

Oct. 11, 1966

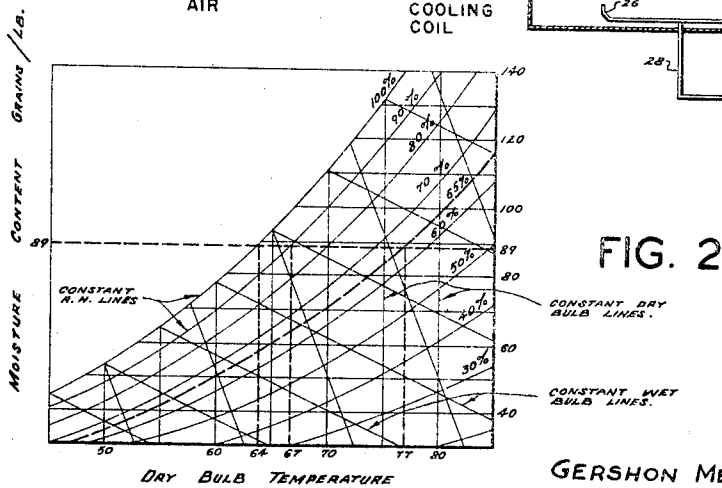
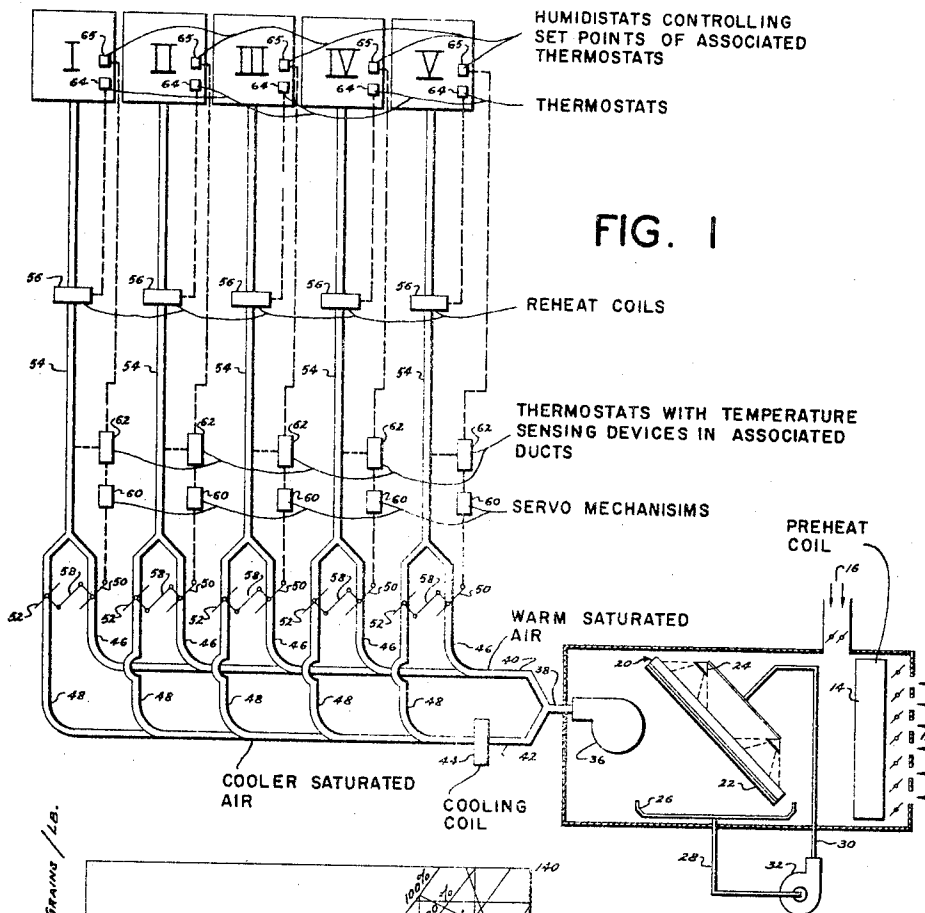
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3,277,954

SYSTEM FOR PRODUCING CONDITIONED AIR

Original Filed March 18, 1963

7 Sheets-Sheet 1



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7 Sheets-Sheet 2

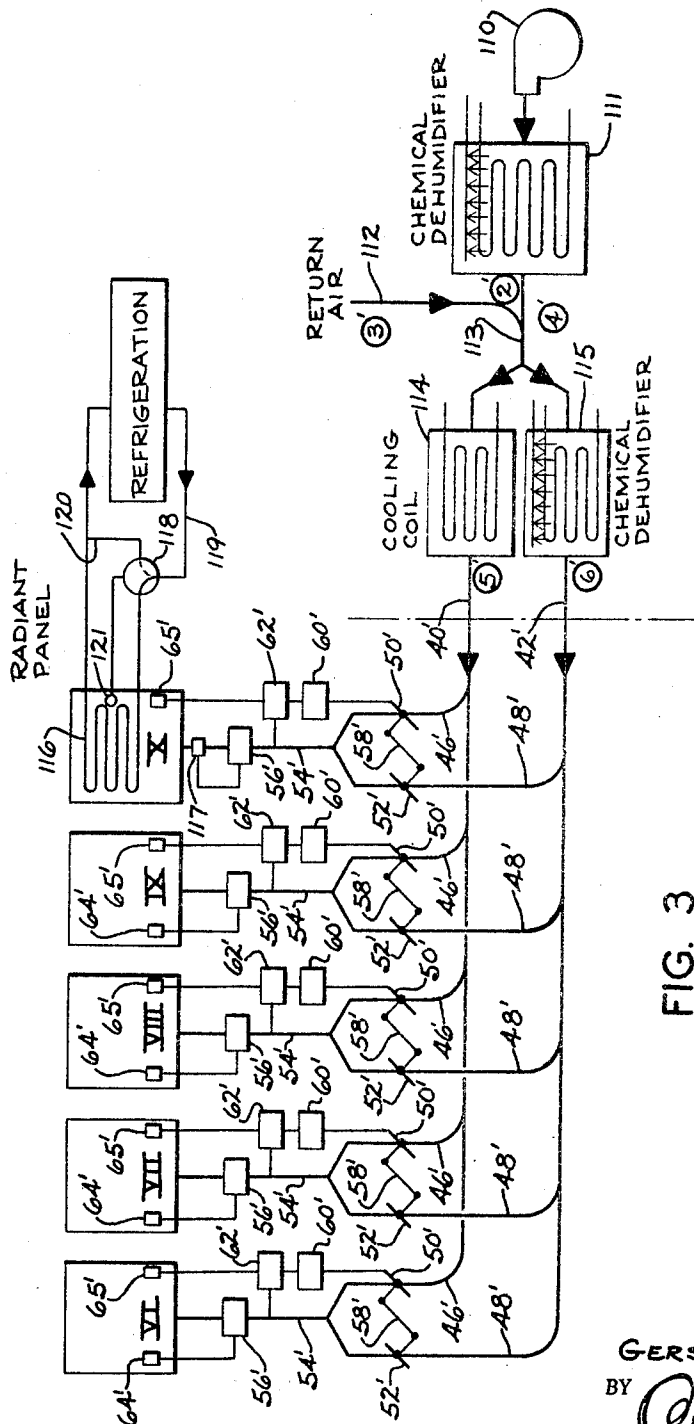


FIG. 3

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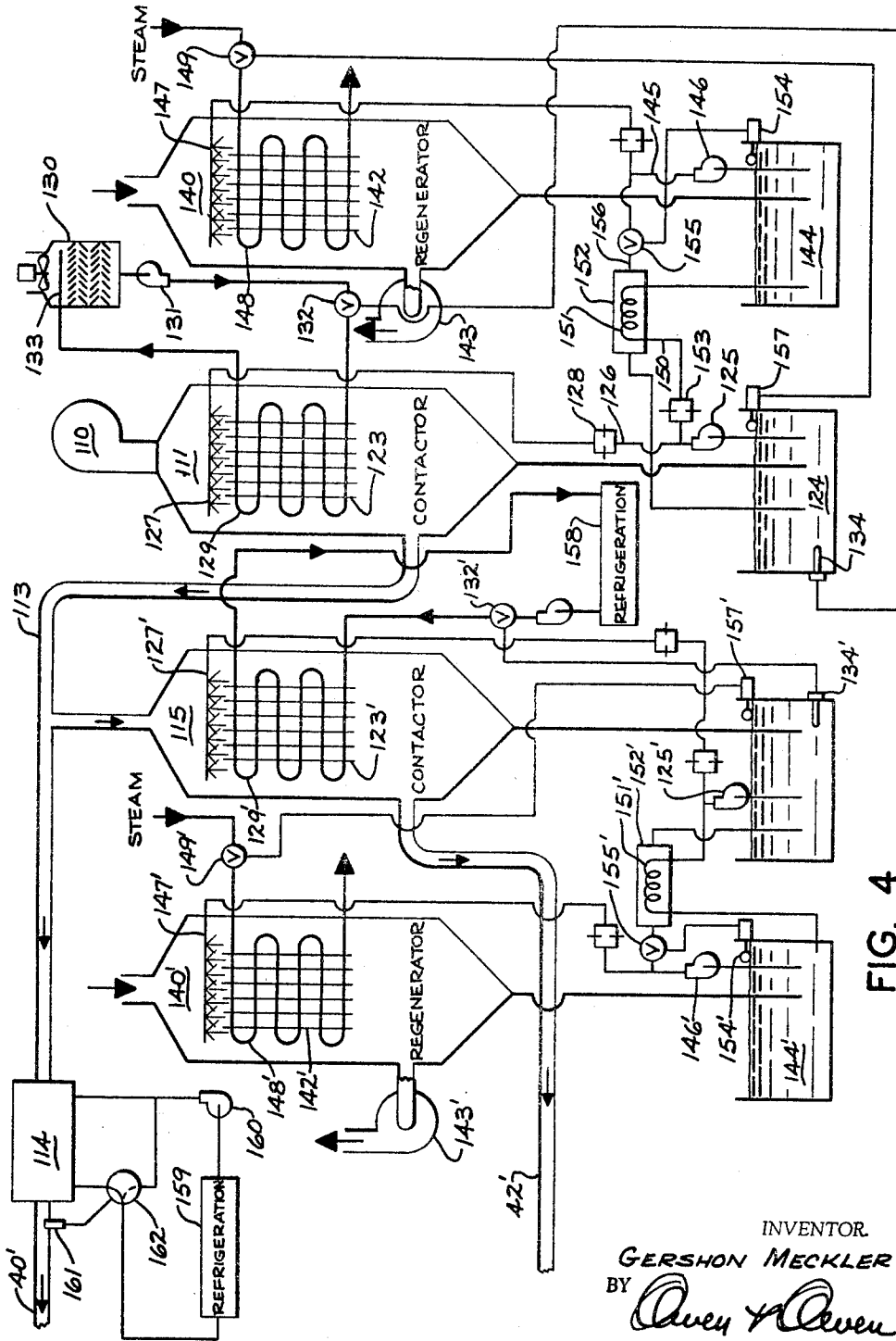
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SYSTEM FOR PRODUCING CONDITIONED AIR

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7 Sheets-Sheet 3



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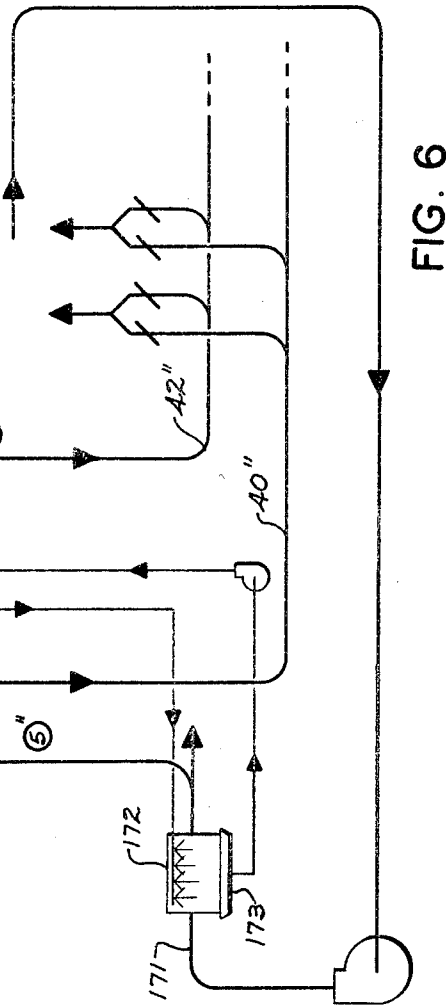
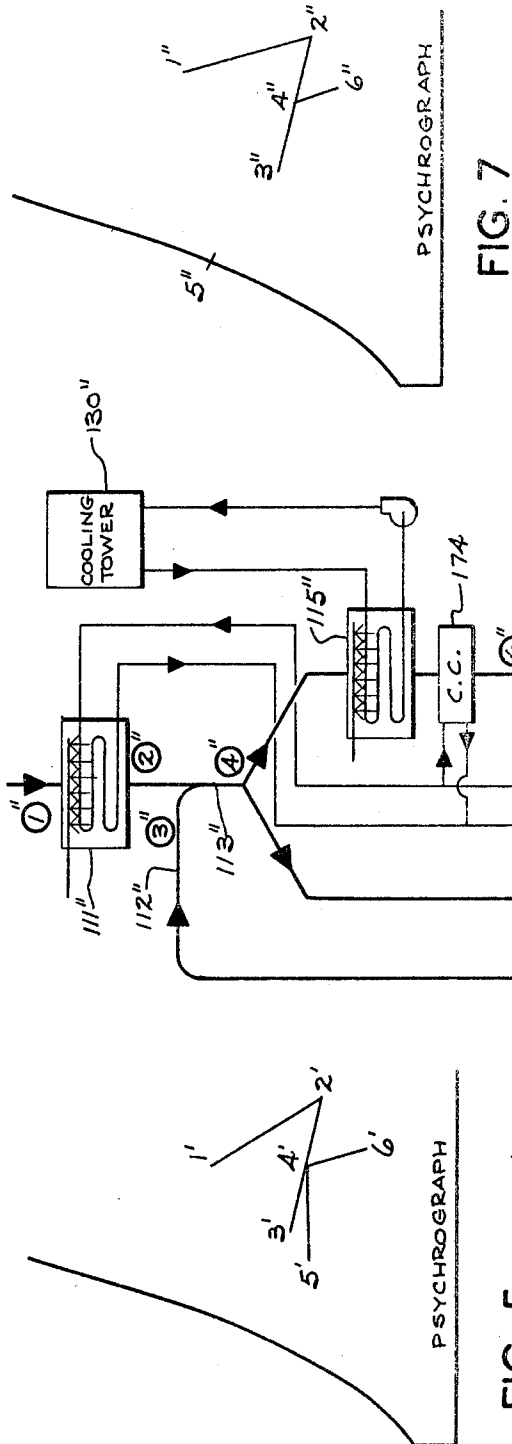
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7 Sheets-Sheet 4



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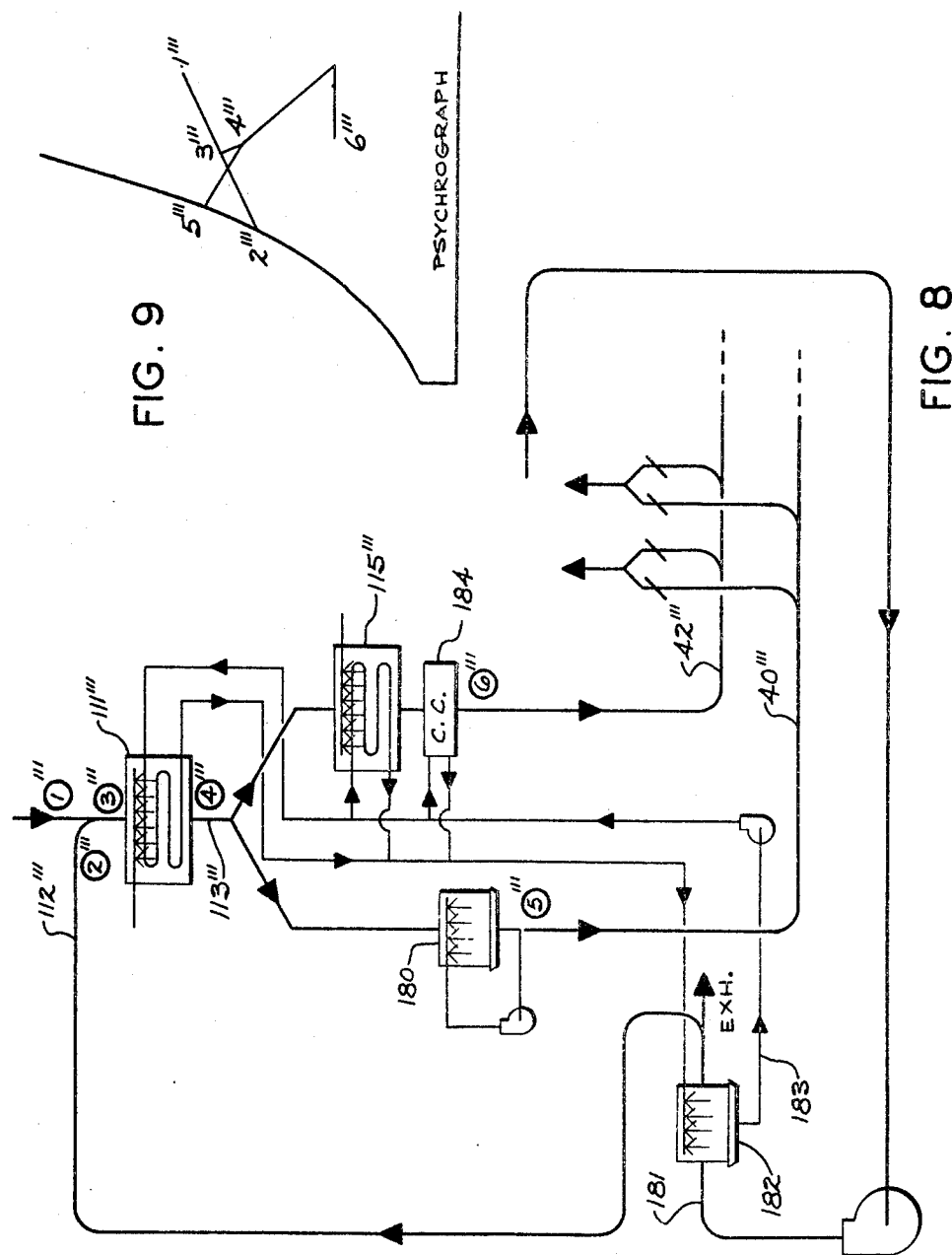
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SYSTEM FOR PRODUCING CONDITIONED AIR

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7 Sheets-Sheet 5



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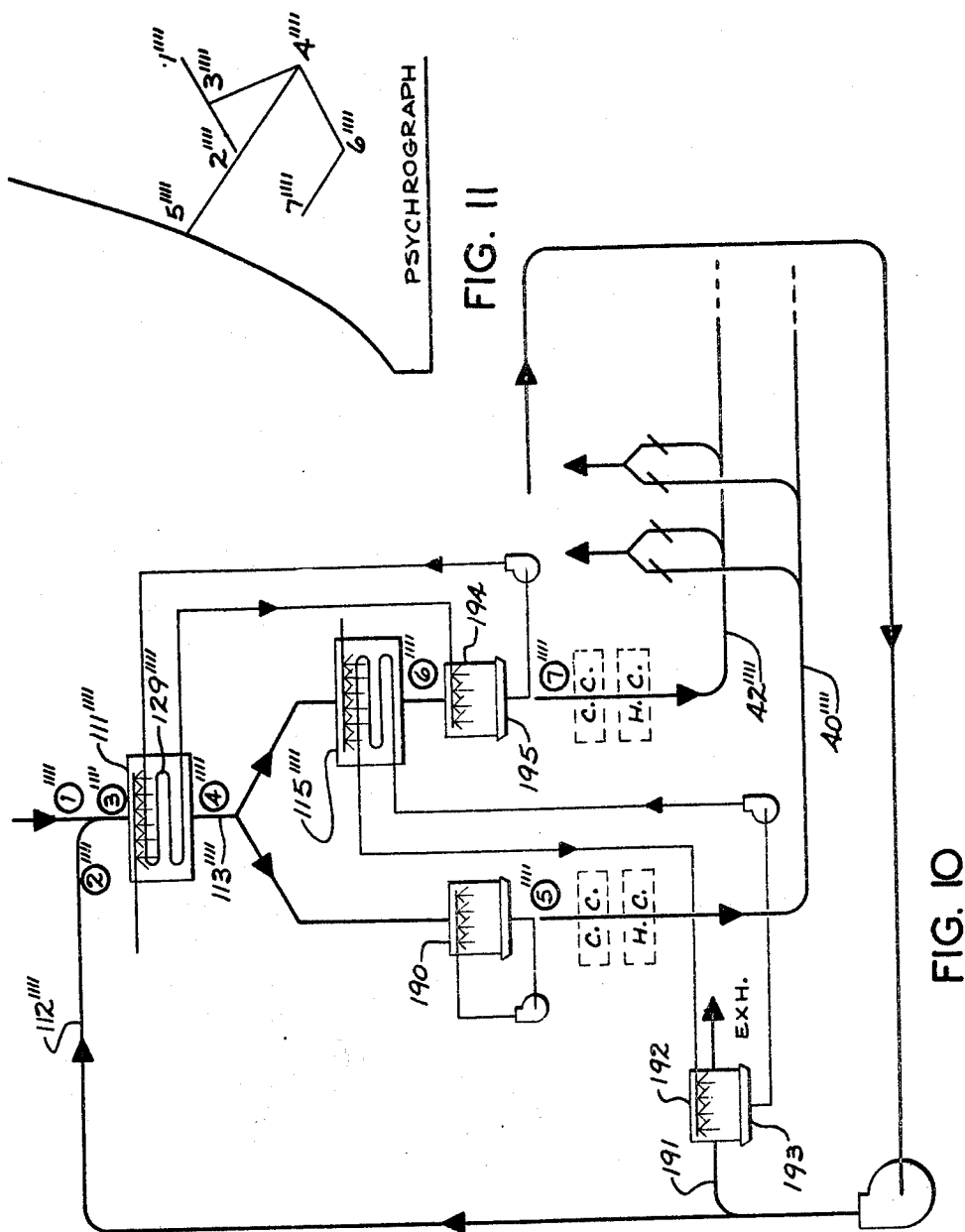
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7 Sheets-Sheet 6



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SYSTEM FOR PRODUCING CONDITIONED AIR

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7 Sheets-Sheet 7

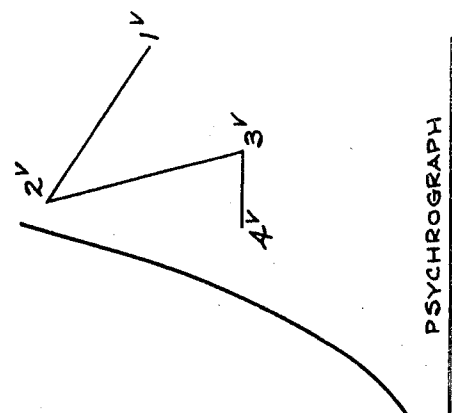


FIG. 13

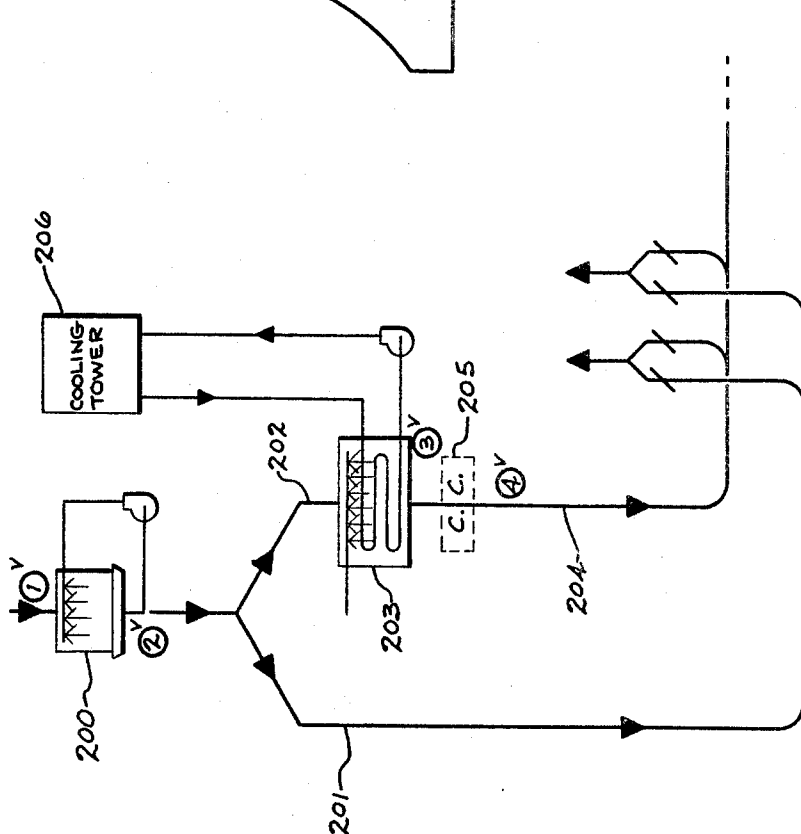


FIG. 12

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SYSTEM FOR PRODUCING CONDITIONED AIR
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Continuation of application Ser. No. 265,992, Mar. 18,
1963. This application Mar. 4, 1966, Ser. No. 531,872
12 Claims. (Cl. 165—20)

This is a continuation of copending application, Serial
No. 265,992, filed March 18, 1963, now abandoned which
was a continuation-in-part of copending application Ser-
ial No. 858,169, filed December 8, 1959, now U.S.
Patent 3,081,943, granted March 19, 1963.

This invention relates to a system for supplying air
under predetermined conditions of temperature and hu-
midity to a space and more particularly to a simplified
system for supplying conditioned air by mixing two
streams of air having predetermined relative humidities
and different temperatures.

The invention has particular advantages where a plu-
rality of spaces are to be provided with air having dif-
fering temperatures and humidities.

According to principles of certain of the embodiments
of the present invention, particular economies and con-
veniences are effected by passing outside air through a
primary air conditioner and then splitting the stream into
two parts. One of the split streams is passed through
a second air conditioner to give one body of air certain
temperature and humidity conditions, and the other split
stream is passed through a third air conditioner to give
another body of air other temperature and humidity con-
ditions, so that the two bodies can be mixed in varying
proportions to give any intermediate temperature and hu-
midity conditions desired.

Humidity sensing apparatus is quite delicate, expensive,
and troublesome to maintain, and in accordance with one
aspect of the invention, the absolute humidity of the mix-
ture can be accurately and easily controlled by causing
the two split bodies of air to be of generally the same
relative humidity, so that mixture thereof will also be
of the same relative humidity. Over the short ranges in
temperature that will normally be involved in the split
air streams, the relative humidity lines of a psychrometric
chart will approach straight lines, so that the absolute hu-
midity of any desired mixture of the two streams can
be very closely approximated by proportioning the mix-
ture according to dry bulb temperature. If, for example,
air of a particular absolute humidity is desired, two sepa-
rate streams having the same relative humidity can be
produced, and the separate streams can be proportioned
according to their dry bulb temperatures to produce air
of the desired absolute humidity.

In one embodiment of the invention, two streams or
bodies of air at the same relative humidity are achieved
by saturating both streams with water so that both are
at substantially 100% relative humidity. In another em-
bodiment the two streams are caused to be at approxi-
mately the same relative humidity by subjecting both
streams to separate chemical dehumidifiers that are at
different temperatures but which use chemical desiccants
of the same concentration or equilibrium conditions with
respect to water. It is a property of chemical dehumidi-
fiers that they produce water-air equilibrium conditions
which vary along lines on a psychrometric chart that are
generally parallel to lines of constant relative humidity.

Further advantages of the invention arise by reason of
the fact that practically all humans feel comfortable in
air of about the same relative humidity (50%) even
though they prefer different temperatures. This being
true, two streams of air which are at the same relative

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humidity but different temperatures can be blended to
give intermediate temperatures that will satisfy different
humans in different spaces.

In its broader aspects, the new conditioning system en-
ables air under predetermined different conditions of dry
bulb temperature and relative humidity to be supplied to
several spaces having different requirements. The system
accomplishes this in a simple manner by utilizing two
streams of air at different predetermined dry bulb tem-
peratures and water vapor contents, which streams are
combined in controlled proportions with the aid of mix-
ing valves responsive to the temperature of the mixture.
The water vapor content of the mixture of the two streams
varies as a straight line function of the temperature of
the mixture. As a consequence, the quantity of water
vapor per unit of dry air can be controlled by control-
ling this mixture temperature. The amount of water
vapor necessary to attain a particular relative humidity
in a space can be determined from a psychrometric chart
and the mixing valves then adjusted to obtain an air
mixture which will contain this amount of water, as con-
trolled by the mixture temperature. The mixture is then
heated by suitable means controlled by the temperature
in the space before being supplied thereto in order to
establish the desired dry bulb temperature. Thus, by
the use of two temperature-responsive devices, one in the
space and one in the air mixture, the dry bulb temperature
and the relative humidity of the air in the space can be
determined and maintained.

The new system employs simple and accurate controls
which are relatively inexpensive and which eliminate the
necessity of employing elaborate networks of unstable
booster humidifiers.

It is, therefore, a principal object of the invention to
provide a system for supplying air under given conditions
to several spaces, which system is simple, accurate, and
inexpensive.

Another object of the invention is to provide a system
for controlling the relative humidity of air in a space
by combining two streams of air having generally the same
relative humidity but different moisture contents.

Another object of the invention is the provision of a
new and improved air conditioning system wherein two
streams of air are provided each of which has been treated
with a liquid desiccant of generally the same concentra-
tion but different temperatures to cause both streams to
be at different temperatures but the same general rela-
tive humidity.

A further object of the invention is the provision of
a new and improved air conditioning system wherein out-
side air is passed through a first chemical dehumidifier
that is cooled by means of a cooling tower, and the air
stream is then split into two streams—one of which is
treated by a second chemical dehumidifier that is cooled
by refrigeration to lower its humidity and temperature, so
that the system employs a minimum of refrigeration to
effect final temperature and humidity conditions.

A still further object of the invention is the provision
of a new and improved air conditioning system wherein
one stream is provided which is warmer and drier than
desired conditions, and another stream is provided that
is cooler and wetter than desired conditions, and the two
streams blended and proportioned to give the desired
conditions.

Other objects and advantages of the invention will be
apparent from the following detailed description of pre-
ferred embodiments thereof, reference being made to the
accompanying drawings, in which:

FIG. 1 is a line diagram of a system for conditioning
air in accordance with the principles of the invention;

FIG. 2 is a simplified psychrometric chart to which

reference will be made in the explanation of the invention;

FIG. 3 is a diagrammatic flow sheet of another embodiment of the present invention using chemical dehumidifiers instead of refrigeration coils to effect dehumidification;

FIG. 4 is a more detailed flow sheet of the dehumidification section of the flow sheet shown in FIG. 3;

FIG. 5 is a psychrometric chart representing the psychrometric path of the air through the system of FIG. 3;

FIG. 6 is a flow sheet of still another embodiment of the invention using chemical dehumidifiers and is similar in this respect to the embodiments shown in FIGS. 3 and 4;

FIG. 7 is a psychrometric chart representing the psychrometric path of the air through the system of FIG. 6;

FIG. 8 is a schematic flow diagram similar to FIG. 6 but showing still another embodiment of the invention;

FIG. 9 is a psychrometric chart representing the psychrometric path of the air through the system of FIG. 8;

FIG. 10 is a schematic flow diagram similar to FIGS. 6 and 8, and showing still another embodiment of the invention;

FIG. 11 is a psychrometric chart representing the psychrometric path of the air through the system of FIG. 10;

FIG. 12 is a schematic flow diagram of another embodiment of the invention; and

FIG. 13 is a psychrometric chart representing the psychrometric path of the air passing through the system of FIG. 12.

Referring to the drawing and more particularly to the embodiment shown in FIG. 1, the illustrated system in accordance with the principles of the invention is capable of supplying air at different dry bulb temperatures and relative humidities to a large number of spaces, five being shown. By way of example, the system can be employed in a hospital in which a space I represents a nursery requiring air having a dry bulb temperature of 77° F. and a relative humidity of 65 percent, space II represents an operating room with the air having a dry bulb temperature of 80° F. and a relative humidity of 55 percent, space III represents patient rooms with the air having a dry bulb temperature of 80° F. and a relative humidity of 50 percent, space IV represents a recovery room with the air having a dry bulb temperature of 75° F. and a relative humidity of 55 percent, and space V represents an allergy room with the air having a dry bulb temperature of 76° F. and a relative humidity of 45 percent.

Outside air or air from any suitable source is drawn through a fresh air intake 12 and heated to a desired temperature by a suitable preheat coil 14. Return air can also be supplied through a duct 16 for mixing with the heated outside air downstream of the coil 14. The heated air is then passed through an adiabatic washer 20 comprising a porous screen or wall 22 over which water is directed from sprays 24. This water is collected in a sump 26 and is recirculated through pipes 28 and 30 by a pump 32 to the sprays 24. The washer 20 has two principal functions. It washes bacteria or other airborne contaminants from the air, which contaminants can be eliminated by control of makeup water, by means of submerged ultraviolet lamps in the sump 26, or by controlled addition of a nonvolatile bactericide or bacteriostat. Secondly, the washer adiabatically saturates the air which makes its dry bulb temperature substantially equal to its wet bulb temperature.

The air is then drawn through a blower 36 from which it is delivered through a discharge duct 38 to a warm air main duct 40 and a cool air main duct 42. The air in the duct 38 is at a slightly higher temperature than after adiabatic saturation because of the work done on it by the blower, and, hence, is slightly below saturation, or has a relative humidity slightly less than 100 percent. That portion of the air passing through the cool air main duct 42 is then cooled by a cooling coil 44 to a tempera-

ture lower than that of the air in the warm air main duct 40 whereby water is condensed from the cooled air. It may be noted that each of the main ducts 40 and 42 contains air which is substantially saturated, having the same relative humidity, but having substantially different dry bulb temperatures, wet bulb temperatures, and moisture contents.

A branch duct 46 leading from the warm air duct 40 is provided for each of the spaces I-V and a branch duct 48 leading from the cool air main duct 42 is similarly provided for each space. The branch ducts 46 and 48 contain mixing valves 50 and 52 for controlling the relative proportions of the warm and cool air which mix in supply ducts 54. These ducts contain reheat coils 56 which raise the temperatures of the air mixtures to the desired dry bulb temperatures to be maintained in the spaces I-V. The relative humidities of the air in these spaces are determined by the moisture contents of the air in the ducts 54 which, in turn, are controlled by the proportional amounts of air supplied from the branch ducts 46 and 48, as determined by the mixing valves 50 and 52. The mixing valves are connected by suitable linkages 58 which cause one valve to move toward a closed position as the other valve moves toward an open position. In this instance the valves 50 are driven by servo mechanisms 60 regulated by temperature-responsive instruments such as thermostats 62 which are responsive to temperatures of the air in the ducts 54. When the temperature in one of the ducts 54 is above that desired, the thermostat 62 in that duct actuates its associated servo mechanism 60 to cause the appropriate valve 50 to move toward a closed position and, through the linkage 58, to cause the valve 52 to move toward an opened position. This increases the proportion of cool air in the mixture and lowers the mixture temperature in the duct 54. The moisture content of the mixture is also decreased because of the larger proportional amount of the cool drier air in the mixture, which air has a lower moisture content than the warm air. When the temperature in the duct 54 is below that desired, the servo mechanism 60 causes the valves 50 and 52 to act oppositely and increase the relative amount of warm air. A thermostat 64 in each of the spaces I-V similarly controls each of the reheat coils 56, supplying more heat thereto when the dry bulb temperature in the space is below that desired and reducing the heat thereto when the temperature is above that desired. A humidistat 65 is also provided in each of the spaces, and each is operatively associated to reset the control point of the corresponding thermostat 62 to establish a new air mixture temperature control point in one of the ducts 54 in response to a desired change in humidity level in any one of the spaces I-V.

The proper amount of moisture necessary to maintain the desired relative humidity in the spaces I-V can be determined from a psychrometric chart. Thus, in the nursery designated space I, the air having a dry bulb temperature of 77° F. and a relative humidity of 65 percent will require moisture in an amount of 89 grains of water vapor per pound of dry air (see FIG. 2) in the supply duct 54 which serves the nursery. From the psychrometric chart, for the air at 100 percent relative humidity in the duct 54 to have a moisture content of 89 grains of water vapor per pound of dry air, it must have a dry bulb temperature of 64° F., which is also the wet bulb temperature. Therefore, by maintaining the temperature in the duct 54 at 64° F. and the room temperature at 77° F., the desired relative humidity of 65 percent is maintained. This is easily accomplished with only the two temperature controls and the mixing dampers. It is not necessary to know the actual proportional amounts of two air streams which are employed nor is it necessary to know the temperature, either wet bulb or dry bulb, of either of the two streams, as long as they have the same relative humidity.

Because the lines representing constant relative hu-

midity are slightly curved upwardly rather than straight (see FIG. 2), and because the conditions representing the resulting mixture of the two streams of air will lie on a straight line between two points representing the conditions for the two streams, the point representing the mixture will lie above the 100 percent relative humidity line. as a consequence, a mixture of two saturated streams would have a slight excess of moisture, above saturation. This would undesirably result in condensation of moisture in the duct 54, maintaining the duct wet and promoting bacteria growth. However, this is overcome by the heating of the air by the blower 36 which produces a relative humidity of the air in the warm air main duct 40 slightly under 100 percent so that no excess moisture will result upon mixing of the slightly less than saturated warm air in the duct 40 with the fully saturated, cooled air in the duct 42.

It may be noted that the moisture content of the air in the cool air main duct 42 must be no greater than the minimum amount required in any of the spaces I-V, in this case about 60 grains per pound of dry air in the space V. To obtain this, reference to a standard psychrometric chart indicates that the air in the duct 42 must be cooled to 53° F. or below at 100 percent relative humidity (not illustrated in FIG. 2). Similarly, the maximum water vapor in the air in the duct 40 must be at least as much as the maximum required in any of the spaces I-V. In this case, the maximum amount of water vapor will be in the nursery and will be about 89 grains per pound of dry air. To obtain this amount, the air in the duct 40 must be at least about 64° F. at 100 percent relative humidity (not illustrated in FIG. 2).

To control relative humidity in the manner previously described by means of the temperature devices 62 in the ducts 54, it is only necessary that the relative humidities of the air in the ducts 40 and 42 be the same and be known. While maintaining these relative humidities at 100 percent is the easiest and preferred method of keeping them equal, they might be maintained at 90 percent, for example, by washing the air in the duct 40 with a dilute solution of lithium chloride at a proper strength and temperature to maintain the air in equilibrium at 90 percent relative humidity, and by washing the air in the duct 42 downstream of the cooling coil 44 with a dilute solution of lithium chloride to produce a relative humidity of 90 percent of the air in this duct, too. With air at 90 percent relative humidity the temperature of the air mixture necessary for a particular moisture content can be determined as easily as with saturated air. Thus, for the nursery, a moisture content of 89 grains per pound of dry air is still necessary. For air at 90 percent relative humidity, a dry bulb temperature of 67° F. (see FIG. 2) will enable the air to carry this amount of moisture.

Depending on the temperature of the outside air or air from some other source employed in the system, a cooling coil might be used in place of preheat coil 14, and, in some instances, the source of air might contain sufficient water vapor that no washer is necessary at all, particularly if other means are employed to remove airborne contaminants therefrom, or if no removal is deemed necessary.

It will be appreciated that an important feature of the invention, as previously described, resides in the elimination of the necessity for cycling of the cooling coil 44. Such coil operates constantly, and is utilized at all times both to cool air and to condense moisture therefrom. It has been found that airborne bacteria tend to collect in condensate on such a coil, but that the bacteria constitute no significant health hazard unless the operation of the coil is cyclic, and then only during the portion of the cycle when the condensate is being reevaporated. During such portion of the cycle collected bacteria from the condensate are introduced into the air stream, with the result that dangerously high bacteria counts are frequently encountered. So long as the coil 44 in the system

according to the invention is operated to maintain saturated air in the duct 42 on the downstream side of the coil, the temperature of the saturated air can vary between the maximum, as discussed above, and freezing without affecting control conditions, so that the system eliminates the need for cycling to effect control.

By control of humidity levels in substantially adjacent spaces I-V it is possible to control by vapor pressure difference staging the path of moisture migration and its associated contamination in air, thereby eliminating it as a significant factor in cross contamination between these areas.

As previously indicated, the embodiment shown in FIG. 3 is generally similar to that shown in FIG. 1 and differs principally in that its dehumidification is accomplished by means of chemical dehumidifiers instead of by cooling coils. Those portions of FIG. 3 which correspond to similar portions of FIG. 1 are designated by a like reference numeral characterized further in that a prime mark is affixed thereto.

In the embodiment shown in FIG. 3, outside air is forced by a blower 110 through a chemical dehumidifier 111—following which it is united with air returning from enclosed spaces VI, VII, VIII, IX and X through a conduit 112. The amount of return air which is used will vary as will be well understood by those skilled in the art, and in some instances it may be desirable to use 100% of outside air from the blower 110 and no return air through the line 112. Following the juncture of the line 112, an air flow header 113 is divided or split, so that the air going to a branch header 40' passes through a cooling coil 114 wherein its sensible heat is reduced and the air portion going to a branch header 42' passes through a second chemical dehumidifier 115.

In the embodiment shown in FIG. 3, the chemical dehumidifier 111 is cooled by means of water from a cooling tower, as will later be explained, so that the outside air is partially cooled and partially dried before it is split into the portions passing through the cooling coil 114 and the second dehumidifier 115, respectively. The returning air through the duct 112 will, of course, be relatively cool, and is mixed with the partially conditioned fresh outside air, so that the air passing to the cooling coil 114 and second dehumidifier 115 will both have a certain percentage of outside air. The air passing through the cooling coil 114 will, of course, have the same absolute humidity as does the air leaving the first dehumidifier 111, and is further cooled, so that the air passing to the duct 40' will generally be cooler and wetter than the air that is desired in any of the enclosed spaces VI, VII, VIII, IX or X. Cooling of the coil 114 is effected by means of a refrigeration system, as will later be explained.

The second chemical dehumidifier 115 is also supplied with a refrigerated cooling medium, so that the air passing to the branch header 42' is generally drier than is required in any of the closed spaces VI, VII, VIII, IX, or X, and is at a temperature equal to or greater than the highest temperature required in any of the closed spaces. The air passing to both the cooling coil 114 and second dehumidifier 115 will, of course, be relatively dry and will be at the same relative humidity. While it is not necessary in all instances, the second chemical dehumidifier 115 can utilize the same concentration of chemical desiccant as does the chemical dehumidifier 111 so that the air passing to the header 42' will be of substantially the same relative humidity as was the air entering from the header 113. The cooling coil 114 does not change the absolute humidity, inasmuch as it merely cools the air, so that the relative humidity of the duct 40' will generally be higher than that of the duct 42'. The air leaving the second chemical dehumidifier 115 will be drier than necessary, while the air in the branch header 40' will be slightly wetter than necessary. So long as the wet and dry bulb temperatures of the air streams in the ducts 40'

and 42' remain constant, however, the absolute humidity in each of the spaces VI, VII, VIII, IX and X can be controlled with the same mechanism, appropriately calibrated, used in the embodiment shown in FIG. 1.

In some instances, however, it may be desired to use a radiant panel in one or more of the air spaces VI, VII, VIII, IX, or X, as shown, for example, in the space X. When a radiant panel 116 is utilized, it will be desirable to control the temperature of the air resulting from the mixture of the flows from headers 46' and 48' to be generally constant, and approximately at or slightly below the desired room temperature, and to control the necessary cooling required by means of the radiant panel 116. One convenient means of control, therefore, is to place a thermostat 117 in a header 54' prior to its entrance to the space X to control its reheat coil 56'. The temperature of the radiant panel 116 is controlled by means of a valve 118 which directs water in a chilled water circuit 119 either through the panel 116 or through a by-pass line 120. The valve 118 is regulated by means of a thermostat and controller 121 in the air space X, so as to regulate flow in the panel 116 as required by temperature changes within the space X. Under some conditions it may be desirable to provide a radiant panel in each of the closed spaces, and in this event the cooling coil 114 may not be necessary.

In order that the details of the construction and operation of the dehumidification section of the flow sheet shown in FIG. 3 can be better understood, reference should now be had to FIG. 4 of the drawings. The second stage chemical dehumidifier 115 is generally similar to the first stage chemical contactor 111 differing principally in size and the temperature of water which is supplied to its cooling coil. These portions of the second chemical dehumidifier 115 which are similar to corresponding portions in the first chemical dehumidifier 111, therefore, are designated by like reference numerals characterized further in that a prime mark is affixed thereto.

The chemical dehumidifier 111 generally comprises a vertically extending tank 122 having a plurality of vertically extending baffles 123 therein. The chemical desiccant, which may be a solution of lithium chloride of approximately 30% concentration, it held within a tank or contactor sump 124 and is sprayed over the baffles 123 by means of a pump 125, riser 126, and spray nozzles 127. In order that this flow may be controlled at a generally fixed rate, an orifice 128 is provided in the riser 126.

The process of absorbing water by the chemical desiccant is an exothermic reaction, so that the baffles 123 are provided with cooling coil 129 to maintain their temperature constant and to maintain the exit air from the chemical dehumidifier 111 at a constant absolute humidity and temperature. The cooling coil 129 can be supplied with cooling water of any suitable temperature, and as will be necessary depending upon the concentration of the desiccant. In the embodiment shown in FIG. 4, cooling tower water is used because of its economy. Cooling water from a cooling tower 130 is forced by means of a pump 131 through a control valve 132, through the coil 129, and then to suitable spray heads 133 in the cooling tower 130. The valve 132 which controls the temperature of the coil 129 is in turn controlled by means of a thermostat 134 that is located in the contactor sump 124 so as to maintain the temperature of the desiccant, and, as a consequence, that of the treated air, constant.

The chemical desiccant that is used in the contactor will, of course, pick up water from the air that is passed therethrough, and thereby gradually become diluted. It it, therefore, necessary continually to regenerate the chemical desiccant so as to maintain its concentration substantially constant. This is accomplished in the embodiment shown in FIG. 4 by means of a regenerator 140 which is generally similar in its construction to the contactor 111, and differs principally therefrom in its size, and in that steam is admitted to its coil to evaporate water from the desiccant. The regenerator 140 comprises a vertical tank

141 having a plurality of vertical baffles 142 therein through which outside air is continually drawn as by the blower 143. The regenerator 140 is also provided with a sump 144 to retain the desiccant that is being regenerated. Desiccant is pumped from the sump 144 through a riser 145 by means of a pump 146 to spray heads 147 from which it is discharged over the vertical baffles 142. In order that the excess water will be boiled off, steam is admitted to its heating coil 148, and the temperature and amount of steam that is used is controlled by a flow valve 149, as will later be explained.

Regeneration of the desiccant is done continuously while the contactor is in operation, and in order that this can be accomplished, a side stream from the riser 126 is caused to pass through a line 150 and one side 151 of a heat exchanger to flow to the sump 144. Desiccant in the contactor 111 is, of course, relatively cool while the desiccant in the regenerator 140 is relatively warm, so that an economy is had by using the cold flow to cool regenerated desiccant that is continually added to the sump 124. The regenerated stream is taken off at the riser 145 to pass through the other side 152 of the exchanger on its way to the sump 124. The branch stream of fluid that is passed to the regenerator sump 144 is controlled generally by means of an orifice 153. The liquid level in the regenerator sump 144 is maintained constant by reason of a float control valve 154 which operates a valve 155 to control the side stream of the hot fluid that is passed through the hot side 152 of the exchanger leading to the sump 124 of the contactor 111. The amount of liquid desiccant in the system, therefore, is a function of the dilution of the system, so that a float control 157 in the contactor sump 124 can be used to control the steam supply valve 149 to the regenerator coil 148.

As previously mentioned, the second stage dehumidifier 115 is similar to the first stage dehumidifier 111, so that it carries like reference numerals characterized further in that a prime mark is affixed thereto. Likewise, its regenerator is similar to the regenerator 140 and its portions which correspond to similar portions of the regenerator 140 are designated by a like reference numeral characterized further in a prime mark affixed thereto. The contactor 115 differs from the first stage contactor 111 in that its cooling coil 129' is supplied with refrigerated water from a refrigeration machine 158.

A refrigeration machine 159 provides chilled water for circulation through the cooling coil 114 by a pump 160. The temperature of the air in the duct 40' is controlled by means of a thermostat 161 which controls a valve 162 in the chilled water recirculation line leading to the coil 114.

FIG. 5 is a schematic psychograph showing the general psychrometric path over which the system shown in FIG. 3 operates. Air enters the system generally in the state indicated by a point 1' and is cooled and dehumidified in the first stage contactor 111 until it has the properties indicated by a point 2'. Return air having the properties indicated generally by a point 3' is mixed with the air from the contactor 111 to form a mixture having the qualities indicated generally by a point 4'. Thereafter, the portion of the air passing through the cooling coil 114 is cooled until it has the properties of a point indicated at 5', and the portion of the air passing through the second stage dehumidifier 115 is cooled and dehumidified until it has the properties indicated generally at 6'. The air passing through the conduit 40', therefore, has the properties indicated generally by the point 5' on the graph while the air passing through the conduit 42' has the properties indicated at the point 6' in the graph, and the two are blended to give air for the spaces VI, VII, VIII, IX and X having properties intermediate these two points.

The embodiment shown in FIG. 6 is generally similar to that shown and described above in connection with FIG. 3, and differs principally therefrom in that it passes outside air flow through a chemical dehumidifier and

then splits the flow so that one branch passes directly to the warm air duct 40'' while the other passes through a second stage of chemical dehumidification. Those portions of FIG. 6 which are similar to corresponding portions in the embodiment shown in FIG. 3 are designated by like reference numerals characterized further in that a double prime mark is affixed thereto.

Another major respect in which the embodiment shown in FIG. 6 differs from that of FIG. 3 is that there is no individual cooling device provided for the branch header 40'' and in its place the return air from line 171 is passed through a humidifier 172 before the return air is blended with the air coming from the first stage chemical dehumidifier 111''. Some or all of the air that is passed through the humidifier 172 is circulated through line 112'' to the air flow header 113''. The water that is sprayed through the humidifier 172 is of course cooled and this water is collected as at 173 and pumped through the coils of the first stage chemical dehumidifier 111'' to cool the small amount of fresh air that is being dehumidified and dissipate the energy of dehumidification. The cooling tower 130'', however, is used to supply water to the second stage chemical dehumidifier 115'' since this requires the larger amount of cooling. At the same time a cooling coil 174 is provided on the exit side of the second stage chemical dehumidifier 115'' and water from the humidifier or direct heat exchanger 172 is circulated through the cooling coil 174 to further cool the air that is supplied to the branch header 42''.

A schematic psychograph for the system shown in FIG. 6 is shown in FIG. 7 wherein conditions of the entering air are shown generally by a point 1''. The entering outside air is dehumidified and cooled until it reaches the conditions indicated generally by a point 2''. Return air has the conditions indicated by a point 3'' so that the mixture of the return, and outside air streams gives the conditions indicated generally by a point 4''. Thereafter the air passing through the direct heat exchanger 170 is saturated, as evidenced by a point 5'', and the air passing through the other branch system is first cooled and dehumidified, and then cooled only by the cooling coil 174 until it has the conditions indicated by a point 6''.

The embodiment shown in FIG. 8 is generally similar to that shown in FIG. 6, so that portions of FIG. 8 which correspond to similar portions of FIG. 6 are designated by like reference numerals characterized further in that a triple prime mark is affixed thereto. The embodiment of FIG. 8 differs from the embodiment of FIG. 6 principally in that no cooling tower water is used to cool any of the system, and that all of the sensible cooling is done by direct heat exchange or humidification. Like the system shown in FIG. 6, the system shown in FIG. 8 uses a humidifier 180 to cool the air which is passed to the branch header 40'''. The total return flow through a header 181 passes through a humidifier 182 following which part of it is exhausted to the atmosphere, while the other part is returned up through the return header 112'''. Inasmuch as all of the air passes through the humidifier 182 more cooling is being done than in the embodiment of FIG. 6; therefore, the cooling tower is omitted. Cool liquid from a collector 183 of the humidifier 182 is circulated through a cooling coil 184 on the outlet side of the second stage chemical dehumidifier 115''', while parallel cooling circuits also are supplied to both the second stage chemical dehumidifier 115''', and the first stage chemical dehumidifier 111'''.

The psychrometric path of the air passing through the system shown in FIG. 8 is generally shown in FIG. 9. The outside entering air generally has the conditions indicated by a point 1''', and the return air in line 112''' is saturated and has the conditions indicated by a point 2'''. The mixture, therefore, gives air having the conditions indicated by a point 3''' and chemical dehumidification of this air gives the conditions indicated by a

point 4'''. Thereafter, the portion passing through the direct heat exchanger 180 constitutes the air which is supplied to the branch header 40''', and has the conditions indicated by a point 5''', whereas the air which passes through the second stage chemical dehumidifier 115''' and the indirect cooler 184 is conditioned or indicated by a point 6'''.

The embodiment shown in FIG. 10 is similar in many ways to the embodiments which have previously been described, and those portions of the embodiment of FIG. 10 which are similar to the portions of the previously described embodiments are designated by like reference numerals characterized further in that a quadruple prime mark is affixed thereto. The embodiment shown in FIG. 10 differs principally from the embodiment shown in FIG. 6 in that a direct heat exchanger has been substituted for the indirect exchanger following the second stage chemical dehumidification. The air from the main header 113'''' which is split for use in the branch header 40'''' passes through a direct heat exchanger or humidifier 190. Part of the return air passes out through a side branch 191 and goes through a humidifier or direct exchanger 192 to cool water that is circulated therethrough. Water from a collector 193 of the exchanger 192 is circulated through the second stage chemical dehumidifier 115'''' to supply the necessary cooling for this stage of dehumidification. Another direct exchanger or humidifier 194 is positioned on the outlet side of the second stage chemical dehumidifier 115''', and the cool water received from its collector 195 is used to provide the necessary cooling for the coil 129'''' of the first stage chemical dehumidifier 111'''. Additional cooling, as by refrigeration coils, can be used in each of the branch headers 42'''' or 40'''' as may be needed to obtain the desired or necessary cooling. Likewise, in some instances, reheat coils can be located to decrease relative humidity should this be necessary.

The psychrometric path of the air flowing through the system shown in FIG. 10 is indicated generally by the graph shown in FIG. 11. Outside air enters the system with the conditions generally indicated by a point 1'''. The condition of the return air is indicated by a point 2''', so that the mixture will generally have the conditions indicated by a point 3'''. First stage chemical dehumidification causes the air to have the conditions indicated by a point 4'''' following which saturation of the air flowing to the header 40'''' causes it to assume the conditions indicated by a point 5'''. The air flowing to the other branch header 42'''' is first dehumidified and cooled to assume conditions of a point 6''', and is, thereafter partially humidified to the conditions of the point 7'''. It will be understood that any suitable mixture having properties between the points 5'''' and 7'''' can be supplied to the various closed air spaces.

In the embodiment shown in FIG. 12, outside air is passed through a humidifier 200 following which the air flow is split between branch headers 201 and 202. The branch header 201 supplies washed partially humidified air to the takeoff for the individual air spaces to be conditioned. The air flowing through the branch header 202 passes through a chemical dehumidifier 203 following which it may either be conducted directly through the branch header 204 to the various air spaces to be conditioned, or can be passed through a cooling coil 205, if cooler air is desired. Cooling water for the chemical dehumidifier 203 can be supplied either from a cooling tower 206 or from a source of chilled water.

The psychrometric path of the air flowing through the system shown in FIG. 12 is indicated generally by the graph shown in FIG. 13. Outside air enters the system with the conditions generally indicated by a point 1v. The air humidifier 200 causes the air to assume the conditions indicated by point 2v following which some of the air at this condition is supplied to the spaces to be conditioned. The remainder of the air is passed through the chemical dehumidifier 203 so that it assumes the conditions in-

licated by point 3^v. Air having the conditions of the point 3^v can be mixed with air having the conditions 2^v in various proportions for conditioning the various air spaces, or the air may be further cooled by the cooling coil 205 until it has the conditions indicated by the point 4^v. Where the cooling coil 205 is used, air having the conditions indicated by the point 4^v is mixed with air having the conditions of point 2^v for conditioning the various air spaces. If chilled water is supplied to the humidifier 200, cooler and drier air is delivered therefrom to the headers 201 and 202.

It will be seen that various combinations of branch systems using two stages of dehumidification can be used, and that certain advantages arise when both branches are caused to have the same relative humidity. Still further advantages occur solely due to use of two-stage chemical dehumidification, and in some instances it will be desirable to use a higher concentration of desiccant in the second stage of chemical dehumidification than in the first stage of chemical dehumidification so that the relative humidity of the air passing from the second stage will have relative humidity which is even lower than that after the first stage chemical dehumidification.

Other modifications of the invention will be apparent to those skilled in the art after reading the above description and viewing the accompanying drawings. It is to be understood that such modifications can be employed without departing from the spirit and scope of the invention as defined in the appended claims.

What I claim is:

1. Apparatus for comfort conditioning of a closed space, said apparatus comprising at least three separate air conditioning devices, a first of said devices being a dehumidifier including a desiccant and effective to remove water from air circulated in contact therewith, a second of said devices being effective to reduce the sensible heat and to change the dewpoint of air circulated in contact therewith, and a third of said devices being effective to lower the sensible heat of air circulated in contact therewith; means for circulating fresh air through the first of said devices; means effective to receive air from the first of said devices, to circulate a first part of such air through the second of said devices and then into the closed space, and to circulate a second part of such air through the third of said devices and then into the closed space; means effective to control the relative proportions of the air circulated through the second and the third of said devices and into the closed space to maintain an instantaneously required dewpoint in the space; transferring means effective to absorb heat from the second and the third of said devices, said transferring means being effective to maintain said devices at a temperature below a predetermined maximum; means operatively associated with said transferring means and effective to reject heat from said transferring means; a circulating system for transferring heat from the first of said devices to a heat transfer medium, said circulating system being effective to maintain said first device at a temperature above the predetermined maximum; and means operatively associated with said circulating system and effective to reject heat from the heat transfer medium.

2. Apparatus for comfort conditioning of a closed space, said apparatus comprising at least two separate air conditioning devices, a first of said devices being a dehumidifier including a desiccant and effective to remove water from air circulated in contact therewith, and a second of said devices being a dehumidifier including a desiccant and effective to lower both the sensible heat and the latent heat of air circulated in contact therewith; means for circulating fresh air through the first of said devices; means effective to receive air from the first of said devices, to circulate a first part of such air through the second of said devices and then into the closed space, and to circulate a second part of such air into the closed space; means effective to control the relative proportions of the air cir-

culated from the first and the second of said devices and into the closed space to maintain an instantaneously required dewpoint in the space; transferring means effective to absorb heat from the second of said devices, said transferring means being effective to maintain said device at a temperature below a predetermined maximum; means operatively associated with said transferring means and effective to reject heat from said transferring means; a circulating system for transferring heat from the first of said devices to a heat transfer medium, said circulating system being effective to maintain said first device at a temperature above the predetermined maximum; and means operatively associated with said circulating system and effective to reject heat from the heat transfer medium.

3. Apparatus for comfort conditioning of a closed space, said apparatus comprising at least three separate air conditioning devices, a first of said devices being a dehumidifier including a desiccant effective to remove water from air circulated in contact therewith, a second of said devices being a dehumidifier including a desiccant effective to reduce the sensible heat of, and to remove water from air circulated in contact therewith, and a third of said devices being effective to absorb radiant energy from the closed space; means for circulating fresh air through the first of said devices; means effective to receive air from the first of said devices, to circulate a first part of such air through the second of said devices and then into the closed space, and to circulate a second part of such air into the closed space; means effective to control the relative proportions of the air circulated from the first and from the second of said devices and into the closed space to maintain an instantaneously required dewpoint in the space; transferring means effective to absorb heat from the second and the third of said devices and to transfer such absorbed heat to a heat transfer medium, said transferring means being effective to maintain said devices at a temperature below a predetermined maximum; means operatively associated with said transferring means and effective to transfer heat from the heat transfer medium; and a circulating system for transferring heat from the first of said devices to a second heat transfer medium, said circulating system being effective to maintain said first device at a temperature above the predetermined maximum.

4. Apparatus for air conditioning of a closed space, said apparatus comprising at least four separate air conditioning devices, a first of said devices being a dehumidifier including a desiccant effective to remove water from air circulated in contact therewith, a second of said devices being a dehumidifier including a desiccant effective to reduce the sensible heat of, and to remove water from air circulated in contact therewith, a third of said devices being effective to absorb radiant energy from the closed space, and a fourth of said devices being effective to reduce the sensible heat of air circulated in contact therewith; means for circulating fresh air through the first of said devices; means effective to receive air from the first of said devices, to circulate a first part of such air through the second of said devices and then into the closed space, and to circulate a second part of such air through the fourth of said devices and then into the closed space; means effective to control the relative proportions of the air circulated from the second and from the fourth of said devices and into the closed space to maintain an instantaneously required dewpoint in the space; transferring means effective to absorb heat from the second, the third and the fourth of said devices and to transfer such absorbed heat to a heat transfer medium, said transferring means being effective to maintain said devices at a temperature below a predetermined maximum; means operatively associated with said transferring means and effective to transfer heat from the heat transfer medium; and a circulating system for transferring heat from the first of said devices to a second heat transfer medium, said circulating system being effective to maintain said first device at a temperature above the predetermined maximum.

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5. Apparatus for air conditioning of a closed space, said apparatus comprising at least four separate air conditioning devices, a first of said devices being a chemical dehumidifier, a second of said devices being a chemical dehumidifier, a third of said devices being an evaporator, and a fourth of said devices being an indirect heat exchanger, means circulating outside air through the first of said devices, means for withdrawing return air from said space, means for combining a portion of return air from said space with air from said first device, said means splitting the combined air flow and causing a first portion to flow through said second device and then through said fourth device to said air space, and causing another portion of combined air to flow to said air space, means for passing another portion of return air from said space through said third device, means for circulating water sprayed through said third device to cool said first and fourth devices, a cooling tower, and means cooling said second device by means of water from said cooling tower.

6. Apparatus for air conditioning of a closed space, said apparatus comprising at least five separate air conditioning devices, a first of said devices being a chemical dehumidifier, a second of said devices being a chemical dehumidifier, a third of said devices being an indirect heat exchanger, a fourth of said devices being an evaporator, a fifth of said devices being an evaporator, means for withdrawing return air from said space and passing the returned air through said fifth device, means for combining return air from said fifth device with outside air and for passing the combination through said first device, means for splitting said air from said first device into first and second portions, means causing said first portion to flow through said second and third devices and then to said air space, and causing said second portion to flow through said fourth device and then to said air space, and means circulating water through said fifth device to cool said water and then passing said cooled water to said first, second, and third devices to cool the air passing through said devices.

7. Apparatus for air conditioning of a closed space, said apparatus comprising at least five separate air conditioning devices, a first of said devices being a chemical dehumidifier, a second of said devices being a chemical dehumidifier, a third of said devices being an evaporator, a fourth of said devices being an evaporator, a fifth of said devices being an evaporator, means for withdrawing return air from said space, means for splitting said return air from said space and passing a first portion through said fifth device, and for passing a second portion to said first device, means for combining said second portion with outside air and for passing the combined flow through said first device, means for splitting the flow through said first device into third and fourth flows, means for passing said third flow through said second and third devices and then to said air space, means for passing said fourth flow through said fourth device and then to said air space, means for circulating water into direct contact with air flowing through said third device to cool said water and for circulating said cooled water to said first device to withdraw heat therefrom, and means for circulating water through said fifth device to cool said water and for circulating said cooled water to said second device to remove heat therefrom.

8. Apparatus for air conditioning of a closed space, said apparatus comprising at least four separate air conditioning devices, a first of said devices being a chemical dehumidifier, a second of said devices being a chemical dehumidifier, a third of said devices being an evaporator, and a fourth of said devices being an indirect heat exchanger, means for circulating outside air through the first of said devices, means for passing return air from said air space through said third device and combining it with air flow from said first device, means for splitting the combined air flow and for causing a first portion to flow to said air space, and for causing another portion to flow

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through said second and fourth devices and then into said air space, means for circulating water sprayed through said third device to cool at least one of said first and fourth devices, a cooling tower, and means for cooling said second device by means of water from said cooling tower.

9. Apparatus for comfort conditioning of a closed space, said apparatus comprising at least three separate air conditioning devices, a first of said devices being a dehumidifier including a desiccant and effective to remove water from air circulated in contact therewith, a second of said devices being a dehumidifier including a desiccant and effective to remove water from air circulated in contact therewith, a third of said devices being an evaporative cooler, means for circulating air through the first of said devices, means for splitting air flow from the first of said devices and for causing a first portion to flow to said air space, and for causing a second portion to flow through the second of said devices and then through the third of said devices to said air space, and means for circulating an evaporative liquid sprayed through said third device to cool at least one of said first and second devices.

10. Apparatus for air conditioning of a closed space, said apparatus comprising at least five separate air conditioning devices, a first of said devices being a chemical dehumidifier, a second of said devices being a chemical dehumidifier, a third of said devices being an evaporator, a fourth of said devices being an evaporator, and a fifth of said devices being an indirect heat exchanger, means circulating outside air through the first of said devices, means for withdrawing return air from said space, means for combining a portion of return air from said space with air from said first device, said means splitting the combined air flow and causing a first portion to flow to said second device and then through said fifth device to said air space, and causing another portion of combined air to flow through said third device and then on to said air space, means for passing another portion of return air from said space through said fourth device, means for circulating water sprayed through said fourth device to cool said first and fifth device, a cooling tower, and means cooling said second device by means of water from said cooling tower.

11. Apparatus for supplying air at a plurality of dry bulb temperatures and containing from X to $X + \Delta X$ grains of water per pound to each of a plurality of zones, said apparatus comprising means forming a supply passage to each of the zones, means for providing a stream of air of substantially constant wet and dry bulb temperature, of Y percent relative humidity and containing more than $X + \Delta X$ grains of water per pound and for delivering such stream to each of said supply passages, means for delivering to each of said supply passages a second stream of air of substantially constant wet and dry bulb temperatures of a relative humidity substantially other than Y percent containing less than X grains of water per pound and at a temperature substantially different from that of the first stream and means effective to control the relative proportions of such first and second streams delivered to each of said supply passages to maintain the absolute humidity of the air in each supply passage at a predetermined value from X to $X + \Delta X$ grains of water per pound.

12. Apparatus for supplying air at a plurality of dry bulb temperatures ranging from T to $T + \Delta T$, and containing from X to $X + \Delta X$ grains of water per pound to each of a plurality of zones, said apparatus comprising means forming a supply passage to each of the zones, means for providing a stream of air of substantially constant wet and dry bulb temperature, of Y percent relative humidity and containing more than $X + \Delta X$ grains of water per pound and at a first temperature and for delivering such stream to each of said supply passages,

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means for delivering to each of said supply passages a second stream of air of substantially constant wet and dry bulb temperatures of a relative humidity substantially other than Y percent containing less than X grains of water per pound and at a second temperature, one of said temperatures being lower than T and the other of said temperatures being higher than $T + \Delta T$, and means effective to control the relative proportions of such first and second streams delivered to each of said supply passages to maintain the absolute humidity of the air in each

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supply passage at a predetermined value from X to $X + \Delta X$ grains of water per pound.

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