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Dobbs(10) **Pub. No.: US 2015/0135743 A1**(43) **Pub. Date: May 21, 2015**(54) **AIR CONDITIONING SYSTEM HAVING
SUPERCOOLED PHASE CHANGE
MATERIAL****Publication Classification**

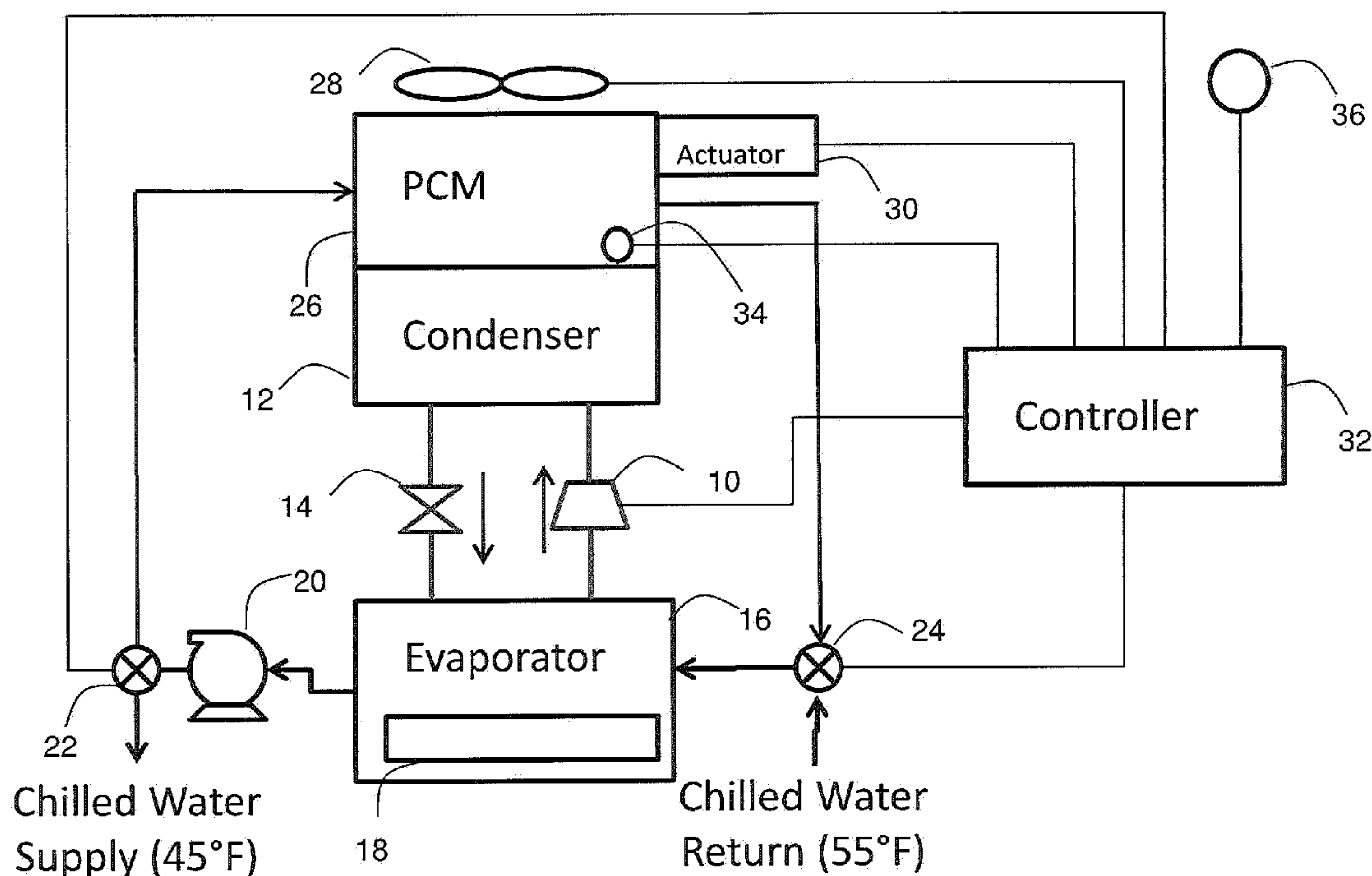
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(2) Date: **Oct. 31, 2014****Related U.S. Application Data**(60) Provisional application No. 61/642,072, filed on May
3, 2012.(57) **ABSTRACT**

An air conditioning system includes a chiller system including a compressor, a condenser, an expansion device and an evaporator; a phase change material in thermal communication with the condenser; an actuator coupled to the phase change material; and a controller providing a trigger signal to the actuator to initiate changing the phase change material from a supercooled state to a solid state.



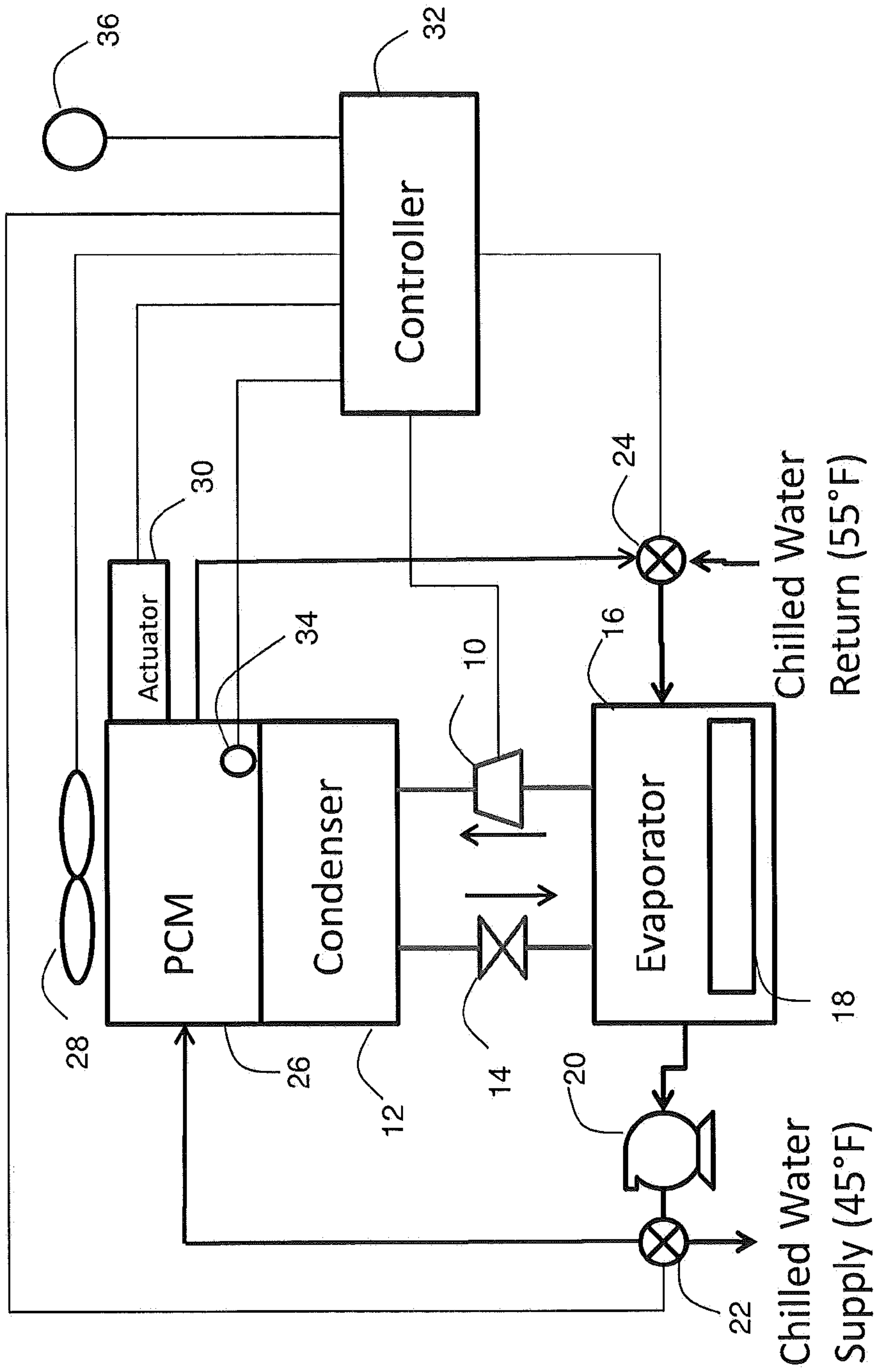


FIG. 1

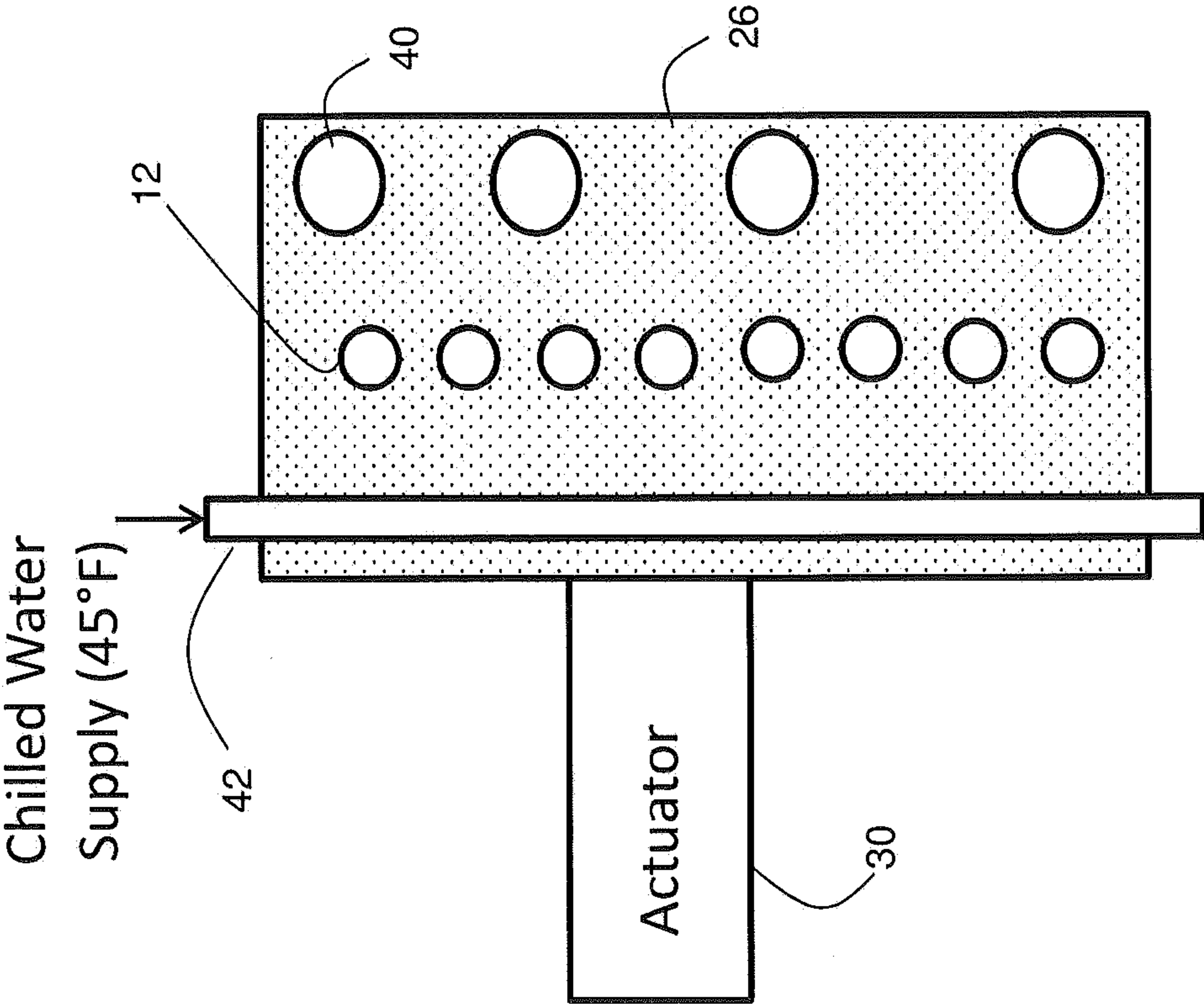


FIG. 2

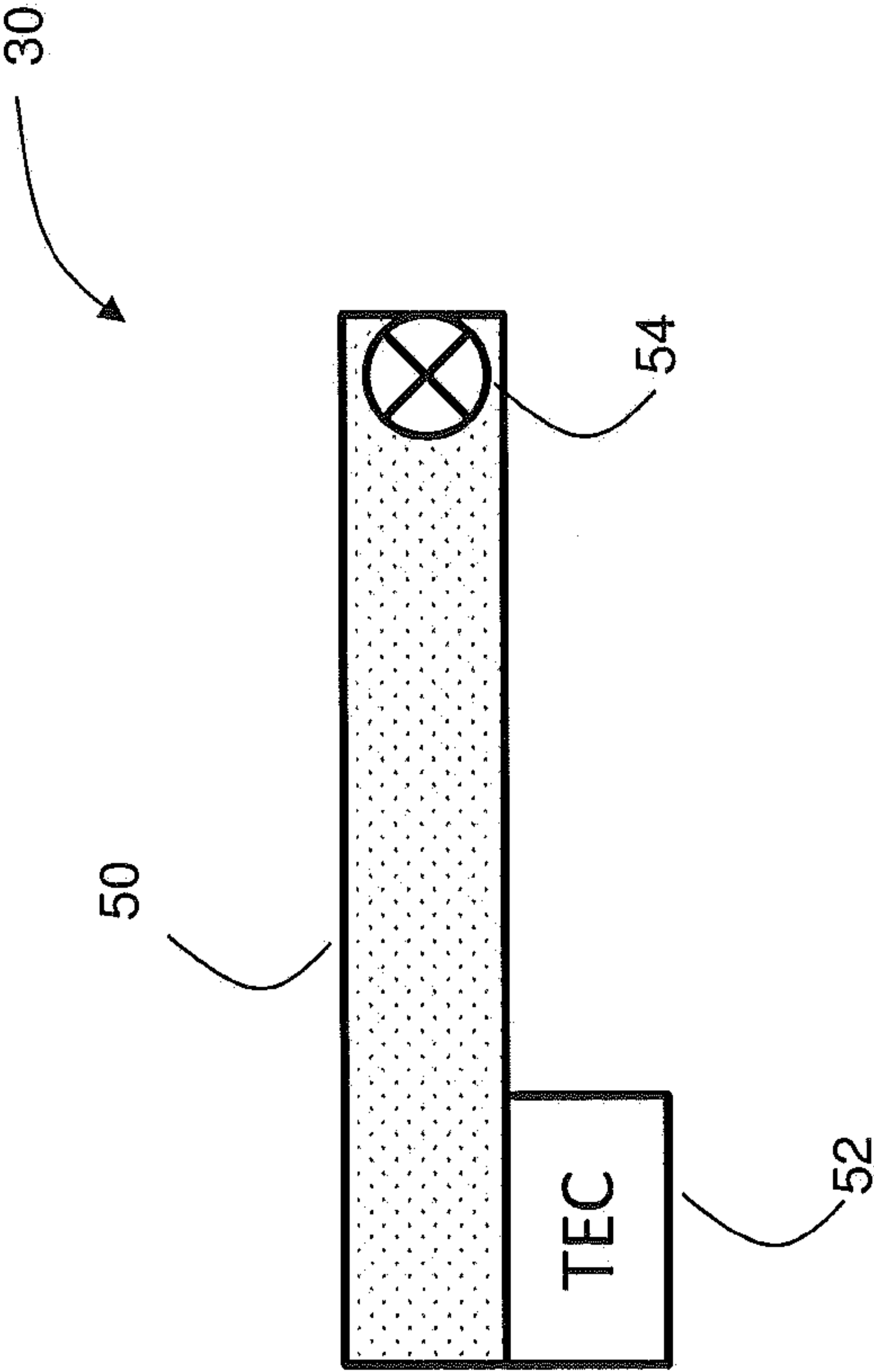


FIG. 3

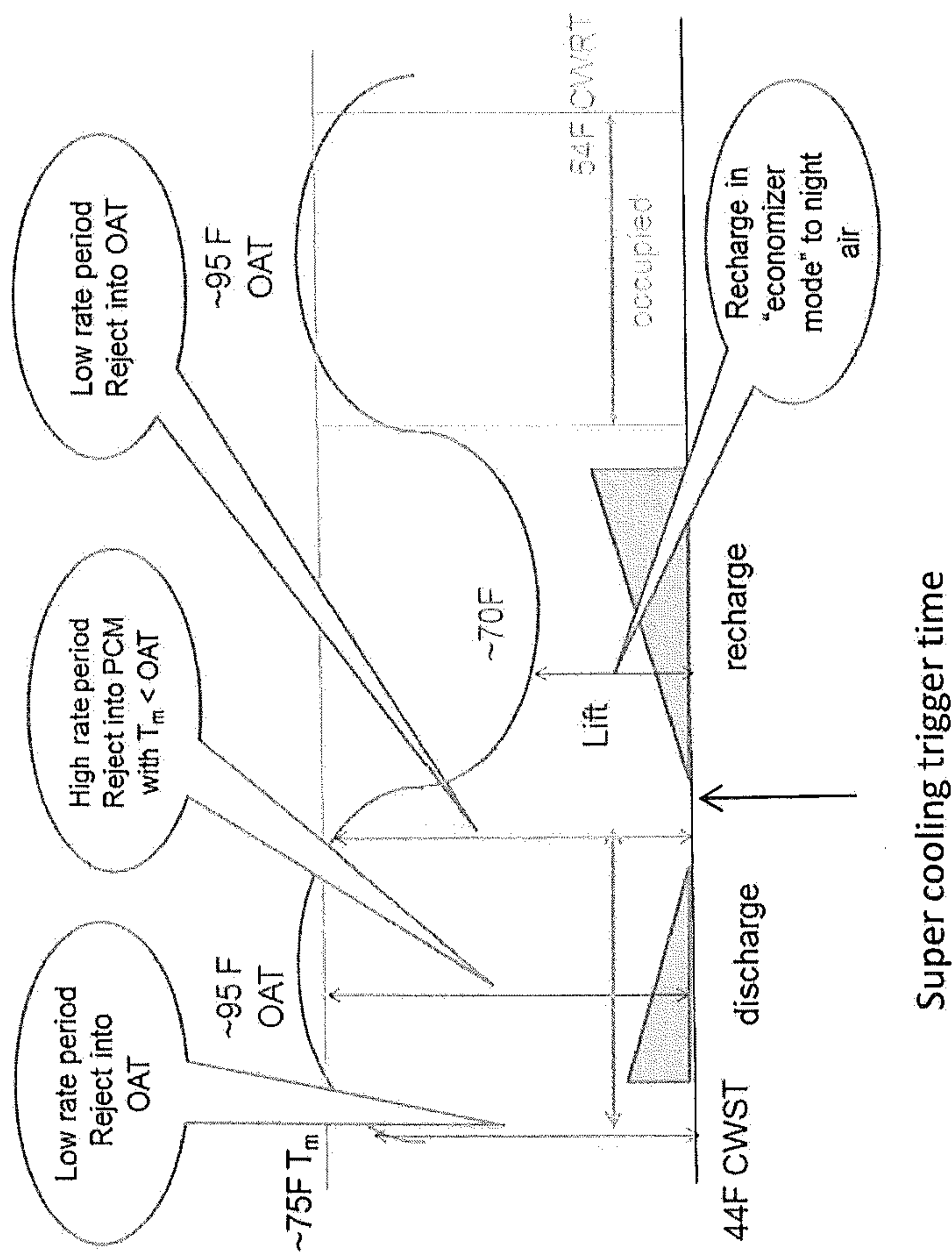


FIG. 4

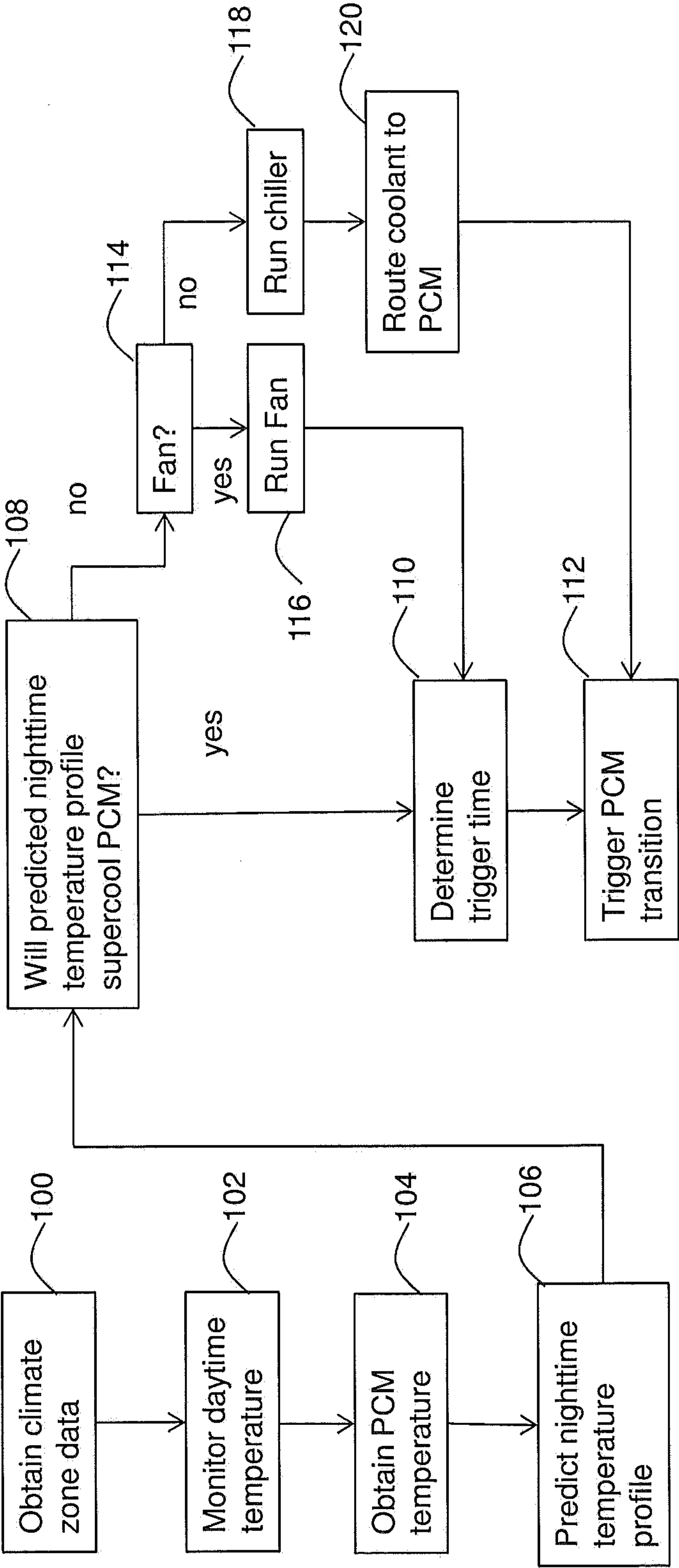


FIG. 5

AIR CONDITIONING SYSTEM HAVING SUPERCOOLED PHASE CHANGE MATERIAL

BACKGROUND

[0001] The subject matter disclosed herein generally relates to air conditioning systems, and in particular relates to an air conditioning system utilizing supercooled phase change material to store thermal energy.

[0002] Existing air conditioning systems employ phase change materials to improve capacity and/or efficiency of the system. Exemplary air conditioning systems include energy storage systems which freeze a phase change material when energy costs are relatively low (e.g., non-peak rates). The phase change material is then used to absorb thermal energy during other modes of operation to improve efficiency and/or capacity of the air conditioning system.

SUMMARY

[0003] One embodiment is an air conditioning system which includes a chiller system including a compressor, a condenser, an expansion device and an evaporator; a phase change material in thermal communication with the condenser; an actuator coupled to the phase change material; and a controller providing a trigger signal to the actuator to initiate changing the phase change material from a supercooled state to a solid state.

[0004] Another exemplary embodiment is a method for operating an air conditioning system having a chiller system including a compressor, a condenser, an expansion device and an evaporator, a phase change material in thermal communication with the condenser, and an actuator coupled to the phase change material, the method including determining whether an ambient temperature profile will result in supercooling of the phase change material; and in response to the determining, triggering the actuator to initiate changing the phase change material from a supercooled state to a solid state.

[0005] Other exemplary embodiments and features are described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] FIG. 1 depicts an air conditioning system in an exemplary embodiment.

[0007] FIG. 2 depicts a condenser coil assembly in an exemplary embodiment.

[0008] FIG. 3 depicts an actuator in an exemplary embodiment.

[0009] FIG. 4 is a plot of temperature versus time, illustrating phase change material state changes in an exemplary embodiment.

[0010] FIG. 5 is a flowchart of a control process in an exemplary embodiment.

DETAILED DESCRIPTION

[0011] FIG. 1 depicts an air conditioning system in an exemplary embodiment. A chiller system includes a compressor 10, a first heat exchanger 12, an expansion device 14 and a second heat exchanger 16. The first heat exchanger 12 may be used as a condenser coil, and may be located outside of a building or space to be conditioned. The second heat exchanger 16 may be used as an evaporator coil. As known in the art, refrigerant is subjected to a vapor compression cycle

through compressor 10, condenser 12, expansion device 14 and evaporator 16. Heat is absorbed at evaporator 16 and heat is discharged at condenser 12.

[0012] The system of FIG. 1 may be a water chiller system. Evaporator 16 is in thermal communication with a heat exchanger 18 (e.g., a coil) that carries a fluid coolant, e.g., water. A supply pump 20 circulates coolant from heat exchanger 18 cooled by evaporator 16 to a supply valve 22. Supply valve 22 supplies chilled water (about 45° F.) to a local zone terminal where a fan draws air over a coil to chill a space as known in the art. A return valve 24 receives fluid returned from the local zone terminal and provides the return fluid to heat exchanger 18. It is understood that embodiments of the invention may be used with other types of air conditioning systems (e.g., forced air) and embodiments are not limited to water chiller systems.

[0013] Condenser coil 12 is in thermal communication with a phase change material 26. Condenser coil 12 may be fully embedded in the phase change material 26 or the phase change material may be in a housing containing condenser coil 12. Alternatively, a portion of the condenser coil may be exposed to ambient air. A fan 28 may draw air through the phase change material 26 to aid in cooling the phase change material 26. In exemplary embodiments, phase change material 26 is a material that achieves a supercooling state. A controller 32 then initiates the transition of the phase change material 26 from supercooled liquid to solid. An actuator 30 is used to initiate the transition of the phase change material 26 from supercooled liquid to solid when the phase change material 26 is in a supercooled state, as described in further detail herein.

[0014] A controller 32 controls operation of the system. Controller 32 may be implemented using a general purpose microprocessor executing computer code stored in a storage medium for performing the functions described herein. Controller 32 receives a phase change material temperature signal from a phase change material sensor 34 in thermal contact with phase change material 26. Controller 32 also receives an ambient temperature signal from an ambient temperature sensor 36. Ambient temperature sensor 36 may monitor the outside air temperature in the vicinity of condenser 12. Controller 32 may send control signals to compressor 10, pump 20, supply valve 22, return valve 24, fan 28 and actuator 30. Operation of the system is described in further detail herein with reference to FIG. 5.

[0015] FIG. 2 depicts a condenser assembly in an exemplary embodiment. Condenser coil 12 is in thermal communication with phase change material 26. In the embodiment of FIG. 2, the condenser coil 12 is embedded in phase change material 26. In other embodiments, a portion of condenser coil 12 may extend beyond the phase change material 26, such that the entire condenser coil 12 is not embedded in the phase change material 26. Air paths 40 are formed in the phase change material 26 to allow air to be drawn through the phase change material 26 by fan 28. The air paths may be arranged in a variety of configurations, and embodiments are not limited to the arrangement shown in FIG. 2. Controller 32 may turn fan 28 on when additional ambient airflow is needed to cool the phase change material 26.

[0016] A coolant supply line 42 is also in thermal communication with the phase change material 26, and may be embedded in the phase change material 26 as shown in FIG. 2. In situations where the ambient temperature is insufficient to adequately cool the phase change material 26 (e.g., to a

supercooled state), controller 32 may direct chilled coolant from supply valve 22 to the phase change material 26 and back to return valve 24. Controller 32 activates compressor 10 to produce chilled coolant in coil 18. Controller 32 sets valves 22 and 24 to route chilled coolant to the phase change material 26 and pump 20 is activated circulate the chilled coolant to the phase change material 26.

[0017] FIG. 3 depicts an actuator 30 in an exemplary embodiment. Actuator 30 is controlled by controller 32 to initiate a transition from supercooled, liquid phase change material to solid phase change material. Supercooled, as used herein, refers to the phase change material 26 being in a liquid state and at a temperature below the phase change material freezing temperature. The actuator in FIG. 3 includes a tube 50 of phase change material and a thermoelectric cooler 52 that maintains the phase change material in tube 50 in a frozen or solid state under all conditions. Valve 54 connects the tube 50 to the main reservoir of phase change material 26. Controller 32 opens valve 54 to trigger freezing of the main phase change material reservoir 26. When valve 54 is opened, some of the unfrozen liquid in phase change material 26 flows toward the frozen volume in tube 50 and begins to freeze. The freeze front moves outward from the valve area to the rest of the phase change material 26 as the latent heat is released. Another embodiment of actuator 30 includes an ultrasonic emitter to produce ultrasonic sound waves to trigger transition of the phase change material 26 from supercooled liquid to solid.

[0018] As described in further detail herein, the phase change material 26 is selected so that the phase change material transitions from liquid to solid when cooling demand on the chiller system is low or non-existent. This may occur in the evening, when ambient temperatures are lower. FIG. 4 illustrates an exemplary diurnal temperature versus time profile, along with states of the phase change material 26. In the example of FIG. 4, the outside air temperature ranges from about a 95° F. day time high to about a 70° F. night time low. If the transition temperature of the phase change material 26 is selected to be about 75° F., then the phase change material 26 will be frozen (or recharged) at night and then melt (or discharge) during the day. During the day, the frozen phase change material 26 absorbs energy from the condenser coil 12, improving the efficiency of condenser 12 when the chiller system is running and increasing efficiency and capacity of the chiller system.

[0019] FIG. 5 is a flowchart of a control process executed by controller 32 in an exemplary embodiment. The process begins at 100 where the controller 32 obtains climate zone data for the system. The climate zone data may be indicated by known climate maps and programmed into controller 32 upon installation of the air conditioning system. At 102, controller 32 monitors the ambient air temperature through ambient temperature sensor 36 and may store multiple ambient temperatures over time. At 104 controller 32 obtains the phase change material temperature from phase change material temperature sensor 34, and may store multiple phase change material temperatures over time.

[0020] At 106, controller 32 predicts a nighttime temperature profile based on the climate zone data and one or more ambient air temperature readings over time. Controller 32 may be preloaded with predicted nighttime temperature profiles indexed by climate zone data and daytime ambient air temperatures.

[0021] At 108, controller 32 determines if the predicted nighttime temperature profile will be sufficient to supercool the phase change material 26, based on one or more phase change material temperature measurements. For example, if the phase change material 26 transition temperature is about 75° F., the current phase change material temperature is about 80° F. and the predicted nighttime temperature profile indicates four hours of ambient air temperature of about 72° F., then controller 32 may determine that the predicted nighttime temperature profile will result in the phase change material supercooling before the next chiller cycle is initiated (i.e., before the space being conditioned requires cooling). This determination will be affected by factors such as the amount of phase change material, its temperature transition characteristics, etc.

[0022] If the ambient temperature alone is sufficient to supercool the phase change material 26, flow proceeds to 110 where the controller determines a trigger time to transition the supercooled phase change material 26 from liquid to solid. Controller 32 attempts to trigger this transition when the ambient temperature is at or near a minimum value, so that the heat released by the phase change material 26 is more rapidly absorbed by the ambient air. At 112, controller sends a trigger signal to actuator 30 at the trigger time to initiate transition of the supercooled phase change material 26 to a solid.

[0023] If at 108 the predicted nighttime temperature profile is insufficient to supercool the phase change material 26, flow proceeds to 114 where it is determined if running fan 28 to draw ambient air through the phase change material 26 will result in supercooling of the phase change material 26. This determination may be made by controller 32 determining, based on the current phase change material temperature, that only a small temperature decrease is needed to supercool the phase change material 26. If so, fan 28 is turned on at 116 and flow proceeds to 110 and 112 as described above.

[0024] If at 114 controller 32 determines that the fan 28 will not supercool the phase change material, flow proceeds to 118 where controller 32 runs the chiller system including compressor 10 and pump 20. At 120, supply valve 22 and return valve 24 are set by controller 32 to direct coolant from coil 18 to the phase change material 26. Flow proceeds to 110 and 112 as described above.

[0025] Embodiments employ a phase change material that meets cost objectives but has a transition temperature high enough so that the nighttime temperature drops below the transition temperature each night. A phase change material is chosen that has a high propensity for supercooling. As the nighttime temperature drops below the starting temperature of the phase change material, sensible cooling takes place according to the heat capacity of the phase change material. When the nighttime temperature is near a minimum, the supercooled phase change material is triggered to release its latent heat quickly.

[0026] The temperature of the phase change material rises according to the heat capacity driven by the latent heat release until the limit of the melting temperature is reached. This provides a higher temperature difference between the outdoor air and the phase change material and the heat transfer from the phase change material to the outside air can occur at faster rates. The heat exchanger design can be optimized to take advantage of this rapid heat release. An example of a candidate phase change material with a transition temperature in

the right region which is known to exhibit supercooling and which may be inexpensive enough is natural coconut fatty acid mixture.

[0027] Embodiments harness supercooling for positive uses by permitting the daytime heat captured in a medium to be released over a shorter period of cooler night air than otherwise would be possible. The difference in temperature created in the phase change material between the outdoor air temperature and the melting point temperature permits faster heat release to the environment and downsizing of the associated heat exchanger. This increases the viability of thermal energy storage from a cost/benefit perspective.

[0028] Chillers normally reject heat into hot outside air (95° F. rating T) during periods of occupancy. The “lift” from the chilled water temperature (CWST) to the outside temperature (OAT) governs chiller efficiency, as illustrated in FIG. 4. The chiller may be off during most of the setback period during unoccupancy.

[0029] The advent of less expensive phase change materials that have a choice transition temperature (T_m) means that systems can be designed to pick the better of the OAT and T_m to reject heat during periods of occupancy, lowering the chiller lift and increasing chiller efficiency when electric rates are typically highest. The phase change material discharges throughout the day. During periods of unoccupancy at night when the chiller runs infrequently, the phase change material is recharged by cooler night air after the night air temperature drops below T_m in an “economizer” mode. Embodiments use a phase change material that exhibits supercooling so that when triggered, the phase change material temperature rises relative to the night air and the recharge goes faster. If necessary, the chiller system can assist so as to complete the recharge of the phase change material before morning occupancy. If the chiller system is needed, it will operate at lower lift than it would have during the day and use cheaper electricity.

[0030] While the invention has been described in detail in connection with only a limited number of embodiments, it should be readily understood that the invention is not limited to such disclosed embodiments. Rather, the invention can be modified to incorporate any number of variations, alterations, substitutions or equivalent arrangements not heretofore described, but which are commensurate with the spirit and scope of the invention. Additionally, while various embodiments of the invention have been described, it is to be understood that aspects of the invention may include only some of the described embodiments. Accordingly, the invention is not to be seen as limited by the foregoing description, but is only limited by the scope of the appended claims.

1. An air conditioning system comprising:
a chiller system including a compressor, a condenser, an expansion device and an evaporator;
a phase change material in thermal communication with the condenser;
an actuator coupled to the phase change material; and
a controller providing a trigger signal to the actuator to initiate changing the phase change material from a supercooled state to a solid state.
2. The air condition system of claim 1 wherein:
the condenser is embedded in the phase change material.
3. The air condition system of claim 1 further comprising:
an ambient temperature sensor providing an ambient temperature signal to the controller.

4. The air condition system of claim 1 further comprising:
a phase change material sensor providing a phase change material temperature signal to the controller.
5. The air condition system of claim 1 wherein:
the phase change material includes an internal airway for allowing ambient air to flow through the phase change material.
6. The air condition system of claim 5 further comprising:
a fan for drawing air through the airway.
7. The air condition system of claim 1 wherein:
the phase change material includes a coolant supply line in thermal communication with the phase change material, the coolant supply line coupled to the chiller system.
8. The air condition system of claim 1 wherein:
the actuator generates a sound wave to initiate changing the phase change material from the supercooled state to the solid state.
9. The air condition system of claim 1 wherein:
the actuator includes frozen phase change material, the frozen phase change material being placed in contact with the phase change material to initiate changing the phase change material from the supercooled state to the solid state.
10. The air condition system of claim 9 wherein:
the actuator includes a valve separating the frozen phase change material from the phase change material, the controller opening the valve to initiate changing the phase change material from the supercooled state to the solid state.
11. The air condition system of claim 1 wherein:
the controller predicts a nighttime temperature profile in response to climate zone data and ambient temperature; and
the controller determining if the phase change material will supercool in response to the nighttime temperature profile.
12. The air condition system of claim 11 wherein:
the controller providing the trigger signal to the actuator in response to the nighttime temperature profile.
13. The air condition system of claim 11 wherein:
the phase change material includes an internal airway for allowing ambient air to flow through the phase change material;
when the controller determines that the phase change material will not supercool in response to the nighttime temperature profile, the controller activating a fan for drawing air through the airway to supercool the phase change material.
14. The air condition system of claim 11 wherein:
the phase change material includes a coolant supply line in thermal communication with the phase change material, the coolant supply line coupled to the chiller system;
when the controller determines that the phase change material will not supercool in response to the nighttime temperature profile, the controller activating the chiller system to cool the coolant supply line to supercool the phase change material.
15. A method for operating an air conditioning system having a chiller system including a compressor, a condenser, an expansion device and an evaporator, a phase change material in thermal communication with the condenser, and an actuator coupled to the phase change material, the method comprising:

determining whether an ambient temperature profile will result in supercooling of the phase change material; and in response to the determining, triggering the actuator to initiate changing the phase change material from a supercooled state to a solid state.

16. The method of claim **15** wherein:

triggering the actuator includes determining a trigger time in response to the ambient temperature profile and triggering the actuator at the trigger time.

17. The method of claim **15** further comprising:

running a condenser fan in response to determining that the ambient temperature profile will not result in supercooling of the phase change material.

18. The method of claim **17** further comprising:

running the chiller system in response to determining that the ambient temperature profile will not result in supercooling of the phase change material and the running the condenser fan will not result in supercooling of the phase change material.

19. The method of claim **18** wherein:

running the chiller system includes cooling the phase change material with coolant.

20. The method of claim **15** wherein:

determining whether the ambient temperature profile will result in supercooling of the phase change material includes predicting a nighttime temperature profile in response to climate zone data, daytime temperature and a phase change material temperature.

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