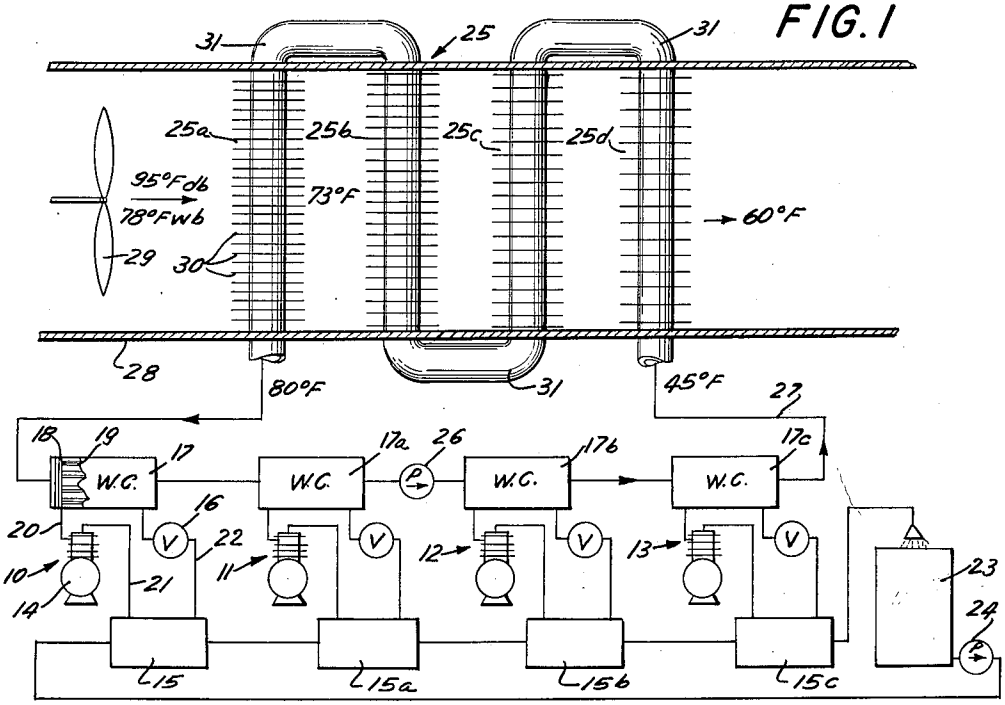
Dec. 11, 1962 A. I. McFARLAN 3,067,592

REFRIGERATION

Filed Feb. 8, 1960 2 Sheets-Sheet 1

FIG. 1



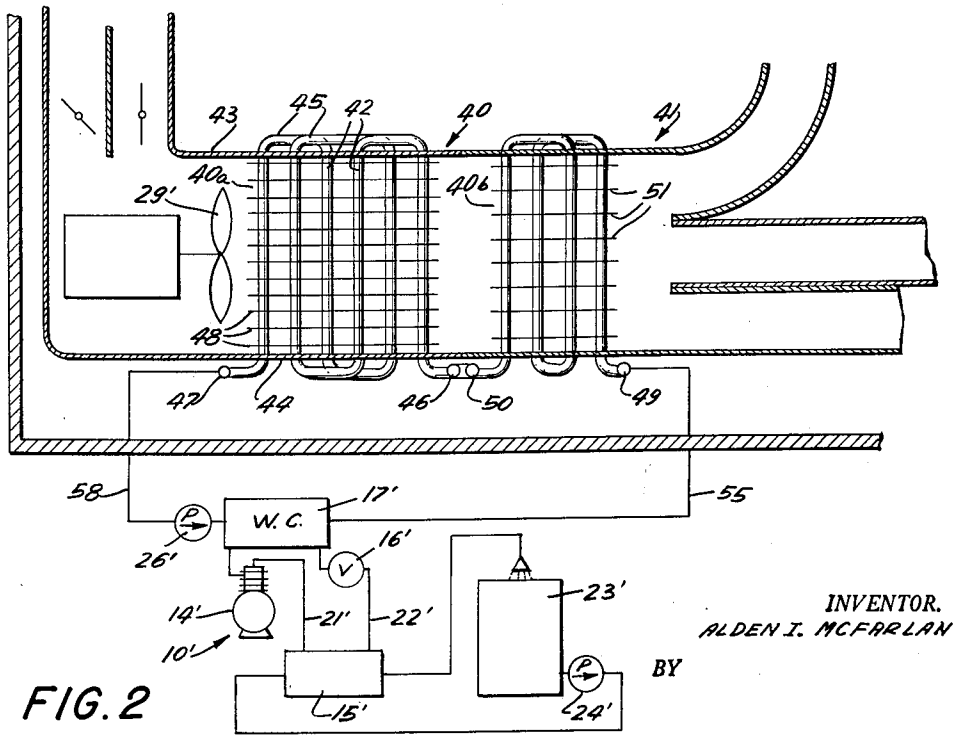


FIG. 2

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REFRIGERATION

Filed Feb. 8, 1960 2 Sheets-Sheet 2

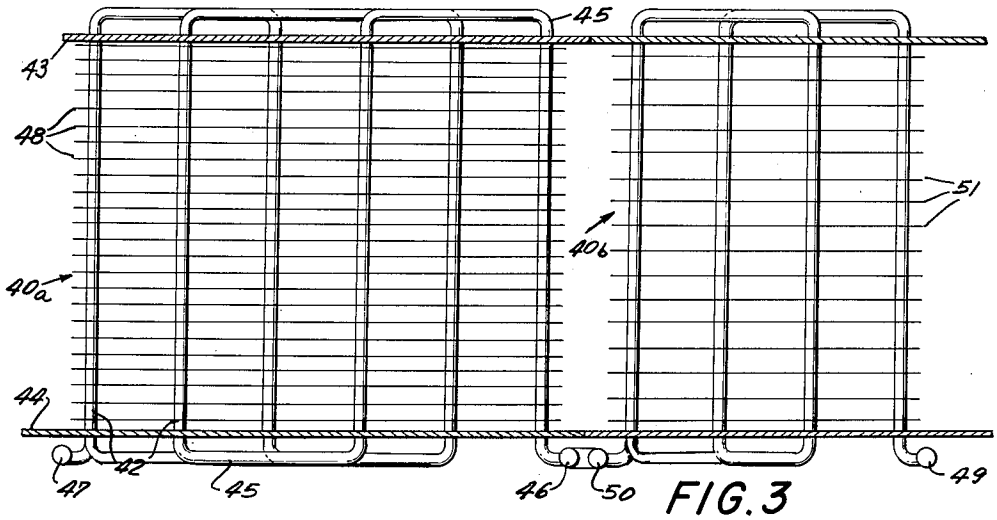


FIG. 3

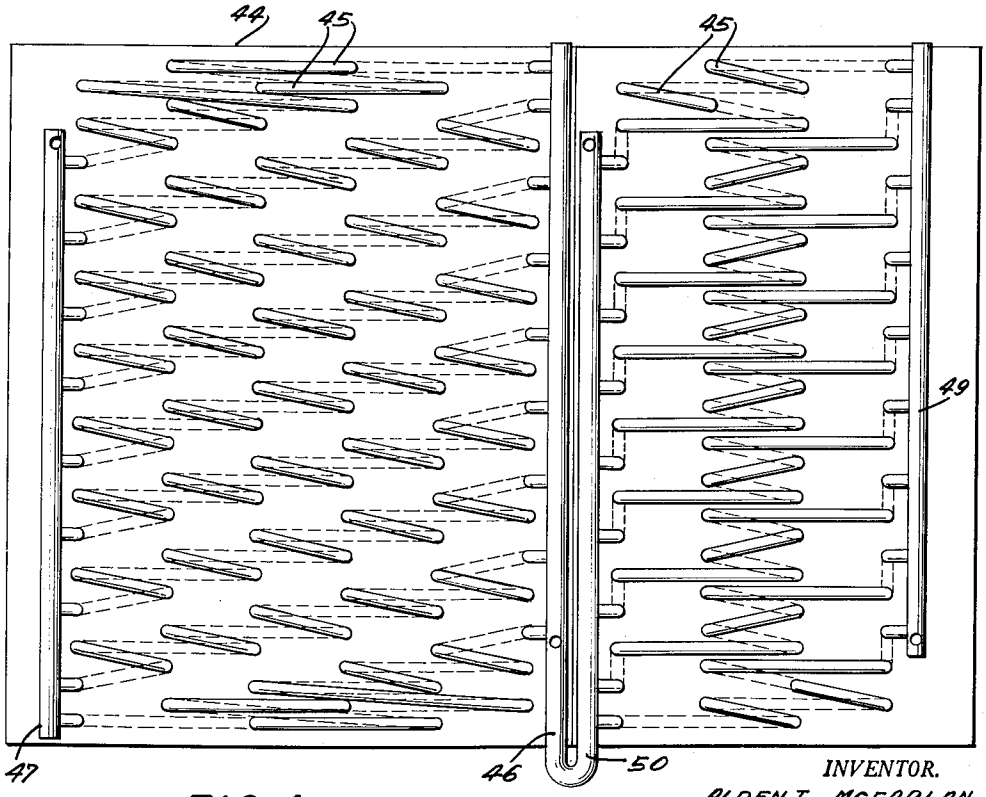


FIG. 4

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3,067,592

REFRIGERATION

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2 Claims. (Cl. 62—426)

The present invention relates to refrigeration and more particularly to a method of and refrigeration system for cooling air to reduce the temperature and humidity of the air to comfort conditions.

In prior air cooling systems it has been conventional practice to use a finned coil to increase the heat transfer between the air and cooling medium. In such systems the finned coil may constitute the evaporator of a refrigeration system or may be supplied with chilled water from a secondary fluid circuit. In either type of system, when the air is cooled below its dew point temperature, moisture condenses from the air and is deposited on the relatively cold fins. The lower the temperature below the dew point temperature, the greater the amount of moisture removed. The amount of moisture condensed from the air depends upon the humidity conditions of the air being conditioned which varies from hour to hour and day to day and, in turn, varies the dew point temperature at which moisture will condense on the cooling coil.

As moisture condenses on the finned coil it tends to block the passages between the fins and reduces the amount of air passing through the coil and the available capacity of the refrigeration apparatus. If air is forced between fins by a high pressure fan when the fins are plugged with condensate the high velocity air may blow the condensate back into the air stream. As a result, the spacing of the fins on a coil for any particular installation in accordance with conventional practice is a compromise between good performance of the system on sensible heat cooling (heat removed without condensing moisture) with poor performance on latent heat cooling and dehumidification (heat required to condense moisture and reduce the relative humidity of the air), or poor performance on sensible heat cooling and good performance on latent heat cooling. Also, the heat transfer coil is usually designed to produce only an 8° to 12° F. rise in the water temperature.

One of the objects of the present invention is to provide a refrigeration system for producing good performance on both sensible and latent heat cooling without materially reducing air flow due to plugging and increased resistance when high latent heat removal is required.

Another object is to progressively increase the free area of the coil through which the air passes in accordance with the rate of moisture removal in the direction of air flow.

Another object is to provide an air cooling system having a heat transfer coil which is adapted to cool large quantities of outside air through a wide temperature range well below its dew point temperature with a correspondingly large amount of moisture removal.

Another object is to provide a refrigeration system for cooling air being conditioned through a wide temperature range and thereby reduce the amount of air required for air conditioning an enclosure.

Still another object is to provide a refrigeration system of the type indicated which is of simple and compact construction to adapt it for economical manufacture and one which is reliable in operation over wide variations in the initial temperature and humidity condition of the air being conditioned.

These and other objects will become more apparent from the following description and drawings in which

like reference characters denote like parts throughout the several views. It is to be expressly understood, however, that the drawings are for the purpose of illustration only and are not a definition of the limits of the invention, reference being had for this purpose to the appended claims.

In the drawings:

FIGURE 1 is a diagrammatic view of a refrigeration system illustrating the principle of the present invention and showing in plan the progressively wider spacing of the fins on successive sections of the heat transfer coil in the direction of air flow;

FIGURE 2 is a diagrammatic view of a coil arrangement adapted for use in a conventional refrigeration system for cooling air through a wide temperature range;

FIGURE 3 is an enlarged plan view of the two sections of the heat transfer coil illustrated in FIGURE 2; and

FIGURE 4 is a side elevational view of the coil sections.

FIGURE 1 of the drawings illustrates the principles of the present invention in an ideal arrangement comprising a heat transfer coil with each successive section contacted by the air having fins of progressively wider spacing and a staged refrigeration system of the type described and claimed in my prior Patents 2,796,740 and 2,796,743, issued June 25, 1957, to cool the air through a wide temperature range. It will be understood, however, that the present invention may be used with other types of refrigeration systems, may cool air with chilled water which is raised through a conventional temperature range of from 8° F. to 12° F. or with direct expansion coils either of the conventional single stage type or multi-staged coils as illustrated and described in my Patent 2,796,743, referred to above and operated at progressively lower temperatures in the direction of air flow.

In the embodiment of the invention illustrated in FIGURE 1, water in a cooling system is cooled by a staged refrigeration system. The staged refrigeration system comprises a plurality of independent refrigeration units **10**, **11**, **12** and **13** with each unit having a compressor **14**, condenser **15**, an expansion valve **16** and a water chilling evaporator **17**. The water chilling evaporator **17** of each unit **10** to **13** may be of the tube and shell type having headers forming an evaporating chamber **18** for refrigerant through which water tubes **19** extend. The suction side of the compressor **14** of each unit is connected to receive refrigerant vapor from its evaporator **17** through a line **20** to cause the refrigerant to evaporate at a low pressure and temperature to chill the water flowing through the tubes **19**. Compressor **14** compresses the refrigerant vapor to a high pressure and temperature and delivers the refrigerant through a line **21** to the condenser **15**. Heat flows from the high temperature refrigerant vapor to a cooling medium to condense the refrigerant vapor to a liquid, and the liquid refrigerant is delivered through a line **22**, including the expansion valve **16**, back into the evaporator **17**. Expansion valve **16** controls the flow of liquid refrigerant to chamber **18** of the evaporator **17** while maintaining the difference in pressure between the high and low pressure sides of the compressor **14**.

The plurality of condensers **15**, **15***a*, **15***b* and **15***c* of the successive units **10**, **11**, **12** and **13** are cooled by an open cooling water system. The open cooling water system includes a cooling tower **23** and a pump **24** for circulating the cooling water through the system. Condensers **15**, **15***a*, **15***b* and **15***c* may be connected either in parallel or in series in the circuit and in the illustrated embodiment they are shown connected in series.

The water chilled by the staged refrigeration system is circulated through the cooling system including the evaporators **17**, **17***a*, **17***b* and **17***c* of refrigeration units

10 to 13, an air cooling heat transfer coil 25 and a pump 26. The outlet from the water chilling evaporator 17c is connected to the heat transfer coil 25 by a line 27 for flow through the coil in a direction countercurrent to the direction of air flow therethrough. As illustrated diagrammatically in FIGURE 1, the coil 25 is positioned in an air duct 28 through which air is circulated by a fan 29. Fan 20 moves air from left to right as viewed in FIGURE 1 while the chilled water moves through the coil from right to left so that the air is progressively cooled and the chilled water is progressively heated through temperature ranges approaching the difference between the inlet temperatures of the air and chilled water. The air flowing through the coil 25 is first cooled down to its dew point temperature without removal of any moisture (sensible heat cooling) and thereafter is cooled below the dew point temperature to remove progressively increasing amounts of moisture from the air (latent heat cooling) and sensible heat below the dew point temperature.

In accordance with the present invention the heat transfer coil 25 comprises separate sections successively contacted by the air and the successive sections have fins 30 spaced progressively wider in the direction of air flow. For the purpose of illustrating the principle of the invention, the heat transfer coil in FIGURE 1 is shown as comprising a single row of parallel pipe sections 25*a*, 25*b*, 25*c* and 25*d* extending across the air duct 28 with U-shaped fittings 31 connecting the ends of adjacent sections alternately at opposite ends to form a serpentine coil. Thus, chilled water flows in a direction countercurrent to the direction of air flow so that the air is progressively cooled and the chilled water is progressively heated during flow through the coil.

The coil section 25*a* first contacted by the air has its fins 30 spaced in the ratio of 14 to the inch throughout the length of the coil to transfer heat at a maximum rate. As the temperature of the chilled water in coil section 25*a* is above the dew point temperature of the air, only sensible heat is transferred. Thus, the coil remains dry and the entire face area of the coils between the fins is open at all times to permit the free flow of air therethrough. The chilled water in successive sections 25*b*, 25*c* and 25*d* are at a temperature below the dew point temperature of the air and at progressively lower temperatures in successive sections and condenses moisture from the air at progressively increasing rates on successive sections. However, the coil sections 25*b*, 25*c* and 25*d* have fins 30 spaced from each other at progressively increasing widths in the ratio of 12, 10 and 8 fins to the inch, respectively. Thus, the spacing of the fins 30 on each successive coil section provides an increased face area through which the air flows to compensate for the moisture condensed on the fins which tends to plug the space between the fins and reduce the space for air. By proper design, the heat transfer rate and spacing of the fins 30 on successive coil sections may be so correlated as to maintain a flow of air through coil 25 at a substantially constant rate under varying humidity conditions of the air being conditioned with a minimum fan horsepower per cubic foot of air delivered. Furthermore, the dividing of a heat transfer coil into separate sections with fins of progressively wider spacing on successive sections in the direction of air flow eliminates plugging of the fins with condensate, permits cooling and dehumidification of air through a predetermined temperature range with less water circulated and heated through a wide temperature range which decreases the size of the chilled water mains, insulation, pumps, controls, etc., as well as improving the efficiency of the refrigeration apparatus with a resulting material decrease in the cost of air conditioning per ton of refrigeration produced. While the heat transfer coil 25 is shown as having four successive sections it is within the scope of the present invention to provide additional sections with the fins 30 on successive sections spaced progressively wider in a range from 6 to 16 fins per inch. One form of the invention having now been explained in detail, the mode of operation is next described.

Assuming for purposes of description that the refrigeration system is operating and delivers chilled water at 45° F. from the evaporator chiller 17*c* of the last refrigeration unit 13 to the section 25*d* at the right-hand end of the coil 25; and that the fan 29 is delivering air at 95° F. D.B. and 78° F. W.B. with a corresponding dew point temperature of 71.8° F. Further assuming that the air will be cooled to 60° F. and the water heated to 80° F. as they flow through the coil 25 in countercurrent relation. Thus, the air flowing through the first section 25*a* of the coil 25 will be cooled to a temperature approaching the temperature in the coil section, for example 73° F., so that no condensation of moisture occurs. Thus, the coil remains dry and sensible heat is transferred at a maximum rate due to close spacing of the fins 30 without any pressure drop due to plugging of the coils by condensate. As the air passes through successive sections it is progressively cooled to lower temperatures below the dew point temperature so that progressively increasing amounts of moisture are condensed from the air. This moisture accumulates on the fins 30 and runs down the sides of the fins by gravity. The film of moisture on the sides of adjacent fins reduces the space between the fins through which air can pass which would ordinarily reduce the volume of air passing through the coil section. However, the wider spacing of the fins 30 of each successive section 25*b* to 25*d* compensates for the condensate thereon to prevent plugging of any portion of the coil sections to maintain the velocity and volume of air flowing through each coil section substantially constant.

Thus, the temperature of the water is increased through a wider temperature range with a substantially equal air cooling range which reduces the water required over conventional systems with a corresponding decrease in the size of the mains, insulation, controls, valves, pumps, etc. The water thus heated to a higher temperature may be cooled by the successive units 10 to 13 of the staged refrigeration system having a smaller total capacity than conventional systems. As the successive stages of the refrigeration system cool the water through only a portion of the total temperature range and as the first units 10 and 11 operate with a small pressure and temperature head, the efficiency of the refrigeration system is increased and the air cooling system as a whole operates with a minimum power input per ton of refrigeration produced.

While the use of an air cooling coil 25 divided in sections with fins 30 of progressively wider spacing is shown in an ideal system as illustrated in FIGURE 1, it can also be used to advantage with a conventional refrigeration system. FIGURES 2, 3 and 4 illustrate a coil arrangement used in several installations having a single refrigeration unit 10', but of a capacity to maintain the entire cooling load. The unit 10' has the same compressor 14', condenser 15', expansion valve 16' and evaporator water chiller 17' and connected to each other in the same way as the unit 10 in FIGURE 1 to circulate chilled water through an air cooling coil 40. The condenser 15' is also cooled by an open cooling water circuit having a cooling tower 23' and pump 24' as previously described.

The air cooling coil 40 shown in detail in FIGURES 3 and 4 comprises two sections 40*a* and 40*b* arranged in series in an air duct 41. Section 40*a* of the coil 40 first contacted by the air has a plurality of tubes 42 extending horizontally between vertical end plates 43 and 44 and arranged in six vertical rows connected by end connectors 45 in nine parallel circuits between vertical headers 46 and 47. Fins 48 in thermal contact with all of the tubes 42 are equally spaced, twelve to the inch, throughout the length of the tubes. Coil section 40*b* last con-

tacted by the air has four vertical rows of tubes 42 connected in nine water circuits between headers 49 and 50 with fins 51 common to all of the tubes and equally spaced, eight to the inch. As illustrated in FIGURE 4, each water circuit of the coil sections 40*a* and 40*b* connects the tubes 42 laterally in a general incline between headers 46, 47 and 49, 50, respectively, so that the coils are self-draining.

The outlet from the evaporator chiller 17' of the refrigeration unit 10' is connected by a line 55 to the header 49 at rearward or right-hand end of the coil section 40*b* as illustrated in FIGURE 2. The chilled water flows through the parallel water circuits of the coil section 40*b* forwardly or to the left from header 49 to header 50 in a direction countercurrent to the direction of air flow therethrough. The header 46 of the coil section 40*a* is connected to the header 50 of the coil section 40*b* so that the chilled water leaving the forward end of coil section 40*b* enters the rearward end of coil section 40*a*. The chilled water then flows through the different water circuits of the section 40*a* between the headers 46 and 47 in a direction countercurrent to the direction of air flow. The outlet header 47 of coil section 40*a* is connected by a line 58 to the evaporative chiller 17' of the refrigeration unit 10' to complete the water circuit.

In operation, the fan 29' directs air through the air duct 41 which contacts the coil sections 40*a* and 40*b* successively to cool and dehumidify the air. Pump 26' continuously circulates chilled water through the evaporative chiller 10' to chill the water and then through the coil section 40*b* and 40*a* in a direction countercurrent to the direction of air flow. As the chilled water passes through the coil sections it is progressively heated by transfer of heat from the air and is then returned to the evaporative chiller 17' of the refrigeration unit 10' to complete its circuit. Due to the close spacing of the fins 48 on the coil section 40*a* first contacted by the air, a maximum heat transfer occurs with a minimum plugging of the fins. As the stream of air flows through the second section 40*b* of the coil 40 it is cooled below its dew point temperature with removal of moisture from the air. The wider spacing of the fins 51 on the second section 40*b*, however, compensates for the film of moisture thereon to reduce plugging of the coil section with condensate over conventional coils having the same fin spacing throughout.

Coil 40 in separate sections 40*a* and 40*b* as illustrated in FIGURES 2, 3 and 4 have been substituted for damaged coils in particular installations of conventional design. In one installation, for example, the coils previously used had 7 fins per inch and maintained a temperature of 82° F. in the space being air conditioned with an outside temperature of 95° F. When the coil arrangement of the present invention was substituted for the original coil in two separate sections with twelve fins to the inch and eight fins to the inch, respectively, the same refrigeration system maintained the enclosure at 78° F. with the same outside conditions. This improved performance resulted from more heat being transferred to the coil even through the amount of water used was reduced approximately 40% allowing the remainder of the water to be used elsewhere. Also, conventional coils, even though deeper coils were used, would have reduced the air volume due to greater resistance on the existing fans. No perceptible reduction in air volume was observed. Thus, the application of the coil arrangement of the present invention to a conventional air cooling system improved the performance of the system as a whole.

It will now be observed that the present invention provides an air cooling system which produces good performance in both sensible and latent heat cooling through a wide temperature range of the chilled cooling water. It

also will be observed that the present invention increases the space between the fins of an air cooling coil in the direction of air flow to compensate for increased moisture removal from the air. It will further be observed that the present invention provides for cooling air without plugging the coil with condensate and permits the use of a smaller quantity of chilled water. It will still further be observed that the present invention provides an air cooling system which is of simple and compact construction to adapt it for economical manufacture and one which is reliable in operation over wide variations in the initial temperature and humidity of the air being conditioned.

While two embodiments of the invention are herein illustrated and described, it will be understood that further changes may be made in the construction and arrangement of the elements without departing from the spirit or scope of the invention. Therefore, without limitation in this respect the invention is defined by the following claims.

I claim:

1. In an air conditioner for cooling and dehumidifying air to a dew point temperature above freezing for delivery to an enclosure to produce comfort conditions therein comprising a conduit, a refrigeration system having successive finned heat transfer sections mounted in said conduit so as to be contacted by air being conditioned, a fan for directing a stream of air in one direction through the heat transfer sections successively, means for supplying a cooling medium to the successive heat transfer sections so that the successive sections have progressively lower temperatures in the direction of air flow therethrough, and the successive heat transfer sections supplied cooling medium at progressively lower temperatures having fins at a progressively wider spacing, respectively, whereby the air to be cooled first contacts the heat transfer section having closely spaced fins to transfer sensible heat and then contacts the more widely spaced fins after the air has been cooled below its dew point to transfer latent heat.

2. In an air conditioner for cooling and dehumidifying air to a dew point temperature above freezing for delivery to an enclosure to produce comfort conditions therein comprising a conduit, a staged refrigeration system having a plurality of individual refrigeration units, each refrigeration unit comprising a compressor, a condenser and an evaporator for chilling water to a temperature below the ambient and above freezing, a finned coil having successive sections connected in series, a chilled water circuit for circulating water through the evaporator-chillers of the refrigeration units in series and then through successive sections of the finned coil to cool successive coil sections at progressively higher temperatures, means for circulating air to be conditioned through the coil in a direction counter-current to the direction of flow of the chilled water therethrough whereby to contact the warmest air with the warmest coil section and contact the coldest air with the coldest coil section, the fins of the successively colder coil sections contacted by the air being cooled having progressively wider spacing in the direction of air flow, and the fins being spaced in the range of 6 to 14 fins per inch.

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