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(54) INTEGRATED ELECTRICAL AND THERMAL ENERGY SOLAR CELL SYSTEM

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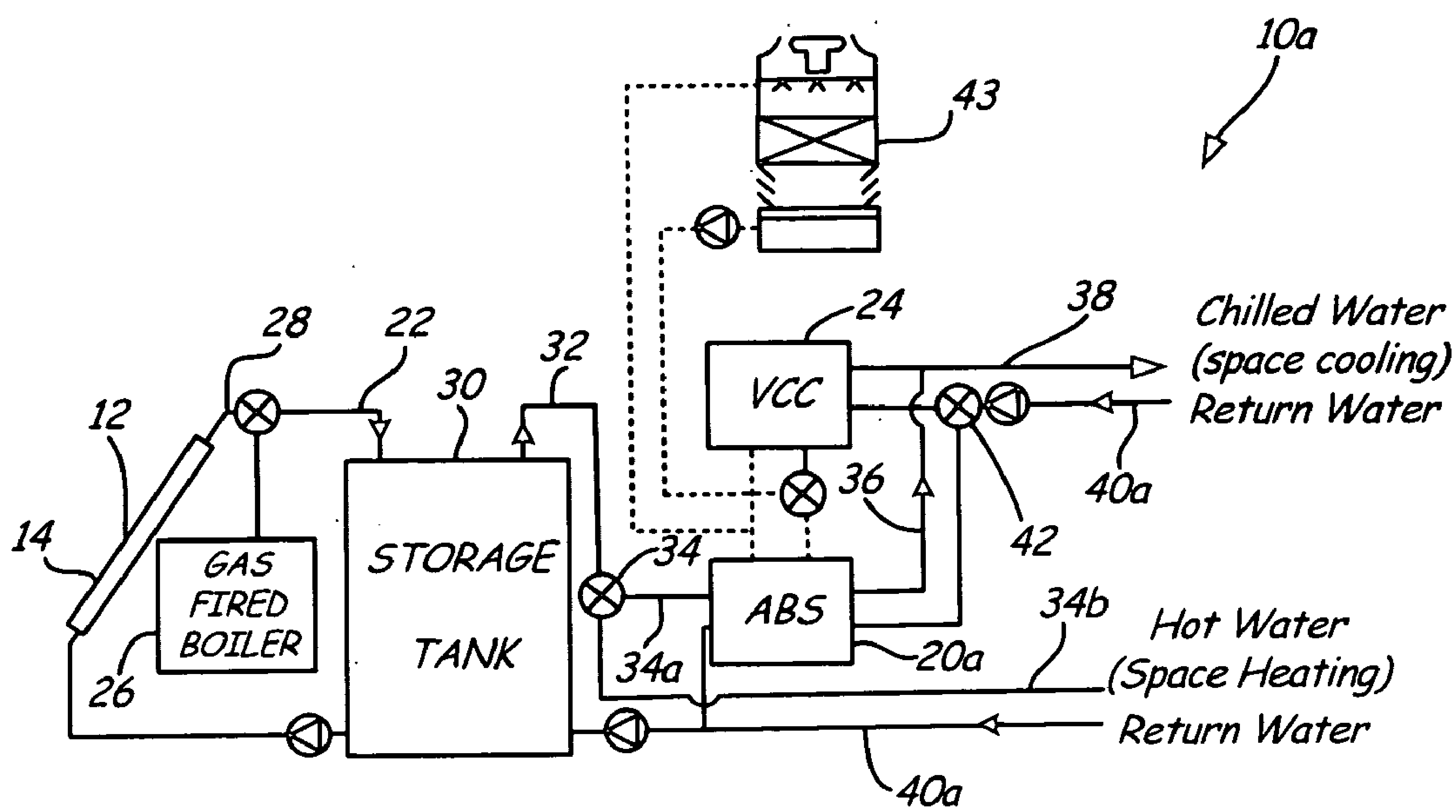
(57) **ABSTRACT**

An integrated solar cell system applies energy created by a solar cell module. The integration system includes a solar cell module, a low-grade heat recovery means, and a process system. The low-grade heat recovery means recovers waste heat from the solar cell module and connects the solar cell module to the process system. The process system is powered at least partially by thermal energy derived from waste heat generated by the solar cell module.



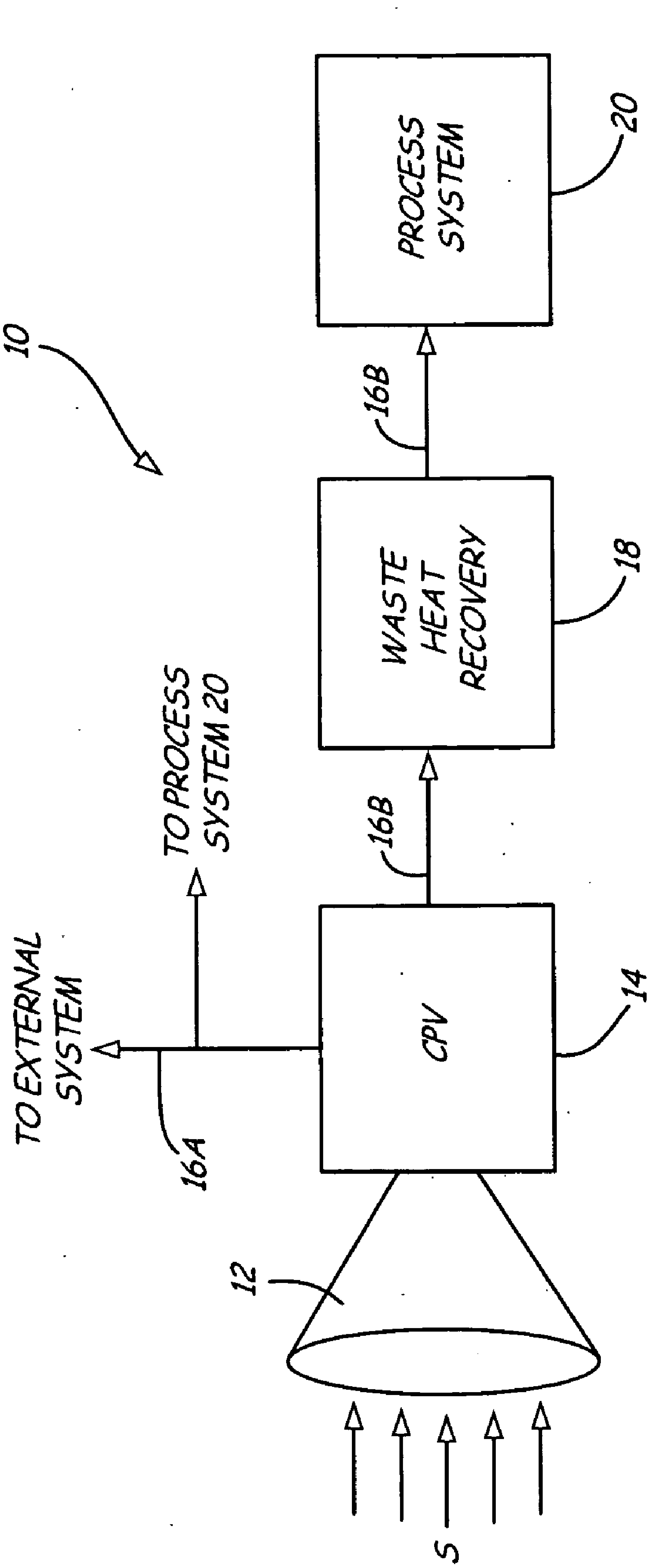

10
PROCESS SYSTEM
20
16B
WASTE HEAT RECOVERY
18
TO PROCESS SYSTEM 20
16B
TO EXTERNAL SYSTEM
CPV
14
16A
12
S

FIG. 1

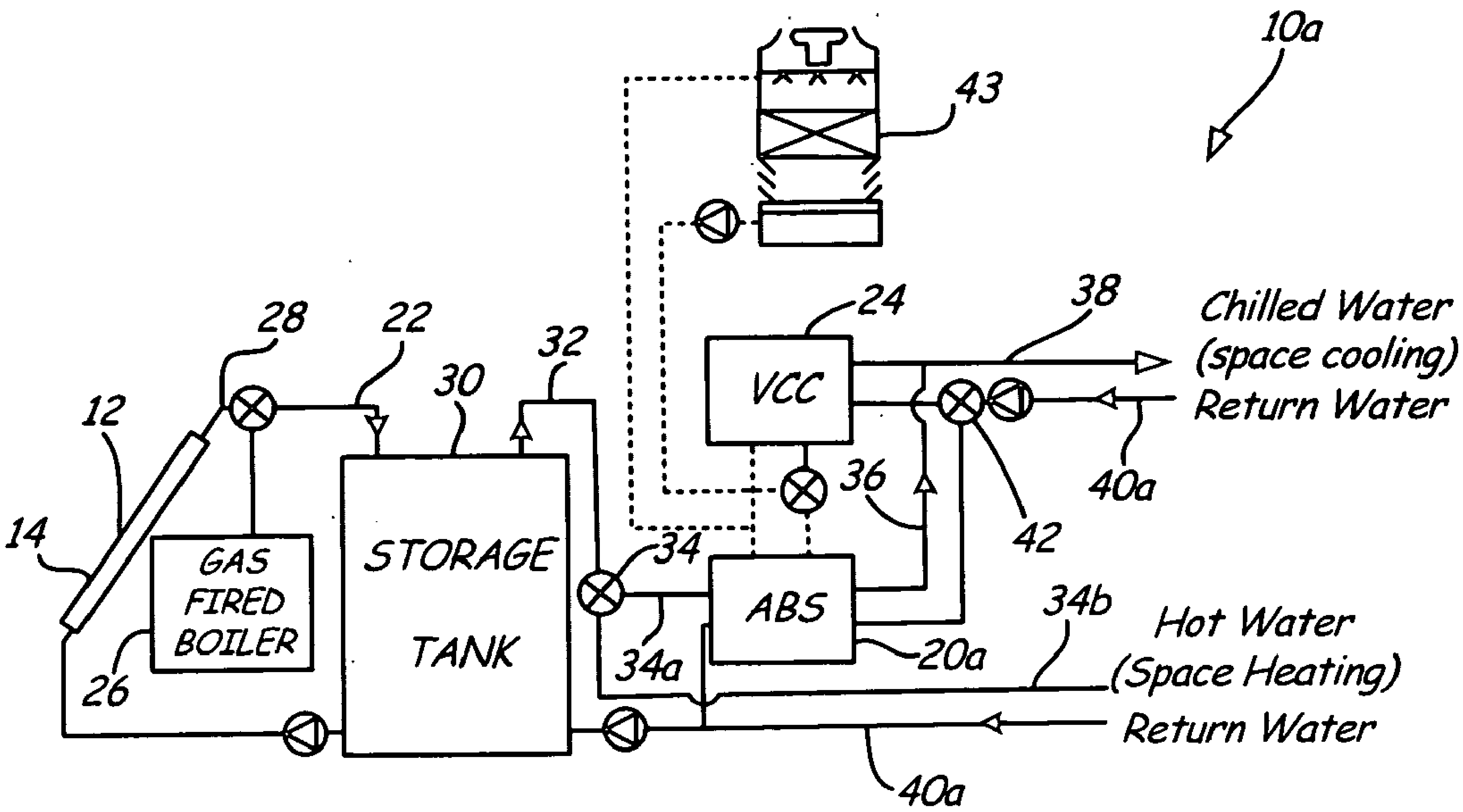

10a
43
Chilled Water
(space cooling)
Return Water
38
24
VCC
28
22
30
32
12
36
40a
42
14
GAS
FIRED
BOILER
STORAGE
TANK
34
ABS
34b
Hot Water
(Space Heating)
Return Water
26
34a
20a
40a

FIG. 2A

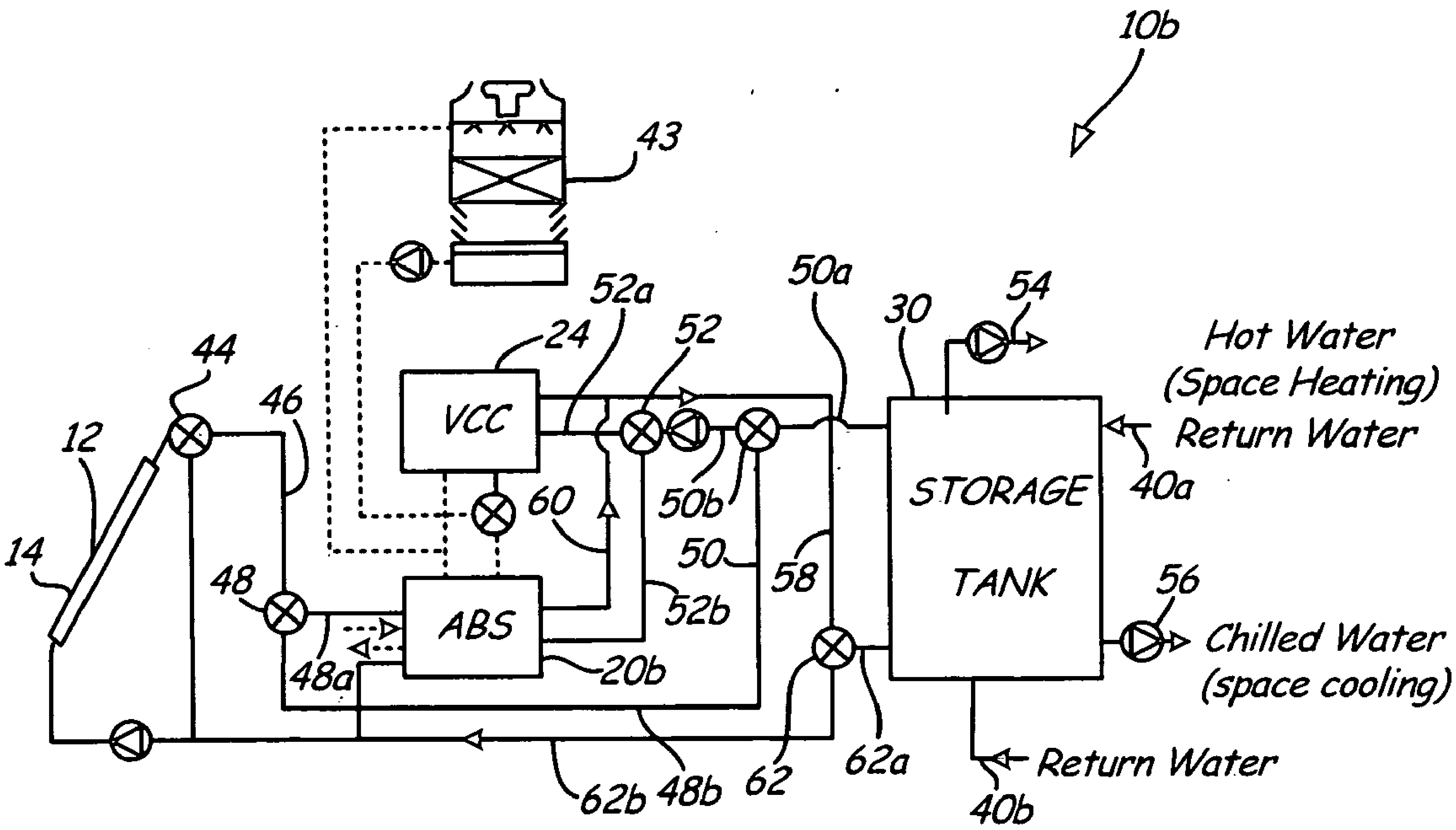

10b
43
52a
50a
54
24
52
30
Hot Water
(Space Heating)
Return Water
44
46
VCC
12
STORAGE
TANK
40a
14
60
50b
50
58
48
ABS
52b
56
Chilled Water
(space cooling)
48a
20b
62b
48b
62
62a
Return Water
40b

FIG. 2B

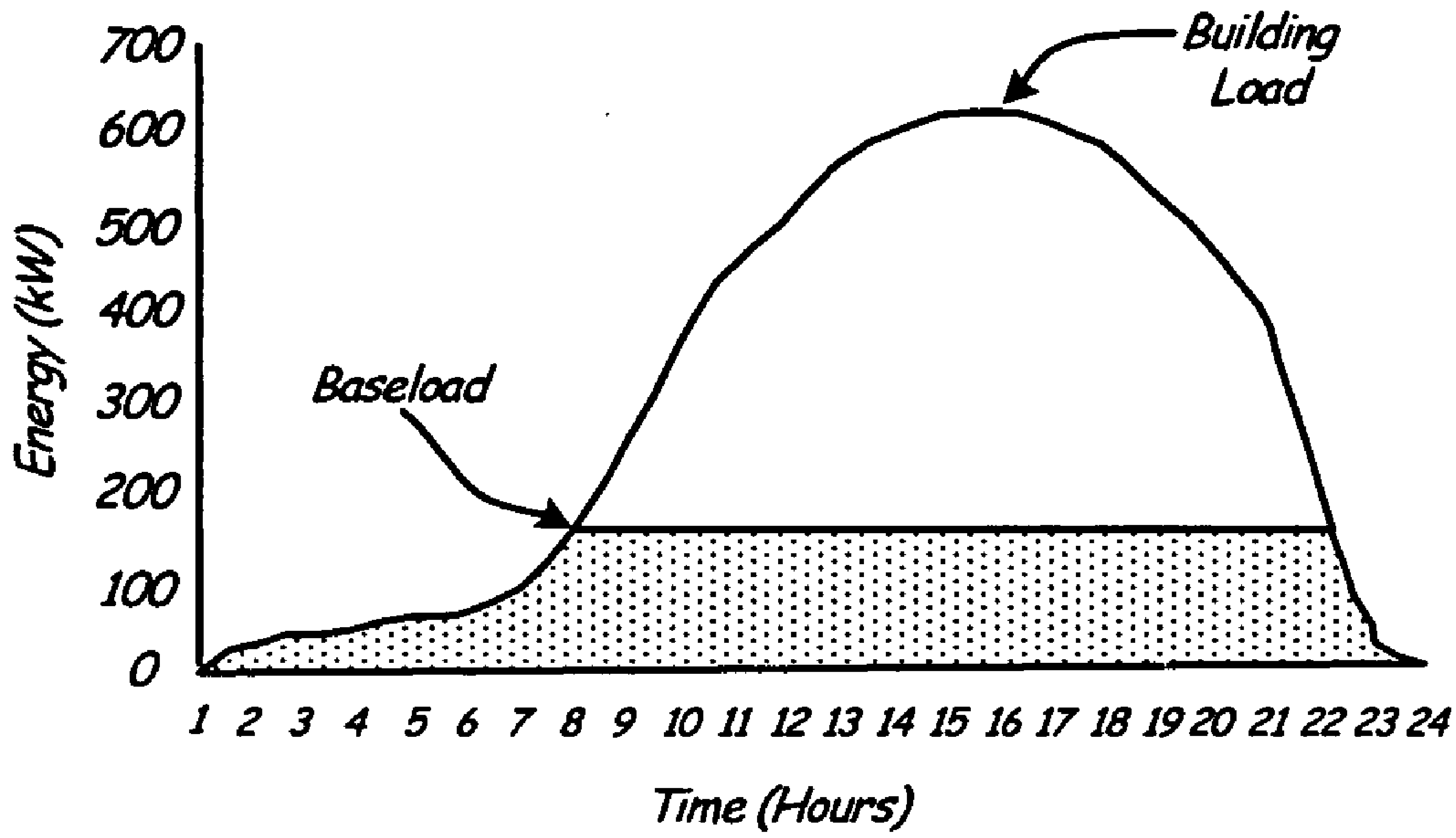

Building Load
Baseload
Energy (kW)
700
600
500
400
300
200
100
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time (Hours)

FIG. 3

INTEGRATED ELECTRICAL AND THERMAL ENERGY SOLAR CELL SYSTEM

BACKGROUND OF THE INVENTION

[0001] Solar cells, or photovoltaic cells, have the ability to convert sunlight directly into electricity. Conventional solar cells are approximately 15 percent efficient in converting absorbed light into electricity. Concentrated photovoltaic cells have the ability to capture more of the electromagnetic spectrum and are thus more efficient, converting absorbed light into electricity at about 30 percent efficiency. The solar energy that is not converted to electricity is converted to heat that is subsequently discarded. Thus, more than 60 percent of the solar energy captured, in the form of heat, is wasted. Due to the small size and the high-energy absorption of the photovoltaic cells, the heat must be efficiently dissipated from the cells to prevent degradation or damage of the cells. One method of removing heat for both conventional and concentrated photovoltaic cells is to use liquid and air heat exchange devices or heat sinks. An integrated solar cell system that can capture the dissipated heat to use as thermal energy to power a process system connected to the solar cell system would be an environmentally friendly power alternative and greatly increase the overall efficiency of the integrated system.

BRIEF SUMMARY OF THE INVENTION

[0002] An integrated solar cell system applies energy created by a solar cell module. The integration system includes a solar cell module, a low-grade heat recovery means, and a process system. The low-grade heat recovery means recovers waste heat from the solar cell module and connects the solar cell module to the process system. The process system is powered at least partially by thermal energy derived from waste heat generated by the solar cell module.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] FIG. **1** is a schematic diagram of an integrated electrical and thermal energy solar cell system.

[0004] FIG. **2**A is a schematic diagram of a first example of the integrated electrical and thermal energy solar cell system.

[0005] FIG. **2**B is a schematic diagram of a second example of the integrated electrical and thermal energy solar cell system.

[0006] FIG. **3** is a graph showing an example load control strategy of the integrated electrical and thermal energy solar cell system.

DETAILED DESCRIPTION

[0007] FIG. **1** shows a first embodiment of an integrated electrical and thermal energy solar cell system **10** that generally includes concentrator **12**, concentrated photovoltaic cell **14**, electrical energy stream **16**A, waste heat energy stream **16**B, waste heat recover system **18**, and process system **20**. Process system **20** uses low-grade waste heat **16**B generated from cell **14** to provide at least a portion of the energy needed to operate process system **20**. Waste heat **16**B is collected by waste heat recovery system **18**, which transports waste heat **16**B to process system **20** for use as thermal energy. Integrated system **10** increases the overall efficiency of concentrated photovoltaic cell **14** and process system **20** by combining the photovoltaic power generated by cell **14** with waste heat recovery. In addition, integrated system **10** produces less pollution by using solar energy as its primary energy source.

[0008] In operation, concentrator **12** is aligned with respect to the sun so that it collects and focuses a maximum amount of solar energy for the dimensions of concentrator **12**. The solar energy is then directed by concentrator **12** to cell **14**, where the solar energy is converted to either electricity or heat. The electricity generated by cell **14** is transported by energy stream **16**A to power an external device of system. Typically in the past, the heat generated by cell **14** discarded into the atmosphere and is thus wasted heat. Integrated system **10** recovers wasted heat **16**B by waste heat recovery system **18** and uses it as thermal energy. Waste heat recovery system **18** recovers the heat by a heat transfer fluid that is pumped through waste heat recovery system **18**. As the heat transfer fluid flows proximate cell **14**, the heat generated from cell **14** is transferred to the heat transfer fluid. Upon recovering the heat from cell **14**, the heat transfer fluid is sent to process system **20** for use. The heat transfer fluid can also optionally be heated to the operating temperature of process system **20** prior to reaching process system **20**.

[0009] Process system **20** of solar cell integrated system **10** requires only thermal energy from cell **14** for power. In one embodiment, process system **18** can be a renewable cooling, heating, and power generating (CHP) system. A combination of thermal energy from waste heat **16**B of cell **14** and biomass is used to generate the power needed for cooling, heating, or other uses, as needed for a specific site. For example, after recovering waste heat **16**B, the heat transfer fluid can be sent to a hybrid cooling system of the renewable CHP system. The burning biomass can then be used to generate electricity with waste heat **16**B from cell **14** after being used for the cooling process. Alternatively, the biomass can be used to create hydrogen fuel. Any spare waste heat from the process can then be used for cooling. Integrated system **10** provides a lower cost alternative to a CHP system that uses natural gas for the cooling/heating system.

[0010] In another embodiment, process system **20** can be a rankine cycle. After recovering waste heat **16**B, the heat transfer fluid is transported to a rankine cycle to produce power. Optionally, the rankine cycle can also be fed waste heat from an alternate source and a control system can be used to optimize the heat input to the rankine cycle from either the heat transfer fluid from cell **14** or from the alternate heat source.

[0011] In another embodiment, process system **20** can be a solid-state energy conversion system that converts waste heat directly to electricity. A solid-state energy conversion system would require no moving parts for converting the waste heat to electricity.

[0012] In another embodiment, process system **20** can be a hydronic heating system. The heat transfer fluid carrying waste heat **16**B is passed through, a heat exchanger that transfers the heat from the heat transfer fluid to a secondary fluid, such as water. The heated water is then used to provide hydronic heat.

[0013] In yet another embodiment of integrated system **10**, process system **20** can be an absorption chiller. When used with an absorption chiller, cell **14** has an operating temperature of at least 80° Celsius (° C.). The heat transfer fluid is pumped to cell **14** at approximately 25° C. The heat transfer fluid can also be heated to a temperature higher than 25° C. as long as it does not exceed the temperature of cell **14**. Upon recovering the heat from cell **14**, the heat transfer fluid is heated to approximately 80° C. or higher. At this temperature, the heat transfer fluid can be used in the regeneration step of a cooling subsystem of an absorption chiller having a back-up burner. A back-up burner is necessary to operate the absorption chiller when the waste heat is not of an adequate grade, or temperature, or when the amount of solar energy absorbed by cell **14** is insufficient to run the absorption chiller. The quality of the waste heat can optionally be improved by a thermoelectric device having a high coefficient of performance to cool cell **14** while rejecting the adequate amount of waste heat.

[0014] In another embodiment of the first embodiment of integrated system **10**, cell **14** and process system **20** have an operating temperature of approximately 50° C. of higher. Due to the lower operating temperature of process system **20**, the quality of waste heat **16**B collected from cell **14** does not have to be as high to run process system **20**. In one embodiment, process system **18** can be an adsorption cooling system. The use of an adsorption cooling system can avoid the use of conventional refrigerants that are currently used in vapor compression systems. These systems also operate at temperatures of between 60° C. and 90° C., making them highly compatible with low grade waste heat sources.

[0015] Optionally, process system **20** can also receive electricity from energy stream **16**A in addition to thermal energy from waste heat energy stream **16**B if process system **20** also requires electricity for power. In one embodiment, process system **20** can be a membrane water purification system. In operation, cell **14** operates at a temperature of at least 50° C. The thermal energy carried by the heat transfer fluid can be used to power a membrane water purification bed of the membrane water purification system. The electricity carried by energy stream **16**A can be used to power water pumps of the membrane water purification system. The overall energy consumption required to run a membrane water purification system is significantly less than the overall energy consumption required to run a conventional flash distillation system. In addition, integrated system **10** can easily be scaled up or down depending on the energy and water requirements of the specific application.

[0016] In another embodiment of integrated system **10**, process system **20** is a solid state cooling system having a cold zone and a hot zone that enables water desalination and/or purification. The thermal energy from cell **14** collected by the heat transfer fluid can be used in a membrane distillation water purification subsystem to evaporate the water and separate it from impure water. Alternatively, solid state cooling devices that use electricity to create cold zones can be used to freeze desalinate water for purification. The heat from the hot zone of the solid state cooling device can then be coupled with a waste heat driven cooling or heating process to create a fully integrated comfort system that provides power, cooling, heating, and water purification functions. Integrated system **10** with a solid state energy conversion system does not require moving parts for either generating power or for the cooling system and additionally does not require refrigerants in either the cooling or heating systems.

[0017] FIGS. **2**A and **2**B depict integrated systems **10***a* and **10***b*, respectively, that generally includes concentrated photovoltaic cell **14** having concentrator **12**, process system **20**, waste heat recovery stream line **22**, and large capacity water-cooled vapor compression chiller (VCC) **24**. As discussed in FIG. **2**A, process system **20** is a small capacity single-effect absorption chiller **20***a*. As discussed in FIG. **2**B, process system **20** is a small capacity double-effect absorption chiller **20***b*. Small capacity absorption chiller **20** (ABS) is placed in parallel with vapor compression chiller **24** so that the solar energy absorbed by cell **14** can be used to supply a relatively small fraction of the energy required to power a structure connected to integrated system **10***a* or **10***b*, with the remaining power supplied by vapor compression chiller **24**. The initial capital cost of integrated systems **10***a* and **10***b* are thus significantly reduced while significantly improving economic competitiveness.

[0018] Concentrated photovoltaic cell **14** collects solar energy from sunlight in order to provide part of the power required to run integrated system **10***a*. In one embodiment, cell **14** is an evacuated tube solar collector with a compound parabolic concentrator that is set up in parallel with back-up gas-fired boiler **26**. Together, cell **14** and gas-fired boiler **26** generate hot water for integrated system **10***a* either with solar energy collected from cell **14** or from gas-fired boiler **26** when there is insufficient solar energy. Input valve **28** is switchable between a first position and a second position and controls whether the hot water is received from cell **14** or gas-fired boiler **26**. Although FIG. **2**A depicts only one cell **14**, any number of cells can be used to form an array of cells as needed to generate sufficient power to run integrated system **10***a*.

[0019] A working fluid refrigerant and absorbent flow through integrated system **10***a*. The refrigerant has a high affinity for the absorbent and will boil at a lower temperature and pressure than under normal conditions. Water is typically used as the refrigerant and flows through waste heat recovery line **22** to transport the thermal energy collected from cell **14** to storage tank **30** and subsequently to absorption chiller **20***a* and vapor compression chiller **24**. Storage tank **30** is a well-insulated hot water storage tank for storing the hot water until it is needed for use. Although FIG. **2**A discusses the working fluid as being water, the working fluid can be any thermally conductive fluid, including, but not limited to: water, a water/glycol mixture, steam, oil, or any combination thereof.

[0020] When needed, hot water from storage tank **30** is passed through hot water line **32** to hot water valve **34**. Hot water valve **34** is switchable between a first position and a second position. When hot water valve **34** is in the first position, water from hot water line **32** is directed through first intermediate line **34***a* to absorption chiller **20***a*, which is driven by thermal energy. The hot water is used as the driving heat source for absorption chiller **20***a* to produce chilled water. The chilled water is then passed through output line **36** to chilled water line **38** for space cooling. When hot water valve **34** is in the second position, water from hot water line **32** is directed through second intermediate line **34***b* to be used in other applications, including, but not limited to: space heating and providing domestic hot water. The thermal energy can also be used as fuel to generate exhaust gas, hot water, or steam to ensure the operability of integrated system **10***a* when the solar energy collected by cell **14** is insufficient to meet the building load of the structure connected to integrated system **10***a*. Once the hot water and the chilled water has been used for their respective purposes, they are returned to integrated system **10** through return water lines **40***a* and **40***b*, respectively, for reuse. Return valve **42** is switchable between a first position and a second position and controls whether the water returning through water line **40***b* is fed to absorption chiller **20***a* or vapor compression chiller **24**.

[0021] Vapor compression chiller **24**, which is in parallel with absorption chiller **20***a*, serves to meet the cooling load that exceeds the capacity of absorption chiller **20***a* or as a back-up cooling equipment, when the amount of solar energy absorbed by cell **14** is insufficient to meet the building load. When needed, chilled water from vapor compression chiller **24** is sent through chilled water line **38** to provide any additional space cooling. Due to its high fuel to electricity conversion efficiency, vapor compression chiller **24** can be effectively used as the primary source of cooling equipment for commercial buildings. Additionally, because vapor compression chiller **24** is powered by electricity, cell **14** can also provide electricity to run vapor compression chiller **24**.

[0022] Depending on system specifications, process systems in addition to absorption chiller **20***a* and vapor compression **24** can also be connected to integrated system **10***a*. As an example, cooling tower **43** could be connected to integrated system **10***a*, as shown by the dotted lines in FIG. 2A. The dotted lines represent additional potential integration opportunities that could be accomplished given additional energy collection and recovery within integrated system **10***a*.

[0023] Small capacity absorption chiller **20** can also be a double-effect absorption chiller **20***b*, as shown in FIG. 2B. Double-effect absorption chiller **20***b* differs from single-effect absorption chiller **20***a* in that double-effect absorption chiller **20***b* includes a two-stage heater that regenerates the working fluid. A portion of the internal heat in absorption chiller **20***b* is also recycled to provide part of the energy needed in the generator of absorption chiller **20***b* to create a high-pressure refrigerant vapor. While double-effect absorption chiller **20***b* outputs more cooling per power input, the system is also more complicated than single-effect absorption cooler **20***a*.

[0024] In integrated system **10***b*, cell **14** is used to generate steam. Feed valve **44** is positioned proximate the outlet of cell **14** and controls steam input. When steam is needed, feed valve **44** allows steam to pass through feed line **46** to steam valve **48**, which splits feed line **46** into primary line **48***a* and secondary line **48***b*. Steam valve **48** is switchable between a first position and a second position. When steam valve **48** is in the first position, the steam passes through primary line **48***a* to absorption chiller **20**. Depending on the temperature of the steam, the steam can be fed to a low temperature generator of double-effect absorption chiller **20***b*, which is steam/gas-fired dual source driven, to produce chilled water. Alternatively, the steam can also be sent to a high temperature generator of absorption chiller **20***b* if the quality of the waste heat is high enough. When steam valve **48** is in the second position, the steam passes through secondary line **48***b* to first valve **50**.

[0025] Depending on the position of first valve **50**, the steam can be passed through first intermediate line **50***a* to storage tank **30** or through second intermediate line **50***b* to second valve **52**. The steam in first intermediate line **50***a* is stored in storage tank **30** until needed. When needed, the steam can be sent from storage tank **30** through hot water line **54** as hot water to provide space heating or through chilled water line **56** as chilled water to provide space cooling. Second valve **52** is also switchable between a first position and a second position and feeds the steam from cell **14** to either vapor compression chiller **24** through third intermediate line **52***a* or absorption chiller **20***b* through fourth intermediate line **52***b*.

[0026] Storage tank **30** receives chilled water from vapor compression chiller **24** through VCC line **58**, which passes chilled water from vapor compression chiller **24** and chilled water from absorption chiller **20***a* through ABS line **60**, which is connected to VCC line **58** upstream of storage tank **30**, to chilled water valve **62**. Chilled water valve **62** is switchable between two positions and sends the chilled water from vapor compression chiller **24** to storage tank **30** through fifth intermediate line **62***a* and to cell **14** and valve **44** through sixth intermediate line **62***b*. Similar to FIG. 2A, although FIG. 2B depicts only one cell **14**, any number of cells can be used to form an array as needed to generate sufficient power to run integrated system **10***b*. Also similar to integrated system **1***a*, additional process systems in addition to absorption chiller **20***b* and vapor compression **24** can be connected to integrated system **10***b*, such as cooling tower **43**.

[0027] FIG. **3** is a graph showing an example load control strategy of integrated system **10***a* or **10***b*. Small capacity absorption chiller **20** is placed in parallel with vapor compression chiller **24** so that the solar energy absorbed by cell **14** can be used to meet a relatively small fraction of the building load of a structure connected to integrated system **10***a* or **10***b* as a baseload. The building load is the total energy consumed by a structure for electricity, cooling, and heating. The baseload is the typical average energy consumed by the structure for an 8760-hour period (i.e., averaged over a year). Vapor compression chiller **24**, which is low-cost compared to cell **14**, can be used to meet the remaining building load, as shown in FIG. **3**.

[0028] The integrated electrical and thermal energy solar cell system utilizes a renewable and environmentally-friendly source of energy to run process systems in parallel with a solar cell system. Use of a solar cell system in parallel with a process system enhances the overall efficiency of the system and makes use of thermal energy that is typically wasted. The integrated system captures the low-grade waste heat generated by photovoltaic cells during the absorption of solar energy and the production of electricity. The low-grade waste heat is transported by a heat transfer fluid flowing through a waste heat recovery line to a process system in parallel with the solar cell system. The process system can include, but is not limited to: an absorption chiller, an adsorption cooling system, a hydronic heating system, a rankine cycle, or a renewable cooling, heating and power generating system. In some systems, both electricity and thermal energy are needed to run the process system. These process system can include, but is not limited to: a membrane water purification system, a solid state cooling system, or an absorption chiller in combination with a vapor compression chiller.

[0029] Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention.

1. An integrated solar cell system comprising:

a solar cell module that converts solar energy to electrical energy and waste heat;

a low-grade heat recovery means for recovering the waste heat from the solar cell module; and

a process system connected to the solar cell module by the low-grade heat recovery means, wherein the process system is powered at least in part by thermal energy derived from the waste heat recovered from the solar cell module.

2. The integrated system of claim 1, wherein the solar cell module is a concentrated photovoltaic cell.

3. The integrated system of claim 1, wherein the low-grade heat recovery means comprises a heat transfer fluid.

4. The integrated system of claim 1, wherein the process system comprises a hydronic heating system.

5. The integrated system of claim 1, wherein the process system comprises a solid-state energy conversion system.

6. The integrated system of claim 1, wherein the solar cell system has an operating temperature of at least 80 degrees Celsius.

7. The integrated system of claim 6, wherein the process system comprises an absorption chiller.

8. The integrated system of claim 1, wherein the solar cell system has an operating temperature of at least 50 degrees Celsius.

9. The integrated system of claim 8, wherein the process system comprises an adsorption cooling system.

10. The integrated system of claim 1, wherein the process system comprises a rankine cycle.

11. The integrated system of claim 1, wherein the process system comprises a renewable cooling, heating, and power generating system.

12. The integrated system of claim 1, wherein the process system comprises a membrane water purification system.

13. The integrated system of claim 1, wherein the process system is also powered at least in part by electricity generated from the solar cell system.

14. The integrated system of claim 13, wherein the process system comprises a membrane water purification system.

15. The integrated system of claim 13, wherein the process system comprises a solid state cooling system.

16. The integrated system of claim 15, wherein the solid state cooling system comprises a water desalination system.

17. The integrated system of claim 13, wherein the process system comprises an absorption chiller system integrated with a vapor compression chiller.

18. A method for using energy created by a solar cell system, the method comprising:

capturing energy from sunlight directed at the solar cell system;

generating electricity from the sunlight captured by the solar cell system;

recovering heat dissipating from the solar cell system; and

transporting the recovered heat to a process system for use.

19. The method of claim 18, wherein transporting the recovered heat to a process system for use comprises transporting the recovered heat to a hydronic heating system, a solid-state energy conversion system, an absorption chiller, an adsorption cooling system, a solid state cooling system, a rankine cycle, a membrane water purification system, an absorption chiller system integrated with a vapor compression chiller, or a renewable cooling, heating, and power generating system.

20. The method of claim 18, wherein generating electricity comprises sending the generated electricity to a membrane water purification system, a solid state cooling system, or an absorption chiller system integrated with a vapor compression chiller.

* * * * *