

[54] **REFRIGERATION SYSTEM WITH HEAT EXCHANGER EMPLOYING EUTECTIC**

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[51] Int. Cl. **F25d 11/04**

[58] Field of Search **62/439, 515 K, DIG. 7, 62/498; 260/414, 429, 439; 252/67, 68, 69, 71**

[56] **References Cited**
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[57] **ABSTRACT**

This invention is a unique environmental control unit of the vapor-compression system type which incorporates a dual operation heat exchanger of the circulated air variety. The heat exchanger embodies spaced plate containers of eutectic material with evaporator coils effectively embedded therein such that air circulation and the normal evaporation process is not unduly impeded during regular operation and holdover cooling is provided when electric power for the compressor fails. In accordance with the invention, a separately powered air circulation means is provided.

5 Claims, 5 Drawing Figures

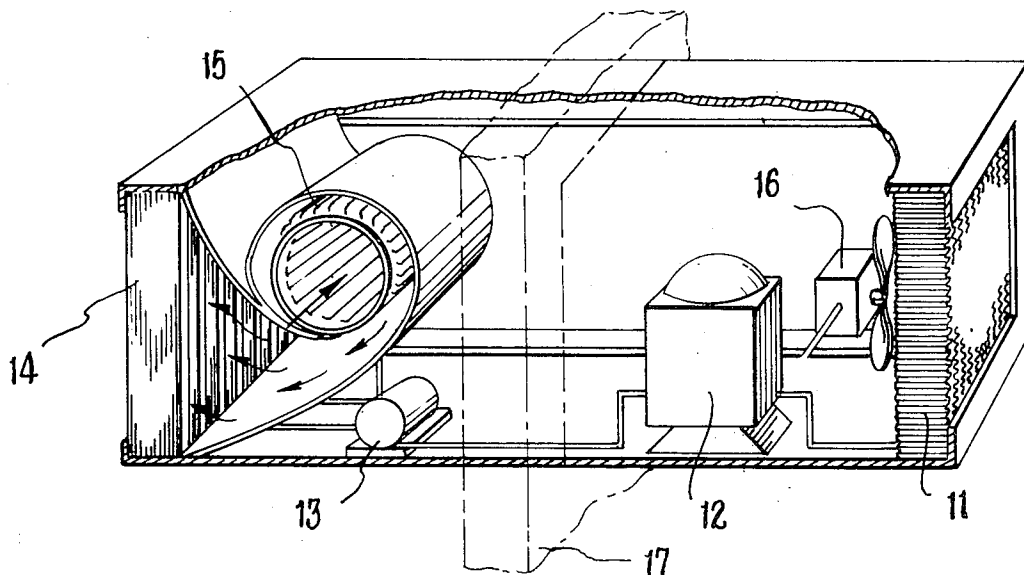


Fig. 1

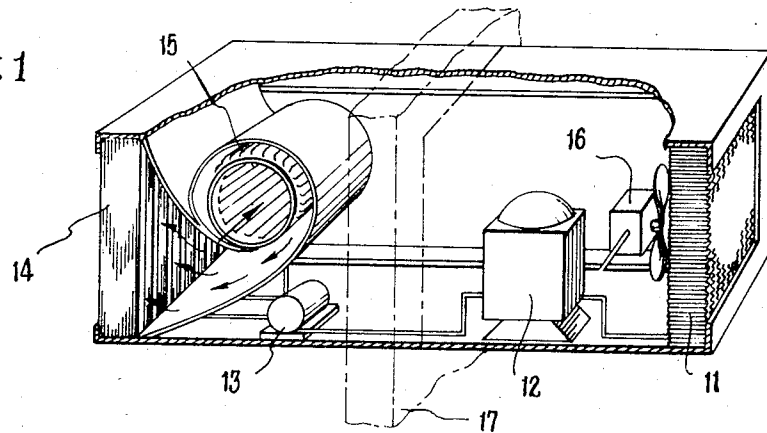
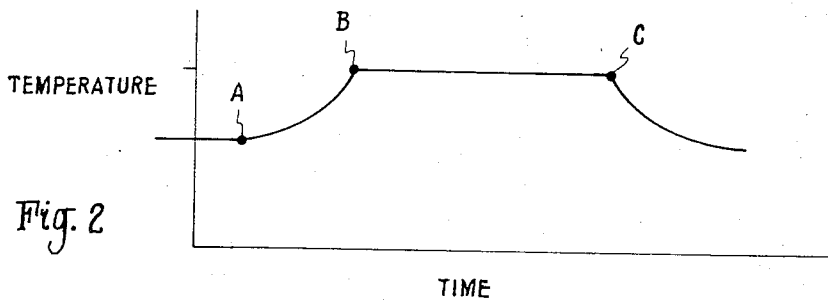


Fig. 2

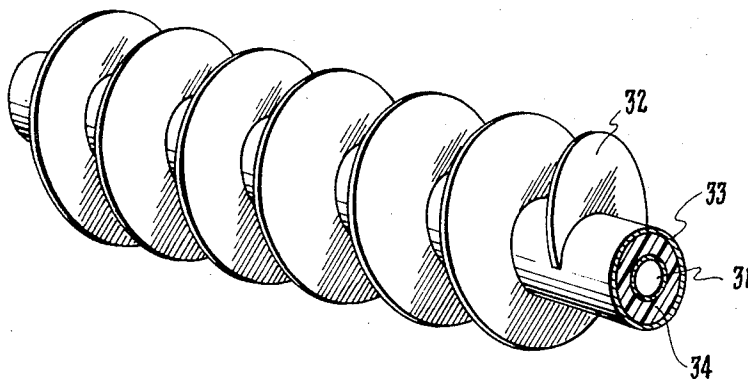


Fig. 5

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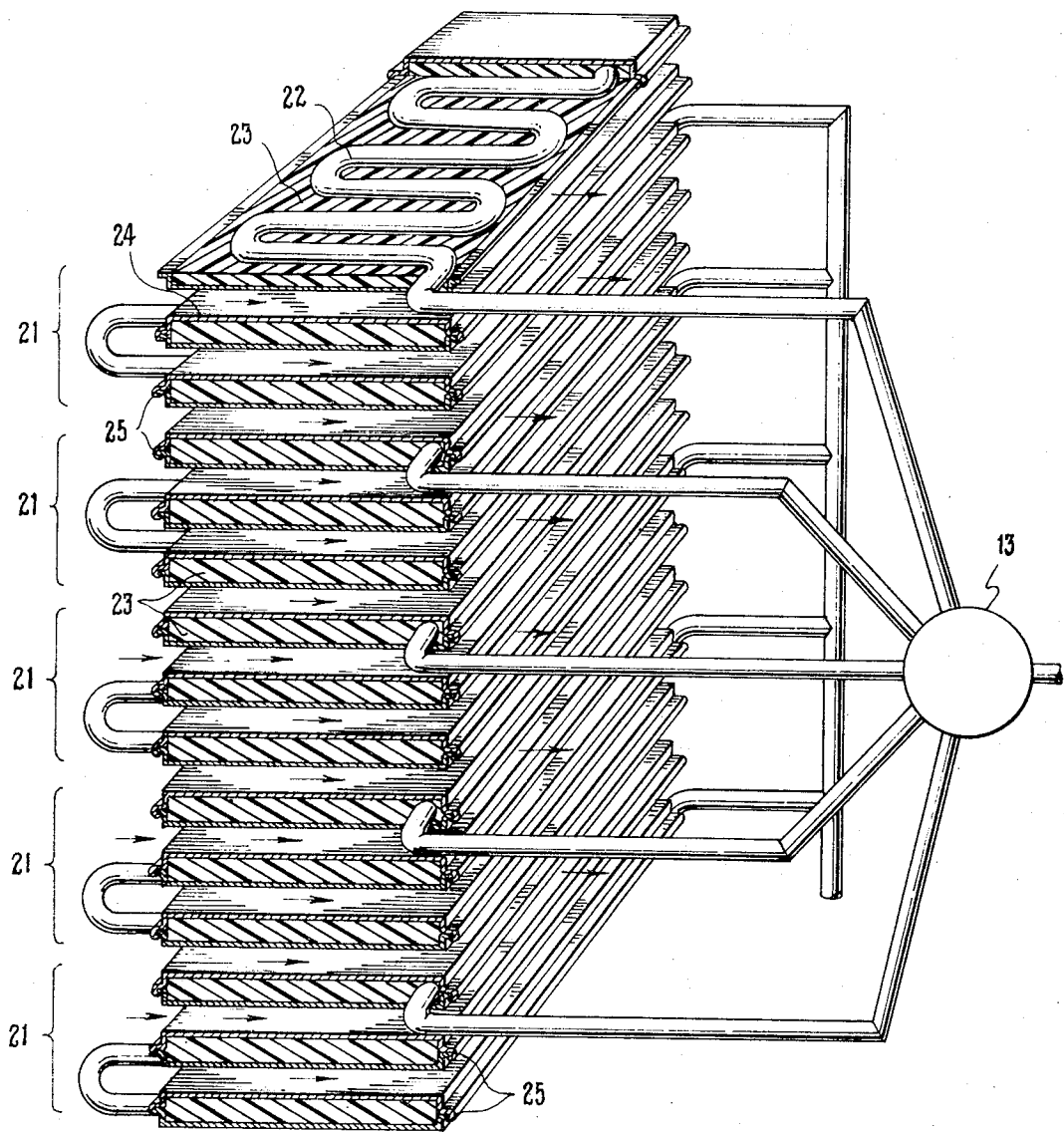


Fig. 3

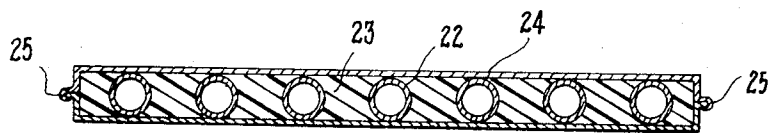


Fig. 4

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GOVERNMENT USE

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment to me of any royalties therefor.

BACKGROUND OF THE INVENTION

Environmental control units of the vapor-compression cooling system variety normally are utilized to control the temperature in a room size, closed area. In a closed room application, when an electric power interruption occurs and the temperature reduction process ceases, obviously, the temperature rapidly increases if the heat source continues to generate heat. When temperature sensitive equipment is contained within the closed area, even a short term interruption in electric power to the environmental control unit can be disastrous. However, recognizing the relatively high current demand of the compressor unit in such systems, it is desirable, in military applications especially, to minimize power consumption by programmed shutdown of the compressor unit for short periods of time.

Various thermal holdover systems have been devised to maintain a controlled temperature in a closed room size area when such programmed interruptions occur. In general, temperature is maintained by an alternate cooling system which may be activated automatically when power ceases. For example, battery powered equipment which provides outside air ventilation of the room may be turned on. In other instances, the air conditioning unit may incorporate several different types of heat exchangers whereby upon deactivation of one heat exchanger by loss of power, for example, a second heat exchanger in the system, essentially a heat sink which does not require electric power, affords a "hold-over" for a period of time. It will be appreciated that a heat sink or an alternate cooling system may be precluded by size or weight considerations alone in many military applications requiring environmental control units.

In a generally related technical area, small volume portable cold storage applications, cooling often is provided by use of frozen wall surfaces and in one known example, the U.S. Patent to G. G. Lorch, U.S. Pat. No. 3,006,167, a narrow wall container containing a liquid eutectic material has been utilized as the wall surface. In such small volume portable applications, no vapor-compression cooling system maintains the temperature of the chamber; the frozen wall surfaces are the sole cooling means, essentially a substitute for dry ice; and no air circulation system is involved.

It is readily apparent that a means for extending the cooling period provided by a vapor-compression cooling system which utilizes available components of the cooling system is needed and would be welcomed as a substantial advancement of the art.

SUMMARY OF THE INVENTION

The environmental control unit of this invention performs its cooling function in a relatively conventional manner when operating in its normal mode. An evaporator coil, which is subjected to a forced flow of air, serves to cool the air passing therethrough as the refrigerant

circulates in the cooling system. As the invention primarily is directed to military application, provision is made for continued operation upon loss of the heavy power drain compressor unit. Sufficient power to maintain forced air flow is required.

In the unique system of the invention, standard components are utilized for the compressor, condenser and expansion valve. The evaporator coil, however, is a more complex structure which cools the air passing through the evaporator in a conventional manner when refrigerant is circulating and continues to cool the air passing therethrough for a limited time period after the refrigerant stops circulation. The useful cooling period is extended by selective disposition of a liquid container in direct contact with the evaporator coil along its entire length, by use of a eutectic material, having a desirable heat of fusion as the contained liquid and by continued operation of the evaporator forced air circulation means. In normal operation of the environmental control unit, the eutectic material is in a frozen solid state. In the event of compressor power shutdown, the air which continues to pass through the evaporator is cooled by the walls of the container housing the frozen eutectic material. A significant cooling advantage is obtained as the eutectic material changes from its solid to its liquid state.

It will be appreciated that the principal objective of the environmental control unit of this invention is to provide a relatively short term holdover cooling for use during planned or unscheduled electric power to the compressor interruptions.

Other objects of the invention will become apparent upon a more comprehensive understanding of the invention for which reference is had to the following description of preferred embodiments and the drawings wherein:

FIG. 1 is illustrative of a typical vapor-compression cooling system which affords holdover cooling in accordance with the present invention.

FIG. 2 is a graphical presentation of a typical temperature cycle for eutectic material utilized in the environmental control unit of this invention.

FIG. 3 is a more detailed cutaway showing of one embodiment of an evaporator suitable for use in the system of this invention depicted in FIG. 1.

FIG. 4 is a cross-section showing of a portion of an evaporator section of the type utilized in the embodiment of FIG. 3.

FIG. 5 is a cutaway showing of a section of another type of evaporator tubing also suitable for use in this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT OF THE PRESENT INVENTION

The vapor-compression cooling system of FIG. 1 comprises a condenser 11, a compressor 12, an expansion valve 13, an evaporator 14, an inside air circulator 15 of the squirrel cage variety and a direct drive outside air circulator 16. In accordance with the invention, the inside air circulator 15 is adapted, by battery means, not shown, for example, for separate powered operation when the principal power for the system is shut down. The system is installed through a wall 17 such that the evaporator 14 is exposed to the interior air of the chamber to be cooled and the condenser 11 is exposed to the outside air. The evaporator 14 consists of a plurality of planar coil sections connected via differ-

ent ports of the expansion valve 13. While a three outlet port expansion valve with three lines leading to the evaporator sections is shown, it will be appreciated that the expansion valve may have a greater number of outlet ports, if desired. In FIG. 1, the coils and sections thereof are vertically disposed in planar and parallel relation. In place of the finned section normally attached to the cooling coil-evaporator 14, however, the planar region defined by each coil is completely filled by a parallel wall, sealed compartment which contains an eutectic material. The eutectic material may be, for example, sodium chloride - sodium sulphate decahydrate, $\text{NaCl} \cdot \text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$, which has a liquid state similar to heavy oil and a solid state similar to pliable plastic. The heat of fusion of $\text{NaCl} \cdot \text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$, that is, the quantity of heat required per unit mass, without any change in temperature, to solidify this crystalline substance is 70 BTU. The above-mentioned eutectic material, which has a fusion temperature of 55°F, has been found to have an acceptable expansion characteristic which, when appropriately contained, will not cause rupture of its container upon expansion incident to solidification.

Selection of the proper eutectic material is determined primarily by the fusion temperature and the heat of fusion benefit derived at change of state, of course. However, selection also may involve a consideration of compatibility with the container material and tubing material. Frequently, aluminum is utilized as the tubing material and container material and corrosion is minimized by anodizing. Sealing the unit, in itself, reduces the corrosive effect, of course. Other eutectic materials which have been found suitable for use in the evaporator structure described herein are sodium chloride-ammonium chloride-sodium sulphate hydrate- $\text{NaCl} \cdot \text{NH}_4\text{Cl} \cdot 2\text{Na}_2\text{SO}_4 \cdot 20\text{H}_2\text{O}$; sodium manganate decahydrate $\text{Na}_2\text{MnO}_4 \cdot 10\text{H}_2\text{O}$; sodium chromate decahydrate $\text{Na}_2\text{CrO}_4 \cdot 10\text{H}_2\text{O}$; nickel oleate $\text{Ni}(\text{C}_{18}\text{H}_{33}\text{O}_2)_2$ which have fusion temperatures of 58°F, 63°F, 66°F and 64°-68°F, respectively. Sodium chloride - ammonium chloride - sodium sulphate hydrate $\text{NaCl} \cdot \text{NH}_4\text{Cl} \cdot 2\text{Na}_2\text{SO}_4 \cdot 20\text{H}_2\text{O}$ has been found to be especially useful in that it has a 78 BTU heat of fusion characteristic.

FIG. 2 illustrates the temperature response of the first identified eutectic material when the refrigerant flow stops in the environmental control unit of this invention. During normal operation of the unit, the ambient temperature in the immediate vicinity of the evaporator is maintained at a selected temperature, for example, 75°F and the temperature of the refrigerant R-12 Freon, for example, is 40°F. In accordance with the invention, the fusion temperature of the eutectic material is intermediate these temperatures and might be, for example, 55°F.

At time A, when refrigerant flow stops, the ambient temperature in the immediate vicinity of the evaporator 14 and the temperature of the eutectic material contained as an internal part thereof, gradually rises, as shown, until the fusion temperature of the eutectic material, for example 55°F is reached. The rate of increase in temperature is, of course, a function of the heat source load, the nature of air flow in the vicinity of the evaporator and other factors peculiar to the environmental control application.

As the temperature of the eutectic material increases, heat energy is removed from the room as the air continues to circulate through the evaporator and at time B, when the eutectic material begins to melt,

the amount of heat energy which is removed is substantially increased as the change in state occurs. Thus, the cooling effect of the evaporator 14 increases during the melting period. Assuming the heat source is introducing heat energy at a determined BTU rate, the temperature of the room increases in proportion to the difference in heat energy introduced by the heat source and removed by the evaporator 14. Obviously, the capability of the evaporator 14 to remove heat energy determines the time period of acceptable temperature control of the room area. Thus, the vapor-compression system of this invention with its single unit, dual action, heat exchanger-evaporator provides a significant extension of the cooling time period after compressor power shutdown. In actual operation of the system of this invention in an instrument and equipment room temperature control application, it has been found that system easily will afford a thirty minute extension beyond the normally expected holdover period, that is, beyond the time B on the FIG. 2 curve to time C. After time C, the cooling effectiveness of the evaporator 14 would diminish, of course, unless the refrigerant circulation is resumed as shown in FIG. 2.

As shown in more detail in FIG. 3, the evaporator 14 normally is made up of a plurality of sections, indicated at 21. Each section is connected via a respective port of the expansion valve 13 to enable a predetermined, sequential refrigerant flow therethrough. While an expansion valve with three ports is shown in FIG. 1 and a five section evaporator is shown in FIG. 3, it will be appreciated that the number of ports and sections must conform. The number of expansion valve ports and the corresponding number of evaporator sections, of course, is determined by the optimum pressure drop in the evaporator, normally 2-3 lbs/square inch.

In FIG. 3, each of the sections 21 comprises three portions of the evaporator in which each portion consists of tubing folded upon itself in a planar form as indicated at 22. The sections 21 and respective portions 22 thereof are disposed in spaced parallel relation such that air to be cooled may be moved through the planar section defined spacing by the air circulator 15. While the sections are shown in horizontal disposition for purposes of illustration in FIG. 3, it will be recognized that the vertical disposition shown in FIG. 1 is preferred for condensate drainage purposes.

In the FIG. 3 embodiment of this invention, the folded tubing is embedded in a eutectic material, indicated at 23, and both the tubing 22 and the eutectic material are sandwiched between thin sheets of aluminum or other material of high heat conductivity, indicated at 24. As more clearly shown in FIG. 4, the sheets 24 are disposed in direct contact heat conductive relation with the outward facing sides of the tubing 22 in its planar form. Also, in accordance with the change of state concept of the invention, the edges of the sheet material 24 are folded and crimped, as indicated at 25, or otherwise interconnected to form a sealed container for the eutectic material which confines the eutectic material in its fluid state.

It is not essential to the invention that the eutectic material be confined in the precise manner shown in FIGS. 3 and 4, of course. For example, the sheet material 24 may be embossed to conform to the folded tubing to provide a greater exposure of the outward facing side surface of the folded tubing to the circulating air, if desired. Conversely, the sheet material walls may be

embossed to provide a eutectic material container which is wider than the tubing 22 and thus contains a greater amount of eutectic material 23, if desired. In the latter instance, of course, it is especially important that sufficient air circulation be provided to insure a full functioning of the evaporative process during normal operation of the vapor-compression cooling system.

Indeed, it is not essential that the eutectic material container be formed of parallel sheet material, embossed or otherwise. In an alternative construction, a container having a configuration which fills the voids between folds of the tubing in each section may be formed of any heat conductive material and placed in direct heat conductive relation with the interfacing walls of the folded tubing 22 along its length.

It will be appreciated that for efficient heat transfer, the eutectic material should substantially fill its container but that allowance must be made for a limited expansion of the eutectic material upon solidification. It has been found that the narrow parallel wall configuration shown in FIG. 3 is particularly desirable in that the parallel walls may bulge to a limited degree upon expansion of the eutectic material with no adverse effect upon the container over an extended period of operation provided, of course, the eutectic material is selected from those having an expansion characteristic within reasonable limits. The degree of bulge permitted is determined by the air circulation in the particular application.

In actual test of the system of this invention, utilizing ¼ inch o.d. tubing and a eutectic material consisting of sodium sulphate (69%) - sodium chloride (31%) hydrate in a 9,000 BTU military air conditioning application, it has been found that operation is improved by closer spacing between folds in the folded tubing planar sections and by closer disposition of the planar sections with respect one another.

FIG. 5 depicts another evaporator tubing configuration suitable for use in the vapor-compression system of this invention. Spiral finned tubing, as shown in FIG. 5, may be adapted for use in planar folded tubing sections of the variety in FIG. 3, if desired. More commonly in evaporator design, however, spiral finned tubing is disposed in a spiral coil configuration with air circulation through the core of the coil.

In the configuration of FIG. 5, the conventional spiral finned tubing consisting of tubing 31 and continuous spiral fin 32 has been modified by the addition of a tubular wall member, indicated at 33, which encompasses the tubing 31 and is terminated at its ends by conventional means, not shown, to form a container about the tubing 31 along its length. As in the configuration of FIG. 3, a eutectic material, indicated at 34, is contained within the container formed by the wall section 33 and the outer surface of the tubing 31.

It will be noted that the continuous spiral fin member 32 is directly attached in heat conductive relation to the tubular wall member 33 for manufacturing simplification purposes. Ideally, the spiral fin member 32 is connected directly to the tubing 31 and may be so connected periodically along its length by means, not shown, if desired. In the finned tubing configuration, the heat conductivity characteristic of the eutectic material as well as its fusion temperature, heat of fusion, and expansion characteristics must be considered in selection of the appropriate eutectic material.

Of those eutectic materials presently known, sodium chloride - ammonium chloride - sodium sulphate hydrate $\text{NaCl} \cdot \text{NH}_4\text{Cl} \cdot 2\text{Na}_2\text{SO}_4 \cdot 20\text{H}_2\text{O}$ is preferred for use in the spiral finned tubing configuration. It should be recognized, however, that the spiral finned tubing configuration inherently introduces a preliminary cooling time delay in normal operation of the vapor-compression cooling system in that the eutectic material must be cooled to the requisite temperature of the refrigerant in the evaporator before normal cooling operation can begin. Consequently, the configuration shown in FIGS. 3 and 4 is preferred in the cooling system of this invention.

Although this disclosure of invention is directed to the more conventional vapor-compression cooling system and the invention is considered as a patentable improvement thereover, it will be recognized that the invention is not restricted to the particular illustrated cooling system. For example, the invention is not restricted to cooling systems for maintaining a temperature within any specific temperature range and eutectic materials, having an appropriate fusion temperature and a desirable heat of fusion characteristic, other than those specifically disclosed herein, may be substituted. Likewise, the evaporator forced air circulation means may be powered by the principal power means which energizes the compressor during normal operation, if desired, provided, of course, an auxiliary power means, which may be switched on in event of principal power means outage, is available.

I claim:

1. An extended cooling period, vapor-compression cooling system incorporating a condenser for dissipating heat energy to an outside area; a compressor operative on a refrigerant fluid; an evaporator for absorbing heat energy from an interior area to be cooled, including a forced air circulation means; and a refrigerant fluid adapted to be circulated within said system wherein:

said evaporator consists of refrigerant fluid containing tubing adapted and disposed with respect air circulation produced by said forced air circulation means to absorb heat energy from said interior area to be cooled, said tubing has a plurality of sections with each section having at least two tubing portions, with each tubing portion disposed in spaced relation with respect other portions;

wherein at least one sealed container is intrinsically disposed in direct contact with each of said tubing portions along its length and disposed, with respect air circulation produced by said forced air circulation means, to absorb heat energy from said interior area to be cooled;

wherein each of said sealed containers contains an eutectic material having a fusion temperature characteristic greater than the normal operating temperature of said refrigerant fluid when circulating in said evaporator and less than the ambient temperature to be maintained in said interior area and a heat of fusion characteristic above 40 BTU, said eutectic material is a composition material selected from the group of composition materials consisting of:

sodium chloride - sodium sulphate decahydrate, having a chemical symbol $\text{NaCl} \cdot \text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$;

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sodium chloride - ammonium chloride - sodium sulphate hydrate, having a chemical symbol $\text{NaCl} \cdot \text{NH}_4\text{Cl} \cdot 2\text{Na}_2\text{SO}_4 \cdot 20\text{H}_2\text{O}$;

sodium manganate decahydrate, having a chemical symbol $\text{Na}_2\text{MnO}_4 \cdot 10\text{H}_2\text{O}$;

sodium chromate decahydrate, having a chemical symbol $\text{Na}_2\text{CrO}_4 \cdot 10\text{H}_2\text{O}$; and

nickel oleate, having a chemical symbol $\text{Ni}(\text{C}_{18}\text{H}_{33}\text{O}_2)_2$.

2. A vapor-compression cooling system as defined in claim 1 wherein said eutectic material is sodium chloride - sodium sulphate decahydrate, having a chemical symbol $\text{NaCl} \cdot \text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$.

3. A vapor-compression cooling system as defined in claim 1 wherein said eutectic material is sodium chloride - ammonium chloride - sodium sulphate hydrate, having a chemical symbol $\text{NaCl} \cdot \text{NH}_4\text{Cl} \cdot 2\text{Na}_2\text{SO}_4 \cdot 20\text{H}_2\text{O}$.

4. A vapor-compression cooling system as defined in claim 1 wherein said portions of said tubing are folded such that each folded portion is in planar form and said planar portions are disposed in spaced parallel relation,

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and each of said sealed containers has a relatively narrow, substantially parallel wall configuration and is intrinsically disposed substantially within its respective planar portion, each of said substantially parallel walls being of heat conductive material and wherein said eutectic material is sodium chloride - sodium sulphate decahydrate, having a chemical symbol $\text{NaCl} \cdot \text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$, and each of said planar tubing portions is substantially encased by its respective sealed container with said substantially parallel walls thereof in heat conductive relation with said folded tubing along its length.

5. A vapor-compression cooling system as defined in claim 1 wherein said sealed container substantially encompasses said tubing along its length and said tubing includes outwardly extending radiation fin members disposed in heat conductive relation with respect said sealed container and extending therefrom and wherein said eutectic material is sodium chloride - ammonium chloride - sodium sulphate hydrate, having a chemical symbol $\text{NaCl} \cdot \text{NH}_4\text{Cl} \cdot 2\text{Na}_2\text{SO}_4 \cdot 20\text{H}_2\text{O}$.

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