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A direct expansion type heating and cooling system is provided with means for supplying a heat exchange coil with proportioned mixtures of liquid refrigerant and hot refrigerant gas. Constant temperature is maintained in the conditioned area at any point from full cooling to full heating, by proportioning refrigerant condensate and hot, uncondensed refrigerant gas to the heat exchange coils. Proportioning is attained by modifying the refrigerant condensate expansion valve to move in the direction of closing in response to an increase in uncondensed refrigerant gas flow into the heat exchange coils. The amount of uncondensed refrigerant gas flow into the heat exchange coils is controlled in response to the temperature of the conditioned area. The feed to the heat exchange coils may vary between 100 percent condensate and no uncondensed refrigerant gas, to 100 percent uncondensed refrigerant gas and no condensate. Normally, a mixture of condensate and refrigerant gas is introduced into the evaporator coil.

Electric resistance heaters may be used in conjunction with the heat exchange coils to supplement heating and to "fine tune" temperature controls.

12 Claims, 1 Drawing Figure

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[58] **Field of Search** 165/29, 30; 62/196

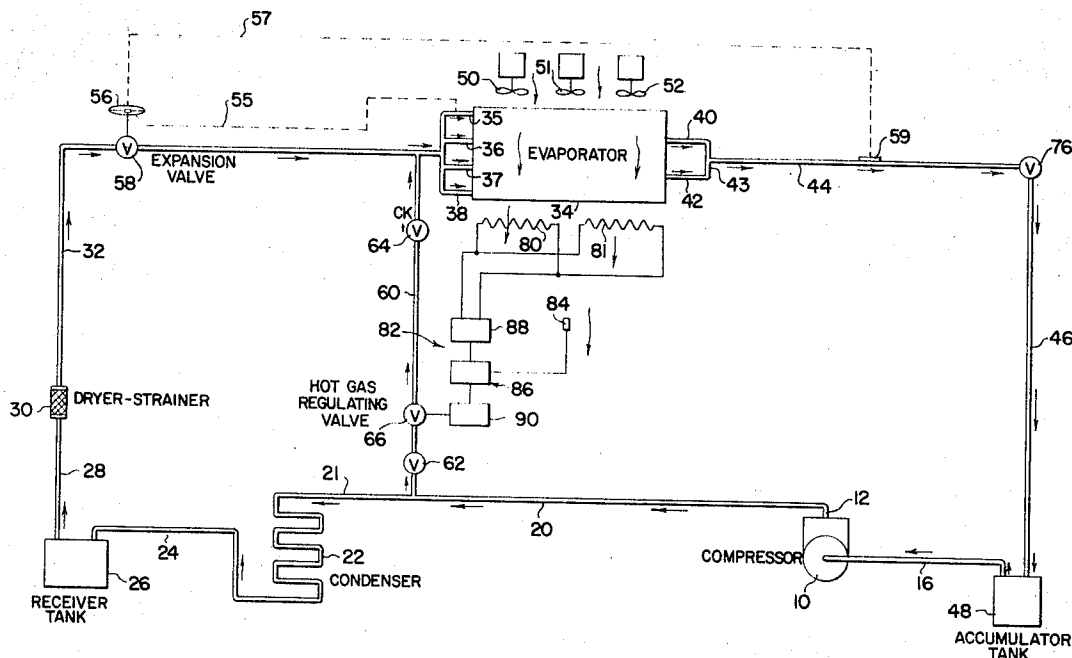
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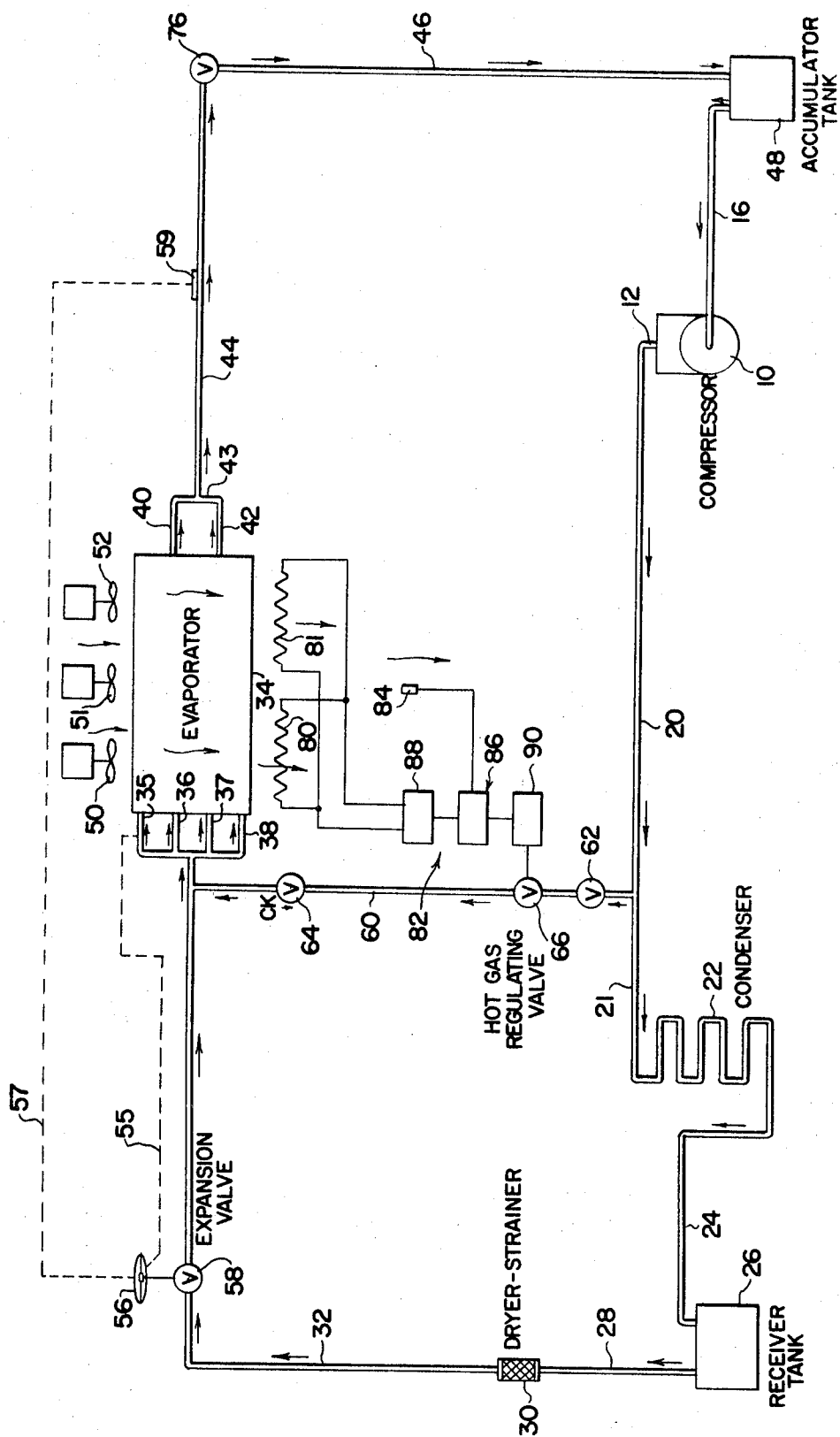
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HEATING AND COOLING SYSTEM

This application is a continuation-in-part application to copending application Ser. No. 821,889, filed May 5, 1969 and now abandoned, and assigned to the assignee of this application.

The present invention is concerned with the art of heating and cooling and, more particularly, to a direct expansion - type heating and cooling system wherein the compressor is operated under constant load and temperature is precisely controlled at any predetermined point from full heating to full cooling by supplying the heat exchange coil with proportioned mixtures of expanded refrigerant condensate and hot refrigerant gas.

The invention is especially suited for use as a temperature control apparatus for environmental growth chambers and the like, and will be described with particular reference thereto. However, it will be appreciated the invention has broader application, and can be used in substantially any type of installation as a heating or cooling apparatus. The invention provides simple, relatively inexpensive single apparatus which may serve as a heater or as a cooler for any desired purpose. Precise temperature control of the area to be heated and/or cooled and a broad range of temperature is provided.

In environmental chambers of the type used for biological experimentation, it is necessary to maintain temperature levels to extremely close tolerances for extended periods of time. Most modern systems used for this purpose (or for any other purpose where precise temperature control is required) have included direct expansion refrigeration units, i.e., units wherein a compressed, condensed refrigerant liquid is evaporated inside a cooling coil, combined with large electrical resistance heaters to balance the overall heat input. The direct expansion refrigeration portions of the systems have been continually developed to improve their control range and efficiency. The more recent have included compressor suction line solenoid controls with evaporator pressure regulation, crankcase pressure regulation, dual evaporators and expansion valves, hot gas bypass regulation, liquid injection valves and liquid shutoff solenoid valves. With these refinements, the compressor could be expected to operate continuously, balancing direct-expansion cooling with a false heat load of hot refrigerant gas bypassed around the condenser and into the cooling coils to maintain reasonably constant demand on the evaporator.

These complex systems, which usually include trimming and protective elements, are typically controlled by a network of relays and a sensitive electronic temperature sensing system. By a large number of small off - on cycles or oscillations about the true control point, they can produce a good, nearly steady temperature control and, with ancillary anticipating-type control subsystems, the control achieved is about as good as any cycling system could be expected to attain.

Another prior art approach is to employ a proportional control system. A proportional control cooling system is one in which a portion only of the coolant circulating through the heat exchange coil is cooled, the remainder being directly recycled from the heat exchange coil outlet to the inlet. The proportion of coolant directly recycled is controlled by a proportioning valve which is responsive to the temperature sought to

be maintained. Proportional control cooling heretofore was used only in secondary medium systems, which are systems wherein direct expansion of refrigerant is used to cool a ballasting secondary medium, e.g., an ethylene glycol-water mixture. The secondary medium is pumped from the cooling point to the heat exchange coils in the area to be cooled and introduced to the coils through a proportioning valve through which a portion of uncooled secondary medium recycled from the heat exchange coils is also passed. The degree of cooling may be increased simply by increasing the proportion of secondary medium which is cooled.

Proportional control cooling thus provides, in a ballasted or secondary medium system, a very close approach to thermal balance at all loads, i.e., good temperature control. In operation, all elements in such a system run continuously without off - on cycling, and the proportioning valve must move only slightly to maintain the proper proportion of fresh, cold secondary medium to be added to the recirculating loop of relatively warm secondary medium entering the heat exchange coil. Anticipating controls are often used which maintain the required setting without imposing unduly excessive cycling of the direct expansion refrigerant system which cools the secondary medium.

Although secondary medium systems are very satisfactory operationally, they do have drawbacks. Firstly, the direct expansion refrigeration unit at the cooling point is required to operate on a cyclical basis, although with reduced frequency. Secondly, although proportional in their cooling, the systems could not, of course, add heat to the chamber. Consequently, a supplemental heating system is required. Thirdly, and of primary significance, the secondary medium system, while providing considerable economies in operation, reliability and maintenance, require a substantially increased first cost due to the added equipment required to accommodate and circulate the secondary medium and to provide heat exchange between it and the refrigerant system. As a result, secondary medium systems are normally used only in large installations where maintenance and operating cost savings can justify the increased first cost.

The present invention provides a two-phase, single medium, fully proportional control heating and cooling system wherein direct expansion of refrigerant condensate is proportioned with direct injection of hot, uncondensed refrigerant gas to attain precise control of temperature in the cooled or heated area.

In accordance with one aspect of the invention, an improved heating and cooling system is provided wherein a refrigerant compressor has its output connected via first conduit means conventionally through a condenser and expansion valve to a heat exchange coil, and via second conduit means through a modulating valve directly to the heat exchange coil. The first conduit means and the second conduit means, as well as their associated equipment, are each of a capacity sufficient to handle the entirety of the compressor output.

The expansion valve through which refrigerant condensate is expanded into the heat exchange coil is provided with means to sense the quantity of hot gas supplied to the heat exchange coil via the second conduit means. The expansion valve is of modified construction so that it reduces the flow of refrigerant condensate to

the heat exchange coil in response to an increase in hot gas flow.

In accordance with another more limited aspect of the invention, electric heaters are positioned at the air discharge side of the heat exchange coil to provide a fine adjustment control for the system.

Accordingly, a primary object of the invention is the provision of a direct expansion refrigerant type system which is capable of fully proportional control operation for both heating and cooling.

Another object of the invention is the provision of a direct expansion type heating and cooling system wherein the compressor can operate under continuous and relatively constant load at any setting from full heating to full cooling.

A further object is the provision of a system of the type described wherein fully proportional control of operation is achieved throughout the entire heating and cooling range without the need for any control relays or solenoid valves.

A further object of the invention is the provision of a system of the type described which is simply to construct, has a low first cost, and low maintenance and operating cost when compared to prior art systems capable of performing similar functions.

Another object of the invention is to provide a compact, simple apparatus capable of heating or cooling to maintain any temperature setting between about -25°C and about $+50^{\circ}\text{C}$.

These and other objects and advantages of the invention will become apparent from the following detailed description of a preferred embodiment of the invention and the accompanying single FIGURE which forms a part thereof and which shows, in schematic fashion, a two-phase, single medium direct expansion type heating and cooling system constructed in accordance with the invention.

The embodiment of the invention illustrated in the FIGURE includes a conventional refrigerant compressor 10, from the output 12 of which compressed, hot refrigerant gas is conducted through line 20 past its connection with line 60, then through line 21 to the inlet of condenser 22. Condenser 22 is preferably a standard finned tube or tube-in-tube air cooled condenser wherein sufficient heat is removed from the compressed gas to condense it to liquid refrigerant condensate. Obviously, any type of condenser, air or liquid cooled, or both, may be employed.

From condenser 22 the refrigerant condensate is passed through line 24 to a receiver tank 26. From the receiver tank 26 the refrigerant condensate is passed through line 28 through a dryer-strainer 30 thence through line 32 and modified expansion valve 58 to inlet of evaporator 34. Evaporator 34 may be of any type, either plate or finned; however, it is preferably a conventional finned tube heat exchange unit having multiple inlets 35, 36, 37 and 38 as required for capacity. The outlets 40, 42 from the evaporator 34 are connected to a common header 43 which connects through line 44, crankcase pressure regulating valve 76 and line 46, with an accumulator tank 48. Refrigerant medium enters the compressor inlet from accumulator tank 48 via line 16.

The above-mentioned components are those which are conventionally (except for the modification of valve 58) found in direct expansion type refrigeration systems. In addition, other items of equipment such as

filters, valves, fittings, oil separators, return lines, etc., may be employed and are not shown, being standard and well-known in the art.

The condensate expanded through modified expansion valve 58 vaporizes and provides a cooling effect to the heat exchange coils (not shown) within evaporator 34. The vaporizing liquid condensate comprises one phase of the two-phase system of the invention.

Uncondensed hot refrigerant gas, passed directly from outlet 12 of compressor 10 via lines 20 and 60 to the inlet of evaporator 34, provides the second, gaseous phase of the invention. By being passed "directly" to the evaporator, it is meant that the hot, compressed refrigerant gas bypasses condenser 22 in going from the compressor outlet to the evaporator inlet.

Line 21 thus comprises a first conduit means to pass compressor output to the condenser, thence to the evaporator, and line 60 comprises a second conduit means to pass compressor output directly to the evaporator.

Line 60 is seen to be directly connected from a point upstream of condenser 22 (in relation to the direction of fluid flow) to the inlet of evaporator 34. Line 60 includes a standard shutoff valve 62 and a check valve 64 arranged to prevent reverse flow through line 60. Regulating valve 66 is also positioned in line 60. Regulating valve 66 is the hot gas injection valve and is provided with a motor operator 90. Motor operator 90 and electric resistance heaters 80, 81 are controlled by a temperature sensing and control circuit, generally indicated by the numeral 82.

Control circuit 82 comprises temperature sensing element 84 which senses the temperature of the air or other atmosphere conditioned by heat exchange coils of evaporator 34. In the embodiment shown, temperature sensor 84 is connected with a bridge circuit controller 86. The temperature input signal to controller 86 supplies appropriate outputs to respectively controller 88 which controls electric resistance heaters 80, 81 and to motor operator 90 which controls hot gas regulating valve 66.

Expansion valve 58 is positioned in refrigerate condensate line 32 and has a temperature sensing bulb 59 conventionally attached to outlet line 44 of evaporator 34. An increase in temperature of refrigerant leaving evaporator 34 via line 44 tends to open valve 58 by increasing pressure on the upper portion of a diaphragm 56 via line 57 in conventional manner. Line 55 is a pressure equalization line for valve 58 and is connected to the underside of diaphragm 56 so that an increase in pressure in line 55 will tend to close expansion valve 58. Pressure equalization line 55 is thus the conventional equalization pressure line except that it is positioned at the point at which hot gas is injected into the inlet to the heat exchange coil in evaporator 34, i.e., connecting the equalization line so it senses the pressure of injected hot gas, causes valve 58 to move in a closing direction in response to an increase in hot gas injection. The movement in a closing direction will be offset somewhat by the movement in an opening direction imposed as increased temperature is sensed by sensing bulb 59. However, the opening tendency imposed by line 57 will be overridden by the closing tendency imposed by line 55 to the extent the heat input to the heat exchange coil is taken up by the heating requirement of the air or other atmosphere being heated, or cooled by being passed over the coils of evaporator

34 by fans 50, 51, 52. In operation, pressure equalization line 55 differs from conventional expansion valve equalization lines in that it functions as a shut-off device for the expansion valve rather than merely as a pressure referencing means from which temperature bulb 59 is set. That is to say, conventionally, temperature bulb 59 would control the operation of valve 58, with pressure equalization line 55 merely serving to set the pressure reference from which the temperature bulb works.

The closing movement of expansion valve 58 caused by hot gas injection in accordance with the invention is to be contrasted with prior art hot gas injection into the coils of the evaporator which was for the purpose of imposing an artificial heat load which would tend to move the expansion valve in the opening direction in response to the increased temperature of the gas leaving the coils of the evaporator.

In operation, a decrease in the temperature sensed by temperature sensing device 84 moves regulating valve 66 in an opening direction. This causes an increase in hot gas flow through line 60 (valve 62 being normally in the open position) and the increased pressure causes thereby is sensed by equalization line 55 which urges expansion valve 58 in a closing direction.

An increase in the temperature sensed by temperature sensing element 64 will move valve 66 in a closing direction.

Any suitable controlling mechanism may be employed in conjunction with valve 58. Normally, the control mechanism comprises essentially two chambers separated by a flexible diaphragm. The diaphragm flexes in response to an imbalance of pressure between the two chambers. The movement of the diaphragm adjusts the valve in a closing or opening direction. Normally, upward movement of the valve stem tends to close the valve and downward movement tends to open it so that an increase in pressure on the underside of the diaphragm will tend to close the valve while an increase in pressure on the underside of the diaphragm will tend to open the valve.

As valve 66 moves in a closing direction, valve 58 tends to open wider by virtue of the reduction of pressure in pressure equalization line 55 and additional and enhanced cooling effect is obtained. It is thus seen that in accordance with the invention, a fully proportional control between hot refrigerant gas and liquid condensate is attained in response to the set point at which temperature sensing device 84 is positioned.

This is to be contrasted with the usual means of employment of an equalization line on the refrigerant expansion valve which is to balance the inlet (or outlet, in the case of an external equalization line) condensate pressure against the refrigerant demand as sensed by the remote temperature bulb. Normally, internal equalization is used only with the evaporator coils which sustain a small pressure drop. See, for example, *HANDBOOK OF AUTOMATIC REFRIGERANT CONTROLS*, Alco Valve Company, St. Louis, Missouri, 1955, pages 25 thru 30. When a significant pressure drop of the refrigerant occurs across the coil, pressure equalization at the outlet end of the coil, i.e., external pressure equalization, is required in order to prevent excessive superheating of the exit refrigerant gas. Although the injection of hot gas via line 60 into the evaporator inlet in accordance with the invention increases the pressure drop across the evaporator coils dramatically, external equalization is not employed in accordance

with the invention. For example, with hot gas injection in accordance with the invention to provide a full or significant heating effect, a pressure drop of as much as 30 to 50 lbs/sq. inch may be sustained across the heat exchange coils of the evaporator. Even without hot gas injection, a pressure drop of as much as 10 lbs/sq inch may be sustained across the refrigerant coils. Notwithstanding the substantial pressure drop, external equalization of valve 58 is not employed, but rather a modified form of internal equalization via line 55 is employed. In contrast, the prior art practice in utilizing conventional hot gas injection is to employ external equalization of the expansion valve because of the higher pressure drop. See, for example, *SPORLAN VALVE COMPANY BULLETIN 90 - 10*, page 13, which shows conventional hot gas injection and external equalization. The fully proportioning effect between refrigerant condensate and hot compressed refrigerant gas provided by the invention permits steady operation of the compressor regardless of whether the demand on the evaporator is for heating or cooling. The invention has obvious advantages in maintaining precise temperature control because the proportioning between refrigerant condensate and hot refrigerant gases may be varied in infinitely small increment from full heating to full cooling. That is to say, the entire compressor output may be diverted through line 60 so that hot gases serve to heat the coils of evaporator 34 and it operates in a full heating mode. Alternatively, the entire compressor output may be diverted through condenser 22 and line 24 so that the evaporator operates in a full cooling mode. In the usual case, the evaporator will operate somewhere between the two extremes in order to maintain temperature control at the point desired, and may be adjusted at any point between the two extremes in response to a temperature sensing device or any other control means. In the sense that the apparatus of the invention can conveniently be employed as a heating as well as a cooling device, it has some of the characteristics of a heat pump with the significant practical advantages that the valving, solenoid switches, and other moving parts required in a true heat pump in order to reverse the condenser and evaporator roles as required are not needed. It is to be particularly noted that the apparatus of the invention may function with fully proportional control without the employment of a single solenoid or relay switch. This simplicity of maintenance and low cost reflected by the simple structure of the invention which nonetheless has completely and infinitely adjustable settings along a given temperature range between full cooling and full heating is highly advantageous. For example, in one embodiment of the invention, a cooling - heating range from between about -25°C to $+50^{\circ}\text{C}$ may be obtained in a single, simple piece of equipment in accordance with the invention. Such equipment is highly useful, and may be employed as, for example, in testing electronic equipment at various extremes of hot and cold temperatures. Such apparatus may be employed in a small insulated chamber and the temperature therein may be readily maintained at any desired point.

Another advantage of the invention over the conventional prior art hot gas injection mode of operation is that with conventional hot gas injection to impose a false heat load on the compressor, the duty load on the condenser increases because of the increased amount of refrigerant which must be condensed, thereby in-

creasing the amount of utilities required and the size of condenser required. The present invention does not impose a false heat load on the compressor and thereby increase condenser requirements, but in responding to, for example, a decrease below the temperature set point, heat from the compressed hot gases is directly placed into the heat exchange coils to overcome the temperature decrease. This mode of operation tends to decrease rather than increase the condenser requirements, since less compressed refrigerant gas need be condensed therein. Further, a built-in defrosting capability is attained by directly injecting hot gases into the evaporator coils.

As hereinabove mentioned, a crankcase pressure regulating valve 76 is positioned between the outlet of the evaporator 34 and the inlet of the compressor 10. This valve is responsive to the pressure within line 46 and functions to prevent overloading of compressor 10 during the high rates of hot gas admission which may occur during a general system heat-up or a system defrost.

According to a further aspect of the invention, it is preferable that electrical resistance heaters be provided to give final control balance to the system. As shown in the FIGURE, two resistance heaters 80, 81 are positioned downstream of evaporator coil 34 in relation to the direction of air or other atmosphere flow. As hereinabove noted, heaters 80, 81 are controlled by the same regulating temperature sensing control system 82 which controls regulating valve 66.

As noted above, electric resistance heaters 80, 81 may be supplied in accordance with a limited aspect of the invention. Output from one leg of bridge circuit 86 goes to electrical resistance heater controller 88, in response to a demand sensed by temperature sensor 84 for further heating of the air or other atmosphere being conditioned. The provision of supplemental heaters, although not normally required, permits extra-fine tuning of the temperature and also increases the total heat output capacity of the system. In most cases, however, as noted above, such supplemental heating is not required for control because of the inherent fine tuning control built into the system by virtue of its fully proportional, infinitely small increments, operating characteristics.

This invention has been described in great detail sufficient to enable one of ordinary skill in the heating and cooling art to make and use the same. Obviously modifications and alterations of the preferred embodiment shown will occur to others upon the reading and understanding of the specification and it is intended to include all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.

What is claimed is:

1. A direct expansion-type heating and cooling system for controlling the temperature within an area including a compressor, a first conduit means connecting the output of said compressor to a condenser, thence to an expansion valve, and thence to a heat exchange coil, the improvement comprising;

a second conduit means connecting the output of said compressor to a hot gas regulating valve means thence directly to said heat exchange coil, means for responding to the temperature within said area and adjusting said hot gas regulating valve means to control the rate of flow of hot refrigerant

gas to said heat exchange coil in accordance with the temperature level desired, and

means associated with said expansion valve for sensing the quantity of hot refrigerant gas supplied to said exchange coil, and structurally associated with said expansion valve to reduce the flow of refrigerant condensate through said expansion valve in response to an increase in hot gas flow, and to increase the flow of refrigerant condensate through said expansion valve in response to a decrease in hot gas flow.

2. The improved system of claim 1 wherein said first conduit means and said condenser and expansion valve are of a capacity sufficient to conduct substantially the entire output of said compressor therethrough, and said second conduit means and said hot gas regulating valve are of a capacity to conduct substantially the entire output of said compressor therethrough.

3. The improved system of claim 1 wherein said second conduit means is connected to said compressor outlet upstream of said condensor and is connected to the inlet to said heat exchange coils downstream of said expansion valve, both as sensed in relation to the direction of flow of refrigerant through the system.

4. The improved system of claim 1 wherein said means associated with said expansion valve for sensing the quantity of hot refrigerant gas supplied to said heat exchange coil comprises pressure equalization means connected to the inlet of said heat exchange coils so that the pressure of hot refrigerant gas introduced thereto will be imposed through said pressure equalization means and transmitted to the control mechanism of said expansion valve.

5. The improved system of claim 4 wherein said means associated with said expansion valve comprises a pressure equalization line, one end of which is connected to a valve control mechanism so that an increase in the pressure sensed by the equalization line will move the valve control mechanism in a direction tending to close said expansion valve.

6. The improved system of claim 1 further including electric heating means positioned in series flow relationship with the atmosphere passing over said heat exchange coils.

7. The improved system of claim 1 further including fan means to pass the atmosphere over said heat exchange coils.

8. The improved system of claim 1 further including a control circuit comprising temperature sensing means to sense the temperature of the conditioned atmosphere, and means to control said regulating valve in response to the sensed temperature.

9. The improved system of claim 8 further including electric resistance heaters positioned in series flow with said heat exchange coil with respect to the conditioned atmosphere flow, and means whereby said electric resistance heaters are controlled simultaneously with said hot gas regulating valve in response to the temperature sensed by said temperature sensing means.

10. In a direct expansion-type heating and cooling system for controlling the temperature within an area including a compressor having its output connected to a first conduit with a condensor and thence a heat exchange coil, the improvement comprising:

second conduit means for bypassing said condensor and supplying hot compressed refrigerant gas directly from said compressor to the inlet of said heat

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exchange coil, regulating valve means in said second conduit means and expansion valve means in said first conduit means,
control means for sensing the temperature within the conditioned area and means for adjusting, respectively, said regulating valve and said expansion valve to vary the relative proportions of hot compressed refrigerant gas and refrigerant condensate supplied to said heat exchange coils, in accordance with the temperature level desired in said area.

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11. The improvement defined in claim 10 wherein said regulating valve is controlled in response to the temperature sensed in said conditioned area, and said expansion valve is controlled in response to the amount of hot gas flow into said heat exchange coils.

12. The improved system of claim 11 wherein said control means decrease the flow through said expansion valve in proportion to an increase in flow through said regulating valve.

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