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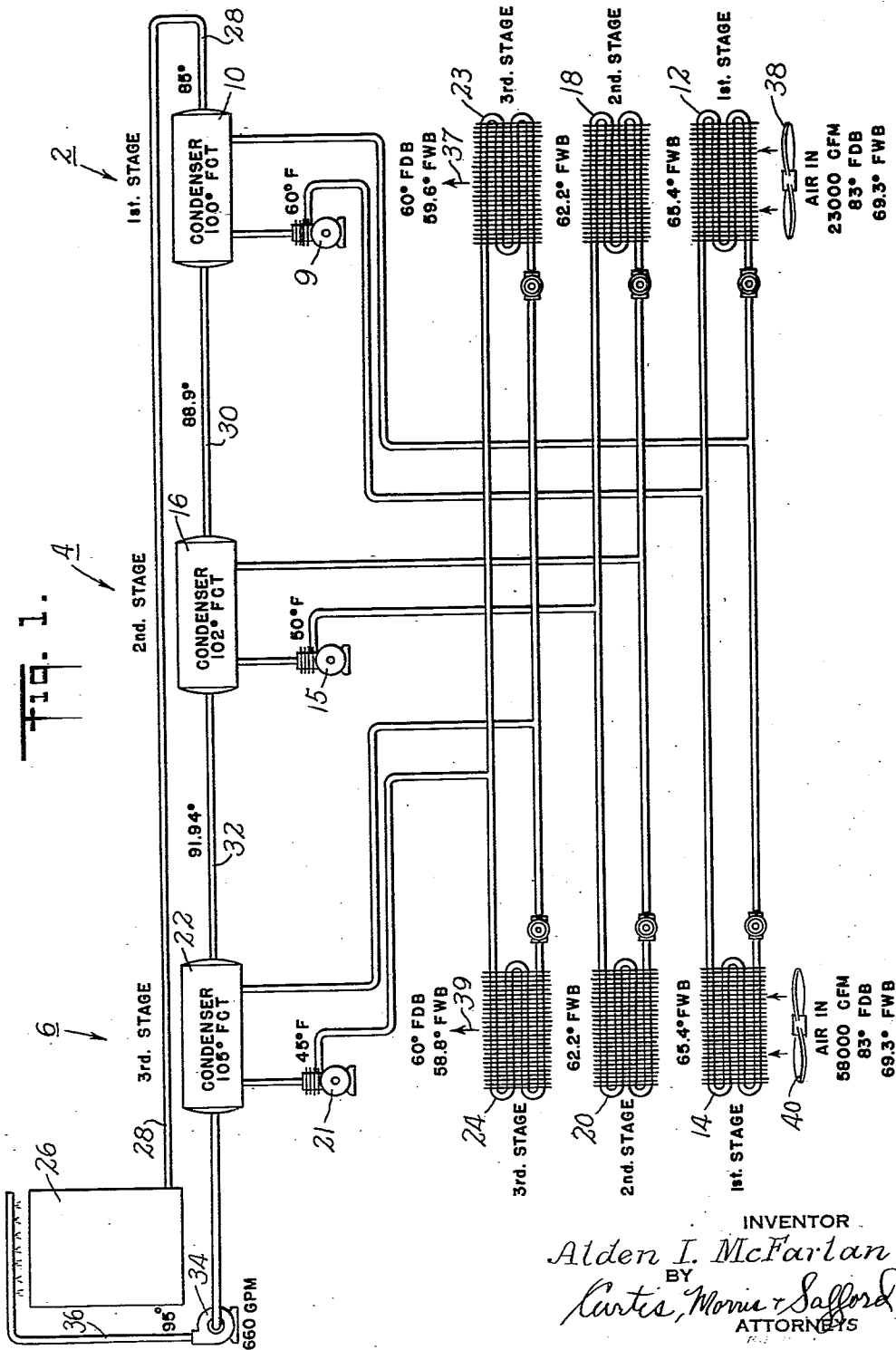
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2,796,743

PLURAL STAGE AIR CONDITIONING SYSTEM

Filed March 11, 1954

2 Sheets-Sheet 1



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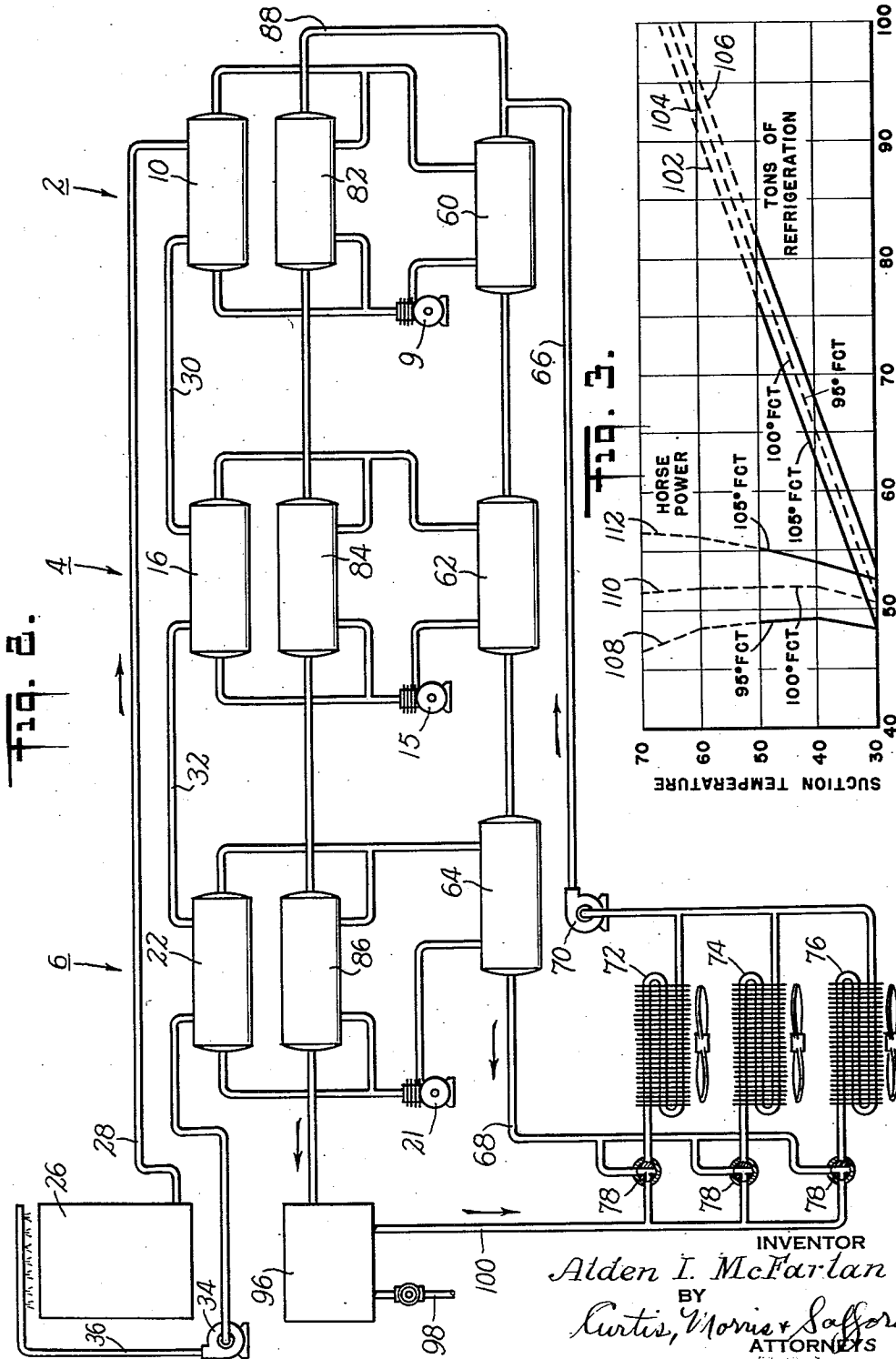
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PLURAL STAGE AIR CONDITIONING SYSTEM

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9 Claims. (Cl. 62—117.6)

This invention relates to air conditioning, and more in particular to relatively large air conditioning systems for use in cooling buildings, for example, retail stores and the like.

An object of this invention is to provide improved air conditioning systems which are less expensive to install and operate than those previously obtainable. A further object is to provide such systems which operate with improved efficiency and which are capable of reducing the air temperatures very rapidly on the conditioned spaces. Another object is to provide systems of the above character which produce substantially greater cooling for given compressor capacities than the normally accepted practices and standards. A still further object is to provide systems of the above character which are relatively light in weight and compact, and efficient in operation at all times. These and other objects will be in part obvious and in part pointed out below.

In the drawings:

Figure 1 is a schematic representation of one embodiment of the invention;

Figure 2 is a view similar to Figure 1, and representing another embodiment of the invention; and,

Figure 3 is a diagram of one characteristic of operation of the system of Figure 1.

Referring to the drawing, an air conditioning system has three similar but distinct and separately operating refrigeration systems, a first stage system 2, a second stage system 4, and a third stage system 6. System 2 has a compressor 9, a condenser 10, a pair of evaporator coils 12 and 14; system 4 has a compressor 15, a condenser 16, a pair of evaporator coils 18 and 20; and, system 6 has a compressor 21, a condenser 22, a pair of evaporator coils 23 and 24. Each system has standard controls to obtain automatic operation. The condensers shown are all of the water tube shell type, and they have their water circuits connected in series. Accordingly, a stream of cold water is supplied from a cooling tower 26 through a cold water line 28 to condenser 10, thence through a line 30 to condenser 16, thence through a line 32 to condenser 22, and from condenser 22 through a pump 34 and a line 36 back to the cooling tower.

Evaporator coils 12, 18, and 23 are positioned in series along the cooling path of a stream 37 of air which is directed through the coils by a blower fan 38. Evaporator coils 14, 20, and 24 are similarly positioned in series along the cooling path of a stream 39 of air from a blower fan 40.

In the illustrative embodiment of the invention, a specific system is disclosed for cooling two spaces, the basement, and the first floor and mezzanine of a retail store. The stream 37 of air from fan 38 is distributed for cooling the basement, and the stream 39 of air from fan 40 is distributed for cooling the first floor and mezzanine. In the illustrative embodiment, fan 38 handles 23,000 cubic feet per minute, with the air entering at 83° F., dry bulb, and 69.3° F. wet bulb, and leaving at 60° F., dry bulb,

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and 59.6° F., wet bulb; and fan 40 handles 58,000 cubic feet per minute of air entering with identical characteristics and leaving at 60° F., dry bulb, and 58.8° F., wet bulb. The difference in wet bulb temperatures of the conditioned air takes care of the difference between the relative latent and sensible heat loads in the two spaces. That is, there is a relatively higher latent heat load in the basement than in the first floor and mezzanine.

In this system, it is assumed that water flows to tower 26 at 95° F. and leaves the tower at 85° F., so that, the first stage condenser 10 receives water at 85° F., and this condenser is operated at a condensing temperature of 100° F. It is assumed that the water temperature rises in condenser 10 to 88.9° F., and this water passes to the second stage condenser 16 which is operated at a condensing temperature of 102.5° F. The temperature of the water rises in condenser 16 to 91.4° F. and flows through line 32 to the third stage condenser 22, which operates at a condensing temperature of 105° F. Hence, there is a staged rise in the water and condensing temperatures through the condensers 10, 16, and 22.

There is also a difference in the evaporator temperatures of the various evaporator coils of the three refrigeration systems. That is, the first stage evaporator coils 12 and 14 operate at 60° F.; the second stage evaporator coils 18 and 20 operate at an evaporator temperature of 50° F.; and the third stage evaporator coils operate at an evaporator temperature of 45° F. Hence, as each of the two streams of air flows through and encounters the respective evaporator coils the air becomes colder, but the temperature of the coils also drops. That is, the warm air in stream 37 at 83° F., dry bulb, and 69.3° F., wet bulb, encounters coil 12 which has a refrigerant temperature of 60° F., and the air gives up the major portion of its heat and leaves this coil at 65.4° F., wet bulb; it then encounters coil 18 which has a refrigerant temperature of 50° F., and the air is cooled to 62.2° F., wet bulb; and, it encounters coil 23 which has a refrigerant temperature of 45° F. and the air is cooled to its final condition of 60° F., dry bulb, and 59.6° F., wet bulb. The warm air in stream 39 is cooled by coils 14, 20, and 24 in the same exact manner except that it has its wet bulb temperature reduced to 58.8° F. by coil 24.

By maintaining the staged coil temperatures, that is, with the coil surfaces being of reduced temperature, as the air temperature drops the air is cooled in an efficient and dependable manner. Each of the refrigeration systems operates at high efficiency, and the entire system requires relatively low power for all conditions of operation. There is also a reduction in the time required to "pull down" the system when it is first started, for example, at the beginning of an operating day.

The net cooling effect is in the order of 250 tons of refrigeration with the three 50-horsepower compressors. Cooling tower 26 is smaller than would be required for comparable systems not using the staged operation for the condensers. With this system, the over-all weight and size of the components of the system are reduced materially; there is a reduction of 25 to 50 percent in the rated horsepower of the compressors; reductions in the sizes of the water lines carrying the tower water, the water pumps, the cooling tower fan and its motor, and the auxiliary equipment.

It is contemplated that the condensers may be operated in parallel, rather than in series as in Figure 1, and yet certain advantages of the invention will still be obtained. For example, where unlimited amounts of low-cost water are available, the cooling tower is eliminated and the condensers are operated in parallel and they maintain the lowest possible condensing temperatures. This results in the least compressor motor horsepower. Under some

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circumstances, the condensers may be of the air and evaporative water type, or they may be in parallel or series flow relationship with respect to the air stream. While separate compressors are illustrated, it may be desirable to provide a single compressor having a number of different cylinders which act as separate compressors. In Figure 1, the coils 12, 18, and 23 are shown as separate coils, and it is contemplated that they be built into a single coil with three separate circuits, as indicated. The same applies to coils 14, 20, and 24. It is understood that controls are provided to maintain the operating conditions set forth. The controls may include arrangements for limiting the refrigerant suction pressure of compressor 21 so as to reduce the compressor capacity automatically for positional load conditions. This limits the motor horsepower, and consequently reduces the operating cost.

In the embodiment of Figure 2, the staged refrigerant systems, such as those of Figure 1, are used to cool a stream of water which is then circulated to cooling coils, and air is cooled and dehumidified by the cooling coils. Accordingly, in Figure 2, the first stage refrigeration system 2 has a single water-cooling evaporator 60. The second stage refrigeration system 4 has a single water-cooling evaporator 62, and the third stage refrigeration system 6 has a single water-cooling evaporator 64. A stream of water passes from a line 66 in series through the evaporators 60, 62, and 64, and it flows from evaporator 64 through a line 68. Circulation is produced by a pump 70 which directs the water from the respective air coils 72, 74, and 76 through line 66. Each of coils 72, 74, and 76 has a fan which directs air through the coil in a counter-current flow. Each of the coils is also provided with a valve 78 which automatically stops the flow through the coil when the cooling effect is to be reduced. With this arrangement, the advantages of staged cooling are obtained, so that the various stages produce substantially more refrigeration than would be produced otherwise.

In the embodiment of Figure 2, an arrangement is also provided for utilizing the heat of condensation from the condensers to satisfy part or even all of the heating load in the conditioned space. In this respect the present invention is related to that of my copending application, Serial No. 399,507, filed December 21, 1953. Accordingly, in Figure 2 the refrigeration systems 2, 4, and 6 are provided respectively with auxiliary condensers 82, 84, and 86. Each of these condensers is connected in parallel with the main condenser of its system. The auxiliary condensers have their water circuits connected in series in a closed water-heating circuit which is connected by a line 88 with line 66 of the water cooling circuit of the evaporators 60, 62, and 64. Hence water may flow from line 66 through line 88, and thence through the auxiliary condensers 82, 84, and 86 in series. Connected in the outlet line from auxiliary condenser 86 is an auxiliary water heater 96 which receives steam for heating through a line 98. Accordingly, a supply of hot water is provided in line 100 extending from auxiliary heater 96. Line 100 extends to the valve 78 at the inlet of each of the coils 72, 74, and 76. Each valve 78 is controlled by the cooling or heating requirements of its space, so that its coil is supplied with the proper amount of hot or cold water to maintain the desired conditions in the space.

With this arrangement the auxiliary condensers are used for a sufficient amount of the heating load at all times to take care of the heating requirements in the various zones and spaces. For example, if the space served by only one of the coils requires heating, then that coil receives hot water, and the other coils may receive cold water for effective cooling and dehumidification. Where fully automatic controls are desired, these are provided.

Figure 3 illustrates the operation of the system of Figure 1 under varying conditions. In this figure, the performance curves are shown for a typical fifty horsepower reciprocating compressor of the type used in the range of human comfort conditions. The vertical values represent

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the temperature corresponding to the suction pressure, and the horizontal values represent tons of refrigeration produced and also horsepower required to drive the compressor. The curves 102, 104, and 106 show the increase in tons of refrigeration produced at the respective condensing temperatures indicated as the suction temperature rises. The substantially vertical curves 108, 110, and 112 show the horsepower required to drive the compressor to produce the refrigeration effects at the conditions of curves 102, 104, and 106. It is to be noted that for 100° F. condensing temperature and for suction temperatures above 50° F. the horsepower falls off, while the tons of refrigeration increase. Hence, with the staging of the condensers, as herein disclosed, the maintenance of 100° F. condensing temperature in the first stage, and operating at about 60° F. suction temperature, it is impossible to overload the compressor motor.

This is an important feature, since single stage compression systems as normally used with a suction temperature of 35° F. to 45° F. and a condensing temperature in the order of 105° F. frequently overload the compressor during the "pull down" period when the conditioned space is hot. With such operation, the suction pressure is such that the horsepower rises as the suction temperature tends to increase, due to the abnormally high temperature conditions. The present invention corrects this very objectionable condition, and it also effects great economy in the initial cost and in operation.

Another important advantage of the invention is that the system will operate with fairly acceptable results even if one of the stages is incapacitated. Under such circumstances, the remaining stages produce in the order of 70-75 percent of capacity, and the system does not break down because of overloading.

I claim:

1. In an air conditioning system of the character described, the combination of, a plurality of refrigeration units each of which has a condenser and an evaporator, each of said condensers being adapted to be cooled by water, a cooling tower which is adapted to cool water, circuit means connecting the water circuits of said condensers in series, pump means to circulate water through said condensers and said cooling tower in series, and means to pass a stream of a fluid to be cooled through said evaporators, said plurality of refrigeration units being operable to produce staged heating of the water flowing through the respective condensers and staged cooling of the fluid by said evaporators, and said circuit means connected to deliver water from said cooling tower to the condenser of the refrigeration unit producing said first stage of cooling whereby said refrigeration system with the highest temperature evaporator has the lowest temperature condenser to cool at a maximum rate.

2. A system as described in claim 1, wherein said fluid to be cooled is air and wherein each of said evaporators is formed by a plurality of evaporator sections for cooling separate streams of air and each stream of air flows through an evaporator section forming part of each of said refrigeration units.

3. A system as described in claim 1, wherein the fluid cooled by said evaporators is a circulating liquid, conduits connecting said evaporators in series to provide a circuit for the circulating liquid, and wherein each of said refrigeration units includes an auxiliary condenser, coil means through which said fluid is circulated into heat exchange relationship with air to be conditioned, and means to selectively flow liquid from said auxiliary condensers in series and from said evaporators in series through said coil means.

4. In an air conditioning system, the combination of, a plurality of independent refrigeration units having evaporators operable at progressively lower temperatures and condensers operable at progressively higher temperatures, means for directing a stream of fluid to be cooled in heat exchange relationship with the evaporators of

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the several refrigeration units in series to cool the fluid in successive stages through a wide temperature range in excess of 20° F., and the evaporators and condensers being arranged so that the highest temperature evaporator is connected in the refrigeration unit having the lowest temperature condenser and the lowest temperature evaporator is connected in the refrigeration unit having the highest temperature condenser.

5. In an air conditioning system, the combination of, a plurality of independent refrigeration units, means for directing a stream of fluid to be cooled in heat exchange relationship with the evaporators of the plurality of refrigeration units in series to cool the fluid in successive stages through a wide temperature range in excess of 20° F., means for directing a second fluid in heat exchange relationship with the condensers of the plurality of refrigeration units, and the plurality of refrigeration units being arranged so that the temperature and pressure difference between the evaporator and condenser in the refrigeration unit for the first stage is a minimum and progressively increases to the maximum required for the low temperature cooling in the last stage whereby to produce maximum cooling in the first stage.

6. In an air conditioning system, the combination of, a plurality of independent refrigeration units each of which has an evaporator for cooling one fluid and a condenser cooled by another fluid, said evaporators being arranged to cool said one fluid in stages at progressively lower temperatures and said condensers being arranged to be cooled by said other fluid at progressively higher temperatures, and the evaporators and condensers of the respective units being arranged so that the highest temperature fluid being cooled flows in heat exchange relation with the evaporator of the refrigeration unit having the lowest condenser temperature and the lowest temperature fluid being cooled flows in heat exchange relation with the evaporator of the refrigeration unit having the highest condenser temperature whereby to cool the fluid through a wide temperature range in successive stages with a minimum temperature and pressure difference in the refrigeration units.

7. In an air conditioning system, the combination of, a plurality of closed refrigeration units with each having an evaporator for cooling one fluid and a condenser cooled by another fluid, means for passing a stream of said one fluid through a path in heat exchange with the evaporators of the plurality of refrigeration units in series to progressively cool the fluid in successive stages through a wide temperature range in excess of 20° F., means for

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passing a stream of said other fluid through another path in heat exchange with the condensers in series to cool the condensers in successive stages, and the separate paths of flow for the fluids being so constructed and arranged that the refrigeration unit with the highest temperature evaporator has the lowest temperature condenser and the refrigeration system with the lowest temperature evaporator has the highest temperature condenser whereby to cool said one fluid in progressive stages at a high capacity and efficiency.

8. In an air conditioning system, the combination of, a plurality of staged refrigeration units independent of each other, each of said refrigeration units having an evaporator and a pair of condensers, a cooling tower, heat exchange means for conditioning air, an open circuit connecting one of the condensers of each refrigeration unit and cooling tower in series, a circulator for circulating a liquid in said open circuit, a closed circuit having separate parallel branches connected to the heat exchange means, one of said branches of said closed circuit connecting the other condensers of the refrigeration units in series, the other branch of said closed circuit connecting the evaporators of the refrigeration units in series, a circulator for circulating a liquid in said closed circuit, and valve means for connecting one or the other of said branches of the closed circuit to the heat exchange means.

9. An air conditioning system in accordance with claim 8 in which the liquid circulating in said one branch of the closed circuit is progressively cooled in stages through a wide temperature range in excess of 20° F., and the separate branches of the closed circuit connecting the evaporators and condensers, respectively, of the plurality of refrigeration units in series so that the refrigeration unit with the highest temperature evaporator has the lowest temperature condenser and the refrigeration unit with the lowest temperature evaporator has the highest temperature condenser whereby to cool the liquid in stages at a high capacity and efficiency.

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