

April 26, 1966

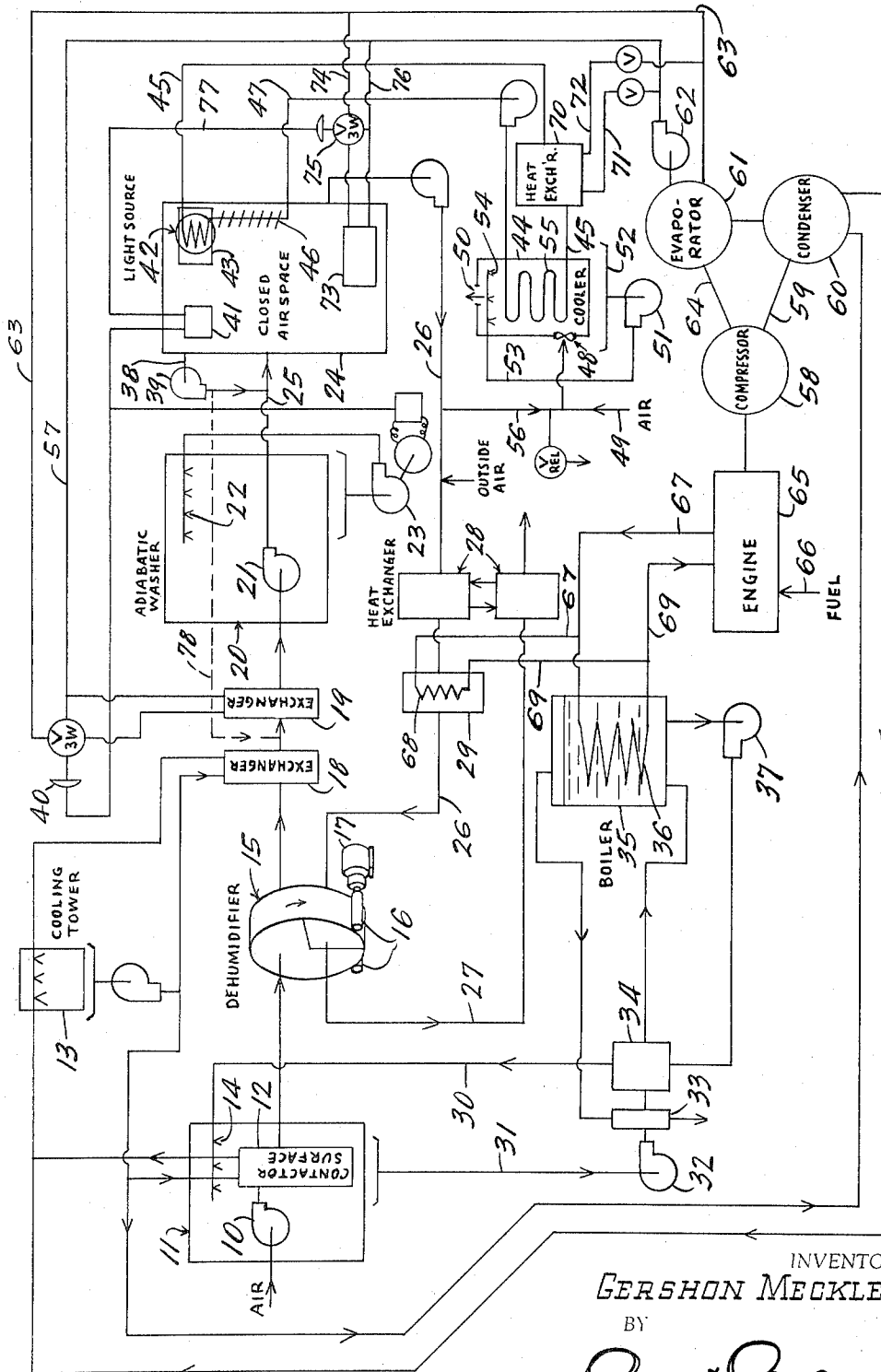
G. MECKLER

3,247,679

INTEGRATED COMFORT CONDITIONING SYSTEM

Filed Oct. 8, 1964

2 Sheets-Sheet 1



INVENTOR:  
GERSHON MECKLER.

BY

*Owen & Owen*  
ATT'YS.

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2 Sheets-Sheet 2

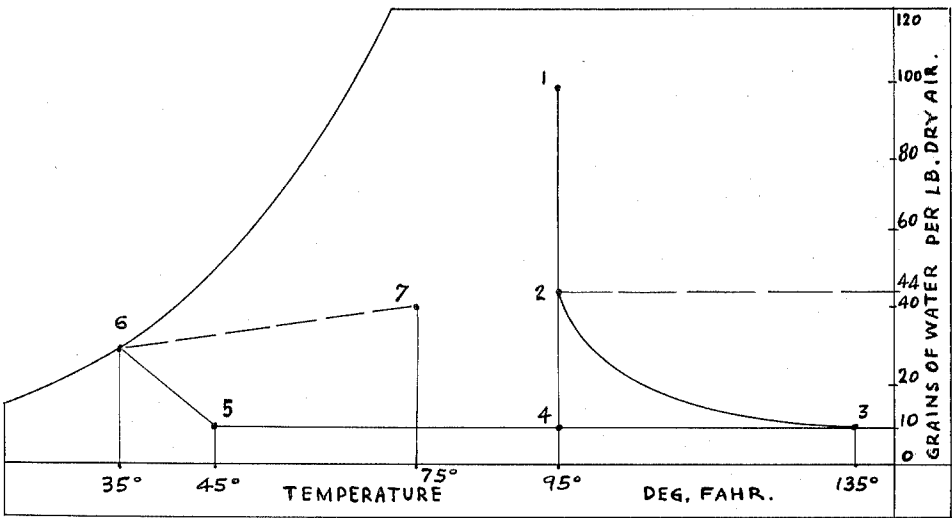


FIG-2-

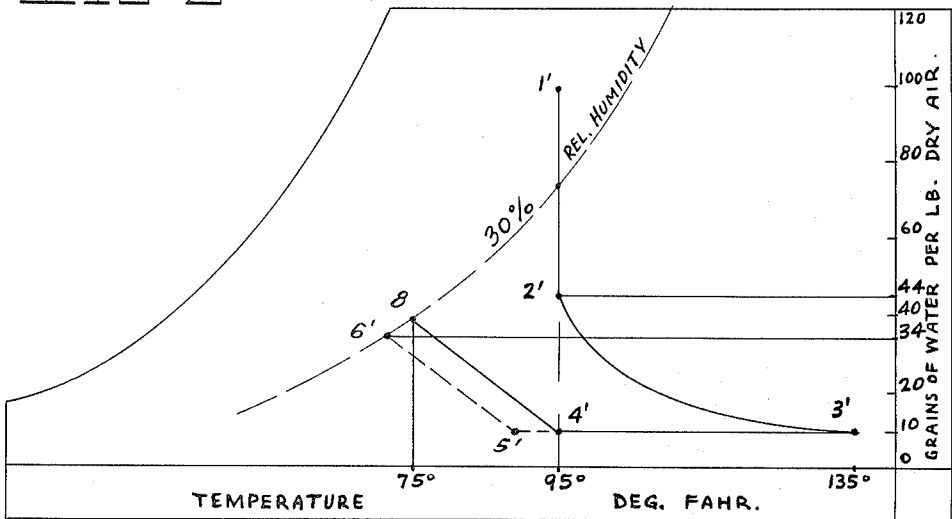


FIG-3-

INVENTOR:  
GERSHON MECKLER.

BY

*Owen & Owen*

ATT'YS.

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## INTEGRATED COMFORT CONDITIONING SYSTEM

Gershon Meckler, Toledo, Ohio, assignor to Lithonia Lighting, Inc., Conyers, Ga., a corporation of Georgia  
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16 Claims. (Cl. 62-271)

The present invention relates to a process and apparatus for cooling air; and more particularly to a process and apparatus which will both cool and dehumidify air.

An object of the present invention is the provision of a new and improved process and apparatus for cooling and dehumidifying air to well below ambient conditions with a maximum amount of the heat that is removed from the air being removed by means of a coolant at a temperature above that of the cooled and dehumidified air and a minimum amount of the heat which is removed from the air being removed by conventional refrigeration equipment.

Another object of the present invention is the provision of a new and improved process and apparatus for conditioning an enclosed space in which process the total amount of refrigeration used in cooling and dehumidifying the air for the space is a minimum.

Another object of the invention is the provision of a new and improved process and apparatus for cooling air to a temperature at or near freezing without using a coolant at a temperature below freezing.

A further object of the invention is the provision of a new and improved process and apparatus for cooling air to a temperature near freezing in equipment which will not frost, and which utilizes a maximum of cooling obtained from a non-refrigerated source such as a cooling tower, and a minimum of cooling obtained from refrigeration equipment operated above freezing temperatures.

Another object of the invention is the provision of a new and improved process and apparatus in which air for an enclosed space is both cooled and dehumidified and in which exhaust heat from a heat engine which drives the necessary refrigeration equipment is used for the regeneration of the desiccant of the dehumidifier.

Still another object of the invention is to provide improved process and apparatus where exhaust heat from a heat engine which drives refrigeration equipment is used for the regeneration of the desiccant of the dehumidifier, and any excess of dehumidification capacity which results from such use of the exhaust heat is utilized for sensible cooling of a space to be conditioned.

Yet another object of the invention is to provide improved air conditioning process and apparatus where both exhaust heat and shaft work from a heat engine are used to perform work and to attack by different mechanisms the several sources of problem heat, and where substantially all available energy from fuel driving the engine is utilized in performing air conditioning functions under varying ambient conditions because the work performed by exhaust heat reduces the need for work performed by shaft work.

Further objects and advantages of the invention will become apparent to those skilled in the art to which it relates from the following description of a preferred em-

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bodiment described with reference to the accompanying drawings, in which:

FIGURE 1 is a diagrammatic view of an apparatus for cooling and dehumidifying air according to the invention, and for regenerating the materials used to dehumidify the air and including a heat engine used to produce shaft work for driving refrigeration equipment as well as exhaust heat for the regeneration of the chemical desiccant used in the dehumidification of the air;

FIGURE 2 is a psychrometric chart showing the psychrometric path through which air may be taken by the apparatus shown in FIGURE 1 when operated according to one embodiment of the invention; and

FIGURE 3 is a psychrometric chart showing the psychrometric path through which the air may be taken by the apparatus of FIGURE 1 when operated according to another embodiment of the invention.

The apparatus shown in FIGURE 1 generally comprises a blower 10 which forces air through a chemical dehumidifier 11 which uses a liquid desiccant such as an ethylene glycol or lithium chloride solution. The chemical dehumidifier 11 includes a contactor surface 12 which is cooled indirectly by means of a coolant from a non-refrigerated source 13, such as a deep well, an evaporative cooler, or a cooling tower. The source shown in the drawing is a cooling tower. The liquid desiccant is sprayed as at 14 over the air contactor surface 12. Air leaving the chemical dehumidifier 11 may be generally at ambient temperatures but may have as much as approximately half of its water vapor removed.

Air from the chemical humidifier 11 then passes to a second chemical dehumidifier 15 which uses a solid desiccant to remove moisture therefrom. Any type of equipment which will support a solid desiccant such as calcium chloride, silica gel, activated alumina or the like, and which will enable regeneration, can be used. The dehumidifier 15 is of a preferred type wherein a solid desiccant is supported in a honeycomb material made of asbestos and housed within a drum. The drum is supported by rollers 16, one of which is rotated by a motor 17, and air to be dried passes through one sector of the drum, while air for regenerating the desiccant passes through another sector of the drum. Such equipment is presently commercially available. The air leaving the dehumidifier 15 may have approximately one-fourth the water content of that received from the first dehumidifier 11, and will be raised in temperature due to the heat of absorption.

Air leaving the second dehumidifier 15 then passes to a first indirect heat exchanger 18 that is cooled by means of water from the non-refrigerated coolant source 13, so that the air leaving the first indirect heat exchanger will be very dry and will be cooled approximately to ambient temperature. In the embodiment shown in FIGURE 1, air from the first indirect heat exchanger 18 then passes to a second indirect heat exchanger 19 which is cooled by a coolant at a temperature well below ambient conditions, but preferably above freezing, and most desirably between 32° F. and 50° F. in order that frost will not collect on the refrigeration equipment and air cooling coils. Air will therefore leave the second indirect heat exchanger 19 with very little moisture and at a quite low temperature, preferably between about 40° F. to

about 50° F. The air thereafter passes to an adiabatic washer or humidifier 20.

The adiabatic washer 20 may include a blower 21 to offset pressure drop through the equipment. The washer 20 causes the air to come in contact with water under adiabatic conditions: sensible heat from the air causes water evaporation, and this lowers the dry bulb temperature of the air. The usual adiabatic washer will include a spray head 22 which is supplied with water from a pump 23 that in turn receives make-up water from a suitable source (not illustrated) plus water which previously passed through the washer without being evaporated. In those instances where the air enters the adiabatic washer at close to freezing temperatures, it will be possible for the washer 20 to lower the temperature leaving the washer below 32° F. In most instances, however, it will be desirable to have the air leaving the adiabatic washer at just above 32° F. in order to prevent frost from collecting on the ducts and air handling equipment. The second indirect heat exchanger 19 and the adiabatic washer 20 are preferably operated, therefore, under conditions such that the air leaving the adiabatic washer 20 is just above freezing temperatures. In those instances where the air leaving the adiabatic washer 20 is to be saturated, the second indirect heat exchanger 19 is controlled to prevent saturation in the washer 20 from lowering the temperature of the exit air below freezing so that the air leaving the exchanger is at a wet bulb temperature just above 32° F. When it is desired that the air leaving the adiabatic washer be above freezing but unsaturated, a limited amount of water is circulated through the washer 20 and the temperature of the air leaving the second indirect heat exchanger 19 is controlled accordingly. Because the air leaving the adiabatic washer 20 is at a low temperature close to freezing, the amount thereof which must be circulated to an air space 24 through duct work 25 to compensate for a given heat load in the space is substantially the minimum possible without causing frost to build up on the equipment. Consequently, the size of the duct work 25 can be a practical minimum.

As previously indicated, the solid desiccant in one sector of the chemical dehumidifier 15 is being regenerated while air is being dehumidified by the desiccant in another sector. Inasmuch as air at a low absolute humidity is circulated to the air space 24, and the air therein is drier than ambient air, the system shown in the drawing circulates part of the air that is withdrawn from the air space 24 through a duct 26 and uses it for regeneration of the desiccant in the dehumidifier 15. Normally, it will require approximately one-fourth of the quantity of air that is dehumidified by the dehumidifier 15 for regeneration of the desiccant thereof. The air stream that is used for regeneration must be heated to approximately 300° F. before being used to dry the desiccant. Any suitable means can be used to heat the air, and inasmuch as the regenerative air which leaves the dehumidifier, as through a duct 27, will be at an elevated temperature, it is preferable that some type of heat exchange apparatus be used as at 28 to take heat from the exit air and partially to heat the air in the duct 26 on its way to the dehumidifier 15. The preferred heat exchange apparatus 28 is a foraminous rotating member made from a heat absorbing material. The air to be heated passes through one-half of the rotating member, and the air to be cooled passes through the other half of the rotating member. Heat from the exit air is thereby picked up by the rotary member and transferred to the air stream in the duct 26 going to the dehumidifier 15 as schematically represented by arrows. A heat exchange apparatus 28 of the type described is known and is commercially available.

In place of the heat exchange apparatus 28 above described, a heating coil can be used in the duct 26, a cooling coil can be used in the exhaust duct 27 from the

dehumidifier, and a suitable heat exchange liquid can be circulated from the cooling coil to the heating coil and back to the cooling coil by means of a pump or the like. The heat exchange liquid will preferably be a high boiling one, such as high boiling water solutions, high boiling organic liquids and in some instances water. Additional heat must be supplied to the air in the duct 26 to provide the stream at 300° F. required for regeneration: this heat can be supplied by a heat exchanger 29. Any suitable source of heat can be used for the heat exchanger 29, such as steam, or combustion products from gas or oil, or it can be heated by an electrical resistance heating element, but a preferred embodiment of a heat exchanger is shown in FIG. 1, as subsequently discussed in more detail.

The first stage chemical dehumidifier 11 under some conditions may be supplied with a 95 percent ethylene glycol solution through a supply line 30, while a 93 percent ethylene glycol solution is removed from the dehumidifier 11 through a return line 31. Liquid from the return line 31 is pumped as at 32 through a first indirect heat exchanger 33 and a second indirect heat exchanger 34 to an evaporator 35 having a heating coil 36 therein. Sufficient steam flashes from the ethylene glycol solution in the evaporator 35 to increase the concentration of the solution to approximately 95 percent. The steam that is flashed in the evaporator 35 is conducted to the first indirect heat exchanger 33 where it condenses and is drained off. The hot 95 percent solution from the evaporator 35 is pumped as at 37 through the heat exchanger 34 and then to the supply line 30. Heat must be added in the evaporator by the coil 36 to raise the temperature of the returning liquid desiccant to boil the necessary water to concentrate the solution to approximately 95 percent.

The operation of the system as above described will now be explained with reference to the psychrometric chart of FIGURE 2. Under one set of conditions, air may enter the blower 10 at 95° F. with 98 grains of moisture per pound of dry air (point 1 in FIG. 2). The cooling tower 13 will supply the chemical dehumidifier 11 with cooling water at 85° F. The ethylene glycol solution in the chemical dehumidifier will be diluted to approximately 93 percent so that the air leaving the first stage chemical dehumidifier is at 95° F. and has 44 grains of moisture per pound of dry air (point 2 in FIG. 2). The chemical dehumidifier 15 will be operated under such conditions that air leaving the dehumidifier 15 will be at 135° F. with 10 grains of moisture per pound of dry air (point 3 in FIG. 2). The first indirect heat exchanger is supplied with cooling tower water at 85° F. so that the air leaving the exchanger is at 95° F. with 10 grains of moisture per pound of dry air (point 4 in FIG. 2). The second indirect heat exchanger is supplied with chilled water at 45° F. which leaves at a temperature of 50° F. so that the air leaving the second indirect exchanger 19 is at 45° F. with 10 grains of moisture per pound of dry air (point 5 in FIG. 2). Thereafter the air is adiabatically cooled in the adiabatic washer 20 to saturation at 35° F. with 30 grains of moisture per pound of dry air (point 6 in FIG. 2). Inasmuch as none of the equipment used to produce the air at 35° F. is operated at a temperature below 32° F., a minimum amount of air is required and the duct size used to supply air to the air space 24 can be a practical minimum. Air at 35° F. would, however, cause discomfort; it is preferred, therefore, to temper this air with air recirculated from the space 24, for example, through a duct 33 and by a blower 39, or by any suitable, known induction means. Air from the space is represented by a point 7 in FIG. 2, and mixtures thereof with air from the washer 20 are represented by a broken line joining points 6 and 7.

The amount of air required for regeneration of the solid desiccant in the dehumidifier 15 will generally be one-fourth of the air stream being dried. Under most conditions air may be taken from the space 24 at 75° F. and 40 grains of moisture per pound of dry air, and be

raised by the heat exchange apparatus 28 to a temperature within the range of 125 to 200° F. The heat exchanger 29 raises the temperature of the air stream in the duct 26 to 300° F. The regenerating air may leave the dehumidifier at a temperature from 200 to 250° F. with 125 to 200 grains of moisture per pound of dry air, and may leave the heat exchange apparatus 28 at a temperature from 100 to 200° F.

The ethylene glycol solution leaves the chemical dehumidifier 11 at approximately a 93 percent concentration and 95° F. and is heated to a temperature of approximately 330° F. The steam from the evaporator 35 heats the dilute solution in the first indirect heat exchanger 33 to approximately 120° F. The heat exchanger 34 heats the return solution to approximately 300° F., and the coil 36 supplies the necessary heat to raise the temperature of the return solution to 330° F. and boil the amount of water necessary to concentrate the solution to 95 percent. The concentrated solution is pumped at 330° F. to the exchanger 34, and the solution leaves the exchanger 34 at approximately 140° F. Tower water cools the concentrated solution in the dehumidifier 11 to approximately 95° F.

Under some conditions, it may be desired to circulate a predetermined quantity of air through the closed space 24 for ventilation purposes. This may be 0.2 c.f.m. for each square foot of floor space. If the heat load in the closed space is relatively small the amount of air required for ventilation purposes when cooled to 32° F. would produce too low a temperature in the closed space and would be wasteful of refrigeration. In order to conserve refrigeration, therefore, the temperature of the refrigerated second indirect heat exchanger would be controlled in cooperation with the adiabatic washer to provide the desired temperature of air leaving the adiabatic washer 20. This may involve controlling the temperature of the refrigerant supplied the second indirect heat exchanger 19, or as shown in FIG. 1 may involve a three-way control valve 40 which controls the rate of refrigerant flow through the exchanger 19 by by-passing refrigerant that is not required. The flow control valve 40 is in turn controlled, together with the operation of the washer 20, in response to a temperature sensing element 41 in the closed space. Where a high temperature heat source delivers its heat to the closed space, such as a light source 42, the amount of refrigeration required in the second indirect heat exchanger 19 can be kept to a minimum by providing a panel 43 in position to remove the high temperature radiation of the light source. This can be done using a coolant at a temperature above that in the closed space, and the panel 43 in FIG. 1 is shown as supplied with cooling water from an evaporative cooler 44 through a conduit 45. Effluent from the panel 43 is returned to the cooler 44 through a thermal louver 46 which is positioned to intercept solar energy entering the space, for example through windows, and a return line 47.

The cooling circuit comprising the panel 43, the thermal louver 46, the evaporative cooler 44 and the conduits 45 and 47 constitutes an important part of the apparatus according to the invention. Two substantial sources for problem heat in the space 24, or in any space to be comfort conditioned, are solar heat which enters the space through windows and radiant energy from artificial light sources, particularly in buildings which are designed for high lighting intensities. It is possible to intercept and transfer to relatively high temperature water, e.g., at 80° F. or higher, a major part of the problem heat from these two sources by means of the panel 43 and the thermal louver 46. Under most ambient conditions which prevail, it is also possible to reject such intercepted heat from the system in the evaporative cooler 44 by inducing, by means of a fan 48, a flow of ambient air through a conduit 49, and the evaporative cooler 44, and therefrom through a vent 50. The evaporative cooler

44 is of the indirect type. Cooling is achieved by evaporation of water circulated by a pump 51 from a pan 52, through a conduit 53 and from sprays 54 in direct contact with circulated air and back to the pan 52. Water from the conduit 47 is circulated through a coil 55 where it is cooled and back to the conduit 45 for return to the panel 43.

As has been indicated previously, about one-fourth of the relief air from the space 24 is required for circulation through the duct 26 for regeneration of the dehumidifier 15. This means that about three-fourths of the relief air is available for circulation through a duct 56 and the duct 49 to the evaporative cooler 44. The relatively low humidity of relief air from the duct can be a significant factor, particularly under conditions of high ambient humidity, at improving the effectiveness of the evaporative cooler 44, and the proportion of the solar load and of the lighting load, intercepted in the thermal louver 46 and in the panel 43, which is rejected in the evaporative cooler 44. Under other ambient conditions, e.g., low humidity, air from the duct 56 can be vented through a relief valve (designated by legend), in which case outside air could be circulated from an inlet (also designated by legend) through the duct 26 and the exchangers 28 and 29 to the dehumidifier 15.

The embodiment of the invention shown in FIG. 1 also includes a refrigeration machine for supplying chilled water for delivery through a conduit 57 to the valve 40, as well as a heat engine for driving the refrigeration machine. The exhaust heat of the heat engine is used to supply heat to air in the exchanger 29 and to the coil 36 of the evaporator 35. The refrigeration apparatus is of the conventional mechanical type comprising a compressor 58 which discharges a refrigerant through a conduit 59 to a condenser 60 which is cooled by water from the cooling tower 13. Liquid refrigerant from the condenser 60 flows to an evaporator 61 where it expands to a gas and cools a fluid circulating medium such as water. The water is circulated from the evaporator by a pump 62 and through the conduit 57 to the valve 40 which controls the amount of flow and hence the amount of cooling that is produced in the exchanger 19. The refrigerated water becomes heated in the exchanger 19 by the air flow therethrough, and the warmed water is returned to the evaporator 61 through a return conduit 63. Refrigerant gas from the evaporator 61 is returned to the compressor 58 through a conduit 64 to repeat the cycle.

The compressor 58 may be driven by any suitable type of heat engine, and is shown in the drawing as driven by an internal combustion engine 65, which can be, e.g., a diesel or a gas engine. Fuel that is supplied to the engine 65 through a line 66 is converted into both shaft work for driving the compressor 58 and exhaust heat, a substantial part of which is absorbed in a heat exchange fluid such as water in a cooling system associated with the engine 65. Hot heat exchange fluid from the engine 65 is conducted through a conduit 67 to both the coil 36 of the liquid desiccant regenerator 35 and a heating coil 68 of the exchanger 29 in the duct 26. The heating coil 68 is positioned between the apparatus 28 and the dehumidifier 15. The heat exchange fluid which flows from the engine 65 through the conduit 67 can be liquid or vaporous, e.g., steam. In either case, a relatively hot liquid is returned from the coils 68 and 36 through a conduit 69, and may be further cooled by any suitable heat exchanger (not illustrated) before return to the cooling system of the engine 65.

As indicated above, both heat from artificial light sources and solar heat are high temperature sources of problem heat in the sense that high temperature water, e.g., at 80° F. or higher, can be used effectively to prevent the heating of the space thereby, for example in the thermal louvers 46 or in the panel 43. From the energy con-

servation standpoint, therefore, it is usually logical to remove heat from such devices using high temperature water, e.g., from the evaporative cooler 44. In some cases, however, for example when ambient humidity is high, it is preferred with the combination of FIG. 1 to use refrigeration to remove a part of the heat from such devices. Accordingly, the combination also includes an indirect heat exchanger 70 in the line 45 to which chilled water can be circulated, if required, from the conduit 57 through a line 71 to the exchanger 70 for indirect heat exchange with the water from the evaporative cooler 44 and ultimate return through a line 72 to the conduit 63.

It will be noted that the panel 43 is shown as having a substantial lateral extent on opposed sides of the light source 42. The panel 43 would ordinarily constitute the reflector for the light 42, and can additionally extend laterally as shown. The lateral extensions of the panel 43 would serve no significant purpose with high temperature water, e.g., at 80° F. or higher, circulated to remove heat therefrom, but can control temperature in the space 24 when cooled to a low temperature. Fundamentally, the extensions are members which "see" the space 24 and are, therefore, when cooled to a sufficiently low temperature, operable to absorb heat therefrom. The invention also contemplates the operation of the FIG. 1 combination so that substantially all of the sensible cooling in the space is done by the lateral extensions on the panel 43. This is accomplished by pumping heat from the lateral extensions of the panel 43 to heat exchange fluid in thermal contact therewith, e.g., by means of a thermoelectric heat pump (not illustrated) to maintain the extensions at a sufficiently low temperature to perform the required cooling, and operating the second heat exchanger 19, if required, and the washer 20 to deliver air at substantially the dry bulb temperature desired in the space 24. Temperature control is achieved through the heat pump by regulation of the temperature of the extensions of the panel 43.

Temperature in the space 24 can also be controlled, when air supplied thereto is at substantially the desired dry bulb temperature, by means of a panel 73 to which chilled heat transfer fluid is supplied through a line 74, under the control of a three-way valve 75 which directs chilled heat transfer fluid to the panel 73 or to a return line 76 as required to maintain a desired dry bulb temperature, and under the control of the sensing device 41, as schematically represented by a line 77 from the device 41 to the valve 75.

FIG. 3 of the drawings shows the psychrometric path of air passing through the apparatus of FIG. 1 when the lateral extensions of the panel 43 are used to control temperature of the space 24, or when the panel 73 is so used, as just described. The air is at the same conditions at the points 1', 2', 3' and 4' as in the FIG. 2 chart, 4' representing 95° F. and approximately 10 grains of moisture per pound of dry air. After passing through the adiabatic washer 20 the air is at 76° F. and 30 percent relative humidity (point 8). Under these conditions, operation of the second refrigerated indirect exchanger 19 is not required. As subsequently discussed in more detail, operation of the second indirect heat exchanger 19 to accomplish at least a small amount of refrigeration is peculiarly advantageous, even when the major load is carried and temperature control is provided by the extensions of the panel 43 or by the panel 73. For example, the air can be cooled to point 5' in FIG. 3 before being adiabatically cooled in the adiabatic washer 20 to the point 6'. Points 6' and 8 represent air sufficiently dry to accomplish humidity control within the closed space 24, and the lower absolute humidity of the point 6' enables the use of lower temperatures in the extensions of the panel 43 or in the panel 73, and more effective temperature control thereby.

It is to be understood that the method and apparatus according to the invention are peculiarly advantageous

in many respects. An important feature is the provision of extremely dry air, as represented by the points 4 and 4' in the psychrometric charts of FIGS. 2 and 3 without the expenditure of any shaft work for refrigeration. This is practically possible only when ambient air is treated by a first stage of chemical dehumidification employing a liquid desiccant and then by a second stage of chemical dehumidification employing a solid desiccant. While extremely low humidities can be realized from a second stage of chemical dehumidification employing a liquid desiccant, accomplishment of this result requires temperatures well below the range which can be achieved with cooling tower water, and, consequently, the expenditure of shaft work for refrigeration to accomplish the result. The low humidity represented by the points 4 and 4' enables use of the adiabatic washer 20, essentially to convert sensible heat to latent heat, and again without the expenditure of shaft work for refrigeration. Accordingly, with a minimum or no expenditure of shaft work for refrigeration, a stream of air is so conditioned that, in the apparatus and method of the instant invention, it is capable of performing, when circulated at approximately the minimum rate required for ventilation, its part of the conditioning of the space 24. In the embodiment represented by the psychrometric chart of FIG. 2, the air so conditioned and circulated performs the entire function of humidity control and sensible cooling in the space 24, while, in the embodiment illustrated by the psychrometric chart of FIG. 3, the air so conditioned and circulated performs the function of humidity control, while substantially the entire job of sensible control within the space 24 is performed by the extensions of the panel 43 or by the panel 73. The ability to perform a required conditioning job in the space 24 with a minimum of circulated air is an important feature of the apparatus and method according to the invention, particularly in a multi-story building because the use of a low pressure air circulating system of minimum size is thereby enabled, and the necessity for a high pressure air circulating system or for a low pressure system which occupies a substantial percentage of the entire available space within a building enclosure, is avoided.

When air is circulated to the conditioned space 24 at approximately the minimum rate required for ventilation thereof, and in substantially the condition represented by point 6 in FIG. 2, such air is incapable of performing the entire sensible cooling job within the space 24 unless at least a substantial part of the heat from the light source 42 and from solar energy which would ordinarily enter the space through a window adjacent the thermal louver 46 is intercepted to minimize the space requirement for sensible cooling. A substantial portion of such heat is intercepted, in the method and apparatus according to the invention, by the panel 43 and by the thermal louver 46 to enable the accomplishment of the required sensible cooling by the conditioned air, or by the panel 73 or the lateral extensions of the panel 43 in the embodiment illustrated psychrometrically in FIG. 3. As has previously been discussed, the heat so intercepted is transferred to air vented from the evaporative cooler 44, and any excess, above that so transferred to air, is transferred to a chilled heat transfer fluid in the exchanger 70.

The ability to convert sensible heat to latent heat in the adiabatic washer 20 is a peculiarly significant feature of the apparatus and method of the invention when the internal combustion engine 65 is used to drive the compressor 58 while exhaust heat therefrom is used to supply heat for regeneration of the dehumidifiers, as shown in FIG. 1. The total load imposed upon the system is made up of a plurality of components attributable: (1) to ambient wet bulb temperature, (2) to ambient dry bulb temperature, (3) to solar energy entering the space, (4) to lights and other inanimate energy sources, and (5) to occupancy of the space by living beings. The ap-

paratus and method according to the invention counteract problem heat from each of these five sources by a combination of heat energy for dehumidifier regeneration and shaft work on the compressor 58, the ultimate result of which is chilled heat transfer fluid supplied to the conduit 57. For example, under conditions of relatively high ambient humidity, the temperature to which heat transfer fluid circulated thereto from the panel 43 and the thermal louver 46 by the line 47 can be cooled in the evaporative cooler 44 is higher than when ambient humidity is lower when, as is usually the case, at least some ambient air is circulated through the evaporative cooler. As a consequence, evaporatively cooled water returned through the line 45 to the panel 43 and the thermal louver 46 varies as a direct function of ambient humidity, and the amount of radiant energy from lights and solar energy intercepted by the two varies as an inverse function of ambient humidity. This means that an increase in ambient humidity necessitates increased sensible cooling to accomplish conditioning of the space 24. The increased sensible cooling can be provided by either the exchanger 19 or the panel 73, and, in either case, requires an increase in shaft work. An increase in ambient humidity also requires increased dehumidification capacity to maintain the same absolute humidity in the air supplied to the space 24. Since only heat from the engine 65 is used in the apparatus and method of the invention to provide dehumidification (disregarding cooling from the tower 13), and since the increased output of the engine 65 required to drive the compressor 58 involves a consequential increase in exhaust heat, there is cooperation among the several components, and a built-in compensation. A similar result occurs, but in a different manner, with an increase in load in the space 24 caused by an increase in ambient dry bulb temperature, an increase in solar load, an increase in load from lights or other inanimate energy sources, or increased occupancy of the space. Each of these increases in load requires increased sensible cooling of the space 24. Sensible cooling is accomplished in part by the heat exchanger 19 or by the panel 73, and, in part, by the conversion of sensible heat to latent heat in the adiabatic washer 20. An increase in output of the engine 65 to increase the output of the compressor 58 and to enable the heat exchanger 19 or the panel 73 to do increased sensible cooling also involves a consequential increase in exhaust heat from the engine 65. Again, the increased exhaust heat is used to increase the capacity to dehumidify air delivered to the adiabatic washer. However, in these cases, there has been no increase in ambient humidity, so the result is that air of lower absolute humidity is delivered to the adiabatic washer 20, thereby increasing its capacity to convert sensible heat to latent heat and enable the air circulated therefrom to the space 24 to do an increased portion of the sensible cooling. Occupancy of the space 24 by living beings increases both the sensible cooling load and the humidity load therein, and is, therefore, somewhat analogous to a simultaneous increase of ambient wet bulb and ambient dry bulb. Accordingly, in the instance where an increased load is the result of increased occupancy by living beings of the space 24, a part of the increased dehumidification capacity which results from an increased load on the engine 65 can be used, if required, to lower the absolute humidity of the air delivered to the space 24, while the rest is used to lower the dry bulb temperature of the air so delivered. The combination of FIG. 1, operated in the manner just described, makes effective use, relative to the conditioning of the space 24, of both shaft work and heat which result from the operation of the engine 65, thereby utilizing substantially all available energy from the fuel. This result is accomplished by using the exhaust heat from the engine in connection with the regeneration of the chemical dehumidifiers 11 and 15, operating the dehumidifiers 11 and 15 to deliver air

to the indirect heat exchanger 18 at an absolute humidity below the maximum which would provide the required humidity control in the space 24, and then converting sensible heat in the conditioned air to latent heat in either the adiabatic washer 20 or the evaporative cooler 44. This reduction in sensible heat reduces the requirement for refrigeration by chilled water in the indirect heat exchanger 19, in the indirect heat exchanger 70, or in the panel 73. It is impossible to accomplish this result if the compressor 58 is driven either by an electric motor or by a steam engine because, in either case, there is no by-product heat available to accomplish the regeneration. Optimum balancing of exhaust heat and shaft work can be achieved in the FIG. 1 apparatus only when the adiabatic washer 20 is used, because the evaporative cooler 44 is not capable of direct sensible cooling of the space 24.

Ordinarily, when the indirect heat exchanger 19 is used to chill the air delivered to the adiabatic washer 20, the conditioned air delivered through the duct 25 is adequate to condition the space 24 effectively when water evaporatively cooled in the cooler 44 is delivered through the line 45 to the panel 43 and the thermal louver 46. The indirect heat exchanger 70, however, is available whenever required to reduce the temperature of the evaporatively cooled water so circulated.

Operation of the apparatus of FIG. 1 according to the embodiment psychrometrically represented in FIG. 2, and mixing air withdrawn from the space 24 with cold air, for example by means of the duct 38 and the blower 39 is preferred. For example, in a multi-story building, the dehumidifiers 11 and 15, the indirect heat exchangers 18 and 19, and the adiabatic washer 20 would ordinarily be located in a central equipment room, so that mixing return air with the conditioned, circulated air in the duct 25 for a single room or a single zone of a building eliminates the unnecessary use of space within the building for return of such air to the equipment room. Insofar as operation of the system is concerned, however, it is immaterial whether the return air is mixed as described, using the duct 38 and the blower 39, or equivalents, between the indirect heat exchanger 18 and the indirect heat exchanger 19, for example through a duct 78 shown in dotted lines in FIG. 1, or between the indirect heat exchanger 19 and the adiabatic washer 20. The same result, psychrometrically, can be achieved by mixing return air, for example, at a dry bulb temperature of 75° F. and containing 40 grains of water per pound of dry air with saturated air at 35° F., and in such proportions that the temperature of the mixture is 50° F., or by mixing the return air with air from the indirect heat exchanger 18 at a dry bulb temperature of 95° F. and containing 10 grains of water per pound of dry air, and cooling the resulting mixture in the indirect heat exchanger 19 to such a temperature that air delivered from the adiabatic washer is at a dry bulb temperature of 50° F. and has the humidity represented by the broken line joining points 6 and 7 in FIG. 2 at 50° F.

Under conditions of winter operation the series flow of water from the panel 43 through the thermal louver 46, through the evaporative cooler 44 and back to the panel 43 is peculiarly significant. As has been indicated above, the function of the panel 43 and of the thermal louver 46 is to intercept and to transfer to the evaporatively cooled water a major portion of the load which would otherwise be imposed upon the air circulating system by artificial lights and by sun, respectively. Whenever it is necessary, in conditioning the space 24, to supply heat thereto, this heat can be supplied by the water, at, say 80 to 85° F. leaving the panel 43, and as it flows through the thermal louver 46. Water at such a temperature is effective to compensate for heat losses from the space 24 under most ambient conditions, but is also effective simultaneously to absorb heat from the thermal louver which results from the interception by the louver of solar energy. Accordingly, this arrangement is not only effective under con-

ditions of winter operation, but also prevents or at least minimizes temperature fluctuations which occur in many air conditioning systems as a consequence of the intermittent incidence of solar energy on windows adjoining the conditioned spaces. This result is achieved in part because the water in the louver 46 is at a substantially neutral temperature relative to the space but at a low temperature relative to solar energy, and in part because glass is substantially opaque to radiation from a louver at 80 to 85° F.; as a consequence, the louver reacts to load fluctuations incident to variations in amount of solar energy, rather than to changes in space conditions which would result from such fluctuations, and supplies heat by radiation and convection to the adjacent window surface to compensate for heat losses by conduction and convection but not through the window to the outside.

The thermal louver 46 can be of the type disclosed and claimed in U.S. Patent 3,013,397. Such an assembly can be merely a plurality of hollow, extruded louver members mounted in a window opening, and operatively associated with headers or the like to enable the circulation of water through the louvers. In most instances, the louvers would be mounted for rotational or other movement to enable varying the amount of solar heat and light passing through the assembly. Other types of thermal louvers are also operable, for example, window structures which are effective to intercept solar heat, for example by means of metal strips associated with the glass or because the glass itself is opaque at least to radiant heat energy, and means for conducting heat which results from interception of the radiant heat energy to a circulated heat transfer fluid. The latter means can be metal strips in thermal contact with the heat transfer fluid or a transparent, thermally conductive film on at least one of the major glass surfaces, and in thermal contact with the fluid. Heat absorbing glasses are peculiarly effective, so long as means are provided for transferring the heat absorbed to the circulated heat transfer fluid. The heat absorbing glasses can be of the "stable" type, which have constant light- and heat-absorption characteristics, or can be of the type which increase in opacity relative to radiation in the visible and heat ranges of frequency when solar energy is directly incident thereon and return to a state of reduced opacity when solar energy is no longer directly incident. A structure of either of the latter types, under conditions of winter operation, is effective as a full equivalent of the previously discussed thermal louver structure only when there is a radiation shield, for example a pane of heat absorbing glass or of ordinary glass, disposed exteriorly of the glass which is in thermal contact with the circulated heat transfer fluid, as such radiation shield is necessary to prevent direct radiation to the outside, and excessive heat losses.

The instant invention has heretofore been discussed in connection with the conditioning of a single space 24 which includes both a light source 42 and a glass area adjacent the thermal louver 46. The system is peculiarly adapted for the conditioning of a large building, which would frequently have a plurality of floors. Such a building would ordinarily include both perimeter zones where there would ordinarily be glass to a greater or lesser extent and interior zones having no outside exposure. The thermal louver 46 is effective to compensate for heat losses through associated windows or glass curtain walls, as has been discussed, even when it is supplied only relatively cool water from the panel 43, and is simultaneously effective to intercept solar energy transmitted through the associated window or glass curtain wall, thereby preventing overheating of perimeter spaces on which solar energy is incident at any given time. It will be appreciated that any large building has exterior exposures in a plurality of directions, so that preventing overheating by incident solar energy can be a morn-

ing problem for a perimeter portion having an eastern exposure, a noontime problem for a perimeter portion having a southerly exposure, and an afternoon problem for a portion having a westerly exposure. A perimeter portion having a northerly exposure, however, under conditions of winter operation, would require only warm water, and at a comparatively low temperature, as previously discussed, to compensate for heat losses through associated windows or glass curtain walls. Under many conditions of operation, water warmed as a consequence of interception of solar energy by a thermal louver 46 which is at any given time subject to direct sunlight can be circulated to a different thermal louver 46 which is not then subject to direct sunlight, and for the purpose of compensating for heat losses through the associated window or curtain wall. According to this mode of operation, solar energy incident upon one part of a building, rather than light sources within the building, constitute the source for heat to compensate for heat losses from other parts of the building.

It will be appreciated that interior portions of a building are not subject to heat losses, even under conditions of winter operation, so that sensible cooling, for example by the heat exchanger 19 or by the panel 73 is required at all times when the building is in use. Under conditions of winter operation, however, perimeter portions of the building must be supplied heat, since the thermal louvers are effective principally to offset heat losses through associated windows or curtain walls, but usually are not effective to compensate for all heat losses from the perimeter. The apparatus of FIG. 1 is equally well adapted for winter operation to perform both the cooling function required for the interior and the heating function required for the perimeter of a building. Specifically, under conditions of winter operation, humidification rather than dehumidification of incoming air is necessary, so that exhaust heat from the engine 65 is not required for regeneration of the dehumidifiers. Instead, to enable the accomplishment of humidification, preheating of the incoming air is required, and the preheating can be accomplished in a suitable heating coil (not illustrated) positioned ahead of the dehumidifier 11. The same lithium chloride or ethylene glycol solution can then be used in the dehumidifier 11, and at the same concentration, as under summer operation for humidification of the preheated air. It is then necessary only to add make-up water from any suitable source (not illustrated) to maintain the desired concentration. The dehumidifier 15 would not be used under winter operation, nor would the cooling tower 13. Either the exchanger 19 or the panel 73 could be used for sensible cooling in interior portions of the building, as previously discussed, and warm water from the condenser 60, which would then preferably be a split condenser, could be used for further heating of the humidified air for circulation through a separate duct system (not shown) to perimeter portions of the building, or such warm water could be circulated to panels 73 in the perimeter portion of the building.

Under conditions of winter night operation, assuming that a building in which the air conditioning apparatus shown in FIG. 1 is installed is not occupied, and that lights therein are not energized, there are no heat gains in any part of the building, interior or perimeter, so it is necessary only to supply heat to compensate for heat losses from the building. This can readily be accomplished by providing a suitably sized water storage facility (not illustrated) through which exhaust gases from the engine 65 are directed in indirect heat exchange relationship with the water during day operation. This provides a body of water at a substantial temperature, for example approaching 200° F., which can be used directly to preheat air being brought into the building as previously discussed, or to reheat air circulated within the building, for example through the duct 38 by the blower 39 and

either directly back to a given space 24 or through the line 78 and the duct 25 and back to the space. It is not necessary that the water storage facility be sufficiently large to supply all of the heat required during a long winter night. Instead, when the temperature of the water in the storage facility is too low for such water to be used effectively for heating, the engine 65 can be energized to drive the compressor 58, and chilled water from the evaporator 61 can be used further to cool the water in the facility. Water from the condenser 60 and from the cooling system of the engine 65 is then available to do heating, as previously described, and exhaust gases from the engine 65 add heat to the water in the storage facility to offset, in part, the cooling of such water by the evaporator 61.

Under conditions of summer operation, the series flow feature from the panel 43 to the thermal louver 46 is not essential, as these could be connected in parallel, and the water supplied to each could be evaporatively cooled or could be chilled by means of refrigeration.

The valves 40 and 74 in FIG. 1 have been described as controlling the rate of flow of water through the indirect heat exchanger 19 and the panel 43, by means of a by-passing technique. This is a preferred arrangement. However, throttling valves can be used for this purpose, but particularly in a large building, would ordinarily be somewhat complicated from the standpoint of control of rate of flow of cooled or chilled water, requiring, for example, pumps which are controlled to maintain a constant discharge pressure. For large installations, in particular, it is usually preferred to use pumps which operate at constant speed, thereby circulating the same amount of water under all conditions of operation, and to accomplish temperature control by by-passing water around the devices to whatever extent may be necessary, as shown in FIG. 1.

An important feature of the method and apparatus of the invention, from the standpoint of summer operation, is the ability to provide air at near freezing temperatures with a maximum amount of cooling being done by cooling tower water, and a minimum by a refrigerated coolant which need not be at a temperature below freezing. It will further be seen that a definite advantage exists in performing all of the dehumidification above ambient temperatures and in two stages, a first stage using a liquid desiccant and a second stage using a solid desiccant. Air is not only dried by equipment using a liquid desiccant, but is also washed and cleansed. In addition, the equipment is inexpensive, trouble-free, and keeps the temperature of air from being elevated. A definite limit exists, however, in the amount of moisture which can be removed from air without lowering the temperature of the liquid desiccant below ambient conditions. Solid desiccants, however, can produce very dry air, but they raise the temperature of the air to a considerable extent. By subsequently cooling the air discharged from the second stage dehumidifier in an indirect exchanger using non-refrigerated water, all of the latent heat of evaporation of the water that is removed from outside air during dehumidification is removed at a temperature level high enough that non-refrigerated water can be used to extract the heat. By finishing the dehumidification process with a solid desiccant, drier air can be produced than will finally be required even at low rates of air flow, and a final stage of cooling can be accomplished using adiabatic humidification which obviates the need for a refrigerant at a temperature below the temperature of the finished cooled air.

Inasmuch as heat at elevated temperatures must be used for the regeneration of both the liquid and solid desiccants, a heat engine can advantageously be used to both drive the refrigeration equipment, and produce exhaust heat which can be used to regenerate the chemical desiccants, and for heating, when required. Conservation of energy is therefore accomplished, inasmuch as the heat

which is normally exhausted from a heat engine is used to effect the necessary regeneration of the chemical desiccant, or for heating.

While the invention has been described in considerable detail, it is not to be limited to the particular embodiment shown and described, and it is intended to cover hereby all novel adaptations, modifications and arrangements thereof which come within the practice of those skilled in the art to which the invention relates.

What I claim is:

1. Apparatus for maintaining a predetermined humidity and a predetermined temperature in an air space, said apparatus comprising, in combination: a first chemical dehumidifier which uses a liquid desiccant for absorbing moisture from air passing therethrough, a second chemical dehumidifier which uses a solid desiccant for absorbing moisture from air passing therethrough, an indirect heat exchanger for reducing the temperature of air passing therethrough, a humidifier for humidifying and adiabatically cooling air passing therethrough, means for introducing atmospheric air into a closed circulating system, for circulating air in said system sequentially through said first chemical dehumidifier, said second chemical dehumidifier, said indirect heat exchanger, and said humidifier, and for supplying air from said humidifier to the space, heat exchange means for cooling the liquid desiccant that contacts air passing through said first chemical dehumidifier, cooling means for circulating a coolant in heat exchange relationship with said heat exchange means and with said indirect heat exchanger, and means for absorbing heat from said cooling means, and effective to maintain coolant therein at a temperature above the predetermined temperature.

2. Apparatus for maintaining a predetermined humidity and a predetermined temperature in an air space, said apparatus comprising, in combination: a first chemical dehumidifier which uses a liquid desiccant for absorbing moisture from air passing therethrough, a second chemical dehumidifier which uses a solid desiccant for absorbing moisture from air passing therethrough, a first indirect heat exchanger for reducing the temperature of air passing therethrough, a second indirect heat exchanger for reducing the temperature of air passing therethrough, a humidifier for humidifying and adiabatically cooling air passing therethrough, means for introducing atmospheric air into a closed circulating system, for circulating air in said system sequentially through said first chemical dehumidifier, said second chemical dehumidifier, said first indirect heat exchanger, said second indirect heat exchanger, and said humidifier, and for supplying air from said humidifier to the space, heat exchange means for cooling the liquid desiccant that contacts air passing through said first chemical dehumidifier, first cooling means for circulating a coolant in heat exchange relationship with said heat exchange means and with said first indirect heat exchanger, means for absorbing heat from said first cooling means, and effective to maintain coolant therein at a temperature above the predetermined temperature, second cooling means for circulating a coolant in heat exchange relationship with said second indirect heat exchanger, and means for absorbing heat from said second cooling means, and effective to maintain coolant therein at a temperature below the predetermined temperature.

3. Apparatus for maintaining a predetermined humidity and a predetermined temperature in an air space, said apparatus comprising, in combination: a first chemical dehumidifier which uses a liquid desiccant for absorbing moisture from air passing therethrough, a second chemical dehumidifier which uses a solid desiccant for absorbing moisture from air passing therethrough, an indirect heat exchanger for reducing the temperature of air passing therethrough, a humidifier for humidifying and adiabatically cooling air passing therethrough, means for introducing atmospheric air into a closed circulat-

ing system, for circulating air in said system sequentially through said first chemical dehumidifier, said second chemical dehumidifier, said indirect heat exchanger, and said humidifier, and for supplying air from said humidifier to the space, heat exchange means for cooling the liquid desiccant that contacts air passing through said first chemical dehumidifier, first cooling means for circulating a coolant in heat exchange relationship with said heat exchange means and with said indirect heat exchanger, means for absorbing heat from said first cooling means, and effective to maintain coolant therein at a temperature above the predetermined temperature, panel means positioned for radiative heat transfer with the air space, second cooling means for circulating a coolant in heat exchange relationship with said panel means, and means for absorbing heat from said second cooling means, and effective to maintain coolant therein at a temperature below the predetermined temperature.

4. Apparatus for maintaining a predetermined humidity and a predetermined temperature in an air space, said apparatus comprising, in combination: a first chemical dehumidifier which uses a liquid desiccant for absorbing moisture from air passing therethrough, a second chemical dehumidifier which uses a solid desiccant for absorbing moisture from air passing therethrough, an indirect heat exchanger for reducing the temperature of air passing therethrough, a humidifier for humidifying and adiabatically cooling air passing therethrough, means for introducing atmospheric air into a closed circulating system, for circulating air in said system sequentially through said first chemical dehumidifier, said second chemical dehumidifier, said indirect heat exchanger, and said humidifier, and for supplying air from said humidifier to the space, heat exchange means for cooling the liquid desiccant that contacts air passing through said first chemical dehumidifier, first cooling means for circulating a coolant in heat exchange relationship with said heat exchange means and with said first indirect heat exchanger, means for absorbing heat from said first cooling means, and effective to maintain coolant therein at a temperature above the predetermined temperature, panel means positioned for radiative heat transfer with the air space, second cooling means for circulating a coolant in heat exchange relationship with said panel means, means for absorbing heat from said second cooling means, and effective to maintain coolant therein at a temperature below the predetermined temperature, and means responsive to the temperature of the air space, and effective to control the cooling effect of said second cooling means on said panel means to maintain the air space at the predetermined temperature.

5. Apparatus for maintaining a predetermined humidity and a predetermined temperature in an air space with a high temperature heat source positioned for radiative heat transfer therewith, said apparatus comprising, in combination: a first chemical dehumidifier which uses a liquid desiccant for absorbing moisture from air passing therethrough, a second chemical dehumidifier which uses a solid desiccant for absorbing moisture from air passing therethrough, a first indirect heat exchanger for reducing the temperature of air passing therethrough, a second indirect heat exchanger for reducing the temperature of air passing therethrough, a humidifier for humidifying and adiabatically cooling air passing therethrough, means for introducing atmospheric air into a closed circulating system, for circulating air in said system sequentially through said first chemical dehumidifier, said second chemical dehumidifier, said first indirect heat exchanger, said second indirect heat exchanger, and said humidifier, and for supplying air from said humidifier to the space, heat exchange means for cooling the liquid desiccant that contacts air passing through said first chemical dehumidifier, panel means positioned for radiative heat transfer with the high temperature source, high temperature cooling

means for circulating a coolant in heat exchange relationship with said heat exchange means, with said first indirect heat exchanger, and with said panel means, means for absorbing heat from said cooling means, and effective to maintain coolant therein at a temperature above the predetermined temperature, low temperature cooling means for circulating a coolant in heat exchange relationship with said second indirect heat exchanger, and means for absorbing heat from said low temperature cooling means, and effective to maintain coolant therein at a temperature below the predetermined temperature.

6. Apparatus for maintaining a predetermined humidity and a predetermined temperature in an air space, said apparatus comprising, in combination: a first chemical dehumidifier which uses a liquid desiccant for absorbing moisture from air passing therethrough, a second chemical dehumidifier which uses a solid desiccant for absorbing moisture from air passing therethrough, a first indirect heat exchanger for reducing the temperature of air passing therethrough, a second indirect heat exchanger for reducing the temperature of air passing therethrough, a humidifier for humidifying and adiabatically cooling air passing therethrough, means for introducing atmospheric air into a closed circulating system, for circulating air in said system sequentially through said first chemical dehumidifier, said second chemical dehumidifier, said first indirect heat exchanger, said second indirect heat exchanger, and said humidifier, and for supplying air from said humidifier to the space, heat exchange means for cooling the liquid desiccant that contacts air passing through said first chemical dehumidifier, first cooling means for circulating a coolant in heat exchange relationship with said heat exchange means and with said first indirect heat exchanger, means including a cooling tower for absorbing heat from said first cooling means, and effective to maintain coolant therein at a temperature above the predetermined temperature, second cooling means for circulating a coolant in heat exchange relationship with said second indirect heat exchanger, and means for absorbing heat from said second cooling means, and effective to maintain coolant therein at a temperature below the predetermined temperature.

7. Air conditioning apparatus comprising: refrigerating apparatus, heat engine means effective to convert a fuel into shaft work and exhaust heat, means operatively connecting said heat engine in driving relationship with said refrigerating apparatus, a dehumidifier which employs a desiccant, means for regenerating the desiccant of said dehumidifier, means for directing exhaust heat from said heat engine to said regenerating means and into heat exchange relationship with the desiccant, a humidifier for humidifying and adiabatically cooling air passing therethrough, means for circulating air through said dehumidifier, through said humidifier, and to a space to be air conditioned, and means effective to absorb heat and, as a consequence of such absorption, to remove heat from the space, and to transfer absorbed heat to said refrigerating apparatus.

8. Air conditioning apparatus comprising: refrigerating apparatus, heat engine means effective to convert a fuel into shaft work and exhaust heat, means operatively connecting said heat engine in driving relationship with said refrigerating apparatus, a dehumidifier which employs a desiccant, means for removing desiccant from the dehumidifier for regenerating the desiccant and for returning the desiccant to said dehumidifier, means for directing heat to said regenerating means in two stages including a low temperature indirect heat exchange stage and a high temperature indirect heat exchange stage and into heat exchange relationship with the desiccant in said regenerator to provide a high temperature effluent stream that includes moisture removed from the desiccant, means for communicating said effluent stream to said first indirect heat exchange stage, second means for directing exhaust

heat from said heat engine to said second indirect heat exchange stage, means for circulating air through said dehumidifier into a space to be air conditioned, means effective to absorb heat and as a consequence of such absorption to remove heat from the space, and to transfer absorbed heat to said refrigerating apparatus.

9. Air conditioning apparatus comprising: refrigerating apparatus, heat engine means effective to convert a fuel into shaft work and exhaust heat, means operatively connecting said heat engine in driving relationship with said refrigerating apparatus, a dehumidifier which employs a liquid desiccant, means for regenerating the desiccant of said dehumidifier, means for circulating desiccant from said dehumidifier to said regenerator, and back to said dehumidifier, means for directing exhaust heat from said heat engine to said regenerating means, and into heat exchange relationship with desiccant, means for receiving moisture vaporized from the desiccant in said regenerator, and for directing such moisture vapor in indirect heat exchange relationship with desiccant in said circulating means, and flowing from said dehumidifier to said regenerator, means for circulating air through said dehumidifier and to a space to be air conditioned, and means effective to absorb heat and as a consequence of such absorption to remove heat from the space, and to transfer absorbed heat to said refrigerating apparatus.

10. Air conditioning apparatus comprising: refrigerating apparatus, heat engine means effective to convert a fuel into shaft work and exhaust heat, means operatively connecting said heat engine in driving relationship with said refrigerating apparatus, a dehumidifier which employs a desiccant, means for regenerating the desiccant of said dehumidifier, means for directing exhaust heat from said heat engine to said regenerating means, and into heat exchange relationship with the desiccant, an indirect heat exchanger effective to reduce the temperature of air passing therethrough, a humidifier for humidifying and adiabatically cooling air passing therethrough, means for circulating air through said dehumidifier, through said indirect heat exchanger, through said humidifier, and then to a space to be air conditioned, and means effective to absorb heat from said indirect heat exchanger, and to transfer absorbed heat to said refrigerating apparatus.

11. Air conditioning apparatus comprising: refrigerating apparatus, heat engine means effective to convert a fuel into shaft work and exhaust heat, means operatively connecting said heat engine in driving relationship with said refrigerating apparatus, a dehumidifier which employs a desiccant, means for regenerating the desiccant of said dehumidifier, means for directing exhaust heat from said heat engine to said regenerating means, and into heat exchange relationship with the desiccant, a humidifier for humidifying and adiabatically cooling air passing therethrough, means for circulating air through said dehumidifier, through said humidifier and to a space to be air conditioned, and means including a panel effective to absorb heat from the space and to transfer absorbed heat to said refrigerating apparatus.

12. Apparatus for maintaining a predetermined humidity and a predetermined temperature in an air space, said apparatus comprising, in combination: a chemical dehumidifier which uses a desiccant for absorbing moisture from air passing therethrough, means for regenerating the desiccant of said dehumidifier, an indirect heat exchanger for reducing the temperature of air passing therethrough, a humidifier for humidifying and adiabatically cooling air passing therethrough, means for introducing atmospheric air into a closed circulating system, for circulating air in said system sequentially through said chemical dehumidifier, said indirect heat exchanger, and said humidifier, and for supplying air from said humidifier to the space, cooling means for circulating a coolant in heat exchange relationship with said indirect heat exchanger, and means for absorbing heat from said cooling means, and effective to maintain coolant therein at a tem-

perature below the predetermined temperature, said last-named means including refrigerating apparatus, heat engine means effective to convert a fuel into shaft work and exhaust heat, means operatively connecting said heat engine in driving relationship with said refrigerating apparatus, and means for directing exhaust heat from said engine to said regenerating means wherein said exhaust heat is in heat exchange relationship with the desiccant.

13. Air conditioning apparatus comprising: refrigerating apparatus, heat engine means effective to convert a fuel into shaft work and exhaust heat, means operatively connecting said heat engine in driving relationship with said refrigerating apparatus, a dehumidifier which employs a desiccant, means for regenerating the desiccant of said dehumidifier, means for directing exhaust heat from said heat engine to said regenerating means and into heat exchange relationship with the desiccant, means for circulating air through said dehumidifier and to a space to be air conditioned, first means effective to absorb heat and, as a consequence of such absorption, to remove heat from the space, and to transfer absorbed heat to said refrigerating apparatus, second means effective to absorb heat and, as a consequence of such absorption, to reduce the heat load on the space, and to transfer absorbed heat to a heat transfer fluid, indirect evaporative cooling means for removing heat from the heat transfer fluid, and means for withdrawing relief air from the space and for circulating the relief air through said evaporative cooling means.

14. Air conditioning apparatus comprising: refrigerating apparatus, heat engine means effective to convert a fuel into shaft work and exhaust heat, means operatively connecting said heat engine in driving relationship with said refrigerating apparatus, a dehumidifier which employs a desiccant, means for regenerating the desiccant of said dehumidifier, means for directing exhaust heat from said heat engine to said regenerating means, and into heat exchange relationship with the desiccant, an indirect heat exchanger effective to reduce the temperature of air passing therethrough, means for circulating air through said dehumidifier, through said indirect heat exchanger and then to a space to be air conditioned, first means effective to absorb heat from said indirect heat exchanger, and to transfer absorbed heat to said refrigerating apparatus, second means effective to absorb heat and, as a consequence of such absorption, to reduce the heat load on the space, and to transfer absorbed heat to a heat transfer fluid, indirect evaporative cooling means for removing heat from the heat transfer fluid, and means for withdrawing relief air from the space and for circulating the relief air through said evaporative cooling means.

15. Air conditioning apparatus comprising: refrigerating apparatus, heat engine means effective to convert a fuel into shaft work and exhaust heat, means operatively connecting said heat engine in driving relationship with said refrigerating apparatus, a dehumidifier which employs a desiccant, means for regenerating the desiccant of said dehumidifier, means for directing exhaust heat from said heat engine to said regenerating means, and into heat exchange relationship with the desiccant, means for circulating air through said dehumidifier and to a space to be air conditioned, first means including a panel effective to absorb heat from the space and to transfer absorbed heat to said refrigerating apparatus, second means effective to absorb heat and, as a consequence of such absorption, to reduce the heat load on the space, and to transfer absorbed heat to a heat transfer fluid, indirect evaporative cooling means for removing heat from the heat transfer fluid, and means for withdrawing relief air from the space and for circulating the relief air through said evaporative cooling means.

16. Air conditioning apparatus comprising: refrigerating apparatus, heat engine means effective to convert a fuel into shaft work and exhaust heat, means operatively connecting said heat engine in driving relationship with

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said refrigerating apparatus, a dehumidifier which employs a desiccant, means for regenerating the desiccant of said dehumidifier, means for directing exhaust heat from said heat engine for said regenerating means and into heat exchange relationship with the desiccant, a humidifier for humidifying and consequentially cooling air passing therethrough, means for circulating air through said dehumidifier, through said humidifier, and to a space to be air conditioned, and means effective to absorb heat and, as a consequence of such absorption, to remove heat from the space, and to transfer absorbed heat to said refrigerating apparatus.

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WILLIAM J. WYE, *Primary Examiner.*