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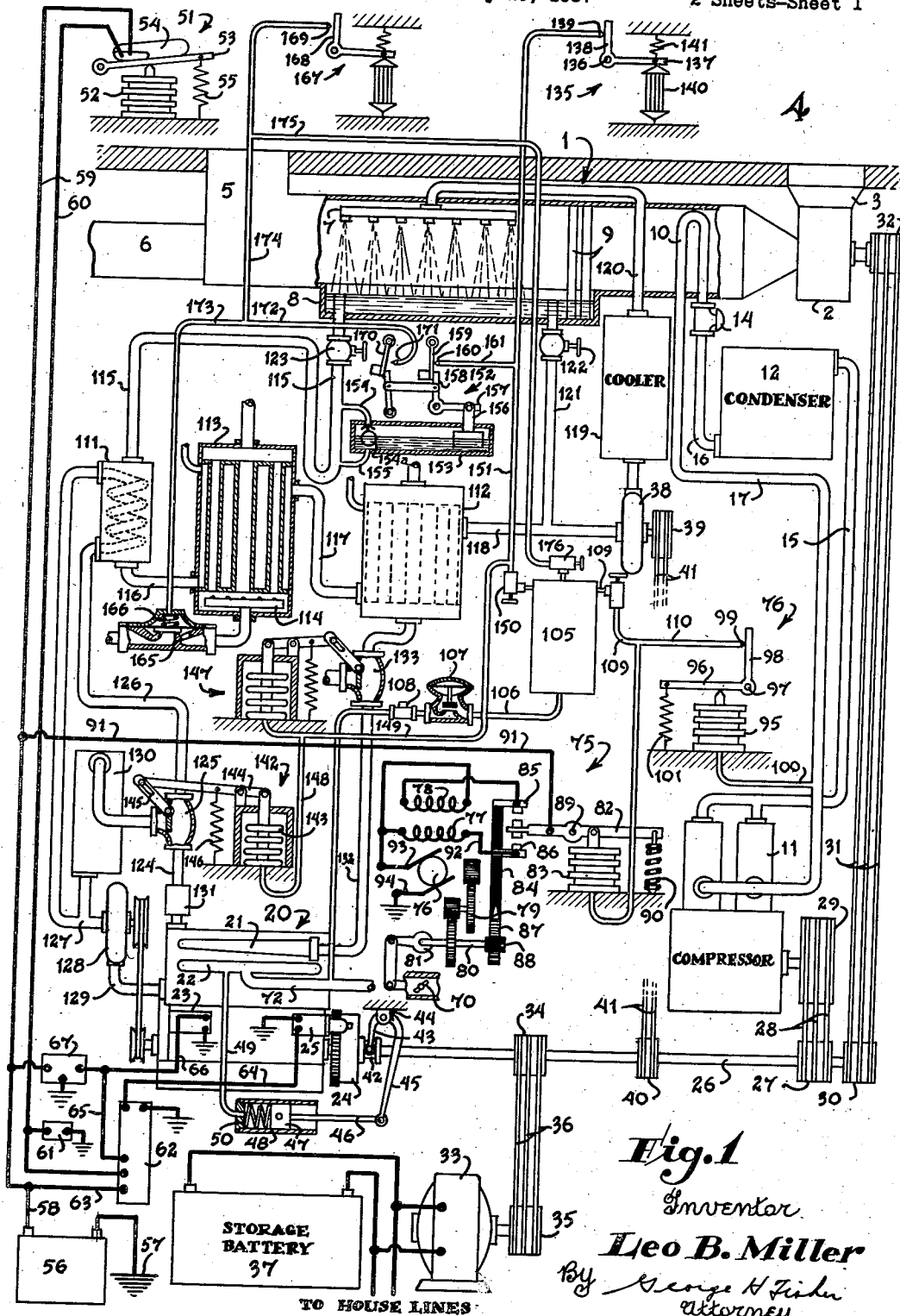
L. B. MILLER

2,284,914

AIR CONDITIONING SYSTEM

Filed July 16, 1937

2 Sheets-Sheet 1



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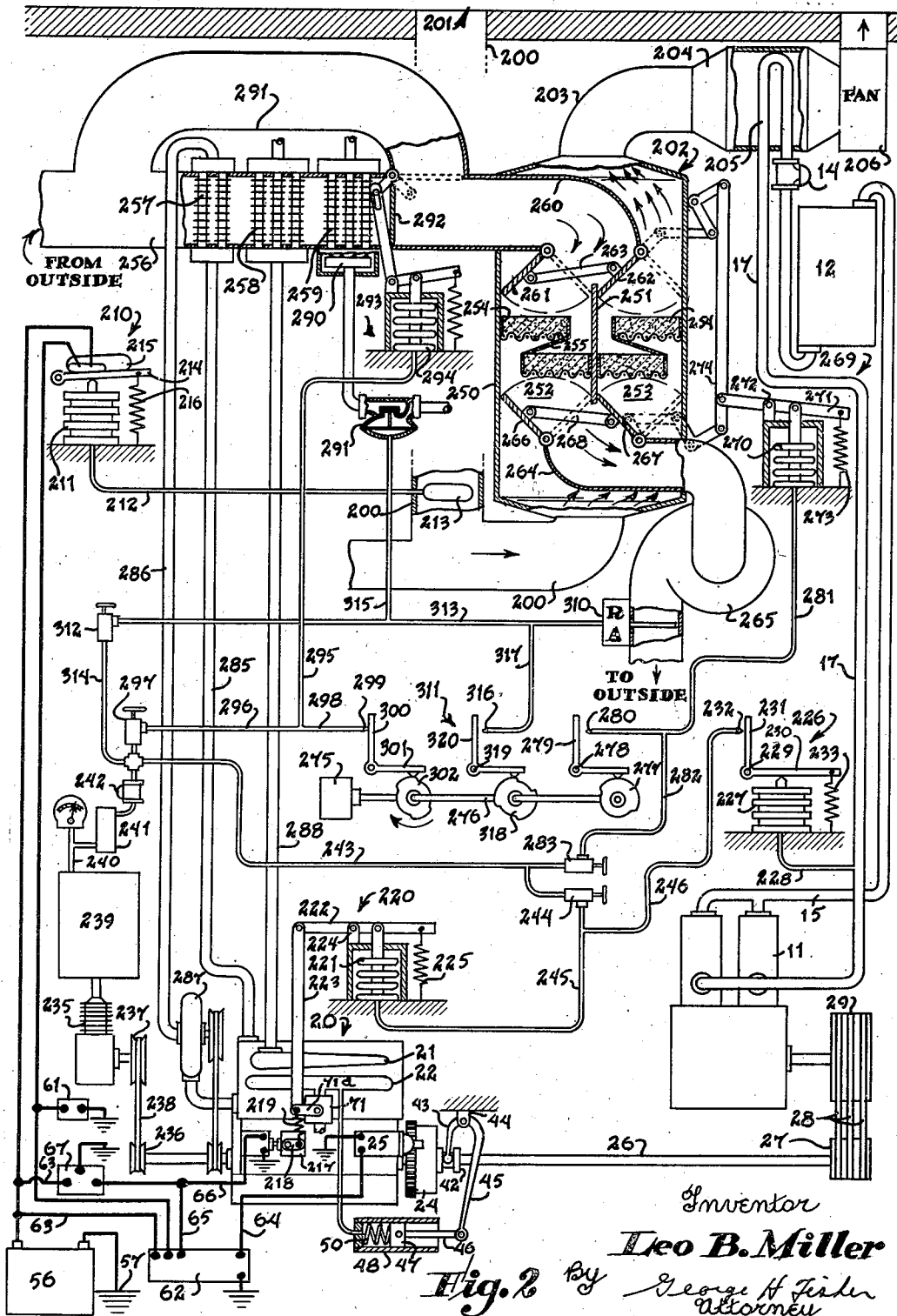
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2 Sheets-Sheet 2



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UNITED STATES PATENT OFFICE

2,284,914

AIR CONDITIONING SYSTEM

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Application July 16, 1937, Serial No. 154,023

18 Claims. (Cl. 183-4)

This invention relates to air conditioning systems and is more particularly concerned with air conditioning systems for summer cooling of the type utilizing a compression refrigeration system wherein the compressor is driven by means of an internal combustion engine.

One object of my invention is to provide a dependable control arrangement for systems of this type, such control arrangement being low in first cost and acting automatically to start the engine when conditioning is required and to stop the engine when there is no demand for conditioning, the control system acting also to modulate the engine speed when in operation in accordance with variations in the demand for air conditioning.

Another object of my invention is the provision of an automatic control system of the type above mentioned wherein the various controllers are pneumatically actuated and wherein the actuating fluid for such controllers is provided by the prime mover which drives the compressor.

A still further object of my invention is to provide improved air conditioning arrangements wherein a dehumidifier of the type employing hygroscopic material is employed for removing moisture from the air, and wherein cooling is done by an internal combustion engine driven compressor, the heat ejected by the internal combustion engine being utilized for reactivating the hygroscopic material.

A more specific object of my invention is to provide a highly economical air conditioning system of the type just mentioned. In accordance with my invention, I provide for passing recirculated air through the dehumidifying unit and adding to the recirculated air just enough fresh air to secure proper ventilation. By utilizing substantially all recirculated air, the amount of dehumidification required for maintaining proper humidity conditions within the conditioned space is held at a minimum. By this arrangement, the heat ejected from the engine is usually sufficient for reactivation of the dehumidifying substance, and hence the necessity of utilizing heat from an outside source for reactivation of the dehumidifying substance is eliminated. For extremely heavy dehumidifying load conditions, the waste heat from the engine will sometimes be insufficient for reactivating the dehumidifier. In order to secure proper operation of the system for taking care of such situations, I provide means for utilizing an outside source of heat for supplementing the waste heat from the engine, and provide automatic control means for placing the auxiliary heating means in operation when the waste heat from the engine is insufficient for reactivating the dehumidifier. This feature forms another object of my invention.

A further object of my invention is to provide

a novel control means for a dehumidifying and cooling arrangement wherein the air is first dehumidified and heated by passage through an absorption or adsorption type of dehumidifier and is then cooled, the cooling means being controlled in accordance with the temperature of the air leaving the dehumidifier to thereby vary the operation of the cooling means in a manner to carry both the latent heat and sensible heat loads on the system.

Other objects of my invention will appear from the following description and from the appended claims.

For a full disclosure of my invention, reference is made to the following detailed description and to the accompanying drawings, in which

Figure 1 diagrammatically illustrates an air conditioning system embodying one form of my invention; and in which

Figure 2 is a diagrammatic view of a modification.

Referring to Figure 1, reference character 1 indicates a conditioning chamber, this chamber discharging into the inlet of a fan 2 which is connected by a discharge duct 3 to the conditioned space 4. At its other end the conditioning chamber 1 is connected to the space 4 by a return duct 5. The conditioning chamber 1 is also provided with a suitable fresh air inlet duct 6, this duct having the usual damper means (not shown) for controlling the flow of fresh air into the conditioning chamber. Located within the conditioning chamber is an adsorption type of drying means, and is herein illustrated as comprising a spray pipe 7 which sprays a suitable hygroscopic liquid, such as a lithium chloride solution, over the air being conditioned. The sprayed liquid is collected in a sump 8 forming part of the conditioning chamber. Reference character 9 indicates suitable separator plates for removing any liquid from the sprayed air, this removed liquid flowing down such plates into the sump 8. In the conditioning chamber 1, downstream of the dehumidifying arrangement just described, is a cooling coil 10 for cooling the air before it is passed to the conditioned space. With the arrangement so far described, it will be apparent that a mixture of fresh and return air is first passed through the dehumidifying spray, then through the separator plates 9, and then over the cooling coil 10 wherein it is cooled before being passed to the space 4.

The cooling coil 10 is herein shown as forming part of a compression refrigeration system, this system including also a compressor 11, a condenser 12 and an expansion valve 14, the discharge of the compressor 11 being connected to the refrigerant inlet of the condenser 12 by a pipe 15, and the refrigerant outlet of the condenser 12 being connected to the expansion valve

14 by a pipe 16. The outlet of the cooling coil 18 is connected by a suction line 17 to the compressor 11. The operation of compression refrigeration systems of this type is well known in the art, and therefore no detailed description is given here. However, it may be stated that operation of the compressor causes chilling of the cooling coil 18 and the temperature of the cooling coil 18 will vary with the speed of the compressor and also with the temperature of the air being passed in contact with said coil.

Reference character 20 indicates generally an internal combustion engine, this engine having the usual exhaust manifold 21, intake manifold 22, generator 23, fly-wheel 24 and starting motor 25. The fly-wheel 24 is connected to a drive shaft 26, this drive shaft having mounted thereon a pulley 27 cooperating with belts 28 which run over a pulley 29 attached to the compressor crank shaft. Attached also to the drive shaft 26 is a pulley 30, this pulley cooperating with belts 31 which run over a pulley 32 attached to the fan shaft. In this manner the engine 20 drives the compressor 11 and also drives the fan 2. The drive shaft 26 also drives a generator 33 by means of pulleys 34 and 35 which cooperate with belts 36. The generator 33 is adapted to supply electricity for domestic use and for this purpose is preferably of the third brush type having a storage battery 37 floating across the generator terminals. It will be understood that a suitable cutout may be provided for preventing discharge of the storage battery through the generator when said generator is not running. The drive shaft 26 is also arranged to drive a circulating pump 38 by means of pulleys 39 and 40 which cooperate with belts 41.

In accordance with my invention, the engine is automatically started and stopped in accordance with the air conditioning load. When the engine is started, it is necessary to disconnect it from its load and for this purpose an automatic clutching device is provided. The fly-wheel 24 contains a suitable clutching mechanism, this mechanism being actuated by means of a clutch collar 42. The clutch collar 42 is actuated by a bell crank lever 43 which is pivoted at 44, and which has an actuating arm 45 connected to the piston rod 46, which in turn is connected to piston 47 located within cylinder 48. The interior of the cylinder 48 is connected to the intake manifold by means of a conduit 49. A spring 50 is located within the cylinder 48 and is arranged to urge the piston 47 outwardly, this causing movement of the clutch collar 42 for disengaging the clutch. When the engine is running, however, a vacuum is developed within the intake manifold 22, this causing evacuation of the cylinder 48, which results in piston 47 moving to the left against the action of spring 50, thereby causing engagement of the clutch. The automatic clutching mechanism just described therefore acts to disengage the clutch when the engine has stopped and to automatically engage the clutch after starting of the engine.

In accordance with the preferred form of my invention, I provide for automatically starting and stopping the engine in accordance with the temperature of the conditioned space. For this purpose a temperature controller generally indicated as 51 is provided. This temperature controller is shown herein as comprising a bellows 52 which is fixedly supported at its lower end and which cooperates with a pivoted switch carrier 53 which carries a mercury switch 54. A tension

spring 55 is connected to the free end of the switch carrier 53 and urges such carrier against the bellows 52. The bellows 52 contains a suitable volatile fluid wherefore the vapor pressure therein varies with the temperature surrounding the bellows 52. Thus, upon an increase in temperature, the vapor pressure within the bellows will increase, this causing expansion of the bellows against the action of the spring 55 and tilting the mercury switch towards closed position. Upon a decrease in temperature, however, the vapor pressure within the bellows will decrease, this causing contraction of the bellows under the action of the spring 55, thereby tilting the mercury switch 54 towards open position.

Reference character 56 indicates a storage battery. One terminal of this battery is grounded as at 57, and the other terminal of said battery is connected to one terminal of mercury switch 54 by means of wires 58 and 59. The other terminal of mercury switch 54 is connected to a wire 60, and this wire 60 is connected to an ignition coil 61 and also to the control terminal of starting relay 62. The starting relay 62 may be of the type shown and described in the Loehr et al. Patent 1,773,913, dated August 26, 1930. This type of starting relay is adapted to automatically energize the starting motor whenever the control circuit of said relay is energized, and for this purpose is connected to the battery 56 and to the starting motor 25 by means of wires 63 and 64 respectively. This starting relay is also arranged to prevent energization of the starting motor so long as the engine is in operation, as evidenced by operation of the generator, and for this purpose is connected to the generator 23 by means of wires 65 and 66. Reference character 67 indicates a suitable generator cut-out for preventing discharge of the battery 56 through the generator when said generator is not in operation.

From the description thus far, it should be apparent that whenever the space temperature is below a predetermined value, the mercury switch 54 will be open, thereby deenergizing the starting relay 62 and the ignition coil 61, this causing the engine to be stopped at which time the automatic clutching mechanism will cause disengagement of the clutch. When, however, the space temperature rises above the value for which the controller 51 is set, the mercury switch 54 will close, thus energizing the ignition circuit for the engine and also energizing the control circuit of the starting relay, this causing operation of the starting motor for starting the engine. After the engine is started, the starting motor is automatically placed out of operation by said starting relay, and also the resulting vacuum in the intake manifold causes operation of the automatic clutching mechanism for engaging the clutch, thereby causing the engine to drive the compressor, the fan, the generator, and the circulating pump.

My invention also contemplates the modulating of the engine speed in accordance with the conditioning load, that is, to increase the engine speed when the conditioning load increases and to decrease the engine speed upon decrease in such conditioning load. For this purpose, a suitable throttle valve 70 is provided in the fuel line 72 to the intake manifold. This throttle valve is shown herein as being positioned by a pneumatically controlled reversible motor generally indicated as 75, this motor being con-

trolled by means of a pneumatic type of suction pressure controller 76.

Referring now to the motor 75, this comprises an armature 76 and a pair of oppositely wound field coils 77 and 78. It will be understood that when field coil 77 is energized, the armature 76 will be rotated in one direction, and that when the field coil 78 is energized, the armature will be rotated in the opposite direction. The armature 76 is arranged to drive through a gear train 79, an operating shaft 80, said operating shaft having attached thereto a lever arm 81 which is connected by suitable linkage to the throttle valve 70. Thus, rotation of the armature 76 will cause movement of throttle valve 70.

For controlling the energization of field coils 77 and 78, a suitable form of primary control and follow-up mechanism is provided, this comprising a switch arm 82 which is actuated by a bellows 83, and a movable contact carrier 84 formed of insulating material, this contact carrier carrying contacts 85 and 86. The contact carrier 84 is arranged to follow up movements of the operating shaft 80 and is herein shown as being secured to a rack 87 cooperating with a pinion 88 which is mounted upon the operating shaft 80. By this arrangement, when the operating shaft 80 is rotated counterclockwise for closing the throttle valve, the contact carrier 84 will be caused to move upwardly, and when the operating shaft is rotated in the opposite direction the carrier 84 will move downwardly. The carrier 84 will therefore assume positions corresponding to the degree of opening of the throttle valve 70.

The switch arm 82 is arranged to cooperate with contacts 85 and 86 and for this purpose is pivoted at 89. Thus, upon expansion of the bellows 83, the switch arm 89 will be tilted counterclockwise to bring its contact into engagement with the contact 86. This will cause energization of the field coil 77 by a circuit as follows: storage battery 53, wire 58, wire 59, wire 91, switch arm 82, contact 86, wire 92, field coil 77, wire 93, armature 76 and wire 94 to ground. This will cause rotation of the operating shaft 80 in a direction to open the throttle valve, this causing downward movement of the carrier 84, thereby disengaging the contact 86 from the switch arm 82, thus deenergizing the motor. Conversely, upon contraction of the bellows 83, the switch arm 82 will be tilted clockwise, thereby bringing it into engagement with the contact 85, this causing energization of the field coil 78 for driving the operating shaft 80 in a direction to close the throttle valve, this simultaneously causing upward movement of the contact carrier 84 which disengages the contact 85 from the switch arm 82. From the foregoing it will be apparent that the electric motor driving mechanism will cause the throttle valve to assume positions corresponding to the degree of expansion of the bellows 83. In other words, as the bellows 83 expands, the throttle valve 70 will be moved towards open position, and as the bellows 83 contracts, the throttle valve will be moved towards closed position.

For controlling the degree of expansion of the bellows 83 and hence the position of the throttle valve 70, the suction pressure controller 76 is provided. Controller 76 comprises a bellows 95, this bellows being fixedly secured at its lower end and cooperating with the actuating arm 96 of a bell crank lever which is pivoted at 97.

The bell crank lever also includes a control arm 98 which forms a valve member cooperating with a port 99 for forming a control valve. The bellows 95 is connected by means of a conduit 100 to the suction line 17 of the refrigeration system. Upon an increase in pressure within the system, the bellows 95 will expand, this causing clockwise rotation of the actuating arm 96 against the action of a spring 101, this moving the valve member 98 away from the port 99. Upon a decrease in suction pressure the bellows will contract under the action of the spring, thereby causing movement of the valve member 98 towards the port 99.

For actuating the bellows 83 of motor 75 in accordance with changes in suction pressure affecting controller 76, I utilize the vacuum developed in the intake manifold of the engine 20. For this purpose I provide a receiver 105, this receiver being connected to the intake manifold of the engine by means of a conduit 106, this conduit having interposed therein a pressure regulating valve 107 and a check valve 108 which is arranged to open towards the intake manifold. The pressure regulating valve 107 is of known form and is arranged to close when the pressure in receiver 105 is reduced to a predetermined value. By this arrangement, a constant sub-atmospheric pressure is maintained within the receiver 105 even though the sub-atmospheric pressure within the intake manifold may vary. Also connected to the receiver 105 is a conduit 109 which leads to the bellows 83. This conduit is also connected to the port 99 of the pressure controller 76 by means of conduit 110. Interposed in the conduit 109 is a restrictor 111. This restrictor is shown as taking the form of a needle valve and this valve is adjusted to have a capacity less than the capacity of the port 99.

When the suction pressure of the refrigeration system falls to a predetermined value, the valve member 98 will be caused to engage the port 99. This will prevent admittance of air into conduit 110 through port 99 thereby causing the pressure within conduits 109 and 110 and within the bellows 83 to decrease to a value equal to the sub-atmospheric pressure maintained within the receiver 105. This will cause the bellows 83 to contract to a maximum extent, thereby rotating the switch arm 82 around its pivot 89 in a clockwise direction, thus compressing spring 90 and causing engagement of switch arm 82 with contact 85. This, in the manner previously described, will cause the motor to rotate until the contact carrier 84 is at its uppermost limit, at which time the throttle valve 70 will be moved to the minimum fuel feeding position. As the suction pressure begins to rise, the bellows 95 will expand causing movement of the valve member 98 away from port 99. This will admit air into the conduits 110 and 109 and into the bellows 83, thereby causing a rise in pressure therein, this rise in pressure permitting expansion of the bellows 83 under the action of the compression spring 90, thereby tilting switch arm 82 in a counterclockwise direction to bring it into engagement with the contact 86, which will cause operation of the motor in a direction to open the valve, the valve thereby being opened to such an extent that contact carrier 83 is moved downwardly a sufficient distance to disengage switch arm 82 from contact 86. Upon a further increase in suction pressure, the valve member 98 of controller 76 will be shifted farther from port 99, thereby admitting more air into the conduits

109, 110 and the bellows 83, thus causing expansion of the bellows 83 farther, which in turn results in the valve 70 being moved further towards open position. When the suction pressure rises to a predetermined maximum the valve member 98 will be moved to a position wherein it leaves port 99 unobstructed, this causing a maximum flow of air through such port, thus causing bellows 83 to be expanded to a maximum, which will in turn result in the throttle valve 70 being moved to a wide open position. From the foregoing, it will be apparent that with the control arrangement just described, the throttle valve will be gradually controlled in accordance with the suction pressure of the refrigeration system, this throttle valve being opened to increase the engine speed when the suction pressure increases, and being closed for decreasing the engine speed when the suction pressure decreases.

Referring to the dehumidifying arrangement, it will be understood that a suitable hygroscopic solution, such as an aqueous solution of lithium chloride, is sprayed over the air, this solution absorbing water vapor from the air, thereby dehumidifying the air. In order to obtain continuous dehumidification it is necessary to remove the absorbed moisture from the dehumidifying solution. This moisture is removed by heating the solution above the boiling point of water, thereby boiling off the water from the solution. In accordance with my invention, the waste heat from the engine is utilized for heating the solution, and for this purpose a jacket water heat exchanger 111 and an exhaust gas heat exchanger 112 are provided. For normal conditions, the jacket heat and the exhaust gas heat from the engine will be sufficient for reactivating or drying the dehumidifying solution. At times, however, this waste heat from the gas engine will be insufficient for providing the necessary reactivation and for this reason I provide a heat exchanger 113 which is heated by means of a gas burner 114, this heat exchanger being placed in operation only when the waste heat from the engine is insufficient for performing the required reactivation.

Leading from the sump 8 of the conditioning chamber is a conduit 115, this conduit conveying the dehumidifying solution from said sump to the inlet of the jacket heat exchanger 111. The outlet of the jacket heat exchanger is connected by a conduit 116 to the inlet of the auxiliary heat exchanger 113, the outlet of said latter heat exchanger being connected by a conduit 117 to the inlet of the exhaust gas heat exchanger 112. The outlet of the exhaust gas heat exchanger 112 is connected by a conduit 118 to the inlet of pump 38, the outlet of this pump discharging into a cooler 119 which is connected by conduit 120 to the spray pipe 7. By this arrangement, the deconcentrated solution is passed first into the jacket heat exchanger where it is preheated, and then into the heat exchangers 113 and 112 wherein it is further heated for driving off the moisture therefrom. The heated and concentrated solution is then passed through the cooler and then sprayed over the air for dehumidifying said air. While I have illustrated the solution as being passed serially through the heat exchangers, it will be understood that if desired the solution may be passed in parallel there-through or even these exchangers may be combined into a single heat exchanger. In systems of this type, it has been found unnecessary to pass

all of the solution through the concentrating means, and therefore a by-pass for the deconcentrated solution around the heat exchangers is provided, this by-pass being shown herein as comprising a conduit 121 leading from the sump 8 to the conduit 118, this by-pass conduit being provided with a valve 122. By adjusting this valve and the valve 123 which is located in conduit 115, the desired proportions of the solution may be passed through the concentrating means and by-passed therearound. In practice, it has been found sufficient to pass only 10% of the solution through the concentrating means and to by-pass 90% of the solution therearound.

The water jacket outlet of the engine 20 is connected by a pipe 124 to the inlet of a three-way valve 125, and one outlet of this three-way valve is connected to the heating coil within heat exchanger 111 by means of a pipe 126. The outlet of this heating coil is connected by a pipe 127 to the inlet of a circulating pump 128 which in turn is connected to the water jacket inlet by pipe 129. The pump 128 may be driven by any suitable means and is shown herein as being driven by the internal combustion engine 20. With the three-way valve 125 in the position shown, it will be apparent that when the engine is in operation, the pump 128 will cause a circulation of cooling water between the engine water jacket and the heat exchanger 111, thereby transferring the jacket heat of the engine to the dehumidifying solution which is being concentrated. When the three-way valve is shifted to its other position, it will be apparent that flow of jacket water to the heat exchanger 111 will be stopped and the water will be forced through an auxiliary cooling device 130 for maintaining the engine cool. For intermediate positions of the three-way valve, a part of the cooling water will flow through the heat exchanger 111, and part will flow through the cooler 130. If desired, a thermostat 131 of known form may be located in the water jacket outlet for maintaining the engine temperature at a proper operating value.

The exhaust gas heat exchanger 112 is connected to the exhaust manifold 21 of the internal combustion engine by means of a conduit 132, a three-way valve 133 being interposed in said conduit for causing flow of exhaust gases through the heat exchanger 112 or for by-passing said gases or a portion thereof around said heat exchanger.

In order to prevent the dehumidifying means from removing more water vapor from the air than necessary to maintain proper humidity conditions within the conditioned space, a humidity controller 135 is provided, this humidity controller being shown as located within the conditioned space and being arranged to control the three-way valves 125 and 133 to thereby vary the amount of heat supplied for drying the solution in accordance with variations in space relative humidity. The humidity controller 135 may be of any suitable form, and is shown herein as comprising a bell-crank lever pivoted at 136, this lever having an actuating arm 137 and a control arm 138 which in effect is a valve member cooperating with a valve port 139. The actuating arm 137 is actuated by means of a humidity responsive device which is shown herein as comprising a plurality of strands 140 of hair or other moisture responsive material, these strands being secured at their upper and lower ends by clamping members as shown. The upper

clamping member is connected to the actuating arm 137 while the lower clamping member is fixedly secured. A spring 141 may be provided for urging the actuating arm 137 upwardly for maintaining the strands 140 taut. Upon an increase in relative humidity, the strands 140 will increase in length, this causing movement of the valve 138 towards the port 139. Upon a decrease in relative humidity, the opposite action will take place, namely, the strands 140 will shrink, this causing movement of the valve member 138 away from valve port 139.

The three-way valve 125 is controlled by means of a pneumatic motor 142. This pneumatic motor may be of known form and is shown as comprising a bellows 143 secured to a pivoted lever arm 144, this lever arm being suitably attached to the actuating arm 145 of the three-way valve. A tension spring 146 is attached to the lever arm 144 and urges said lever arm in a direction for biasing the bellows 146 towards expanded position, thereby biasing the three-way valve 125 in a direction for cutting off the flow of jacket water to the heat exchanger 111. The three-way valve 133 which controls the flow of exhaust gases to the heat exchanger 112 may be controlled by a motor 147 which is identical to the pneumatic motor 142. The bellows of these two pneumatic motors are connected together by air lines 148 and 149, and the air line 149 is shown as being connected to a restrictor 150 which is in turn connected to the tank 105. The air line 149 is also connected to an air line 151 which leads to the port 139 of the humidity controller 135.

When the space relative humidity is excessive, the strands 140 of the humidity controller will be expanded sufficiently to permit the valve member 138 to close the port 139. This will prevent entrance of air through said port and consequently air will flow from the bellows of the two pneumatic motors and the air lines 148, 149 and 151 into the low pressure tank 105, and the pressure within the bellows of motors 142 and 147 will be equal to the pressure existing in tank 105. This will cause maximum contraction of both bellows as shown, which results in the two three-way valves being so positioned that all of the heated fluid from the engine is passed to the heat exchangers 111 and 112. Upon falling relative humidity, the valve member 138 of the humidity controller will be moved away from port 139, this admitting air into port 139 thereby causing the pressure within the two pneumatic motors to increase, which results in the three-way valves 125 and 133 being positioned so as to reduce the amount of heat supplied to the two heat exchangers. This will result in supplying less heat for concentrating the dehumidifying solution and consequently the dehumidifying effectiveness of said solution will be decreased. The control arrangement just described, therefore, acts to vary the dehumidifying effectiveness of the dehumidifying solution as the space relative humidity varies. It will be apparent that if the relative humidity falls to such a value as to completely open the port 139, air will flow into said port at such a rate with respect to air flow through the restriction 150, that a pressure is built up within the two pneumatic motors which will cause the three-way valves to be positioned so as to stop all flow of heat to the heat exchangers 111 and 112, thus placing the dehumidifying apparatus out of operation.

If the hygroscopic solution should become too concentrated, the solution will become supersaturated with salts when reduced in temperature by the cooler 119, this causing precipitation of salts which results in clogging of the sprays and deposits on the cooler surfaces and pipes. To avoid these objectionable results, it is desirable to provide a limit controller for preventing the solution from becoming overconcentrated. Such a controller is illustrated at 152. This controller may comprise a casing 153 which is connected to the conduit 115 by inlet and outlet pipes 154 and 155. A float valve 154a is located within the casing 152 and is arranged to control the flow of solution through the inlet pipe 154 in a manner to maintain a constant level of the solution within the casing. Reference character 156 indicates a float, this float being secured to the actuating arm of a bell-crank lever 157 which has a control arm 158 which actuates a control valve member 159 cooperating with a valve port 160. The port 160 is connected by an air line 161 to the air line 151. The density of the hygroscopic solution increases with the concentration thereof, and hence the float 156 will raise and lower in accordance with changes in concentration of the solution. When the concentration is below an objectionable value, the float 156 will sink sufficiently to permit valve member 159 to completely close the valve port 160, thereby preventing entrance of air through this port into the air line 151 and the pneumatic motors 142 and 147. If, however, the concentration of the solution becomes excessive, the float 156 will rise sufficiently to cause the valve member 159 to be shifted away from port 160, this admitting air into the control system which results in a rise in pressure within the pneumatic motors 142 and 147, which in turn causes positioning of the three-way valves for reducing the amount of heat supplied for concentrating the hygroscopic solution. It will be apparent that when the concentration of the solution reaches a maximum value, the port 160 will be wide open, thereby causing the three-way valves 142 and 147 to be positioned so as to prevent flow of exhaust gases and jacket water to the heat exchangers, thus preventing any further concentration of the solution. When the concentration of the solution is unobjectionable, the controller 152 will leave the humidity controller 135 in full control of the heat supplied for concentrating the solution. When the concentration becomes too high, however, the three-way valves will be moved for reducing the heat supplied to concentrating the solution, irrespective of the humidity controller 135. While I have shown the controller 152 as being of the graduating type, it will be understood that if desired a positive or two-position type of controller may be employed.

For most conditions of operation, the waste heat from the internal combustion engine will be sufficient for concentrating the hygroscopic solution. However, at times the heat available from the engine may be insufficient, due to the dehumidifying load being abnormal, or due to the use of considerable outside air. One feature of my invention is the provision of automatic control means for placing the burner 114 into operation whenever the heat available from the engine is insufficient for concentrating the dehumidifying solution. Preferably the gas burner 114 is placed into operation only when the space relative humidity is excessive, and when at this

time the solution is too deconcentrated. If the space relative humidity is not excessive the burner should not be allowed to operate as it is undesirable to utilize heat from an outside source so long as the relative humidity is not excessive. Also, the burner should not operate whenever the solution is sufficiently concentrated to secure an adequate amount of dehumidification.

For controlling the flow of gas to the burner, a gas valve 165 is provided. This valve, if desired, may be of the type shown and described in Patent No. 1,107,549 issued to G. A. Robertshaw on August 18, 1914. This type of valve is provided with a diaphragm for actuating the valve member and is arranged so that the valve snaps from open to closed positions. Due to the utilizing of engine vacuum as the controlling medium, it is desirable to employ a spring 166 for urging the valve towards closed position so that when atmospheric pressure exists above the diaphragm, the valve will be held closed by this spring.

The gas valve 165 is shown as being controlled by a humidity controller 167, this controller being identical to the controller 135 and having a valve member 168 and a valve port 169. This humidity controller 167 may be adjusted so that the valve member 168 does not close the bleed port 169 until the relative humidity rises above the point at which the port 139 of the humidity controller 135 is closed. In other words, the port 169 of the humidity controller 167 does not close until the relative humidity rises to a value above the control range of the humidity controller 135.

The gas valve 165 may also be controlled by means of a valve member 170 which is operated by the density limit controller 152, this valve member 170 cooperating with a valve port 171. The controller 152 is so arranged that as long as the concentration of the hygroscopic solution is above a predetermined value, the valve member 170 will be held away from port 171. When, however, the solution becomes too deconcentrated to secure effective dehumidification, the float 156 will lower, thus permitting the valve member 170 to approach port 171 for restricting the flow of air through said port.

The valve port 171 is connected by an air line 172 to an air line 173 leading to the space above the diaphragm of the gas valve 165. The air lines 172 and 173 are connected to a line 174 leading to the valve port 169 of humidity controller 167, and this air line 174 is also connected to a line 175 which is in turn connected to a restriction 176, this restriction being connected to the tank 185. The restriction 176 is so adjusted as to have less capacity for flow than either the valve port 169 or valve port 171. By this arrangement, when either valve port 169 or 171 is open, air flow will take place into the air lines and to the space above the gas valve diaphragm, this permitting substantially atmospheric pressure to exist in the space above the valve diaphragm. This atmospheric pressure will permit the spring 166 to hold the valve closed, thereby preventing flow of gas to the burner 114. When, however, both the port 169 and the port 171 are closed, the gas pressure above the diaphragm 166 will be reduced, thus causing upward movement of the diaphragm for opening the valve, thereby placing the burner 114 into operation for providing the necessary extra heat for securing proper dehumidification. The arrangement just described, therefore, acts to hold the gas valve closed as long as either the relative humidity is not excessive, or as long as the concentration of

the solution is not too low. When, however, the humidity is excessive and at the same time the solution concentration is too low, the gas valve 175 will be opened thus placing the burner 114 into operation.

While I prefer to prevent burner operation only when both of these conditions are at improper values, it will be apparent that if desired the gas burner may be controlled by space relative humidity alone, or by the solution concentration alone. While I have illustrated two separate humidity controllers, it will be understood that if desired a single controller having two sets of valves and ports may be utilized instead.

Operation of Figure 1

When the space temperature is below a predetermined value, the temperature controller 51 will cause the engine 20 to be stopped, thereby placing the entire system out of operation. When the space temperature becomes excessive, however, the controller 51 will cause starting of the engine 20 and after said engine is started, the automatic clutching mechanism will engage, thereby causing the engine to drive the compressor, the fan, the circulating pump for the hygroscopic solution, and the generator. Operation of the fan will cause air to be withdrawn from the conditioned space and passed through the dehumidifier and then across the cooling coil and back to the conditioned space. When the air passes through the dehumidifying spray, the water vapor in the air will be condensed and go into solution with the spray solution, thereby deconcentrating such solution. The latent heat of evaporation of the condensed water vapor will cause a rise in temperature of the air. The air when passed through the dehumidifier is therefore both dried and heated. This dried and heated air is then passed over the cooling coil and is thereby reduced in temperature to a point at which it may be admitted to the conditioned space 4.

So long as the system is in operation, the engine speed will be varied in a manner to maintain a constant suction pressure or constant cooling coil temperature. If the space relative humidity is high enough to warrant dehumidification, the humidity controller 135 will cause positioning of the three-way valves in a manner to permit flow of jacket water and exhaust gases to the respective heat exchangers, thereby causing concentration of the dehumidifying solution for causing said solution to be effective in dehumidifying the air. As the relative humidity increases, the controller 135 will cause an increased amount of heat to be supplied for concentrating the solution, thereby increasing the dehumidifying effectiveness of said solution in a manner to prevent further rise in humidity. Conversely, upon falling relative humidity, the humidity controller 135 will cause operation of the three-way valves 125 and 133 for reducing the amount of heat supplied for concentrating the solution, thereby decreasing the dehumidifying effectiveness of the solution upon fall in relative humidity.

This control system automatically causes operation of the engine at a speed just sufficient to carry both the cooling and the dehumidifying loads. Thus, if the temperature within the conditioned space increases, the temperature of the air flowing across the cooling coil will increase, this causing a greater amount of refrigerant to be evaporated within the cooling coil, which re-

sults in the suction pressure of the refrigeration system rising. In response to this rise in suction pressure, the controller 76 causes opening of the throttle valve for increasing the engine speed to carry the increased cooling load. Similarly, upon decreasing space temperature, less refrigerant will be evaporated within the cooling coil, which causes a reduction in suction pressure, this in turn causing the engine speed to be decreased. Due to the transferring of the latent heat of evaporation of the condensed water vapor to the air passing across the cooling coil, the suction pressure controller will also respond to variations in the dehumidifying load. Thus, if the relative humidity should increase, a greater amount of dehumidification will be done, this causing the temperature of the air leaving the dehumidifier to be further increased, and this increase in temperature will cause increase in operation of the engine in the manner just described. Conversely, as the relative humidity decreases, a less amount of dehumidification will be done, this causing less latent heat of evaporation to be transferred to the air, thereby causing a reduction in temperature of the air leaving the dehumidifier, which reduction in temperature will affect the suction pressure controller in a manner to decrease the engine speed.

Under normal operating conditions, the relative humidity will not be excessive and the solution will not be too deconcentrated. Thus normally the gas valve 165 will be held closed, thereby preventing the consumption of gas for concentrating the solution. When, however, the dehumidifying load becomes so heavy that the waste heat from the engine cannot maintain proper concentration of the solution for maintaining proper humidity conditions, the controllers 167 and 152 will cause opening of the gas valve and the supplying of heat from an outside source for securing the proper concentration of the solution.

It should be noted that with the system which I have disclosed, the supply of waste heat from the gas engine will be increased whenever the dehumidifying load increases. Thus, when the relative humidity increases, a greater amount of dehumidification will be done, this resulting in transferring more latent heat of evaporation to the air as it is dried, thus causing the temperature of the air passing over the cooling coil to increase. This increase in temperature will, in the manner previously described, increase the speed of the engine to carry this increased refrigeration load. This increase in speed of the engine will cause a greater amount of waste heat to be ejected from said engine. Hence, as the dehumidifying load increases, a greater amount of waste heat is available from the engine for reactivating the dehumidifying solution.

Figure 2

In Figure 2 I have shown my invention applied to a system employing a silica-gel type of dehumidifying unit. In this figure, reference character 200 indicates a return duct leading from the conditioned space 201, this return duct leading to the inlet of the silica-gel dehumidifying unit 202. The outlet of the dehumidifying unit 202 is connected to a duct 203 leading to a conditioning chamber 204 in which is located a cooling coil 205. The outlet of the conditioning chamber 204 is connected to a fan 206 which is in turn connected by suitable duct means to the conditioned space 201. The cooling coil 205

forms part of a direct expansion refrigeration system identical with that illustrated in Figure 1, the compressor being driven by internal combustion engine 20 in exactly the same manner as shown in Figure 1. These details are therefore not described here.

The internal combustion engine 20 is stopped and started in accordance with space temperature as in Figure 1 and for this purpose I have shown a return duct type of controller 210 for controlling the control circuit of the starting relay 62. This controller comprises a bellows 211 connected by a capillary tube 212 to a control bulb 213 located within the return duct 200. The bellows 211 is arranged to actuate a mercury switch carrier 214 which carries the mercury switch 215. The bellows, bulb and tube are filled with a suitable volatile fluid wherefore the pressure within bellows 211 varies with the temperature of the return air. Hence as the return air or space temperature increases, the bellows 211 will expand against the action of a spring 216, thereby tilting mercury switch 215 towards closed position. When the temperature reaches a predetermined value, the mercury switch 215 will be closed, this causing starting of the engine in the manner described in Figure 1. When the space temperature falls to a predetermined value, however, the mercury switch 215 will be opened, thereby causing stopping of the engine 20.

As in the case of Figure 1, the engine 20 is provided with a throttle valve 71 for controlling the fuel supply to the engine. In this case, however, the throttle valve is controlled by an engine speed governor 217 which is indicated as being driven by the generator shaft. This engine speed governor is provided with a control arm 218 which is connected to the control arm 71a of the throttle valve 71 by means of a spring or strain release connection 219. The control arm 71a is also actuated by means of a pneumatic control device 220, this control device comprising a bellows 221 which is linked to a lever 222, this lever being connected by a link 223 to the control arm 71a. The lever 222 is pivoted at 224 and is connected to a tension spring 225 which biases the bellows 221 towards contracted position. From this arrangement, it will be apparent that the throttle valve will assume a position in which the springs 219, 225 and the action of the bellows are in equilibrium. Thus for a constant pressure in the bellows 221, the governor 217 will change the tension of spring 219 in a manner to position the throttle valve for maintaining the engine speed constant. If the engine speed should increase, the spring tension will be changed to permit the throttle valve to be closed, and if the engine speed should decrease the governor will change the tension of spring 219 to cause the throttle valve to move to a further open position. Should the pressure within the bellows 221 be increased, said bellows will further oppose the action of the spring 225 thereby causing the throttle valve to be moved to another position at which these three forces are in equilibrium. In this case the throttle valve upon an increase in pressure within the bellows 221, will be moved towards open position. Similarly, if the pressure within bellows 221 should decrease, the throttle valve will be caused to move towards closed position. Variations in pressure within the bellows 221 therefore act in effect to adjust the governor 217 to vary the engine speed maintained by said governor.

As in the case of Figure 1, the speed of the

engine when in operation is controlled in a manner to maintain the refrigeration system suction pressure constant. For this purpose I provide a suction pressure controller 226. This controller may comprise a bellows 227 which is connected to the suction line 17 by means of tube 228, said bellows being arranged to actuate a bell crank member 229 having an actuating arm 230 and a control arm 231 which in effect is a valve member cooperating with the port 232. Upon an increase in suction pressure the bellows 227 will expand against the action of a spring 233, thereby causing valve member 231 to be moved towards the bleed port 232. Upon a decrease in suction pressure the opposite action will take place, namely, the bellows 227 will contract thereby causing valve member 231 to move away from bleed port 232.

Instead of utilizing the engine vacuum as an actuating medium for the controllers, as in Figure 1, I here illustrate an air compressor 235 which is driven by the engine 20 by means of pulleys 236 and 237 which cooperate with a belt 238. The compressor 235 discharges into a tank 239 and this tank is connected by an outlet pipe 240 to an oil eliminator 241 which in turn is connected to a pressure reducing valve 242. To the outlet of the reducing valve 242 is connected an air supply main 243 and to this supply main is connected a restrictor 244 taking the form of a needle valve. The outlet of this restrictor is connected to the bellows 221 by a conduit 245 and to the bleed port 232 by a conduit 246. The restrictor 244 is adjusted to pass a smaller amount of air than the bleed port 232 is capable of bleeding.

When the suction pressure of the refrigeration system is above a predetermined value, the valve member 231 will close the bleed port 232, this allowing the full pressure of the air supply main to build up within the bellows 221, this resulting in the engine governor being adjusted to maintain a maximum engine speed. As the suction pressure decreases, the valve member 231 will be shifted to allow bleeding of air from port 232, this causing a reduction in pressure within bellows 221 which in turn adjusts the engine governor to maintain a slower engine speed. If the suction pressure falls to a predetermined low value, the valve member 231 of controller 226 will leave bleed port 232 unobstructed, thereby causing a minimum pressure to exist within the bellows 221 for adjusting the engine speed governor to maintain a minimum engine speed. The control arrangement just described, therefore, acts to modulate the engine speed in accordance with the suction pressure of the refrigeration system.

Referring now to the silica-gel drier 202, this consists of an outer casing 250 having located therein a partition 251 which divides said casing into passages 252 and 253. Located within each of the passages 252 and 253 are screened-bottom troughs 254 adapted to contain a dehumidifying substance such as silica-gel, these troughs being partially superimposed one upon the other and having baffles 255 therebetween for preventing flow of air between the troughs. The silica-gel adsorbs water vapor from the air and it is necessary to remove this adsorbed water periodically in order that the material will continue with its dehumidifying action. As continuous dehumidification is desired and as the dehumidifying substance can operate only intermittently, the two separate dehumidifying pas-

sages are provided, one passage being arranged for dehumidifying while the material in the other passage is being reactivated. The reactivation of the material is accomplished in this type of dehumidifier by passing a blast of hot air through the dehumidifying substance and for this purpose an air heating duct 256 is provided, this duct having located therein a jacket water heat exchanger 257, an exhaust gas heat exchanger 258, and a gas heated air heating device 259. The air heating duct 256 receives air from outside the space being conditioned, and delivers heated air to a duct 260 which leads centrally into the casing 250 and is provided with a pair of dampers 261 and 262 which are arranged to move in unison by means of a connecting link 263. When the dampers 261 and 262 are in the position shown, the heated air from the heat exchanger will be delivered to the passage 252.

At the lower end of the casing 250 is an air outlet passage 264, this passage leading from the lower central part of casing 250 to a fan 265 which discharges the reactivating air outside of the space being conditioned. The outlet duct 264 is provided with dampers 266 and 267 which are connected together with a link 268 so as to move in unison. When these dampers are in the position shown, the heated air which is delivered to the passage 252 is withdrawn through the duct 264 and discharged into outside air. With the dampers 261, 262, 266 and 267 in the position shown, therefore, heated air from the heat exchanger is passed downwardly through the passage 252 for reactivating the gel beds in said passage, this air then being discharged outside of the space. With the dampers in this position also, the passage 253 is placed in communication with the ducts 200 and 203, air thus flowing from the conditioned space around the passage 264 through the gel beds in the passage 253 to the duct 203 from which it passes over the cooling coil back to the space to be conditioned. When the dampers 261, 262, 266 and 267 are shifted to the dotted line positions it will be apparent that the reactivating air will be passed through the passage 253 and the air to be conditioned will be passed through the passage 252.

The dampers 261, 262, 266 and 267 are shifted from one position to the other by means of a fluid actuated motor 269. This motor is of usual form, comprising a bellows 270 arranged for actuating a lever arm 271 which is pivoted at 272. A spring 273 is connected to the lever arm 271 and biases said lever arm against the bellows 270. The lever arm 271 is connected to a link 274 which is suitably connected to both sets of dampers so as to operate said dampers all in unison. When the bellows 270 is contracted as shown, the dampers assume the position shown in which the air to be conditioned is passed through passage 253 while the reactivating air is passed through passage 252. When the bellows 270 is expanded, however, the dampers will be shifted to the dotted line positions.

Any suitable means may be provided for periodically shifting the dampers from one position to the other, and for this purpose I have illustrated a clock 275 which is connected to a shaft 276 carrying a cam 277. The shaft 276 may be driven by the clock at a rate to cause one complete rotation every 20 minutes. The cam 277 is divided equally into a raised portion and a recessed portion, and cooperates with a cam

follower 278 which carries a valve member 279 cooperating with a bleed port 280. The bleed port 280 is connected by a pipe 281 to the bellows 270 and by a pipe 282 to the outlet of a restrictor 283 which in turn is connected to the air supply line 243. By the arrangement just described, it will be apparent that when the raised portion of the cam engages the cam follower 278 the valve member 279 will be moved away from the port 280, thereby permitting contraction of the bellows 270 this causing the dampers to assume the position shown. When the cam 277 is rotated so that the recessed portion engages the cam follower, the valve member 279 will engage the bleed port 280 thereby causing the full air supply pressure to build up within the bellows 270, this causing expansion of the bellows 270 for shifting the dampers to their dotted line positions. The arrangement just described, therefore, periodically shifts the dampers from one position to the other and in this case will shift the dampers every 10 minutes.

Referring again to the air heating means, the heat exchanger 257 is connected to the outlet of the engine water jacket by means of a conduit 285. The outlet of the heat exchanger 257 is connected by a conduit 286 to the inlet of a pump 287 which is driven by the internal combustion engine 20, this pump in turn being connected to the water jacket inlet. By this arrangement, when the engine is in operation, the jacket water is passed through the heat exchanger 257, this providing for cooling the engine and for preheating the air which is being passed to the dehumidifier 202 for reactivating one of the gel beds. The exhaust gas heat exchanger 258 is connected by an exhaust pipe 288 to the exhaust manifold 21 of the internal combustion engine 20. The exhaust gases for the engine are therefore continuously passed through the heat exchanger 258. This heat exchanger and the heat exchanger 257 are preferably heavily built so as to act as heat reservoirs. The purpose of this heavy construction will appear presently. The gas heated heat exchanger 259 is provided with a gas burner 290, the supply of gas to this burner being controlled by means of a valve 291 which may be of the diaphragm type and which is so arranged as to remain closed except at times when air pressure exists under the diaphragm thereof.

Inasmuch as during the period of reactivation, the silica-gel beds are highly heated for driving the water therefrom, it is necessary to cool such beds before the air to be conditioned is passed therethrough. For this purpose, provision is made for stopping the heating of the reactivating air a predetermined period of time before the shifting of the dampers, thereby permitting cool air to be blown through the bed which has just been reactivated, for cooling such bed before the air to be conditioned is passed therethrough. Preferably, this result is achieved by the use of a by-pass duct 291 which permits the reactivating air to be by-passed around the heaters 257, 258 and 259 instead of passing therethrough. For selectively passing the air either through the heaters or through the by-pass, is provided a damper 292, this damper being arranged to either close the heating passage or the by-pass passage. For automatically controlling this damper, is provided a fluid actuated motor 293 which may be of known form, this motor being connected to the damper 292 in such man-

ner that when the bellows 294 of the motor is expanded, as shown, the damper 292 will be positioned for causing the air to flow through the by-pass passage 291. When the bellows 294 is contracted due to venting thereof, the motor 293 will position the damper 292 so as to close off the by-pass and cause flow of air through the heat exchanger. The bellows 294 is connected by air lines 295 and 296 to a restrictor 297, which in turn is connected to the main air supply from the tank 239. The bellows 294 is also connected by the lines 295 and 298 to a bleed port 299. The bleed port 299 cooperates with a valve member 300, which is shown as forming a part of a cam follower 301 which cooperates with a cam 302 mounted upon the shaft 276. The cam 302 is provided with a pair of raised portions, the centers of these raised portions being spaced 180° apart and the raised portions occupying portions of the cam surface corresponding to approximately 3 minutes of rotation. This cam is positioned upon the shaft 276 so that the raised portions thereof will engage the cam follower just 3 minutes in advance of the time that the cam follower 278 rides from one portion of cam 277 to the other. Therefore, 3 minutes ahead of the time that the cam 277 will cause shifting of the dampers, the cam follower 301 will be engaged by a raised portion of cam 302, this causing the valve member 300 to engage the bleed port 299, which results in expansion of the bellows 294 for stopping the flow of reactivating air through the heat exchangers and by-passing such air therearound. This arrangement, therefore, allows a 3 minute cooling interval for the reactivated gel bed before it is placed into service. It will be apparent that after this 3 minute interval, the dampers will be shifted and the damper 292 will again be positioned to permit flow of reactivating air through the heaters to cause heating of the air for reactivating the other gel beds.

It should be noted that the exhaust gases are continuously passed through the heat exchanger 258, and the jacket water is continuously passed through the heat exchanger 257. By making these heat exchangers of heavy construction, these exchangers will act to absorb heat during the period of time that the damper 292 is preventing flow of air therethrough. Therefore, when the damper 292 is in this position, the heat exchangers 257 and 258 will act to store up heat which will be imparted to the air when the damper 292 is shifted to permit flow of air through said heat exchangers. By this arrangement, all of the waste heat from the internal combustion engine is utilized for reactivating the gel beds, and wasting of this heat during the cooling period for the reactivated gel bed is avoided. It should be noted that the cooling water for the engine is continuously passed through heater 257, even when damper 292 is in position for preventing air flow through the heater. This will usually be a satisfactory arrangement, for the volume of water in the heater and pipes 285 and 286 will absorb the engine heat for the short period while damper 292 prevents air flow through the heater 257, without causing overheating of the engine. It will be understood that if desired, a radiator as shown at 130 in Figure 1 may be provided, the water being passed through this radiator when heater 257 is out of operation. Also, if desired, a suitable tank may be provided for increasing the volume of water in the circulation system so as to provide

for accumulation of jacket heat and for properly cooling the engine while heater 257 is out of operation.

In accordance with my invention, the auxiliary heater 259 is placed into operation whenever the waste heat from the engine is insufficient to properly reactivate the silica-gel beds. Whenever the waste heat is sufficient for proper reactivation, however, the auxiliary heater 259 is to be kept out of operation. My preferred method for controlling this auxiliary heater is by opening the gas valve whenever the rate in rise of temperature of the reactivating air leaving the gel bed is too low. It will be understood that at the beginning of the reactivating cycle, the gel bed which has just been taken out of service for reactivation, is relatively cool. When the heated air is passed through such bed the air issuing from the bed will be cooled. As the reactivation period progresses, however, the gel bed will become more and more heated, this resulting in the temperature of the air issuing from said bed increasing. If the reactivating air is sufficiently heated for securing proper reactivation, the temperature of said reactivating air as it leaves the gel bed will rise more quickly than if the temperature of the issuing air is too low for proper reactivation. The rate of rise in temperature of the reactivating air leaving the gel bed is therefore an indication of whether or not the heat supplied to the air is sufficient. I therefore control the gas valve 291 by a means responsive to the rate of rise in temperature of the outgoing reactivating air. This means may consist of a reverse acting type of pneumatic thermostat 310 and a timing arrangement 311 which may be driven by the shaft 276. The thermostat 310 is shown as connected to a restrictor 312 by means of an air line 313, the restrictor being connected by a line 314 to the main source of compressed air. The air line 313 is connected by a line 315 to the diaphragm valve 291 and is also connected to a bleed port 316 of the timing device 311 by a line 317. The thermostat 310 is arranged so that its bleed port remains closed until the temperature of the reactivating air rises to 240° F., at which time the bleed port will be opened.

Referring now to the timing device 311, this comprises a cam 318 which is driven by the shaft 276 and which cooperates with a cam follower 319 which carries a valve member 320 cooperating with the bleed port 316. This cam is provided with a pair of raised portions and a pair of depressed portions, the centers of the raised portions being spaced 180° apart and the raised portions each occupying a portion of the cam surface corresponding to 6 minutes of rotation of shaft 276. This cam is mounted upon the shaft 276 in such a manner that one raised portion engages the follower 319 just 3 minutes ahead of the time that the cam follower 278 rides from one portion of cam 277 to the other. In other words, the cam 318 is so mounted as to cause opening of the bleed port 316 just 3 minutes before the end of a reactivating cycle. Due to the raised portion of the cam surface occupying a 6 minutes' interval, the valve 320 will be held away from bleed port 316 for the last 3 minutes of one cycle and for the first 3 minutes of the following cycle. When valve 320 is held away from port 316, air will bleed from said port, this causing a reduction in air pressure under the diaphragm of the gas valve 291, thereby causing said valve to be closed. This arrangement therefore acts to main-

tain the gas valve 291 closed for the last 3 minutes of a reactivating cycle and for the first 3 minutes of the next following cycle. It should be noted that during the last 3 minutes of a reactivating cycle, the damper 292 is positioned so as to prevent the reactivating air from flowing through the heaters. At this time, the gas valve 291 is kept from opening by the cam 318 and therefore the heater 259 is always out of operation whenever the reactivated air is being by-passed around the heaters.

At the beginning of a reactivating cycle, the dampers 261, 262, 266 and 267 will be shifted to cause the air being conditioned to flow through the gel bed which has just been reactivated, and to cause flow of the reactivating air through the gel bed just taken out of service. At this time, the damper 292 will be shifted to cause the reactivating air to pass through the heaters, thereby causing heated air to flow through the bed being reactivated. For the first 3 minutes of this reactivating cycle, the valve 291 will be prevented from opening, due to the cam 318 causing opening of the bleed port 316. During this time, the temperature of the reactivating air leaving the gel bed will gradually increase, and when the temperature increases to 240° F., the bleed port of the duct thermostat 310 will open. If this condition occurs, the diaphragm chamber of the gas valve will continue to be vented even after the 3 minute interval, when the cam 318 causes closing of the bleed port 316. This arrangement, therefore, acts to maintain the gas valve 291 closed if the temperature of the discharged reactivating air rises to 240° F. within 3 minutes after the beginning of a reactivating cycle. If, however, the reactivating air temperature fails to rise to 240° F. within this interval, both the bleed port 316 and the bleed port of the thermostat 310 will be closed at the end of this interval, this causing pressure to build up under the diaphragm of the gas valve 291 for opening said valve to place the auxiliary heater 259 into operation. This arrangement, therefore, prevents operation of the auxiliary heater 259 so long as the supply of waste heat from the engine is sufficient for securing proper reactivation. When the waste heat is insufficient, however, the heater 259 is automatically placed into operation.

It should be apparent from the foregoing description, that the operation of the system shown in Figure 2 is generally the same as that of the system of Figure 1. Thus, when the space or return air temperature is below a predetermined value, for instance 75°, the controller 210 will cause the engine to be stopped, thereby placing the system out of operation. When, however, the space temperature rises above this value, the space temperature controller 210 will cause starting of the engine. When the engine is in operation, the suction pressure controller 226 will modulate the engine speed in a manner to carry both the sensible heat and latent heat cooling loads, just as occurs in Figure 1.

During the operation of the system, the air being conditioned and the air for reactivation will be passed through the dehumidifying chambers in alternation, thus providing for reactivating one chamber while the other chamber is in use. Also, before the end of each reactivation cycle, the heating of the reactivating air will be stopped, thereby providing for cooling of the gel bed which has just been reactivated, and during this time the auxiliary heater will be kept out of operation by the timing device 311. Also, if the

supply of waste heat is adequate, the auxiliary heater will be kept out of operation, while if the supply of waste heat becomes inadequate, the thermostat 310 and timing device 311 will cooperate to place said auxiliary heater in operation.

While in Figure 2 I have not illustrated a humidity controller, such a controller may of course be employed, and if desired, may be arranged to control the damper 292 in a manner to prevent heating of the reactivating air whenever the relative humidity within the space falls to a predetermined value. Instead of this arrangement, a humidity controlled by-pass around the dehumidifier 202 may be provided.

It will be noted that my system permits the use of all or substantially all return air. By using practically all return air, the total cooling load is considerably reduced as compared to an arrangement in which all outside air is used. By this reduction in load, the waste heat from the engine will be capable of supplying sufficient heat to reactivate the dehumidifier under most conditions. It is of course desirable to utilize a certain percentage of outside air for ventilating purposes even though the total cooling load is thereby increased. When fairly large quantities of outside air are utilized, the waste heat from the engine will not be sufficient for reactivating the dehumidifier, and the auxiliary heating device will come into action for providing the extra heat necessary for reactivating the dehumidifier.

From the foregoing description, it should be apparent that I have provided an air conditioning system which is especially adapted to be actuated by means of an internal combustion engine, this air conditioning system utilizing the waste heat of the engine for also conditioning the air and being automatically controlled in a manner to maintain proper temperature and humidity conditions within the conditioned space.

While my invention is mainly concerned with air conditioning systems utilizing an internal combustion engine, certain features of my invention are of broader application. Also, while I have shown and described novel pneumatic control arrangements, it is to be understood that certain features of my invention may be controlled by electrical arrangements as well as pneumatic control arrangements. Inasmuch as many modifications of my invention will be obvious to those skilled in the art, I desire to be limited only by the scope of the appended claims and the prior art.

I claim as my invention:

1. In an air conditioning system, in combination, a dehumidifying means of the type requiring heat for reactivation, a cooling means for the air, means for actuating said cooling means comprising an internal combustion engine, means for utilizing heat ejected by said internal combustion engine for reactivating said dehumidifying means, and humidity responsive means for controlling the flow of said ejected heat to said dehumidifying means.

2. In an air conditioning system, in combination, a conditioning chamber through which air to be conditioned is passed, a dehumidifying means in said chamber of the type requiring heat for reactivation, a direct expansion cooling coil in said conditioning chamber, means for actuating said direct expansion cooling coil comprising an internal combustion engine driven compressor, a speed controller for varying the speed of said internal combustion engine, a fluid actuated device for causing movement of said speed

controller, means actuated by said engine for providing actuating fluid for said fluid actuated device, means responsive to a condition of the refrigerant evaporated in said cooling coil for controlling the actuating fluid supplied to said fluid actuating device to vary the engine speed in a manner to maintain said evaporated refrigerant condition between predetermined limits, means for utilizing heat ejected by said engine for reactivating said dehumidifying means, and means for controlling the supply of said heat to said dehumidifying means.

3. In an air conditioning system, in combination, a dehumidifier comprising a passage, moisture collecting material in said passage, means for alternately passing air to be dehumidified or air for reactivating said dehumidifying material through said passage, cooling means for cooling the dehumidified air including a cooling coil and means for supplying said cooling coil with cooling fluid, means for utilizing heat ejected from said cooling fluid supplying means for heating said reactivating air, auxiliary heating means for heating said reactivating air, by-pass means for by-passing said first mentioned heating means for causing unheated air to be passed through said dehumidifying material for cooling the same, automatic means for operating said by-pass, means, and means for preventing operation of said auxiliary heating means when said by-pass means is in operation.

4. In an air conditioning system, in combination, a dehumidifier comprising a passage, moisture collecting material in said passage, means for alternately passing air to be dehumidified or air for reactivating said dehumidifying material through said passage, cooling means for cooling the dehumidified air leaving said passage including a cooling coil and means for supplying said cooling coil with cooling fluid, a heat exchanger for transferring heat ejected from said cooling fluid supplying means to said reactivating air for heating the same, by-pass means for by-passing said reactivating air around said heat exchanger to cause unheated air to be passed through said moisture collecting material for cooling the same, and means for controlling said by-pass means, said heat exchanger being of sufficient size to absorb and store heat during the continuous operation of said cooling fluid supplying means while said reactivating air is being by-passed around said heat exchanger.

5. In an air conditioning system, in combination, a conditioning chamber through which air to be conditioned is passed, a dehumidifying means in said chamber of the type utilizing a material causing condensation of the water vapor in the air and transfer of the latent heat of evaporation of the water vapor to the air thereby causing the air to be raised in temperature during the dehumidifying action, a refrigeration system including an evaporator in said chamber for cooling the dried and heated air, said refrigeration system including a compressor driven by an internal combustion engine, means for utilizing heat ejected by the internal combustion engine for reactivating the dehumidifying material, and means responsive to a condition of the refrigerant in said evaporator which varies upon change in load on the evaporator for varying the speed of said internal combustion engine.

6. In an air conditioning system, in combination, a conditioning chamber through which air to be conditioned is passed, a dehumidifying

means in said chamber of the type utilizing a material causing condensation of the water vapor in the air and transfer of the latent heat of evaporation of the water vapor to the air thereby causing the air to be raised in temperature during the dehumidifying action, a refrigeration system including an evaporator in said chamber for cooling the dried and heated air, said refrigeration system including a compressor driven by an internal combustion engine, means for utilizing heat ejected by the internal combustion engine for reactivating the dehumidifying material, means responsive to the demand for dehumidification in said space for controlling said dehumidifying means, and means responsive to a condition of the refrigerant in said evaporator which varies upon change in load on the evaporator for varying the speed of said internal combustion engine.

7. In an air conditioning system, in combination, a conditioning chamber through which air to be conditioned is passed, a dehumidifying means in said chamber of the type utilizing a material causing condensation of the water vapor in the air and transfer of the latent heat of evaporation of the water vapor to the air thereby causing the air to be raised in temperature during the dehumidifying action, a refrigeration system including an evaporator in said chamber for cooling the dried and heated air, said refrigeration system including a compressor driven by an internal combustion engine, means for utilizing heat ejected by the internal combustion engine for reactivating the dehumidifying material, means responsive to the demand for dehumidification in said space for controlling the delivery of heat from said internal combustion engine to said dehumidifying means, and means responsive to a condition of the refrigerant in said evaporator which varies upon change in load on the evaporator for varying the speed of said internal combustion engine.

8. In an air conditioning system, in combination, a conditioning chamber through which air to be conditioned is passed, a dehumidifying means in said chamber of the type utilizing a material causing condensation of the water vapor in the air and transfer of the latent heat of evaporation of the water vapor to the air thereby causing the air to be raised in temperature during the dehumidifying action, a refrigeration system including an evaporator in said chamber for cooling the dried and heated air, said refrigeration system including a compressor driven by an internal combustion engine, means for utilizing heat ejected by the internal combustion engine for reactivating the dehumidifying material, means including timing means for controlling the delivery of heat from said internal combustion engine to said dehumidifying means, and means responsive to a condition of the refrigerant in said evaporator which varies upon change in load on the evaporator for varying the speed of said internal combustion engine.

9. In an air conditioning system, in combination, a conditioning chamber through which air to be conditioned is passed, a dehumidifying means in said chamber of the type utilizing a material causing condensation of the water vapor in the air and transfer of the latent heat of evaporation of the water vapor to the air thereby causing the air to be raised in temperature during the dehumidifying action, a refrigeration system including an evaporator in said chamber for cooling the dried and heated air, said refrig-

eration system including a compressor driven by an internal combustion engine, means for utilizing heat ejected by the internal combustion engine for reactivating the dehumidifying material, means for controlling the delivery of heat from said internal combustion engine to said dehumidifying means, and means responsive to a condition of the refrigerant in said evaporator which varies upon change in load on the evaporator for varying the speed of said internal combustion engine.

10. In an air conditioning system, in combination, a conditioning chamber through which air to be conditioned is passed, a dehumidifying means in said chamber of the type utilizing a material causing condensation of the water vapor in the air and transfer of the latent heat of evaporation of the water vapor to the air thereby causing the air to be raised in temperature during the dehumidifying action, a refrigeration system including an evaporator in said chamber for cooling the dried and heated air, said refrigeration system including a compressor driven by an internal combustion engine, means for utilizing heat ejected by the internal combustion engine for reactivating the dehumidifying material, means responsive to a condition of the refrigerant in said evaporator which varies upon change in load on the evaporator for varying the speed of said internal combustion engine, whereby the heat available from the internal combustion engine is limited when the cooling load is light, auxiliary heating means for supplying additional heat for reactivating the dehumidifying material, and means for placing said auxiliary heating means into operation when the heat available from said engine is insufficient to perform the necessary reactivation.

11. In an air conditioning system, in combination, a conditioning chamber through which air to be conditioned is passed, a dehumidifying means in said chamber of the type utilizing a material causing condensation of the water vapor in the air and transfer of the latent heat of evaporation of the water vapor to the air thereby causing the air to be raised in temperature during the dehumidifying action, a refrigeration system including an evaporator in said chamber for cooling the dried and heated air, said refrigeration system including a compressor driven by an internal combustion engine, means for utilizing heat ejected by the internal combustion engine for reactivating the dehumidifying material, means responsive to a condition of the refrigerant in said evaporator which varies upon change in load on the evaporator for varying the speed of said internal combustion engine whereby the heat available from the internal combustion engine is limited when the cooling load is light, auxiliary heating means for supplying additional heat for reactivating the dehumidifying material, and means responsive to the moisture content of the dehumidifying material for placing said auxiliary heating means into operation when said moisture content rises to a predetermined value.

12. In an air conditioning system, in combination, a conditioning chamber through which air to be conditioned is passed, a dehumidifying means in said chamber of the type utilizing a material causing condensation of the water vapor in the air and transfer of the latent heat of evaporation of the water vapor to the air thereby causing the air to be raised in temperature during the dehumidifying action, a refrigeration

system including an evaporator in said chamber for cooling the dried and heated air, said refrigeration system including a compressor driven by an internal combustion engine, means for utilizing heat ejected by the internal combustion engine for reactivating the dehumidifying material, means responsive to a condition of the refrigerant in said evaporator which varies upon change in load on the evaporator for varying the speed of said internal combustion engine whereby the heat available from the internal combustion engine is limited when the cooling load is light, auxiliary heating means for supplying additional heat for reactivating the dehumidifying material, and time and temperature responsive means for controlling said auxiliary heating means in a manner to place it into operation when the heat from the engine is insufficient.

13. In an air conditioning system, in combination, a conditioning chamber through which air to be conditioned is passed, dehumidifying means in said chamber for dehumidifying said air, said dehumidifying means being of the type requiring heat for reactivation, cooling means for cooling the dehumidified air including a cooling coil and means for supplying said cooling coil with cooling fluid, means for utilizing heat ejected from the cooling fluid supplying means for reactivating said dehumidifying means, auxiliary heating means for supplying additional heat for reactivating said dehumidifying means, means responsive to a condition of the dehumidifying means, means responsive to the humidity of the air in said space, said two responsive means conjointly controlling said auxiliary heating means.

14. In an air conditioning system, in combination, a dehumidifier comprising a passage, moisture collecting material in said passage, means for alternately passing air to be dehumidified or heated air for reactivating said material through said passage, cooling means for cooling the dehumidified air including a cooling coil and means for supplying said cooling coil with cooling fluid, means for utilizing heat ejected from said cooling fluid supplying means for heating said reactivating air, auxiliary heating means for heating said reactivating air, timing means, temperature responsive means responsive to the temperature of the reactivating air passing from said moisture collecting material, said timing means and said temperature responsive means cooperating to control said auxiliary heating means.

15. In an air conditioning system, in combination, a conditioning chamber through which air to be conditioned is passed, dehumidifying means in said chamber for dehumidifying said air, said dehumidifying means being of the type requiring heat for reactivation, cooling means for cooling the dehumidified air including a cooling coil and means for supplying said cooling coil with cooling fluid, means for utilizing heat ejected from the cooling fluid supplying means for reactivating said dehumidifying means, the heat available from the cooling fluid supplying means being limited by the demand for cooling, whereby at times the heat ejected by the cooling fluid supplying means is insufficient for reactivation, auxiliary heating means for supplying additional heat for reactivating said dehumidifying means,

moisture responsive means for controlling the dehumidifying means, means responsive to a condition of the cooling coil indicative of the dehumidifying load for controlling said cooling fluid supplying means, and means actuated when the relative humidity of the air becomes excessive for placing said auxiliary heating means in operation.

16. In an air conditioning system, in combination, a conditioning chamber through which air to be conditioned is passed, dehumidifying means in said chamber for dehumidifying said air, said dehumidifying means being of the type requiring heat for reactivation, cooling means for cooling the dehumidified air including a cooling coil and means for supplying said cooling coil with cooling fluid, means for utilizing heat ejected from the cooling fluid supplying means for reactivating said dehumidifying means, the heat available from the cooling fluid supplying means being limited by the demands for cooling, whereby at times the heat ejected by the cooling fluid supplying means is insufficient for reactivation, auxiliary heating means for supplying additional heat for reactivating said dehumidifying means, and means responsive to a condition of the dehumidifying means and to the humidity in said space for placing said auxiliary heating means into operation when either condition indicates that the dehumidifying effectiveness of said dehumidifying means has become too low.

17. In an air conditioning system, a conditioning chamber through which air to be conditioned is passed, an evaporator coil in heat transfer relationship with said chamber, a compressor for supplying refrigerant to said coil, an internal combustion engine for driving said compressor, a speed controller for said engine, a pneumatic control system for said speed controller including a control valve responsive to a condition indicative of the demand for compressor operation, further conditioning equipment in said duct, means for utilizing waste heat from said engine in connection with the operation of said further conditioning equipment, a pneumatic control system for said waste heat utilizing means, and means driven by said internal combustion engine tending to maintain within the conduits of said pneumatic systems a pressure other than atmospheric pressure.

18. In an air conditioning system, a conditioning chamber through which air to be conditioned is passed, an evaporator coil in heat transfer relationship with said chamber, a compressor for supplying refrigerant to said coil, an internal combustion engine for driving said compressor, a speed controller for said engine, a pneumatic control system for said speed controller including a control valve responsive to a condition indicative of the demand for compressor operation, further conditioning equipment in said duct, means for utilizing waste heat from said engine in connection with the operation of said further conditioning equipment, a pneumatic control system for said waste heat utilizing means, and a connection between the conduits of said pneumatic systems and the intake manifold of said engine tending to maintain a vacuum within said conduit.

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