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(54) **A SYSTEM AND METHOD FOR COOLING A SPACE UTILIZING THERMAL ENERGY STORAGE**

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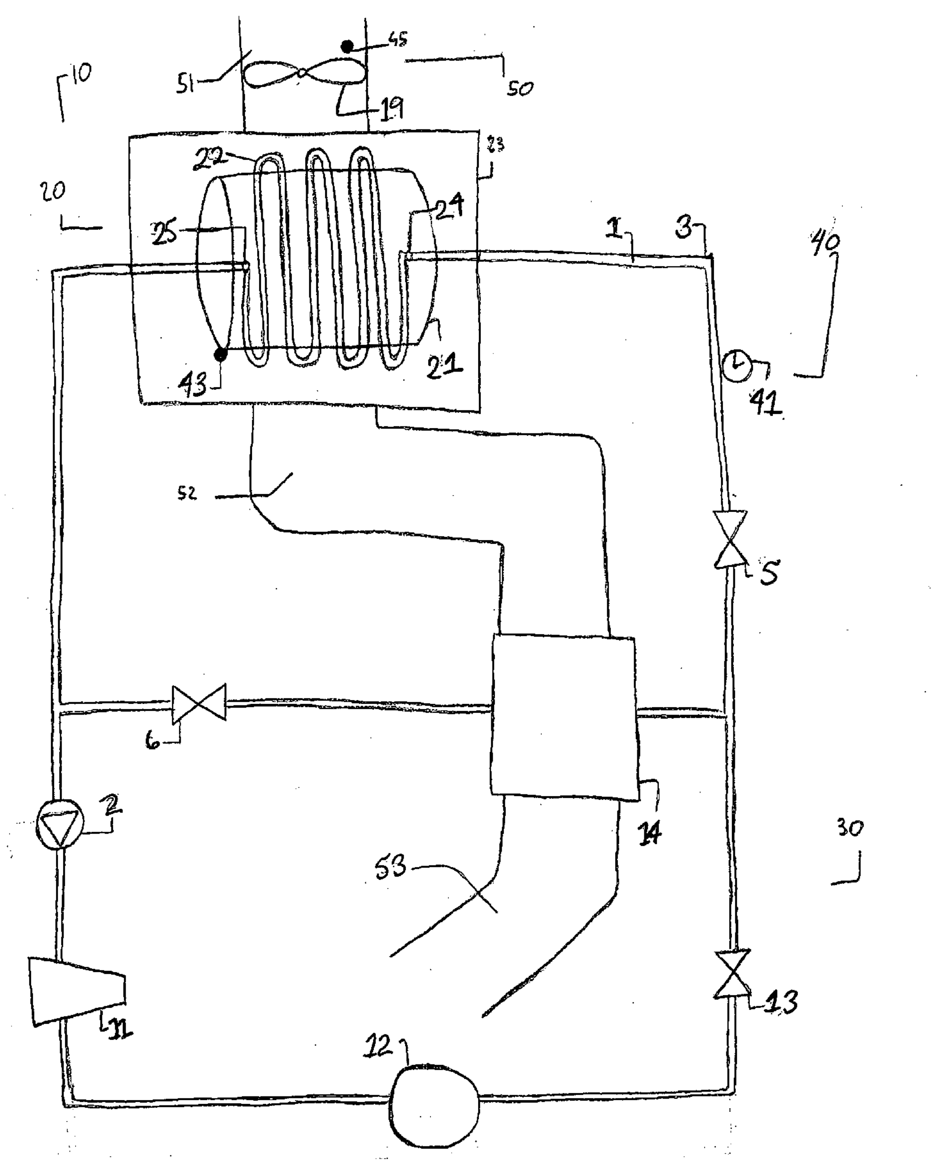
(57) **ABSTRACT**

A system and method of using the system is provided for cooling a building space through the use of thermal storage and release of energy by charging and discharging a phase change material comprising low temperature wax.



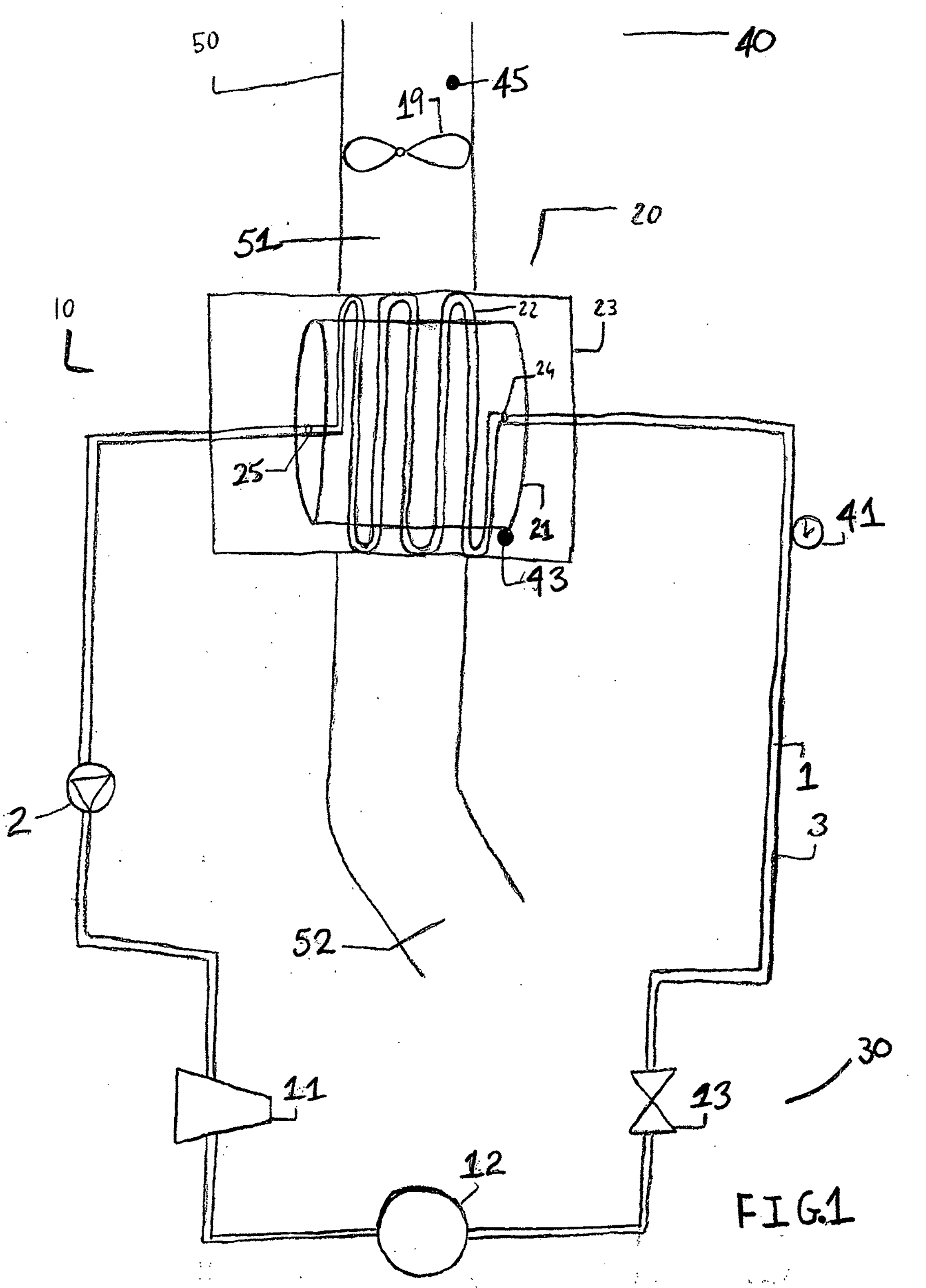


FIG.1

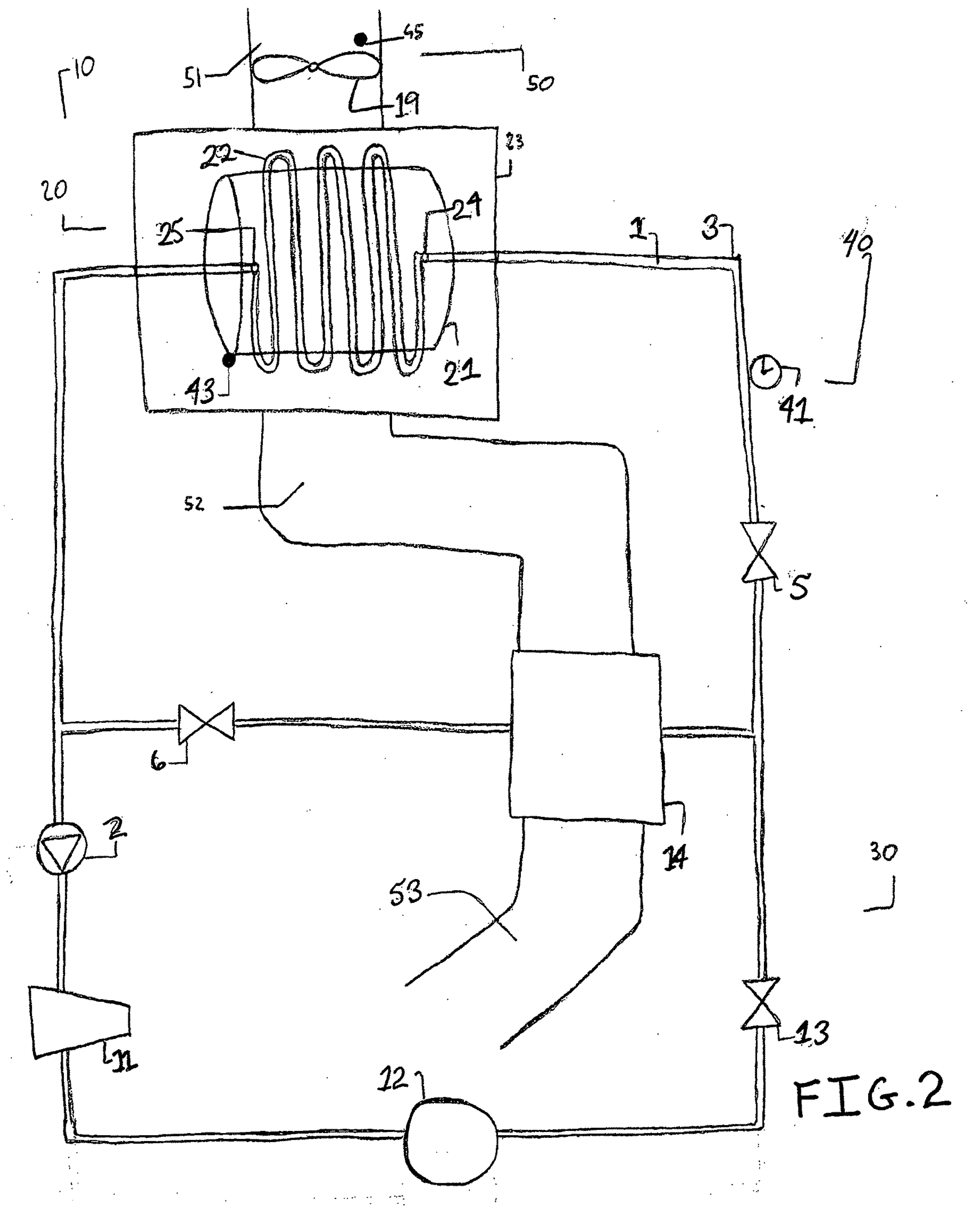


FIG.2

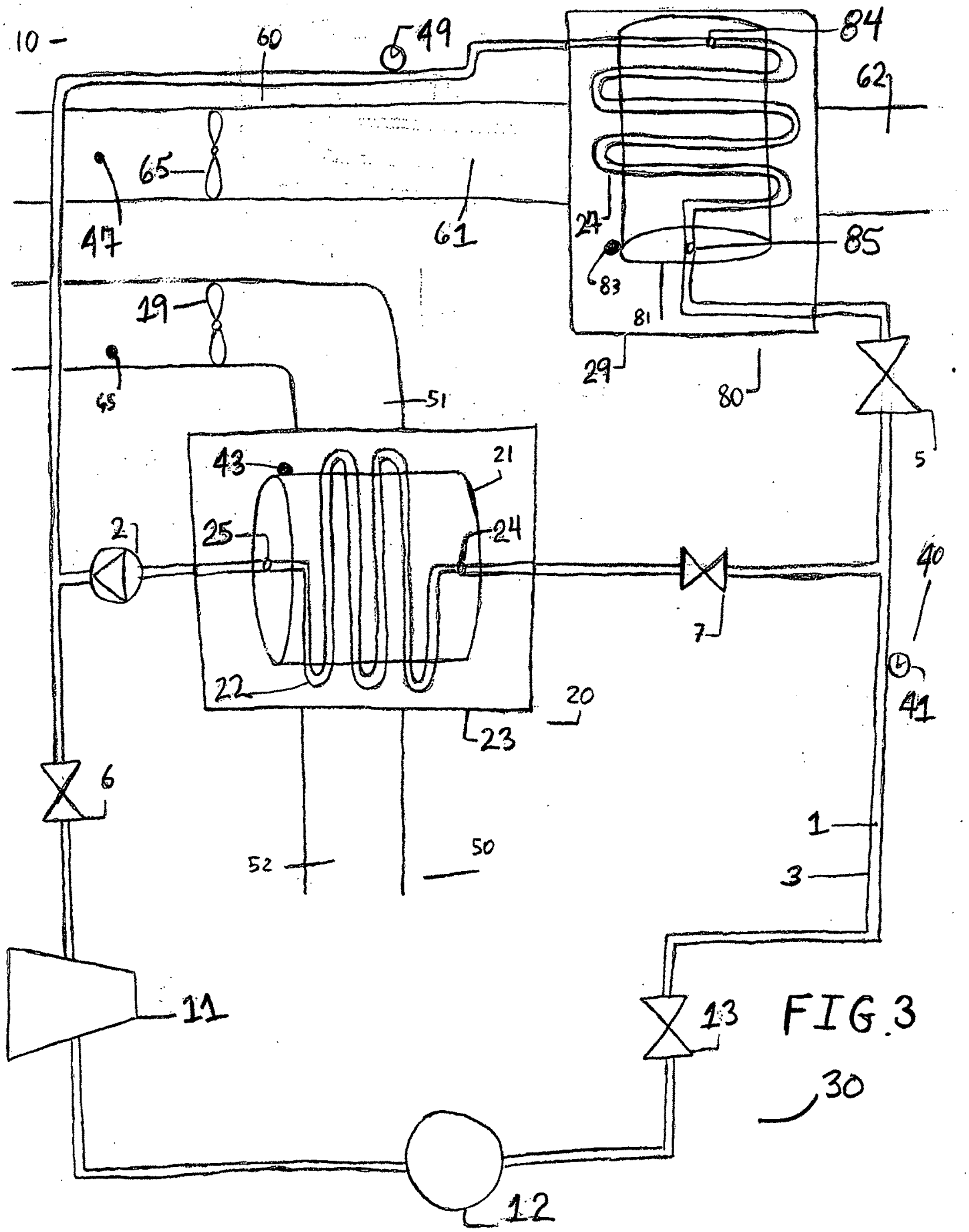

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FIG.3

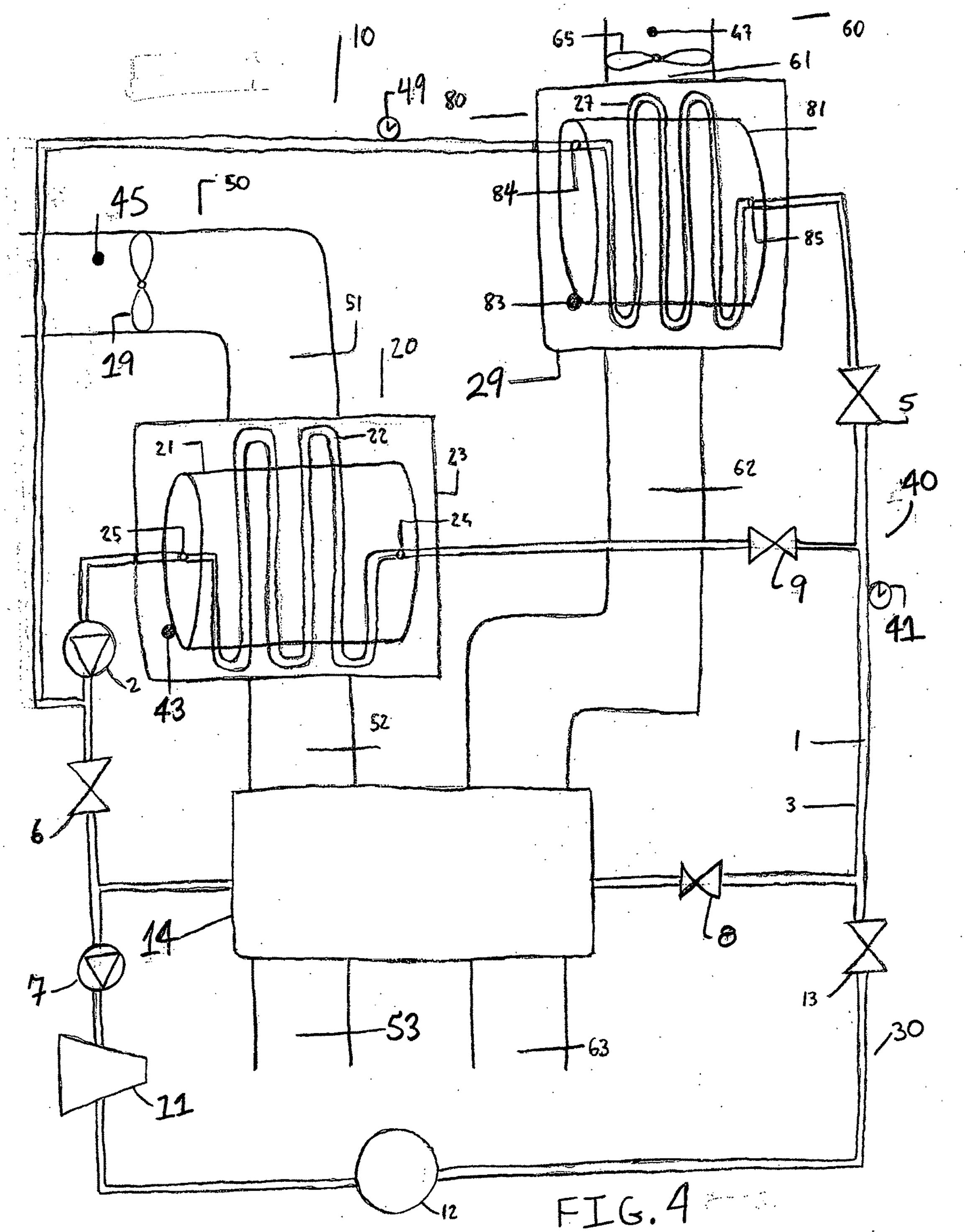
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FIG. 4

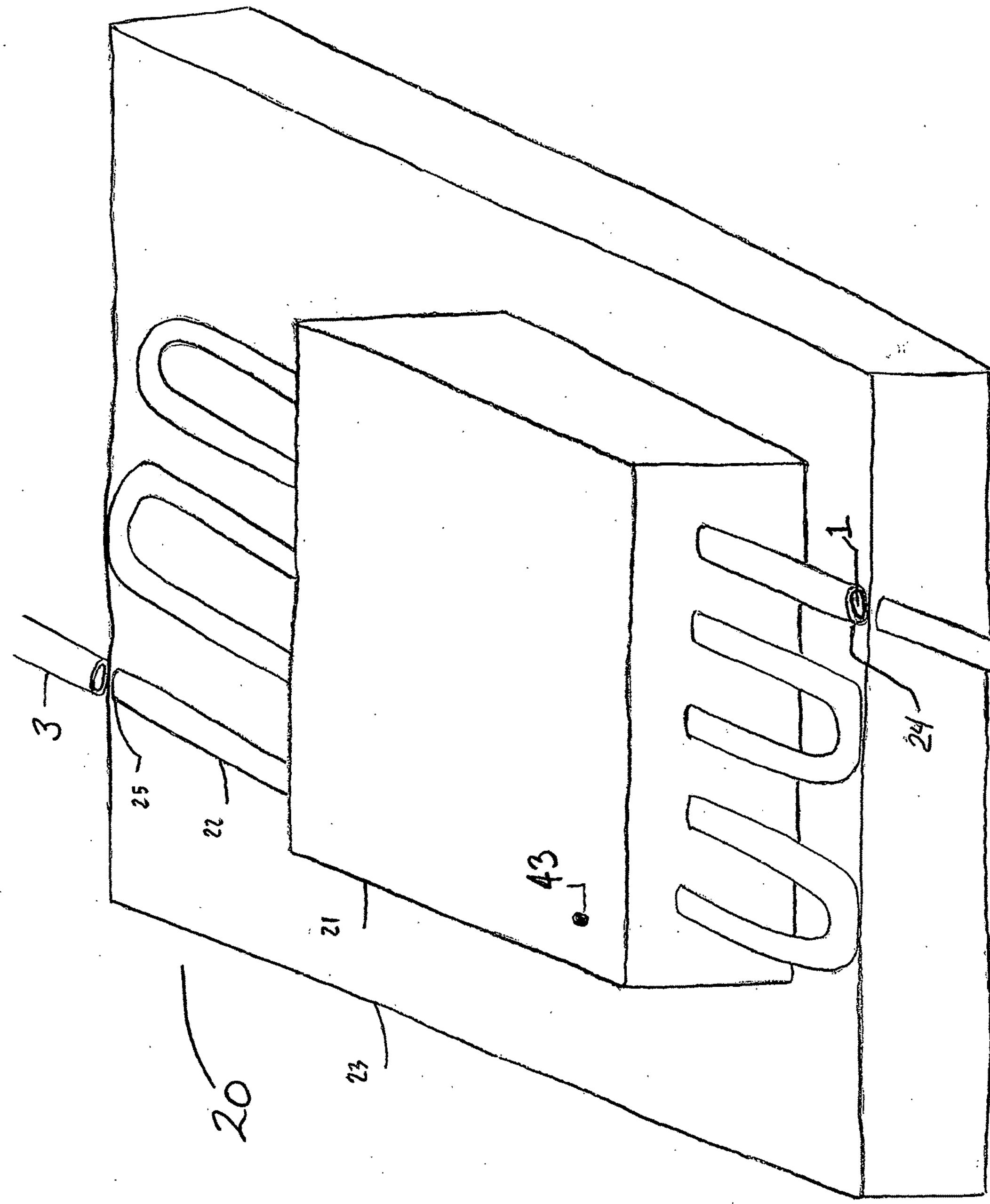

FIG. 5

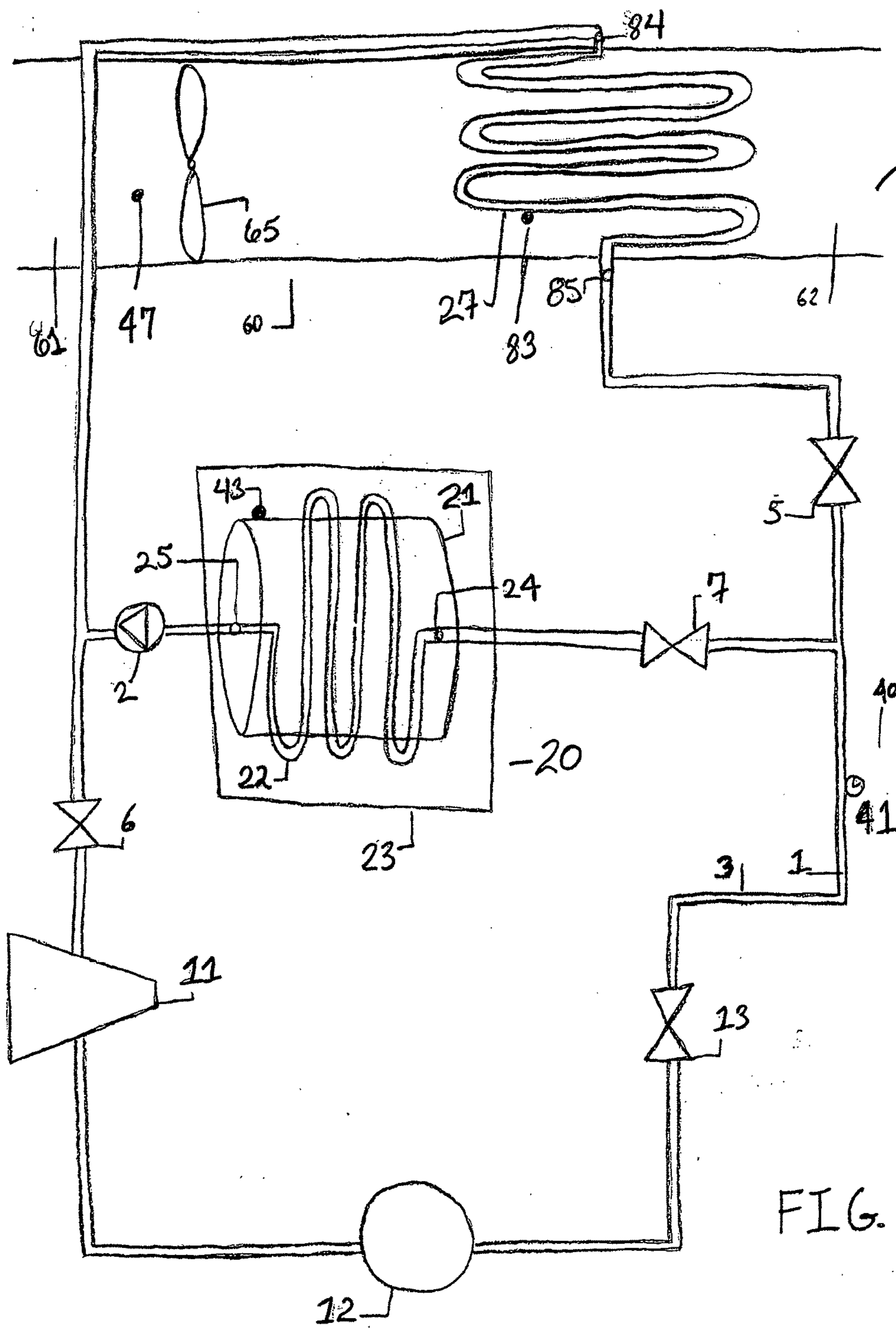
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FIG. 6

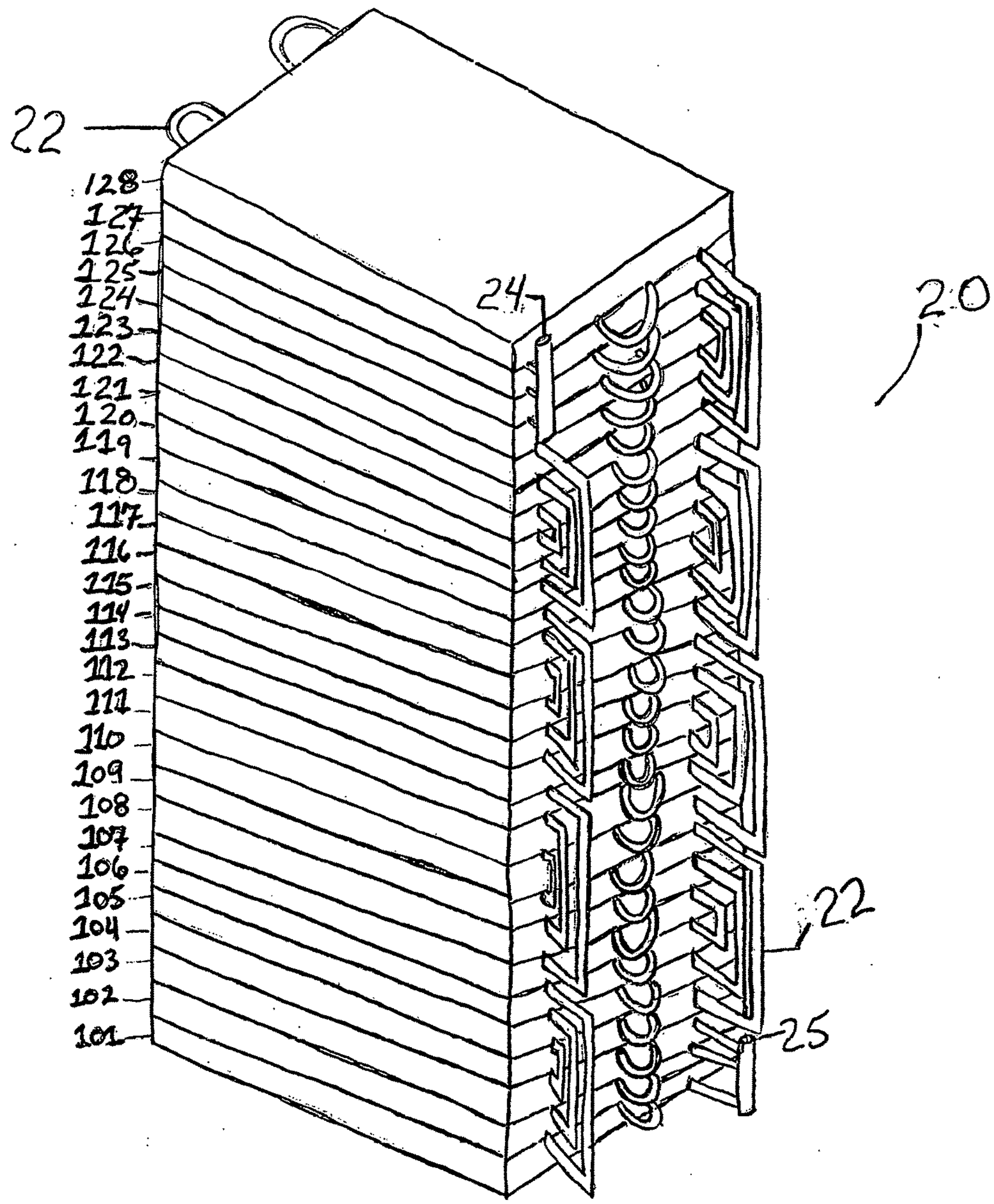
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FIG. 7

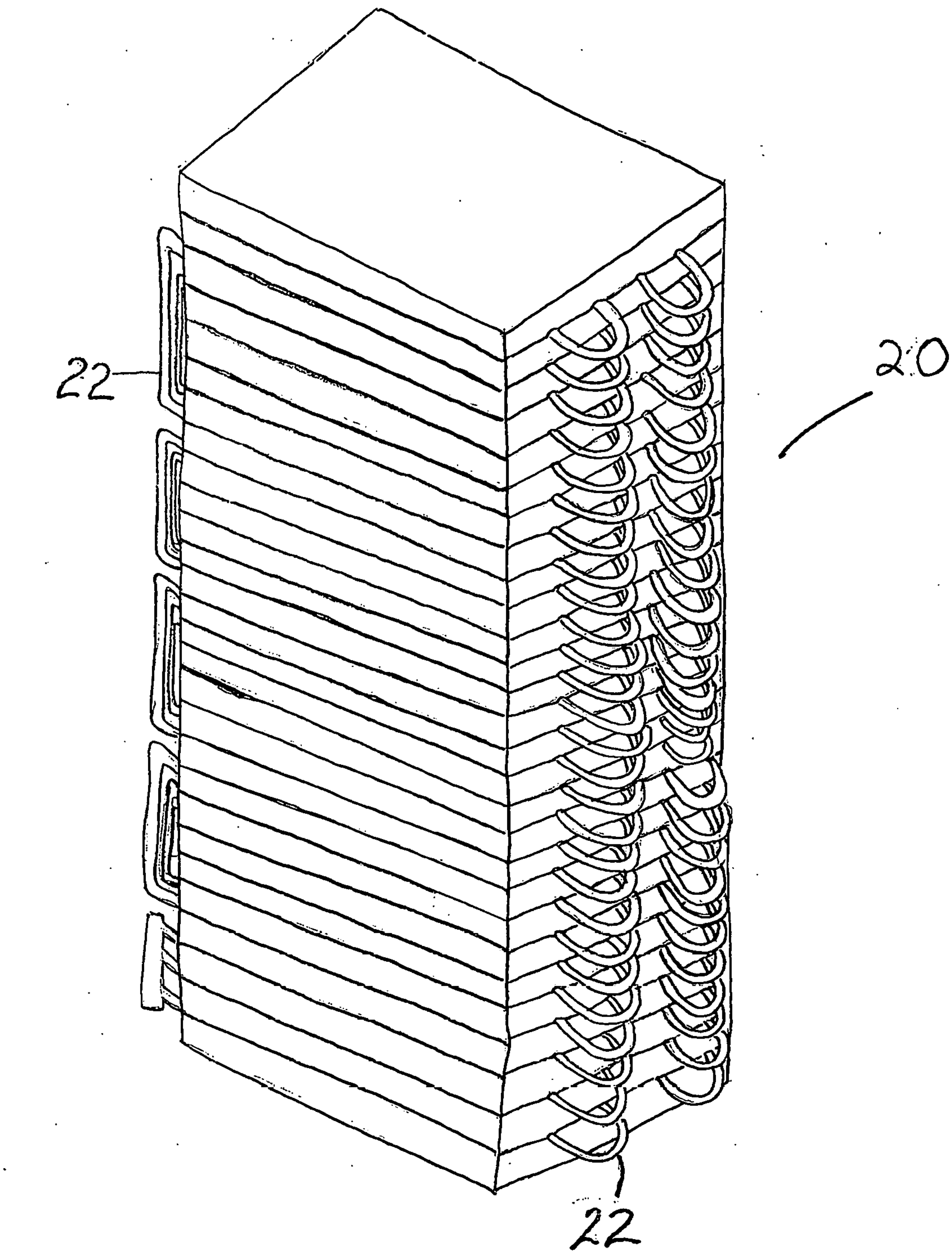

FIG. 8

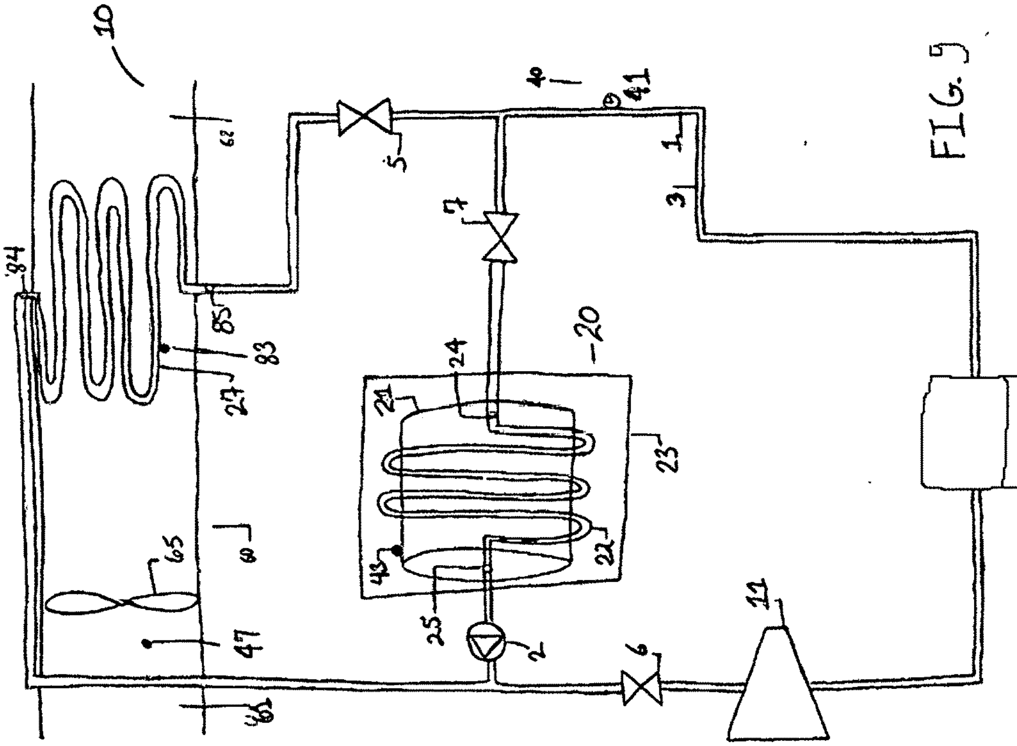

FIG. 9

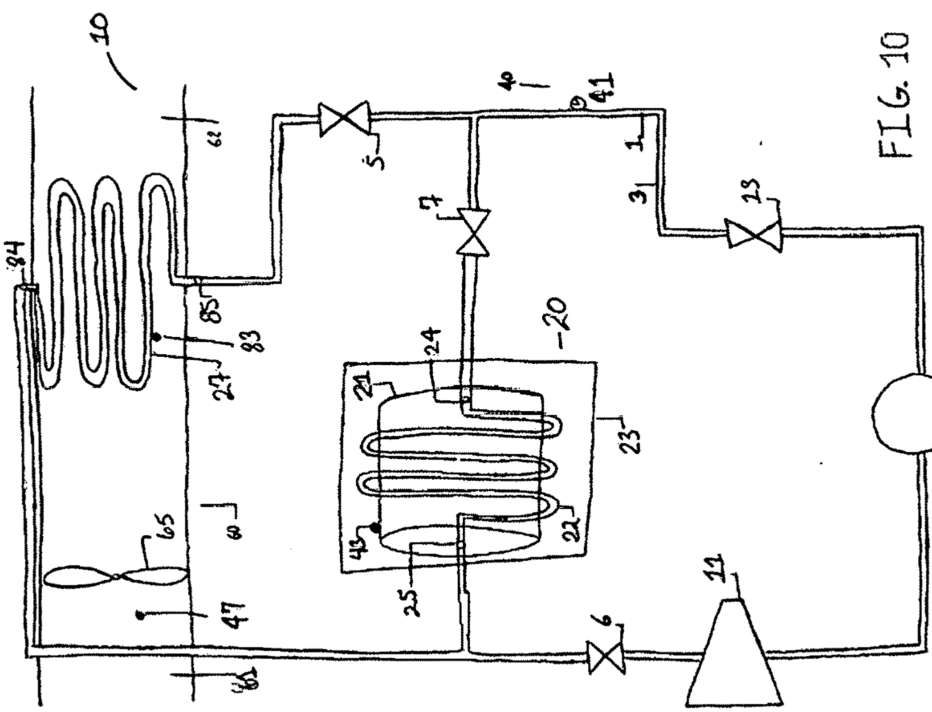

FIG. 10

A SYSTEM AND METHOD FOR COOLING A SPACE UTILIZING THERMAL ENERGY STORAGE

FIELD OF THE INVENTION

[0001] The present invention relates to a system and method for cooling a space utilizing thermal energy storage. More specifically, the invention relates to a system and method for cooling a space through the use of thermal energy storage and the release of thermal energy by utilizing a phase change composite comprising of a phase change material.

BACKGROUND

[0002] For buildings located in warm climates, electricity bills can be quite high due to energy consumption to cool these spaces during peak hours of heat. In the case of restaurants, peak hours are often during breakfast, lunch and dinnertime. In such peak hours, electricity prices are particularly high. On the other hand, during off peak and low cooling hours an air conditioning compressor unit operates at a high coefficient of performance, therefore necessitating lower energy consumption since the energy necessary to reduce the heat is small in proportion to the compressor's operating power, thereby passing lower costs to the owners. In some cases during peak hours electricity price can be 0.05-0.07 $/kWh higher than during off-peak periods.

[0003] Traditional cooling systems for commercial buildings are air conditioning units run continuously throughout the day. These buildings need to be cooled mainly during the day but units that run continuously ultimately result in high consumption costs and low energy efficiency.

[0004] Methods to store thermal energy for cooling purposes have been designed in order to try to manage the increasing demand for high-peak power consumption, while at the same time, minimizing power expenses. The goal is to save power consumption and cost in these systems by the release of previously stored cold thermal energy. Attempts have been made to create hybrid systems that include traditional air conditioning units along with thermal energy storage systems.

[0005] One such hybrid system utilizes ice, for example. The use of ice, however, provides for an inefficient re-charge of the cooling system when it is melted. Using more ice for better performance, in fact, requires more volume and space, an impractical solution. Water/ice, offers a slow response to storing and releasing cold thermal energy due to a much lower thermal conductivity. Ice only melts at 0° C. Clearly, problems remain with overall performance and capacity.

[0006] An effective and cost-efficient solution is needed for managing peak and off-peak times in an energy efficient manner, and therefore effectively reducing costs. Moreover, a system is needed which is simple to implement and to customize to systems already present in pre-existing commercial spaces.

SUMMARY OF THE INVENTION

[0007] The present invention is related to a system for cooling a space of any size utilizing thermal energy storage ("TES") wherein a phase change material composite ("PCC") comprising a phase change material ("PCM") and one or more thermally conductive materials or a PCM alone is coupled to an existing air conditioning refrigerant cycle to cool an environment.

[0008] The present invention is also related to a system that can store cold energy during the night by means of an electrically driven air conditioning unit and a TES unit comprising a PCC or a PCM alone, when electricity prices can be much lower than during the day, and use the energy stored in the TES unit's PCM during the day when electricity prices can be high, while allowing the electrically driven air conditioning unit to rest thus allowing energy and cost savings.

[0009] The present invention is related to a system having a PCM that can absorb a high amount of energy while changing from a liquid to a solid phase and release energy while changing from a solid to a liquid phase.

[0010] The present invention relates to a method for cooling an environment or space by routing hot air circulating from the environment to be in thermal communication with a PCC or a PCM alone which has been previously charged during a refrigeration cycle, thus cooling the air.

[0011] The present invention is further related to a method for cooling an environment or space by using low temperature wax along with graphite, a highly thermal conductive material, which offers much faster charging/discharging periods.

[0012] The present invention is even further related to a system which can be adapted to different applications and operative needs by customizing the composite in the phase change material composite and therefore provide appropriate melting points.

[0013] The present invention is also related to a system which can be adapted to currently existing air conditioning condensing units.

[0014] The present invention is further related to a system configured to have existing air conditioning units and a plurality of thermal energy storage modules function simultaneously or alternatively for cooling.

[0015] The present invention is moreover related to a system that can be implemented at low cost and with low space and volume requirements.

[0016] The present invention is even further related to a system that is simple to install and can be customized to the type of existing or new air conditioning condensing unit and ventilation system needed or already present.

[0017] The present invention is related to a system in which PCMs and PCCs can be in various configurations which enable the storage and release of thermal energy, for example, wrapped or even poured around the refrigerant conduit pipes of the refrigerant coil, or be incorporated into panels in thermal communication with the refrigerant coil.

[0018] The present invention is also related to a system which can utilize pre-existing air conditioning units to provide a more efficient solution for cooling.

[0019] The present invention is further related to a system having a thermal control system which can be automatically changed, manually changed, or be programmable to adjust for desired environmental temperatures.

[0020] These and other features of the present invention are further described in the section entitled the Detailed Description of the Drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] FIG. **1** illustrates an embodiment of the system in accordance with the principles of the present invention;

[0022] FIG. **2** illustrates another embodiment of the system in accordance with the principles of the present invention;

[0023] FIG. **3** illustrates yet another embodiment of the system in accordance with the principles of the present invention;

[0024] FIG. **4** illustrates still another embodiment of the system in accordance with the principles of the present invention;

[0025] FIG. **5** illustrates an embodiment of a PCC of the TES unit of the system in accordance with the principles of the present invention;

[0026] FIG. **6** illustrates still another embodiment of the system in accordance with the principles of the present invention;

[0027] FIG. **7** illustrates an embodiment of the TES unit of the system in accordance with the principles of the present invention;

[0028] FIG. **8** illustrates an embodiment of the TES unit of the system in accordance with the principles of the present invention;

[0029] FIG. **9** illustrates an embodiment of the system in accordance with the principles of the present invention; and

[0030] FIG. **10** illustrates yet another embodiment of the system in accordance with the principles of the present invention.

DETAILED DESCRIPTION OF THE DRAWINGS

[0031] The following detailed embodiments presented herein are for illustrative purposes. That is, these detailed embodiments are intended to be exemplary of the present invention for the purposes of providing and aiding a person skilled in the pertinent art to readily understand how to make and use of the present invention.

[0032] Accordingly, the detailed discussion herein of one or more embodiments is not intended, nor is to be construed, to limit the metes and bounds of the patent protection afforded the present invention, in which the scope of patent protection is intended to be defined by the claims and equivalents thereof. Therefore, embodiments not specifically addressed herein, such as adaptations, variations, modifications, and equivalent arrangements, should be and are considered to be implicitly disclosed by the illustrative embodiments and claims described herein and therefore fall within the scope of the present invention.

[0033] Further, it should be understood that, although steps of various claimed methods may be shown and described as being in a sequence or temporal order, the steps of any such method are not limited to being carried out in any particular sequence or order, absent an indication otherwise. That is, the claimed method steps are considered capable of being carried out in any sequential combination or permutation order while still falling within the scope of the present invention.

[0034] Additionally, it is important to note that each term used herein refers to that which a person skilled in the relevant art would understand such term to mean based on the contextual use of such term herein. To the extent that the meaning of a term used herein, as understood by the person skilled in the relevant art based on the contextual use of such term, differs in any way from any particular dictionary definition of such term, it is intended that the meaning of the term as understood by the person skilled in the relevant art should prevail.

[0035] Furthermore, a person skilled in the art of reading claimed inventions should understand that “a” and “an” each generally denotes “at least one,” but does not exclude a plurality unless the contextual use dictates otherwise. And that the term “or” denotes “at least one of the items,” but does not exclude a plurality of items of the list.

[0036] FIG. **1** illustrates an embodiment of the system **10** of the invention. The system in FIG. **1** has a refrigeration cycle **30**, a thermal energy storage (“TES”) unit **20**, a ventilation system **50**, and a thermal control system **40**.

[0037] The refrigeration cycle **30** and the TES unit **20** are thermodynamically connected via a refrigerant **1** running through a refrigerant management system which includes tubes **3**, valves and one or more liquid pumps. In this embodiment, the refrigerant **1** is housed in a tube **3** and is pumped through the system **10** by a liquid pump **2**.

[0038] The liquid pump **2** can be any liquid pump known in the art to move refrigerant through a heating ventilation and air conditioning (“HVAC”) system. The liquid pump **2** can be placed at any position along the loop that guarantees the movement of the refrigerant **1** through tubes of a refrigerant management system. If required additional pumps can be implemented. The liquid pump **2** pumps low pressure refrigerant **1** in the form of gas into a compressor **11** of the refrigeration cycle **30**. The refrigerant **1** then increases in pressure through the compressor **11** and is moved into a condenser **12** where the refrigerant **1** assumes a liquid phase under high pressure, while heat is released to the environment. Also provided is an expansion valve **13**, which is located after the condenser **12** in the refrigeration cycle **30**, and in use, lowers the pressure of the refrigerant **1** after it leaves the condenser **12**. The expansion valve **13** can be any type of valve understood by a person skilled in the art to lower the pressure of a refrigerant, such as a solenoid valve. In some embodiments the compressor **11** alone could suffice in terms of moving the refrigerant **1** along the loop; therefore a liquid pump **2** could be not necessary.

[0039] The refrigerant cycle **30**, when in use, cools the refrigerant, which then enters the TES unit **20**, thereby thermodynamically connecting the refrigeration cycle **30** and the TES unit **20**.

[0040] The refrigerant **1** leaves the expansion valve **13** in a tube **3** of the refrigerant management system in a cold liquid state, and enters the inlet **24** of the TES unit **20** and into its refrigerant coil **22**. The TES unit **20** also comprises a phase change material (“PCM”) **21** in thermal communication with the refrigerant coil **22** and ultimately the refrigerant **1** therein. The PCM could be a phase change material composite (“PCC”), or could be the PCM only. Since either form of PCM is contemplated to be included in a TES unit **20** of the present invention, PCM will be used for referring to both PCC and PCM, unless otherwise stated.

[0041] In use, the refrigerant **1** enters the inlet **24** of the TES unit **20** and is pumped through the refrigerant coil **22**. The refrigerant coil **22** is either surrounded by or adjacent to the PCM **21** whereby the refrigerant **1** is in thermal communication with the PCM **21**. The PCM **21** can be arranged, for example, in a plurality of slabs (see FIGS. **7** and **8** as one of the possible slabs configurations), through which the refrigerant coil **22** extends. In one embodiment, the refrigerant coil **22** can be made of copper and can exist in the PCM in a serpentine coil disposition. The refrigerant **1** exits the refrigerant coil **22** from the outlet **25**. The refrigerant coil **22** can also be any other material which is conducive to the thermal transfer of energy from the refrigerant to the PCM and vice versa.

[0042] The refrigerant **1** can be any phase change material commonly known and commonly used in the art to run through HVAC systems, for example, but not limited to, water and Freon™ (halo-carbon product or hydro fluorocarbons), propylene glycol or any combination thereof. If the refrigerant **1** is water/glycol, then in the embodiments of the system **10**, the condenser is replaced by a chiller. Moreover, if the refrigerant **1** is water/glycol no expansion valve **13** is required (see e.g. FIG. **9**). If the refrigerant **1** is Freon, then in the embodiments of the system **10**, the liquid pump is not required (see e.g. FIG. **10**).

[0043] A PCM is a thermal energy storage medium. The amount of energy stored or released by the PCM is called 'latent heat of fusion'. Thermal energy is stored by changing the phase of the PCM from liquid to solid or by changing the internal energy. Conversely, thermal energy is released as the material changes its phase solid to liquid. PCMs are designed to present high latent heat of fusion, melt and solidify at specified temperatures and are capable of storing and releasing a large amount of thermal energy.

[0044] An embodiment of the invention is supported by a TES unit **20** having a PCM **21**, which is a low temperature wax, on its own in a supporting structure, and it can be used for the thermal conductivity in the system.

[0045] In another embodiment, the PCM can be a composite, also referred to as a PCM composite ("PCC") including graphite. Aluminum oxide or other conductive metals can be added to the composite in order to further enhance thermal conductivity. A PCC can be characterized by a wide range of melting points. By increasing the number of atoms of carbon in the PCC it is possible to increase the melting point and vice versa. Using different percentages of low temperature wax and graphite, and potentially other materials in the PCC, allows the system to operate at different efficiencies due to the different melting points of the materials involved. Therefore, the system allows for different applications and operative needs by customizing the composite in the PCM and therefore providing appropriate melting points.

[0046] A PCC uses expanded graphite as a supporting porous matrix to hold the phase change material (low temperature waxes) together. Commercially available expanded graphite (EG) is formed by an intercalation reaction with various acids and subsequent heat treatment. Commercial EG is uni-axially compacted using a pneumatic press, or any commercially available press. Examples of pressing pressures range at between about 10 to about 30 psi pressure, and until bulky density of between about 170-about 200 Kg/m^3 is achieved. Different pressures can be applied to achieve different densities. Afterwards, the compressed EG is submerged in a bath of molten PCM (low temperature waxes), kept at a temperature of between about 5-10° C. higher than its melting temperature, and left to soak until the PCM has reached its maximum absorption into the graphite matrix.

[0047] EG density increases with the compaction pressure applied and it can be varied in order to reach higher thermal conductivity. Therefore, thermal conductivity increases with EG density whereas the PCM latent heat of fusion reduces with EG density (lower EG mass involved).

[0048] The PCC composition can for example be, but is not limited to, between about 60-85% PCM, and between about 15-40% EG. These percentages are not meant to be limiting, and the percentages can vary according to the application and operative mode desired. Other materials can also be used to replace EG in a PCC including, for example, but not limited to graphite powder, carbon fibers, graphite/carbon nano-powders/nano-fibers, copper, aluminum powder and conductive foam such as carbon, graphite, copper and aluminum. Other additives such as polymer can also be added to improve the mechanical properties.

[0049] PCMs store or release thermal energy along with a phase change over a prolonged period of time. A PCM is "charged" (and related terms used throughout the application) when it stores cold thermal energy and solidifies, and "discharges" (and related terms used throughout the application) when it releases thermal energy and changes phase from a more solid state to a more liquid state. Some PCMs are more advantageous in the TES unit **20** of the system **10** than others. For example, a PCM composite including low temperature waxes and graphite leads to a much faster charging time due to a high thermal conductivity of graphite. Varying the percentages of graphite and other conductive materials, and low temperature wax, in the PCC leads to varying thermal conductivity that can be tailored to different requirements. This is not possible for traditional PCMs. The system **10** is therefore customizable to many different applications and configurations.

[0050] Low temperature waxes are reliable, non-corrosive and chemically inert below 500° C. A system which has a refrigeration cycle and TES unit as herein described is efficient and therefore cheaper to operate than traditional air conditioning units and refrigeration cycles coupled with water/ice thermal energy storage modules. The use of a low temperature wax instead of water/ice is much more efficient also because of a much higher volumetric energy density (under some conditions more than 32 Wh/Lit compared to the 22 Wh/Lit) which translates into being able to store a much larger amount of heat than water/ice energy storage solutions.

[0051] Good high thermal conductivity is important in order to guarantee fast charge and discharge rates. With a faster charge rate the refrigeration air conditioning cycles need to operate, and therefore consume electricity, for shorter periods of time. Depending on the quantity of refrigerant flowing by the PCM, the system presents fast charging rates. For instance, with refrigerant transferring cold energy to the PCC at a pace of 1.86 GPH (gallons per hour–energy rate equivalent to stored energy content), PCC slabs can be cooled and store cold thermal energy in about 1 hour. At 4.5 GPH (energy rate twice the rate of stored energy content), a PCC can be expected to charge in 20 to 30 minutes, while at 12 GPH (energy rate 3-4 times higher than stored energy content) the PCC can fully charge in approximately 10 to 20 minutes.

[0052] Another important property presented by low temperature waxes is negligible "super cooling", which is the possibility of lowering the temperature of a material below its freezing point without it becoming a solid. Without solidifying, the PCM cannot store thermal energy. Therefore, the use of low temperature waxes in the PCM and the

PCC is advantageous because it experiences negligible super cooling and can thus freeze and store thermal energy.

[0053] Moreover, a PCC composed of low temperature wax and other additives in different combinations has quite a long operative life, possibly of more than 15 years, with an endurance to function for more than 10,000 cycles continuously with an overall efficiency between 80 and 95%.

[0054] Therefore, for comparable performances a much lower volume of PCM is needed compared to other PCMs such as water/ice. Moreover, for comparable performances, a system which uses water/ice as the PCM often requires a second refrigeration cycle unit and components such as a universal refrigerant management system ("URMV") not needed by the present system **10** which utilizes a PCM having low temperature wax and graphite and/or aluminum oxide.

[0055] PCMs can also be any organic material, inorganic materials like salt hydrates, bio-based materials like fatty acids derived from plant and animal sources.

[0056] The TES unit **20** also is comprised of an insulating apparatus **23** that insulates the PCM **21** and the refrigerant coil **22**. The insulating apparatus **23** prevents thermal energy dispersion. The material of the insulating apparatus **23** could be any material commonly known in the art to thermally insulate such as, but not limited to, polyurethane, fiberglass, and wood.

[0057] In use, the refrigerant **1** is pumped through the refrigerant coil **22** in thermal communication with the PCM **21** thus lending its cold thermal energy to the PCM **21**, solidifying the same. The refrigerant **1** exits the TES unit **20** via the outlet **25** of the refrigerant coil **22** and enters the refrigeration cycle **30** via a liquid pump **2** through the refrigerant management system. In this way, the refrigerant **1** can again be made cold for ultimately charging the PCM **21**.

[0058] It should be noted that the refrigerant coil need not exist in the TES unit **20** as a serpentine coil. Any shape or disposition is acceptable as long as the refrigerant **1** remains in thermal communication with the PCM **21**. However, a serpentine coil shape of the refrigerant coil **22** provides ample surface area along which the refrigerant passes by or through the PCM providing good thermal energy transfer to the PCM. The refrigeration coil **22** could be any material known in the art to facilitate heat exchange. Some examples of materials which could be used include, but are not limited to, copper, copper alloys, aluminum, silver, gold, and alloys of the same. On the other hand, the tubes of the refrigerant management system should be covered with an insulating material known in the art to insulate from heat dissipation so that transfer of the refrigerant between the various components of the system does not disperse thermal energy. Some examples of insulating material which could be used include, but are not limited to, polyurethane, fiberglass and polyethylene. The TES unit **20** can, in other words, represents a heat exchanger with a serpentine of internal refrigerant coils **22** where the liquid refrigerant **1** runs through and cools the PCM **21** surrounding the coils. One of the possible configurations of the TES unit **20** can be very similar to a plate heat exchanger, composed of thin plates with a sufficiently large surface to allow an effective thermal communication. This is also true for all embodiments wherein a thermal energy storage unit is used. (FIG. **1-4**, FIG. **6** and FIG. **9-10**).

[0059] The ventilation system **50** is composed of an air inlet **51** and an air outlet **52**. The air inlet **51** is adjacent to the PCM **21** of the TES unit **20**. In this way, the air inlet **51** transports warm environmental air to the TES unit **20** and is configured to put the warm air in thermal communication with the PCM **21**. Therefore, it is more optimal, but not necessary, for the air to be transported between the material of the insulating apparatus **23** and the PCM **21** of the TES system **20**. In operation, the warm air is transported through the air inlet **51** past or through the PCM **21** of the TES unit **20**. The PCM **21** is charged and therefore in a solid state and is able to release cold thermal energy to the air. Opposite to the air inlet **51**, and adjacent the TES unit **20**, resides the air outlet **52**, which in use transports the cooled air to a building's environment, thus cooling the air of the building.

[0060] Any ventilation system which could be considered to operate in a commonly used air conditioning system for a building can be used in the invention. The ventilation system **50** can include, but is not limited to, a propulsion device **19** for moving the air through the air inlet **51** to and through the air outlet **52**. The propulsion device **19** can for example be a fan.

[0061] The system **10** also includes a thermal control system **40**. The thermal control system **40** can be manually monitored and governed, whereby the system is turned on and off manually; can be automatically controlled, whereby the system is set on a timer **41** according to parameters chosen and set as desired, for example depending on past history of energy usage, to heat recordings, to day versus night time usage, and peak demands; and can be monitored by sensors providing real time temperature readings of the building environment **45** and/or the PCM/PPC temperatures **43**, and adjusting the operation of the system **10** according to threshold levels set in the control system. The thermal control system **40** can also be connected to a network system whereby the thermal control system **40** can adjust the operation of the system **10** according to weather forecasts or historical data. The thermal control system **40** can also be provided with an override to an automatic or programmable thermal control system **40** whereby manual override is implemented for emergencies.

[0062] FIG. **2** illustrates another embodiment of the system **10**. The system **10** of FIG. **2** provides a refrigeration cycle **30** with a liquid pump **2**, a compressor **11**, a condenser **12**, an expansion valve **13**, a TES unit **20**, a ventilation system **50**, and a thermal control system **40**. In this embodiment the TES unit presents a PCM **21** in thermal communication with a refrigerant coil **22**, and an insulating apparatus **23** to avoid thermal dispersion and keep the TES thermally insulated. The refrigerant **1** enters the refrigerant coil **22** through the inlet **24** and exits from the outlet **25**. In this particular embodiment, the refrigeration cycle **30** also includes an evaporator **14** that completes the refrigeration cycle. In addition, the system **10** further is provided with a first valve **5** between the TES unit **20** and the expansion valve **13** of the refrigeration cycle **30** and a second valve **6** located between the evaporator **14** and the TES **20**. If in use, the first valve **5** is closed and the second valve **6** is open, then the TES unit **20** is bypassed by the refrigerant **1** thus allowing for only using the refrigeration cycle **30**, which in this case would operate as purely an air conditioning system. In this particular embodiment illustrated in FIG. **2**, however, a liquid pump is disposed between the second valve **6** and the compressor **11** of the refrigeration cycle **30**. By closing the second valve **6** and keeping the first valve **5** open during operation, the evaporator **14** is bypassed and the refrigerant **1** travels through the refrigeration cycle **30** and the refrigerant management system's tubes **3** to the PCM **21** of the TES unit **20**.

[0063] The first **5** and second **6** valves are open and closed alternatively. The first and second valves **5**, **6** can be any valve commonly used or known in the art to stop or allow the flow of refrigerant when in an open or closed position, for example a check valve such as a solenoid valve or a ball valve could be used. When the first valve **5** is open and the second valve **6** is closed the TES unit **20** is charging; on the contrary, when the first valve **5** is closed and the second valve **6** is open the TES unit **20** is bypassed and the system functions as a traditional air conditioning loop as described as follows: the refrigerant fluid **1** reaches the compressor **11** as a low pressure gas. After being compressed the refrigerant moves to the condenser **12** as a high-pressure gas. The refrigerant gas condenses to a liquid state and releases its heat to the outside environment. The high-pressure liquid refrigerant then moves to the expansion valve **13** that lowers its pressure. The low pressure liquid then moves to the evaporator **14** where the heat from the outside air directed to the evaporator by means of a ventilation system **50** is absorbed by the refrigerant, which goes back to a low pressure gas state and moves to the compressor where the refrigeration cycle is concluded. Traditionally, for an air conditioning refrigeration cycle described in this paragraph the refrigerant must be used continuously. This means that the liquid pump **2** must operate repeatedly, resulting in a large amount of electricity needed, although the work of the compressor could be enough to guarantee sufficient transfer of refrigerant **1** throughout the system. The liquid pump **2** can assist the compressor **11** if a consistent transfer energy is required but its use could be redundant in some cases. This invention also provides an embodiment which uses the refrigeration cycle **30** and the liquid pump **2** only during the TES **20** charging phase. While discharging, refrigerant circulation is not necessary; a building can be cooled with only the ventilation system **50** moving hot air past the PCM **21** or past the evaporator **14**.

[0064] Also provided in this embodiment, is an evaporator **14** which allows for the refrigerant **1** in the refrigeration cycle **30**, if used alone bypassing the TES unit **20**, to cool air directed by the inlet **51** across the evaporator **14** of the ventilation system **50**. The evaporator **14** could also serve to further cool air which has already traveled through the ventilation system **50** across the charged PCM **21** of the TES system **20**. The ventilation system **50** can be provided with a propeller like a fan **19** to be able to transfer the air throughout the different cooling stages. Through the outlet **52** of the ventilation system **50**, the air cooled by the PCM **21** can be further cooled passing by the evaporator **14**. The use of the refrigeration cycle **30** and an evaporator **14** therein can provide additional cooling down at least another 5° Celsius. With the use of the evaporator **14** as an extra cooler for the air coming from the outlet **52**, the ventilation system **50** will be able to provide cold air to the environment through a second outlet **53**.

[0065] The thermal control system **40** can operate in the same manner as discussed above with the additional feature of allowing for control of the first and second valves **5** and **6**. The thermal control system **40** can include a timer **41** and temperature sensors **43** located in thermal contact with the PCM **21** and with the building environment or space that needs cooling.

[0066] If the refrigerant **1** is water/glycol a chiller will take the place of the condenser in the same position along the loop. Also an expansion valve might not be required or bypassed if water/glycol is used. If Freon is used as refrigerant **1** the liquid pump will not be required.

[0067] FIG. **3** is yet another embodiment of the system **10** of the present invention, wherein provided is a refrigeration cycle **30**, a TES unit **20**, an external TES unit **80**, a ventilation system **50**, an external ventilation system **60** and a thermal control system **40**. The refrigeration cycle **30** also comprises a compressor **11**, a condenser **12** and an expansion valve **13**. The embodiment illustrated in FIG. **3** also includes a third valve **7** located between the TES **20** and the first valve **5**. In this embodiment, there is shown an external refrigerant coil **27**, external to the TES unit **20**. In addition, heat exchange can take place in a heat exchanger wherein the air and the refrigerant exchange heat. In another embodiment, there could be a plurality of external refrigerant coils **27**, some of which can be part of each of a plurality of external TES unit(s) **80**, each also having a PCM **81**.

[0068] Moreover, this embodiment can also include an external ventilation system **60**, which is configured to put warm air from another location of the same building into thermal communication with the external refrigerant coils **27** and PCM **81**. The ventilation system **50** can be provided with a fan **19** or any equivalent air propeller capable of directing warm air from an area of the building through the PCM **21** of the TES **20**. This air can enter the ventilation system **50** through the inlet **51** and exit from the outlet **52**. The external ventilation system **60** can also be provided with a propeller **65**. The warm air can enter the external ventilation system **60** in the external ventilation system inlet **61** and exit from the external ventilation system outlet **62**. In this embodiment the liquid pump **2** is located between the TES **20** and the external TES **80** and is configured to pump cold refrigerant from the TES **20** to cool the PCM **81** in the external TES **80**. The TES **20** includes the refrigerant coil **22** having an inlet **24** and an outlet **25**. In use, the liquid pump **2** of the system **10** pumps the refrigerant **1** through the refrigerant coil **22** so that the refrigerant is in thermal communication with the PCM **21**. Moreover, the TES **20** is thermally insulated by means of an insulating apparatus **23**.

[0069] In this embodiment, the PCM **21** of the TES unit **20** is charged via the cold refrigerant **1**, which runs through the tubes **3** of the refrigerant management system, which exits the expansion valve **13** of the refrigeration cycle **30**. To charge the TES **20** the third valve **7** and the second valve **6** are open while the first valve **5** is closed. In this way the TES **80** is bypassed. Contrariwise, it is possible to charge the TES **80** bypassing the TES **20** closing the third valve **7** while the first valve **5** and the second valve **6** are open. In use, when the second valve **6** and the expansion valve **13** are closed, while the first valve **5** and the third valve **7** are open, the refrigerant **1** can utilize the charged PCM **21** of the TES unit **20** to deliver cool thermal energy to the external refrigerant coil **27** and charge the PCM **81**. The external TES **80** could also be equipped with an external insulating device **29**, which would prevent dispersion of thermal energy. The refrigerant **1** can enter the external refrigerant coil **27** from the inlet **84** and exit from the outlet **85**. In this way, there can be more than one ventilation system designated to cool different areas of the same building, using the same refrigeration cycle **30**, wherein the first ventilation system **50** resides in thermal communication with only the PCM **21** of the TES unit **20**, and air passing through an external ventilation system **60** can be cooled by thermally communicating with the TES **80**, which includes external refrigeration coil **27** and PCM **81**. It is also possible that there is yet another embodiment that illustrates a plurality of both external refrigeration coils **27** and also external TES units **80**. For such a system **10**, it may be desirable to implement the same with a plurality of liquid pumps **2**.

[0070] In this embodiment, the first valve **5** is disposed between the expansion valve **13** and the external refrigerant coil **27**. The second valve **6** is located between the liquid pump **2** and the compressor **11**. The thermal control system **40** can include, but is not limited to, such features as a timer **41** functioning as described in FIG. **1** but related to the TES **20**, a timer **49** associated with the TES **80**, a PCM temperature sensor **43** for PCM **21**, a PCM temperature sensor **83** for PCM **81**, an environment temperature sensor **45** for a first environment of the building and another environment temperature sensor **47** for a second environment of the same building.

[0071] FIG. **4** also shows an embodiment of the system **10** in accordance with the principles of this invention and a refrigerant **1** running through a system of tubes **3** of the refrigerant management system that connects the components of the different loops. The embodiment in FIG. **4** has a refrigeration cycle **30** with a liquid pump **7**, a compressor **11**, a condenser **12**, and an expansion valve **13** functioning in a manner equivalent to the previous embodiments, a TES unit **20**, a second TES **80** with PCM **81**, external refrigerant coil **27** and an insulating apparatus **29**, a ventilation system **50**, a second ventilation system **60** and a thermal control system **40**.

[0072] In this embodiment is also provided an evaporator **14** for the refrigeration cycle **30** which allows the system **10** to potentially run exclusively as an air conditioning refrigeration unit, but in addition, depending on the placement of the evaporator **14** in relation to the primary ventilation system **50** and the external ventilation system **60**, the evaporator **14** could serve to further chill air running through the primary **50**, external ventilation system **60**, or both i.e. across the TES unit **20** and/or **80** and then the evaporator, down a few more degrees than possible only with the TES unit **20**.

[0073] Moreover, this embodiment presents a second liquid pump **7** in addition to the liquid pump **2**, a third valve **8** and a fourth solenoid valve **9** in addition to the first solenoid valve **5** and the second solenoid valve **6**. The liquid pump **2** is placed between the TES **20** and the TES **80**; the liquid pump **7** is located between the evaporator **14** and the compressor **11**; the first solenoid valve **5** is between the TES **80** and the fourth solenoid valve **9**, while the second solenoid valve **6** is placed between the liquid pumps **2** and **7**. The third solenoid valve **8** is between the evaporator **14** and the expansion valve **13**; the fourth solenoid valve **9** is between the expansion valve **13** and the TES **20**.

[0074] In this embodiment is shown an external refrigeration coil **27**, and thus the system **10**, is configured to charge the PCM **21** of the TES unit **20**, and then to operate in a discharge mode while keeping environmental air cool. The thermal control system **40** can include a timer **41**, associated to the first ventilation system **50** and the first TES unit **20**, functioning as described in FIG. **1**, another timer **49** associated to the second ventilation system **60** and the second TES unit **80**, a PCM temperature sensor **43** for PCM **21**, a PCM temperature sensor **83** for PCM **81**, an environment temperature sensor **45** for a first environment of the building and another environment temperature sensor **47** for a second environment of the same building.

[0075] This particular embodiment can be used as a 2-stage cooling system for air coming from 2 distinct areas of the same building, therefore using the same refrigeration cycle **30**, but with **2** separated ventilation systems (**50** and **60**) and TES units (**20** and **80**).

[0076] The ventilation system **50** has warm air pushed from a building environment through the inlet **51** by means of a fan **19** or any equivalent ventilation propeller towards the PCM **21**. The air exiting the PCM **21** (and the TES unit **20**) is cooled at the exit section **52** of the ventilation system. If directed through the evaporator **14**, the air from the TES **20** is further cooled at the outlet section **53**.

[0077] The ventilation system **60** has warm air pushed from a building environment through the inlet **61** by means of a fan **65** or any equivalent ventilation propeller towards the PCM **81**. The air exiting the PCM **81** (and the external TES unit **80**) is cooled at the exit section **62** of the ventilation system. If directed through the evaporator **14**, the air from the external TES unit **80** is further cooled at the outlet section **63**.

[0078] In the TES **20** the refrigerant **1** coming from the refrigerant management system's tubes **3** is put in thermal communication with the PCM **21** when entering the refrigerant coil **22** from the inlet **24**. The refrigerant **1** exits the PCM **21** from the outlet **25**. An insulating apparatus **23** limits thermal loss and dispersion to the surrounding environment. Similarly, in the TES unit **80** the refrigerant **1** is put in thermal communication with the PCM **81** entering the inlet **84** to the external refrigerant coil **27**. The refrigerant **1** thereafter goes back to the refrigerant management system exiting the outlet **85**.

[0079] In the embodiment represented in FIG. **4** the system **10** can function as a traditional air conditioning system when the valves **6**, **9** and **5** are closed, and the valve **8** and the expansion valve **13** are open. In this way the TES units **20** and **80** are isolated. Warm air from the building can be cooled only through the evaporator **14** if one of the ventilation systems **50** and **60**, or both, are in use. The PCM **21** can be charged and solidify with the refrigeration cycle **30** in use and valves **5** and **8** are closed, while valves **6** and **9** are open. The PCM **81** can be charged when the refrigeration cycle **30** is in use, with valves **8** and **9** closed and valves **5** and **6** open.

[0080] It is also possible to charge the PCM **81** with the cold refrigerant **1** coming from the TES unit **20**, thus with the refrigeration cycle **30** not in use. To achieve this, liquid pump **2** is operational, while liquid pump **7** is not; for this operation the valves **5** and **9** are open while valves **8**, **6** and the expansion valve **13** are closed.

[0081] During discharge mode, the ventilation systems **50** and **60** can be in use alternatively or at the same time, depending on the cooling requirement of the environment.

[0082] FIG. **5** illustrates a TES unit having the PCC configured as a slab. This could be a possible configuration of a TES unit **20** (or **80**) illustrated and discussed in reference to the previous figures. The PCM **21** is shown in a single slab design with the refrigerant coil **22** running though the slab in the shape of a serpentine disposed longitudinally across the PCM **21** slab, with an ample area covered for effective thermal transfer between the refrigerant **1**, coming from the refrigerant management system's tubes **3**, and the PCM **21**. The PCM **21** can be designed to be in many different configurations including, but not limited to, a plurality of PCM **21** slabs stocked in piles, or other convenient geometrical shapes implemented with the same concept illustrated in FIG. **5**. The refrigerant **1** is pumped by means of the pump **2**, or other pumps installed in the refrigerant loop **30**, in the refrigerant coil **22**; the refrigerant **1** enters the refrigerant coil **22** through the inlet **24** from the management system tubes **3** and exits the refrigerant coil **22** from the outlet **25**.

[0083] An insulating apparatus **23** surrounds the PCM **21** and the refrigerant coil **22** to guarantee thermal insulation and avoid the loss of thermal energy to the surrounding environment.

[0084] Also provided is a temperature sensor **43** in thermal communication with the PCM **21** which can be operationally connected with the control system **40** to provide information about the temperature of the PCM material. For instance, when the PCM temperature reaches an established threshold, the control system **40** could start the refrigeration cycle **30** to initiate the charging process of the PCM **21**.

[0085] The PCM **21** and refrigerant coil **22** configuration proposed in FIG. **5** can be adapted for TES solutions in all the 4 embodiments illustrated in FIGS. **1-4** and can be suitable for TES unit **20** as well as TES unit **80**.

[0086] FIG. **6** is yet another embodiment of the system **10** of the present invention, wherein provided is a refrigeration cycle **30**, a TES unit **20**, an external ventilation system **60** and a thermal control system **40**. The refrigeration cycle **30** also comprises a compressor **11**, a condenser **12** and an expansion valve **13**. The embodiment illustrated in FIG. **6** also includes a third valve **7** located between the TES **20** and the expansion valve **13**. In this embodiment, there is shown an external refrigerant coil **27**, external to the TES unit **20**. In another embodiment, there could be a plurality of external refrigerant coils **27**.

[0087] This embodiment includes an external ventilation system **60**, which is configured to put warm air from another location of the same building into thermal communication with the external refrigerant coils **27** that cool the warm air with refrigerant **1** coming from the cold TES unit **20**. The external ventilation system **60** can also be provided with a propeller **65**. The warm air can enter the external ventilation system **60** in the inlet **61** and exit from the outlet **62**. In this embodiment the liquid pump **2** is located between the TES unit **20** and the external refrigerant coils **27** and is configured to pump cold refrigerant **1** from the TES unit **20** to cool the refrigerant coils **27**, when the second valve **6** is closed. The TES unit **20** includes the refrigerant coil **22** having an inlet **24** and an outlet **25**. In use, the liquid pump **2** of the system **10** pumps the refrigerant **1** through the refrigerant coil **22** so that the refrigerant is in thermal communication with the PCC **21**. Moreover, the TES unit **20** is thermally insulated by means of an insulating apparatus **23**.

[0088] In this embodiment, the PCC **21** of the TES unit **20** is charged via the cold refrigerant **1**, which runs through the tubes **3** of the refrigerant management system, which exits the expansion valve **13** of the refrigeration cycle **30**. To charge the TES unit **20** the third valve **7** and the second valve **6** are open while the first valve **5** is closed. In this way the refrigerant coils **27** are bypassed. It is also possible to cool the refrigerant coils **27** bypassing the TES unit **20** closing the third valve **7** while the first valve **5** and the second valve **6** are open. In use, when the second valve **6** and the expansion valve **13** are closed, while the first valve **5** and the third valve **7** are open, the refrigerant **1** can utilize the charged PCM **21** of the TES unit **20** to deliver cool thermal energy to the external refrigerant coil **27** and cool the warm air directed by the ventilation system **60** in thermal communication with the refrigerant coils **27** and back to the building environment through the outlet **62**. The refrigerant **1** can enter the external refrigerant coil **27** from the inlet **84** and exit from the outlet **85**.

[0089] In this embodiment, the first valve **5** is disposed between the expansion valve **13** and the external refrigerant coil **27**. The second valve **6** is located between the liquid pump **2** and the compressor **11**. The thermal control system **40** can include, but is not limited to, such features as a timer **41** functioning as described in FIG. **1** but related to the TES unit **20**, a PCM temperature sensor **43** for PCM **21**, a PCM temperature sensor **83** for the refrigerant coils **27** and an environment temperature sensor **47** for measuring the temperature of the air in the building.

[0090] In this embodiment, the region of the system where thermal exchange between the refrigerant **1** and the warm air from the environment takes place can also be thought or represented by a typical heat exchanger for air conditioning applications where internal coils (in this case our external refrigerant coils **27**) have refrigerant running therethrough. This heat exchanger can be designed in order to have the largest heat exchange surface possible, with as many indentations or fins as possible in order to allow water molecules to remain in the cooled air.

[0091] FIGS. **7** and **8** respectively illustrate the front and rear view in perspective of an embodiment of the TES unit **20** which has twenty eight (28) PCC slabs (**101-128**) of comparable dimensions, arranged in a pile and the refrigerant coil **22** running between the slabs. The embodiment shown in FIGS. **7** and **8** can be enclosed in the insulating apparatus **23** of the TES unit **20** and/or in the insulating apparatus **29** of the TES unit **80**. The refrigerant **1**, after running through the tubes **3** of the refrigerant management system pours into the refrigerant coil **22** from the inlet **24**. **101** is the first slab from the bottom, **105** is the fifth slab from the bottom, **110** is the tenth slab from the bottom and so on; **128** is slab on top of the pile. As shown in the FIG. **7**, in this embodiment of the TES unit **20**, after the inlet **24**, the refrigerant coil **22** penetrates between the PCC slabs from the left side of the front section, splitting into 3 conduit tubes that run from the front section to the rear section in parallel, one over the other, between slabs **128** and **127**, between slabs **127** and **126** and between slabs **126** and **125**. After exiting the PCC slabs from the rear section the parallel tubes of the refrigerant coil **22** go back towards the center of the rear section between the same slabs and exit from the front section. Again the parallel tubes go back to the rear section and come back to the front section. In total, after splitting into 3 tubes, the refrigerant coil **22** runs through each couple of PCC slabs with 4 tubes segments, maximizing the thermal communication between the PCM material **21** and the refrigerant **1**.

[0092] The 3 parallel tubes exiting one last time from the PCC slabs from the front section on its right side curve towards the lower layers of slabs and penetrate in parallel between slabs **125** and **124**, **124** and **123**, **123** and **122** on the right side of the front section. Again, the tubes run back and forth from the front to the rear and from the rear to the front section in parallel between the same slabs twice and exit the front section on its left side before moving to the lower slabs (between **122** and **121**, between **120** and **119** and between **119** and **118**) and repeating the same procedure until reaching the last 4 slabs placed at the bottom of the TES unit **20**. The 3 parallel tubes run through the PCC slabs between slabs 4 and 3, slabs 3 and 2 and slabs 2 and 1 from left to right back and forth 4 times and merge in a single tube refrigerant coil in the bottom-right area of the front section of the PCC slabs pile. The refrigerant **1** exits the refrigerant coil **22** at the outlet **25**. From the outlet **25**, the refrigerant **1** flows into the tubes **3** of the refrigerant management system.

[0093] The design described above and illustrated in FIGS. **7** and **8** can have, but is not limited to, a PCM phase change temperature of between about 5° C. to about 6° C., PCC latent heat of about 180 KJ/Kg and PCC density of about 850 Kg/m^3. In one cooling experiment, 28 slabs were piled one over the other with the TES unit **21** comprising 74% PCC and 11.5% copper tubing for the refrigerant coil **22**. The remaining percentage is mainly the insulating apparatus and sensors. Other characterizing features of this embodiment of a TES unit **20** could be, but are not limited to, a thermal capacity of about 4.2 kWh, PCC's energy density of about 54 Wh/Kg, PCC and copper refrigerant coil **22** energy density of about 46 Wh/Kg and system energy density of about 40 Wh/Kg.

[0094] Several discharge experiments have been conducted at different refrigerant flow rates. For example, at 1.6 L/min a total cooling time of more than 6 hours was achieved with cold refrigerant reaching the external refrigerant coil **27** for the whole period, while the refrigerant flowing through the different slabs was heating up at different rates: less than 1 hour for the refrigerant at the inlet (slab **128** to **125**), 3 to 4 hours at slabs **115** and **119**, **104**, to 105 hours at slab **123**, 5 to 6 hours at slab **107** and 6.25 hours from slabs **104** to **101**.

[0095] FIG. **9** represent an embodiment of the present invention wherein water/glycol used as the refrigerant **1**. The only difference from the previous embodiments is the substitution of the condenser **12** with an electronically controlled chiller **18** and no expansion valve is used in the system.

[0096] FIG. **10** represents an embodiment of the present invention wherein the refrigerant **1** is Freon™. In this embodiment, a liquid pump is not required.

[0097] As to the manner of usage and operation of the present invention, the same should be apparent from the above description. Accordingly, no further discussion relating to the manner of usage and operation will be provided.

[0098] While a preferred embodiment of the system has been described in detail, it should be apparent that modifications and variations thereto are possible, all of which fall within the true spirit and scope of the invention. With respect to the above description then, it is to be realized that the optimum dimensional relationships for the parts of the invention, to include variations in size, materials, shape, form, function and manner of operation, assembly and use, are deemed readily apparent to one skilled in the art, and all equivalent relationships to those illustrated in the drawings and described in the specification are intended to be encompassed by the present invention.

[0099] Throughout this specification, unless the context requires otherwise, the word "comprise" or variations such as "comprises" or "comprising" or the term "includes" or variations, thereof, or the term "having" or variations thereof will be understood to imply the inclusion of a stated element or integer or group of elements or integers but not the exclusion of any other element or integer or group of elements or integers. In this regard, in construing the claim scope, an embodiment where one or more features is added to any of the claims is to be regarded as within the scope of the invention given that the essential features of the invention as claimed are included in such an embodiment.

[0100] Those skilled in the art will appreciate that the invention described herein is susceptible to variations and modifications other than those specifically described. It is to be understood that the invention includes all such variations and modifications that fall within its spirit and scope. The invention also includes all of the steps, features, compositions and compounds referred to or indicated in this specification, individually or collectively, and any and all combinations of any two or more of said steps or features.

[0101] Therefore, the foregoing is considered as illustrative only of the principles of the invention. Further, since numerous modifications and changes will readily occur to those skilled in the art, it is not desired to limit the invention to the exact construction and operation shown and described, and accordingly, all suitable modifications and equivalents may be resorted to, falling within the scope of the invention.

1.-**27**. (canceled)

28. A refrigerant based thermal energy storage and cooling system, comprising:

- a refrigeration cycle comprising an air conditioner condensing unit having a compressor, a condenser, an expansion valve, and an evaporator through which refrigerant runs;
- a thermal energy storage ("TES") unit in thermal communication with a refrigerant, wherein the TES unit comprises a phase change material ("PCM") which stores and releases thermal energy, and a refrigerant coil through which a refrigerant runs, wherein the PCM comprises a low temperature wax;
- a plurality of valves for diverting the system between a charging cycle and a discharging cycle;
- an insulating apparatus which insulates the PCM and refrigerant coil of the TES unit to avoid heat dispersion;
- a refrigerant for transferring thermal energy to and from the compressor, condenser, expansion valve, evaporator and the PCM of the TES unit through a refrigerant management system;
- a refrigerant management system for delivering a refrigerant through the system comprising a plurality of valves and tubes;
- a ventilation system comprising an air inlet and an air outlet disposed in thermal communication with the PCM of the TES unit, and a propeller device; and
- a thermal control system for controlling the thermodynamics of the system,
  - wherein the refrigeration cycle can operate alternative to the charging cycle,
  - wherein the refrigeration cycle can operate alternative to the discharging cycle,
  - wherein the refrigeration cycle can operate simultaneously when the system is in charging cycle, and

wherein the refrigeration cycle can also operate simultaneously when the system is in discharging cycle.

29. The system as in claim **1**, further comprising a plurality of external TES units each comprising a PCM, a refrigerant coil and an external insulating apparatus and wherein the plurality of valves are configured to provide at least one of the PCMs of the external TES units and the PCM of the TES unit with at least one of charging cycle, discharging cycle, simultaneous discharging cycle and refrigeration cycle, and simultaneous charging cycle and refrigeration cycle.

30. The system as in claim **1** whereby the PCM is in the discharging cycle while simultaneously the refrigeration cycle is operated.

31. The system as in claim **1** whereby the PCM is in the charging cycle simultaneously with the refrigeration cycle.

32. The system as in claim **1** further comprising a plurality of liquid pumps.

33. The system as in claim **1** wherein the refrigeration coil is made from a thermally conductive material selected from the group consisting of copper, copper alloys, gold, silver, carbon alloys, aluminum, and alloys thereof.

34. The system as in claim **1** wherein the PCM of the TES unit further comprises at least one from the group consisting of graphite, and graphite and aluminum oxide.

35. A phase change material composite for use in thermal energy storage comprising:

a low temperature wax; and

a porous matrix material which provides structure to a composite configuration,

wherein the porous matrix material is at least one selected from the group consisting of expanded graphite, aluminum oxide, graphite powder, carbon fibers, graphite/carbon nano-powders/nano-fibers, copper, aluminum powder and conductive foam.

36. A method of cooling an environment using the system as in claim **1**, comprising the steps of:

providing a PCM further comprising at least one material from the group consisting of graphite and aluminum oxide, in thermal communication with a charging coil through which the refrigerant passes in the refrigerant management system;

activating a charging cycle whereby the PCM is charged with the cooled refrigerant;

sensing the charged state of the PCM using a sensor;

ceasing circulation of the refrigerant through the charging cycle when the PCM is determined to be charged;

activating a discharging cycle whereby the environment is cooled by passing air through the air inlet of the ventilation system, past the PCM, and out of the air outlet;

establishing a threshold level for activating at least one of the refrigeration cycle and the charging cycle;

monitoring at least one from the group consisting of the temperature of the air exiting the air outlet, the phase state of the PCM, and the temperature of the PCM; and

upon reaching a threshold level, delivering the refrigerant through at least one of the refrigeration cycle and the charging cycle, wherein the refrigeration cycle can operate simultaneously with one selected from the group consisting of the charging cycle and the discharging cycle.

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