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(54) AIR CONDITIONING SYSTEM HAVING SUPERCOOLED PHASE CHANGE MATERIAL

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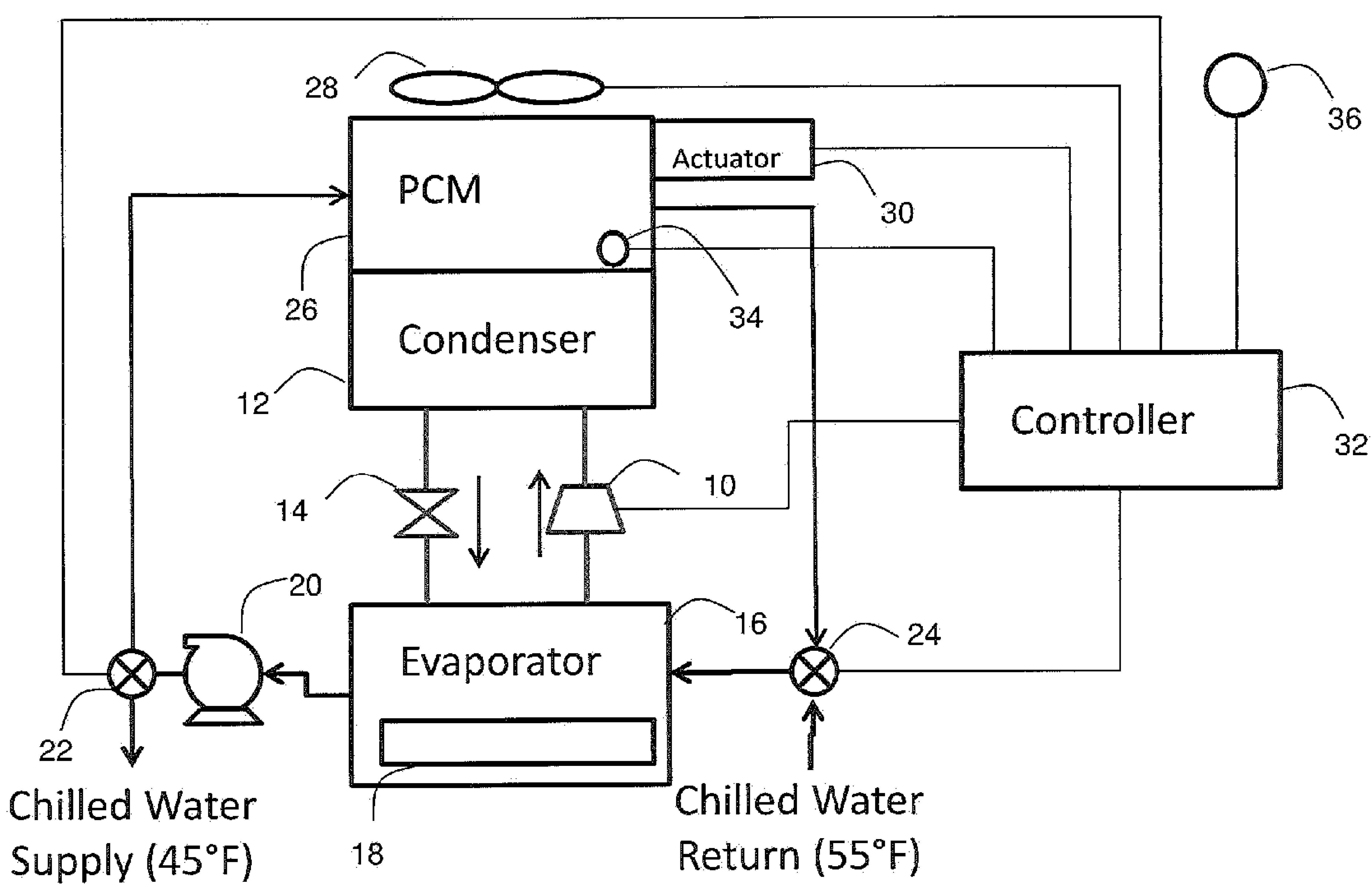
(57) ABSTRACT

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.



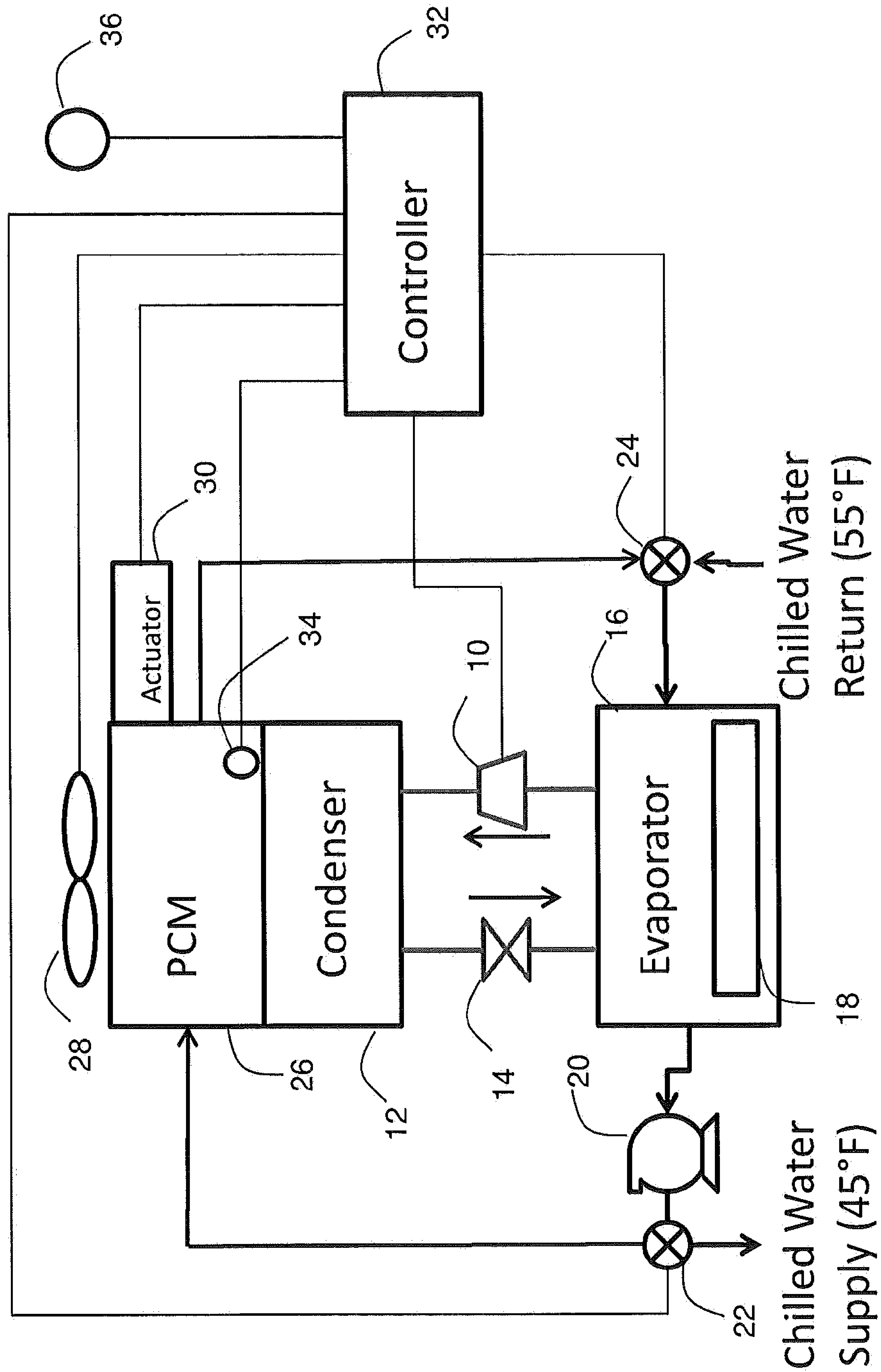
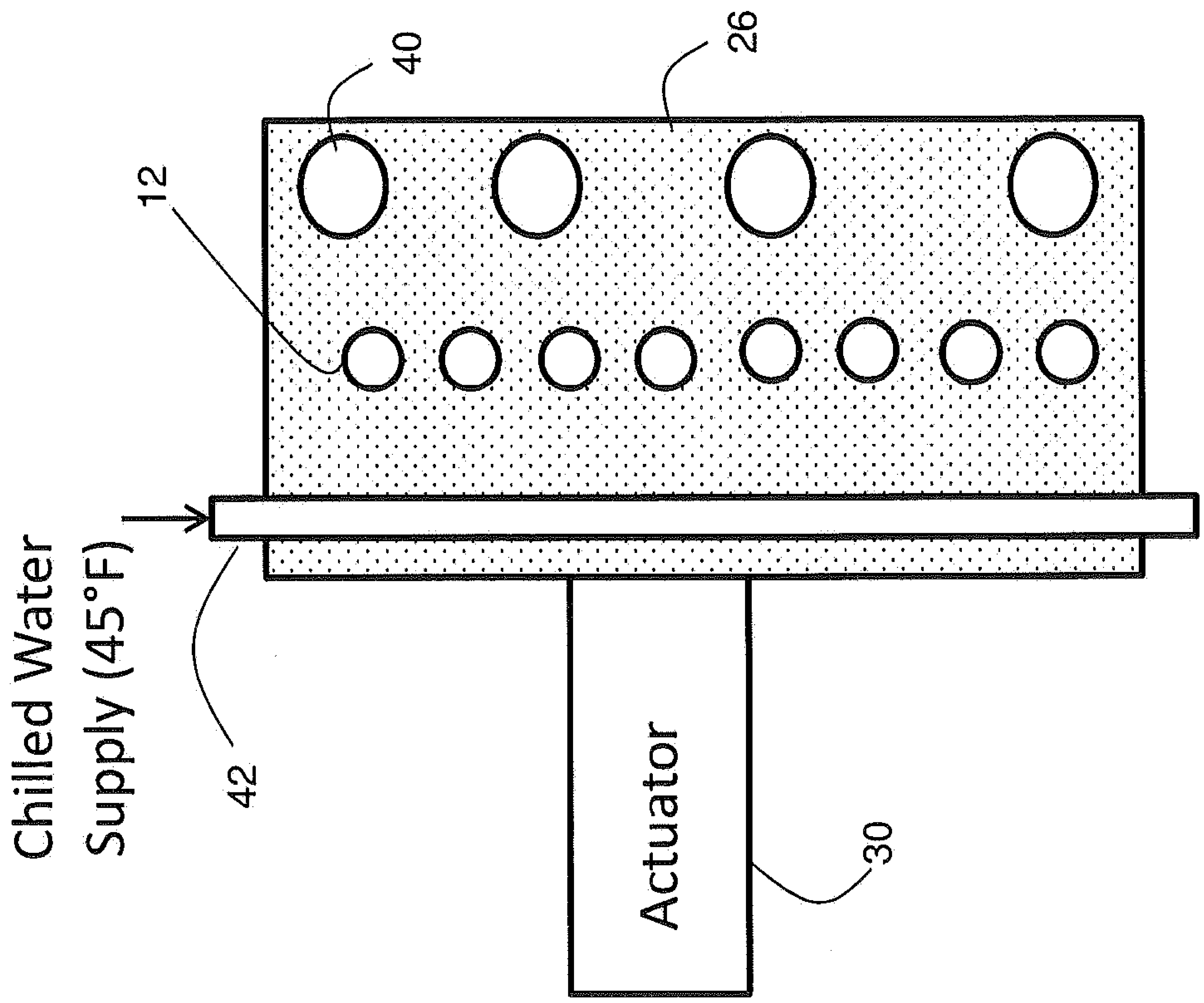

36
32
Controller
30
Actuator
34
10
16
24
Chilled Water Return (55°F)
PCM
Condenser
Evaporator
28
26
12
14
20
18
Chilled Water Supply (45°F)
22

FIG. 1

FIG. 2



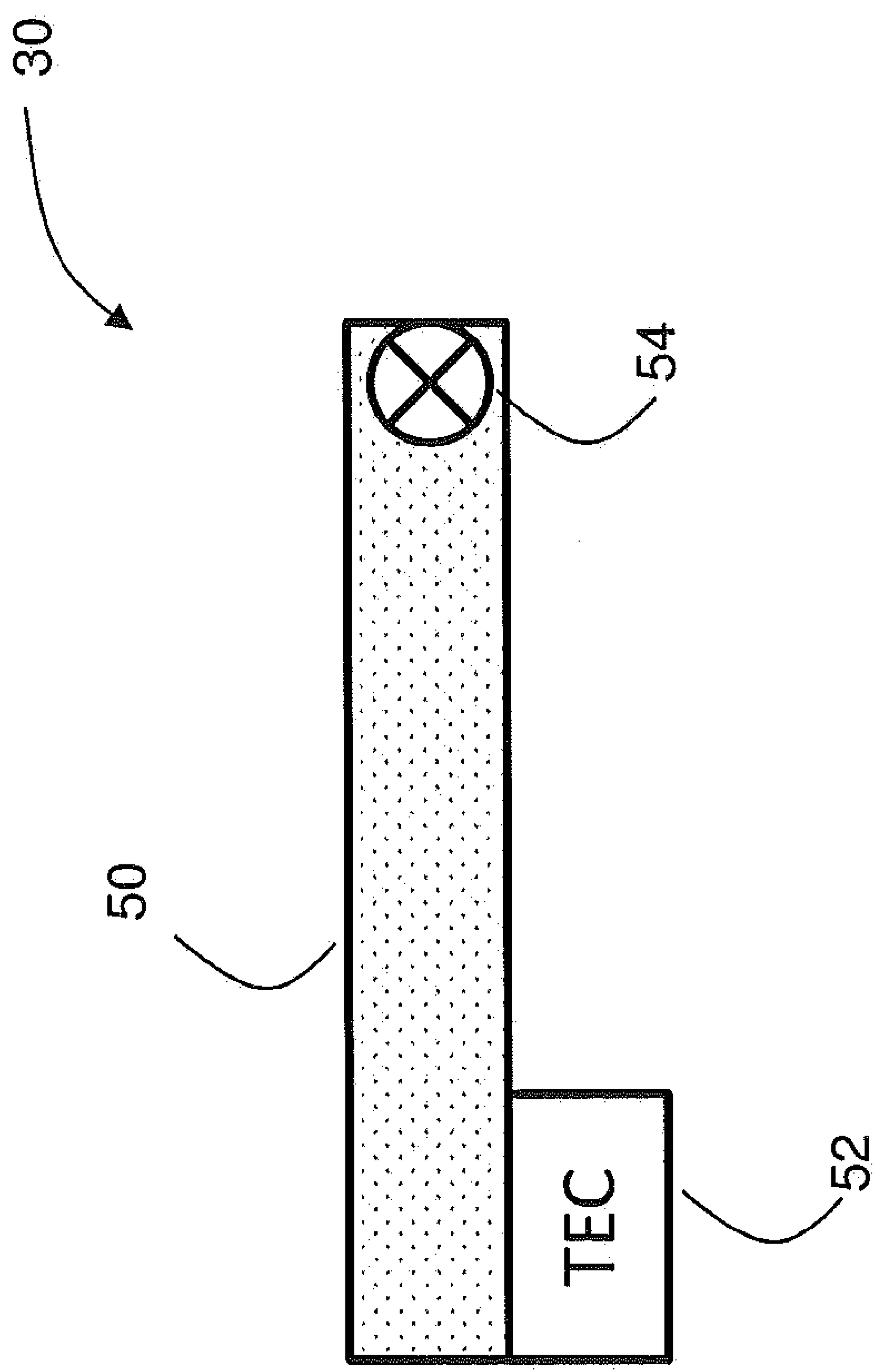


FIG. 3

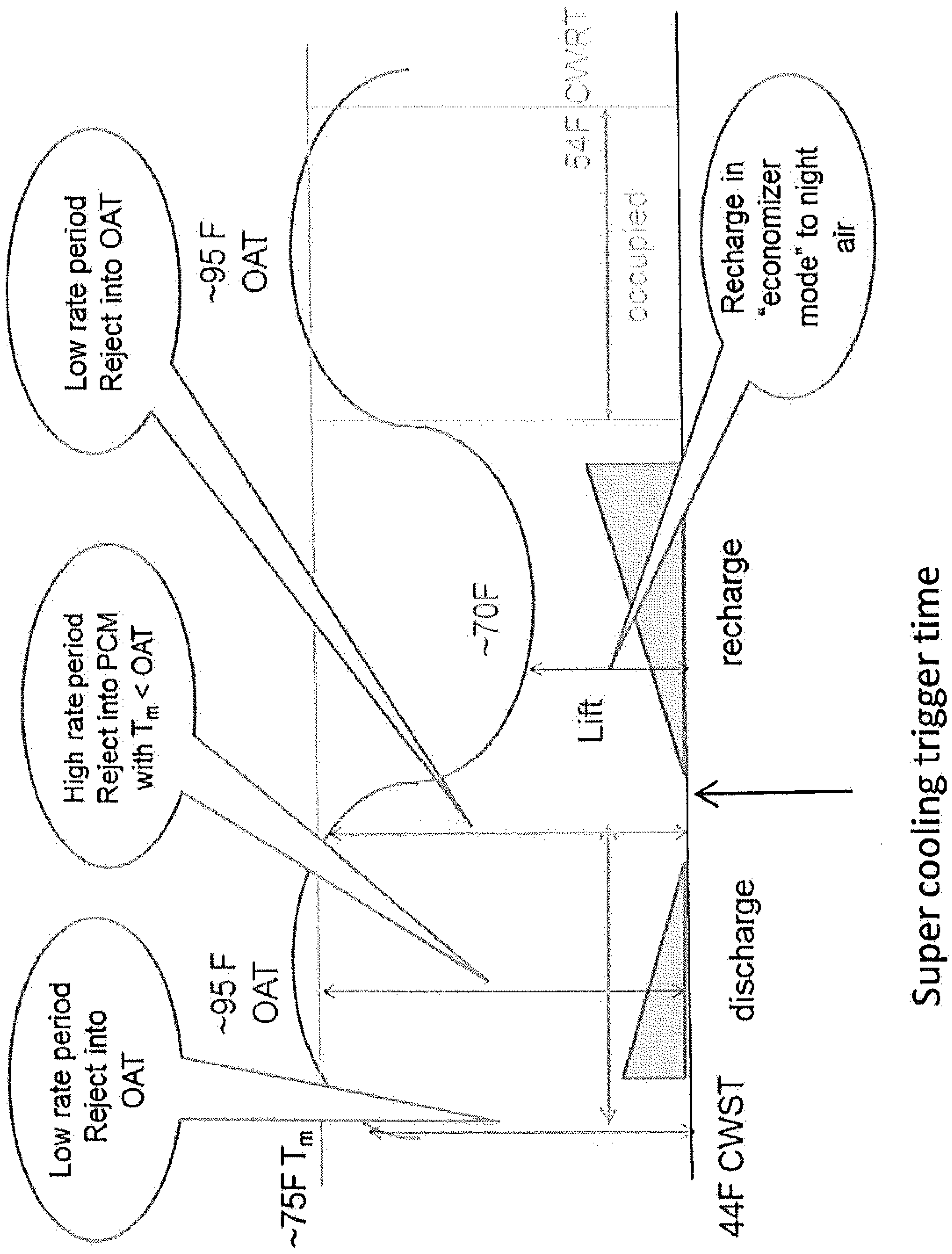

Low rate period Reject into OAT
High rate period Reject into PCM with T_m < OAT
Low rate period Reject into OAT
~75F T_m
~95 F OAT
~70F
~95 F OAT
54F CWRT
occupied
Lift
Recharge in "economizer mode" to night air
44F CWST
discharge
recharge
Super cooling trigger time

FIG. 4

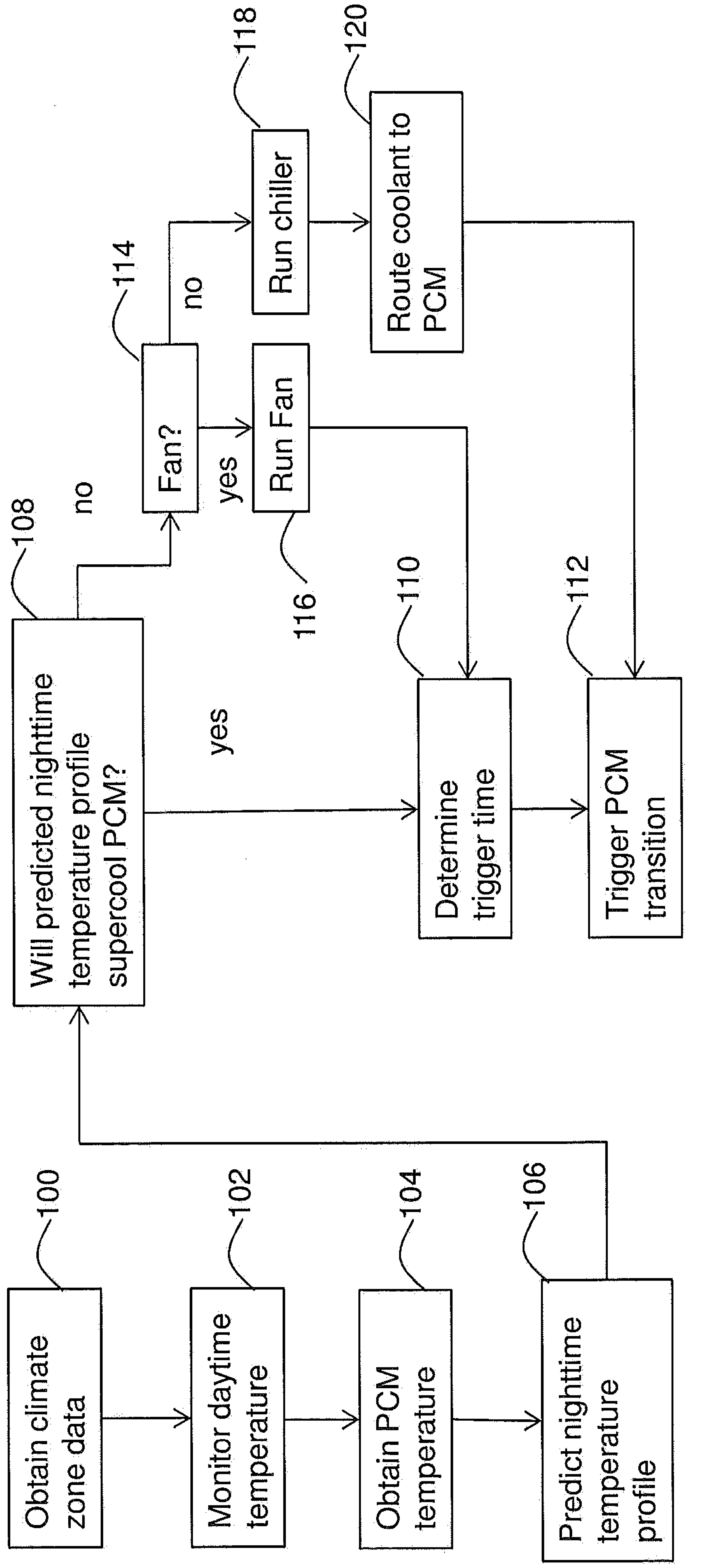

Obtain climate zone data
100
Monitor daytime temperature
102
Obtain PCM temperature
104
Predict nighttime temperature profile
106
Will predicted nighttime temperature profile supercool PCM?
108
yes
no
Fan?
114
yes
no
Run Fan
116
Run chiller
118
Route coolant to PCM
120
Determine trigger time
110
Trigger PCM transition
112

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 chase 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 an 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 optimize 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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