 1940, Serial No. 342,934

9 Claims. (Cl. 250-43)

This invention relates to the destruction of bacteria in air and, more particularly, to the use of ultra-violet generating means in ducts for sterilizing the air transmitted thereby to an auditorium or other room or portion of a building.

The principal object of my invention, generally considered, is the development of calculating charts and a method and apparatus based thereon, whereby ultra-violet generating lamps are disposed to efficiently sterilize the air in conditioning ducts, so that said air may be transmitted to an auditorium or other portions of a building, after being freed of bacteria and other micro-organisms carried thereby.

Another object of my invention is the development of charts which are of assistance in calculating the spacing of "Sterilamps," or other ultra-violet generating apparatus, in air conditioning ducts, for substantially freeing the transmitted air of micro-organisms.

A further object of my invention is the provision of charts useful in calculating the number and distribution of sterilizing lamps used in an air conditioning duct, involving the placing at the proposed position of each lamp, a figure representing the intensity of radiation produced by it at the center of the array.

A still further object of my invention is the efficient distribution of sterilizing lamps in an air conditioning duct, by placing the same in a straight length of duct, distributed over the central half of said length, whereby it is possible to assume that the average intensity over said length is equal to one half the value at the center of the array, said lamps being otherwise equally spaced and disposed as far apart as possible.

Other objects and advantages of the invention, relating to the particular arrangement and construction of the various parts, will become apparent as the description proceeds.

Referring to the drawings:

Figure 1 is a chart showing how the intensity of radiation from an ultra-violet lamp varies with the distance therefrom, plotted on logarithmic coordinate paper.

Figure 2 is a chart showing the intensity of the radiation produced at the center of an array by lamps respectively placed at different positions indicated by the figures.

Figure 3 is a chart representing, as an example only, the relationship between the length of the array and the corresponding number of lamps for 10" spacing in a 75" x 30" duct, and the intensity of the radiation produced in clicks per second.

Figure 4 is a chart showing the relationship between the length of the array of lamps and the length times the intensity at the center of the array, which for 60% "Sterilamps" is numerically equal to the linear velocity of the air at the center of the duct in feet per minute.

Figure 5 is a chart showing the relationship between the number of "Sterilamps" and the linear velocity, as well as the flow in cubic feet per minute, when employed in a 75' x 30' duct, with the lamps arrayed at different distances.

Figure 6 is a horizontal sectional view of an installation of "Sterilamps" positioned in an air duct in accordance with my invention.

Figure 7 is a vertical sectional view along the axis of the duct shown in Figure 6.

It is the function of modern air conditioning systems to provide rooms with air that is at the proper temperature and humidity, and practically free from dust and dirt. This is generally accomplished by recirculating air from the room while adding a small proportion of fresh air through the necessary heating or cooling equipment designed for the purpose. Air in occupied rooms is at times highly contaminated by bacteria and other floating micro-organisms. One observer has determined that bacteria floating in the air may remain in an active state for a considerable time, and that air-borne pathogenic bacteria may be responsible for the transmission of certain respiratory diseases.

Ultra-violet radiation of certain wavelengths is known to have bactericidal properties and has been proposed for killing air borne organisms. There are various places where such ultra-violet radiations may be used for this purpose, one being in air conditioning ducts.

The proper installation of lamps in such ducts requires considerable care. A definite amount of radiation is necessary to kill a given percentage of air-borne organisms as they move rapidly in the duct. The intensity of the radiation is greatest at the surface of the lamp and decreases with increasing distance. The most economical use of radiations in a duct is under conditions in which there is nearly a uniform dosage of the air throughout the cross section. Lamps should be installed in a straight section of the duct in order to utilize the radiations before the air reaches the lamps and after it passes. While the effect of radiation on organisms diminishes with distance, nevertheless the killing will be proportional to the total amount of radiation falling on the bacteria. In many cases a long straight length is not always available, but the minimum

straight portion should, as determined, be at least twice the length occupied by the lamps.

In order to determine the required number of "Sterilamps" to be placed in an air duct of a given size, utilizing a given air velocity, to kill approximately 99% of the bacteria and other micro-organisms in the air, calculations must be made to determine the average intensity of ultra-violet radiation to which the bacteria are exposed in passing through the duct. This was done by first measuring the intensity of the radiation at various distances from one 30", 100% "Sterilamp," that is a discharge lamp manufactured by the Westinghouse Electric & Manufacturing Company under that trade-mark, having an elongated envelope or tube of glass which efficiently transmits bactericidal rays, such as Corning 972 high transmission ultra-violet glass, which is a form of Corex glass. Such lamps are otherwise constructed as described and claimed in the James application, Serial No. 734,620, filed July 11, 1934. From these measurements a chart was made up as shown in Figure 1. The chart shows in full lines the intensity along a line perpendicular to the lamp through its center, and in dotted lines the intensity along a line perpendicular to the lamp through one end. These results are the average of five lamps and are recorded in terms of clicks per second, plotted against the distance from the lamp.

This unit of intensity was used throughout and defines the amount of radiant energy in the bactericidal range which falls per second on a standard tantalum phototube used in a click meter circuit, as described, for example, in the Rentschler et al. patent, #2,037,925 of April 21, 1936, or in the Rentschler et al. application, Serial No. 247,294, filed December 22, 1938.

In view of the fact that the radiation intensity decreases from center to end, as shown in Figure 1, it was decided to have the lamp or lamps extend transverse to the air movement, rather than longitudinally, so as to have the ends at the sides of the duct where the rate of flow was decreased because of turbulence. This arrangement is also better from a practical standpoint, as installation is facilitated.

The next step is to plot an array of lamps in rows and columns at some definite distance, such as 10" apart, as shown in Figure 2. The distance was measured from the center of the array to the axis of each lamp, the intensity then read off the curve of Figure 1, and the numerical value entered at the position of the lamp. The array covers an area 100" x 70" and contains 88 lamps. The intensity in the center, that is, as indicated by the number 17,038 shown in Figure 2, is the sum of the radiations received from the lamps, represented by sum of all the other numbers on Figure 2, as said numbers are the values of the intensity of each lamp at the center of the array. In a similar manner a chart could be plotted for an array having lamps spaced 5" or some other distance apart.

The intensity at any point along the center of the array can be found by adding up the individual intensities of all the lamps which contribute at that point. Thus the intensity at one end of the array is found to be a little greater than one-half that at the center. There will be a gradual decrease in intensity in moving from the center to an end, or from the center to a side, of the array.

From Figure 1 it can be seen that the intensity in a plane normal to the axis of the lamp at an

end, is roughly two-thirds that at a corresponding distance in a similar plane at the center. Thus at the sides of the array at the ends of the lamps, the intensity will also be greater than one-half that at the center.

Figure 2 can be used for an array having a smaller number of lamps by simply omitting those coming outside the desired dimensions. Also, charts for different spacings can be determined in the same way as Figure 2, and greater lengths can be determined by simply extending the calculations as desired.

We now need to know the average intensity along the center of the array which will coincide with the axis of the air duct in which it is placed. Using the array of Figure 2, we find that the intensity at each end is a little more than one-half that at the center. Also, at a point in the duct at a distance of 40" from the center of the array the intensity is considerably greater than zero. Therefore, the average intensity over a length of duct equal to twice the length containing lamps is approximately one-half of the intensity at the center.

The bacteria will then receive the same amount of energy while traveling through a distance equal to the length of the array of lamps under a constant intensity equal to that calculated at the center of the array. For the case in question, this would mean that the bacteria would receive an amount of energy equivalent to that over a distance of 100" at an average intensity of about 17 clicks per second.

The above consideration would be only for bacteria traveling down the center of the duct. It is clear that the average intensity at the sides will be somewhat greater than one-half that at the center and, therefore, bacteria traveling with the same velocity as those at the center would receive only somewhat more than half as much energy. At the corners this is still further reduced to about one-quarter of that at the center. It is found, however, that for ducts of the size considered, and for a normal range of air velocity, the flow is so turbulent at the side walls that there the air velocity will be about one-half that at the center, and in the corners it will be about one-quarter. This means that for the purpose of calculating the required intensity and number of lamps for a given air flow, only that of the center of the duct need be considered.

It has been found that a definite amount of ultra-violet radiation is required to kill a sufficient percentage of bacteria present in flowing air. This amount, as measured on the click meter, has been found to be that equivalent to three clicks. Thus any point in the air receiving an amount of radiation corresponding to three clicks will be sufficiently free from bacteria for the desired purpose.

The air flow in a duct is usually given in terms of number of cubic feet per minute V . We are interested in the linear speed v in feet per minute along the duct. This is given by the formula $v = V/ab$, for a duct of rectangular cross section where a and b are the dimensions in feet of the cross section. If N_0 clicks are required to kill the bacteria, then they must remain in the irradiated section of the duct for a time long enough to receive this amount of energy. If L is the length in feet of the array of lamps, then the time taken by the bacteria to cross the array is $t = L/v$ minutes. The amount of energy received in this time is equal

to $N=60 nt$, where t is in minutes, and n is the average intensity in clicks per second, as determined from the chart of Figure 2, for example, as we have seen n is the intensity in the center of the array. Then

$$N = \frac{60nL}{v} \text{ or } N = 60 \frac{nLab}{V}$$

or putting $N=N_0$, for sufficient killing, and transposing we have

$$nL = \frac{N_0 V}{60ab} = \frac{N_0 v}{60}$$

For $N_0=3$, $nL=3v/60$. If we assume the average lamp intensity at the end of life to be 60% of that shown in Figure 1, then we have

$$nL = \frac{300 \times 12v}{60 \times 60} = v$$

where L is in inches and n in clicks per second. That is, the value of nL is numerically equal to the linear speed of the air in feet per minute.

As an illustration, consider a duct 30" x 75" in cross section, with a flow of 30,000 cubic feet per minute. Assume an array of lamps (as in Figures 6 and 7) so that $n=13$ for an array, as in Figure 2, but shortened from 100" to 40", leaving only 40 lamps, $L=40$ " or 3.3', then

$$N = \frac{60nLab}{V} = \frac{60 \times 13 \times 3.3 \times 2.5 \times 6.25}{30,000}$$

clicks = 1.34 clicks. This is less than the required value of 3 clicks and would not give the substantially complete killing desired. If, however, $V=3000$ cubic feet per minute, we need only three instead of five columns of lamps, since then $n=10.11$, $L=1.67$ feet, and

$$N = \frac{60 \times 10.11 \times 1.67 \times 2.5 \times 6.25}{3000} = 5.27$$

clicks.

Figure 3 is a chart for calculating the intensity at the center of an array for 10" spacing of eight rows of lamps in a 75" x 30" duct, for different lengths of array or different numbers of lamps. It will be noted that two curves are necessary, one when there is an even number of columns of lamps, and an other when there is an odd number of columns. For example, with a length, or value of L , of 40", there is an odd number of lamp columns, that is, five, and we use the curve marked ODD which gives a value of approximately 13 clicks per second with 40 lamps.

If, for example, we have a length of 50", then there is an even number of lamp columns with 48 lamps, giving a value of approximately 13.8 clicks per second at the center of the array.

Figure 4 is a chart showing how the length in inches compares with the value of said length times the intensity at the center of the array which for 60% lamps is numerically equal to the linear velocity in feet per minute. Using this chart we find that with L equal to 40, the linear velocity with 10" spacing may be up to about 520 feet per minute, whereas for 15" spacing it must be decreased to about 235 feet per minute, and for 25" spacing it must be decreased to about 85 feet per minute. Similarly, if we have an air flow of 1000 feet per minute, we can employ an array about 25" long with 5" spacing, about 66" long with 10" spacing, or about 126" long with 15" spacing.

Turning now to Figure 5 which shows the number of 30" 60% "Sterilamps" which should be employed for different air velocities and 75

different lamp spacing in a 75" x 30" duct, we find that with the air traveling at 800 feet per minute, we should use about forty-eight "Sterilamps" if they are spaced 15" from center to center or fifty-three "Sterilamps" if they are spaced 10", or eighty-four if they are spaced 5".

Referring now to Figures 6 and 7, there is shown a typical installation of forty "Sterilamps" spaced 10" between centers in a 75" x 30" duct, and in accordance with our previous calculations the length of the straight portion of this duct is twice the length of the lamp array, that is 80", whereby in accordance with Figure 3 the intensity at the center is about 13 clicks per second, and in accordance with Figure 4 or Figure 5 with 40" length, 10" spacing, and forty lamps we may employ an air speed as high as 520 feet per minute.

In accordance with the foregoing, it will be seen that in order to arrive at the amount of radiation that must be provided in a given air duct, the problem is, first, to determine the intensity at different distances from one "Sterilamp" and then, find the intensity at the center of an array of uniformly spaced lamps. From this we determine an average intensity of radiation along a duct twice as long as the length of the array, in order that the radiations from the lamps may be efficiently employed and a readily calculable arrangement provided, to supply sufficient energy to kill bacteria as they pass therethrough.

In making practical calculations using the foregoing curves, we should consider that four lamps can be operated on the same transformer and if, for example, the number of lamps figures out as thirty-seven for a desired air velocity, we would probably decide on an installation of forty lamps spaced 10" center to center, in a chamber 75" x 30", that is 5 rows of 8 lamps per row, with a lighted length of 40" or a total length of 80" treatment duct, as illustrated in Figures 5 and 6.

It should be pointed out that the calculations and curves produced therefrom, have been checked by practical tests and found to be sufficiently close for use in calculating the number of lamps and lamp spacing to be best employed for given installations. If it is desired to use greater duct size and air velocities, it will be necessary to increase the size of the charts from which to get the necessary data for tables and curves. However, the same principles apply as have been disclosed in the present application. The question of correct percentage to use is dependent upon tube life, temperature and reflection. The sixty-percent example given is an illustration of how percentage enters into the equations, and also greatly simplifies the use of the chart of Figure 4.

Reflection at the walls and absorption by the lamps have not been considered, although it is felt that the former clearly outweighs the latter if reflecting walls are used. The value of three clicks for N_0 is considered to be a typical figure, although the form of the functions from which the curves are plotted will allow other values to be used, if desired, without repeating the calculations.

It should be emphasized that a straight length of duct equal to at least $2L$, that is twice the length in which lamps will be placed, is required if the disclosed calculations are to be used.

Although a preferred embodiment of my in-

vention has been disclosed, it will be understood that modifications may be made within the spirit and scope of the appended claims.

I claim:

1. The method of sterilizing air comprising spacing ultra-violet generating lamps in a straight portion of an air duct, with their axes transverse to the line of movement of air therein, said lamps being spaced so that they are approximately uniformly distributed over the central half of the duct.

2. The method of sterilizing air, comprising positioning elongated ultra-violet generating lamps in a straight portion of an air duct so that their axes extend transverse to the line of movement of air therein and their centers are equally spaced, the length of said duct being twice that of the array of lamps in order to efficiently use irradiations therefrom.

3. The method of sterilizing air, comprising placing generators of bactericidal rays in a straight length of duct distributed over the central half of the duct length, in order to make it possible to assume that the average intensity over said duct length is equal to one-half the value at the center of the array.

4. Apparatus for sterilizing air, comprising a duct, ultra-violet generating lamps disposed in a straight portion of said duct, the axes of said lamps extending transverse to the line of movement of the air, said lamps being spaced so as to be approximately uniformly distributed over the central half of said straight portion.

5. Apparatus for sterilizing air comprising a duct having a straight portion of a predetermined length and ultra-violet generating lamps disposed in said straight portion with their axes extending transverse to the line of movement of air therein, said lamps being spaced so that they are approximately uniformly distributed

over only the central half of said straight portion.

6. The method of sterilizing air comprising spacing ultra-violet ray generating lamps in a straight portion of an air duct so that they are approximately uniformly distributed over the central half of said straight portion.

7. The method of sterilizing air comprising positioning elongated ultra-violet ray generating lamps in a straight portion of an air duct so that their axes extend transverse to the line of movement of air therein and their centers are substantially equally spaced, the straight portion of said duct being extended substantial distances beyond the ends of the array of lamps in order to efficiently use radiations therefrom.

8. Apparatus for sterilizing air comprising a duct having a straight portion of a predetermined length and ultra-violet ray generating lamps disposed in said straight portions and spaced so that they are approximately uniformly distributed over only the central half thereof.

9. Apparatus for sterilizing air comprising a duct having a straight portion enlarged in cross-section as compared with the normal duct section, and ultra-violet ray generating lamps distributed in said straight portion with their axes extending transverse to the line of movement of air therein, said lamps being arranged as a plurality of rows extending longitudinally of said straight portion, said rows being spaced substantially uniformly from one another with the rows adjacent the sides of said straight portion positioned from said sides a distance equal to approximately half the row spacing, said straight portion being extended beyond the ends of said rows a substantial distance and then tapered to the normal cross-section of said duct.

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