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(54) **ACTIVE THERMAL ENERGY STORAGE SYSTEM AND TANK FOR USE THEREIN**

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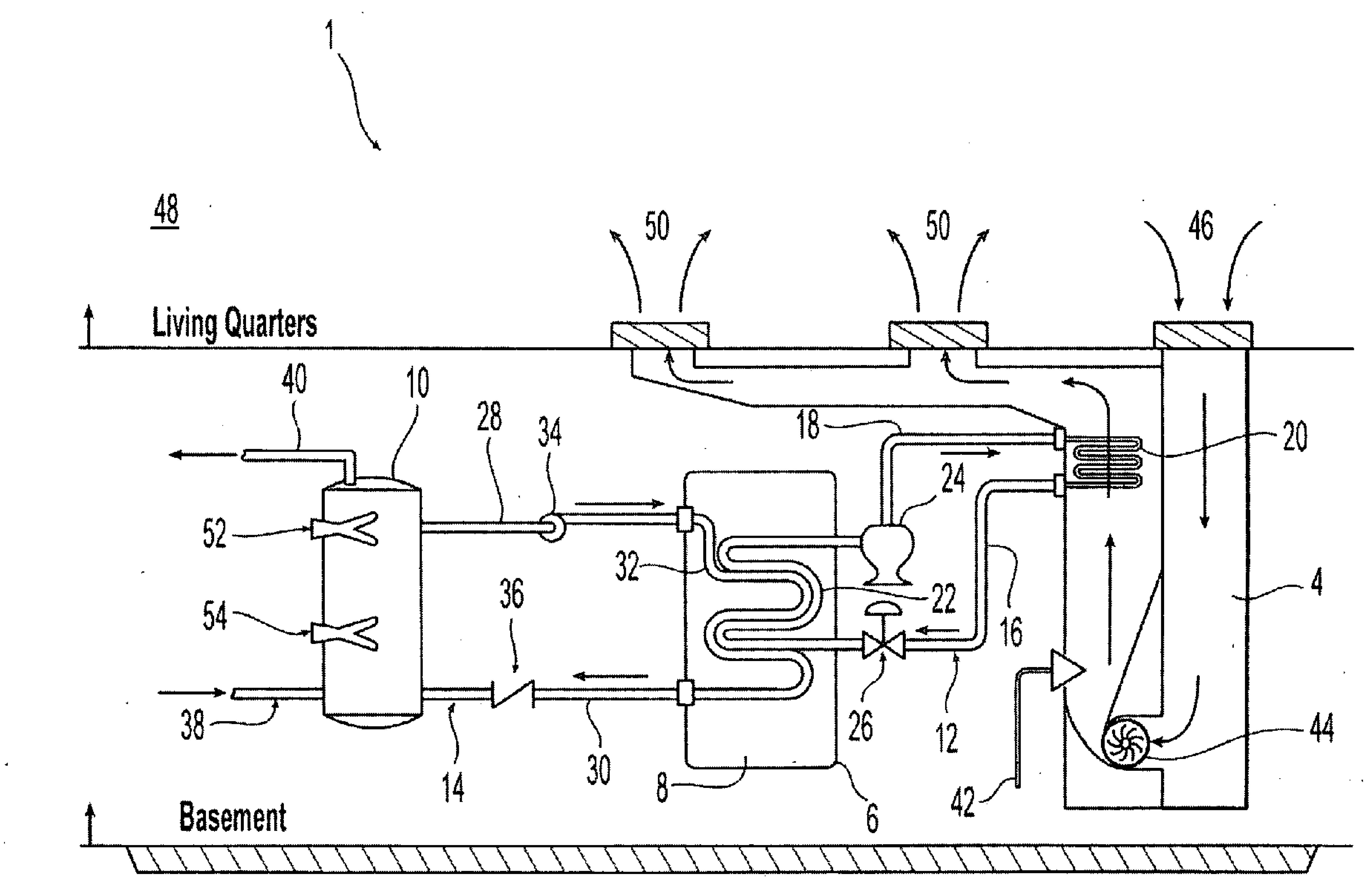
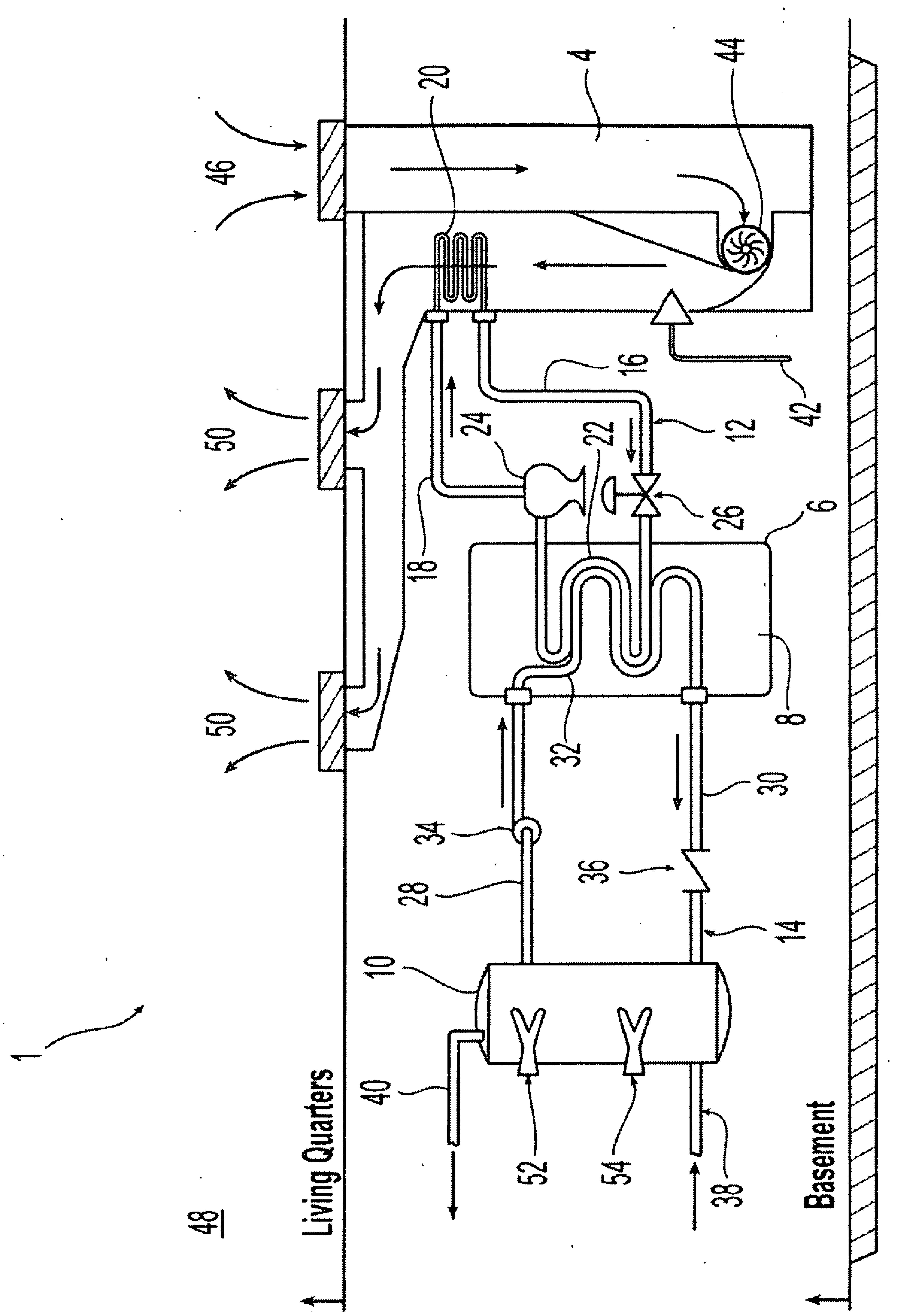
(57) **ABSTRACT**

An active thermal energy storage system is disclosed which uses an energy storage material that is stable at atmospheric pressure and temperature and has a melting point higher than 32 degrees F. This energy storage material is held within a storage tank and used as an energy storage source, from which a heat transfer system (e.g., a heat pump) can draw to provide heating of residential or commercial buildings and associated hot water. The energy storage material may also accept waste heat from a conventional air conditioning loop, and may store such heat until needed. The system may be supplemented by a solar panel system that can be used to collect energy during daylight hours, storing the collected energy in the energy storage material. The stored energy may then be used during the evening hours to heat recirculation air for a building in which the system is installed.

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Basement
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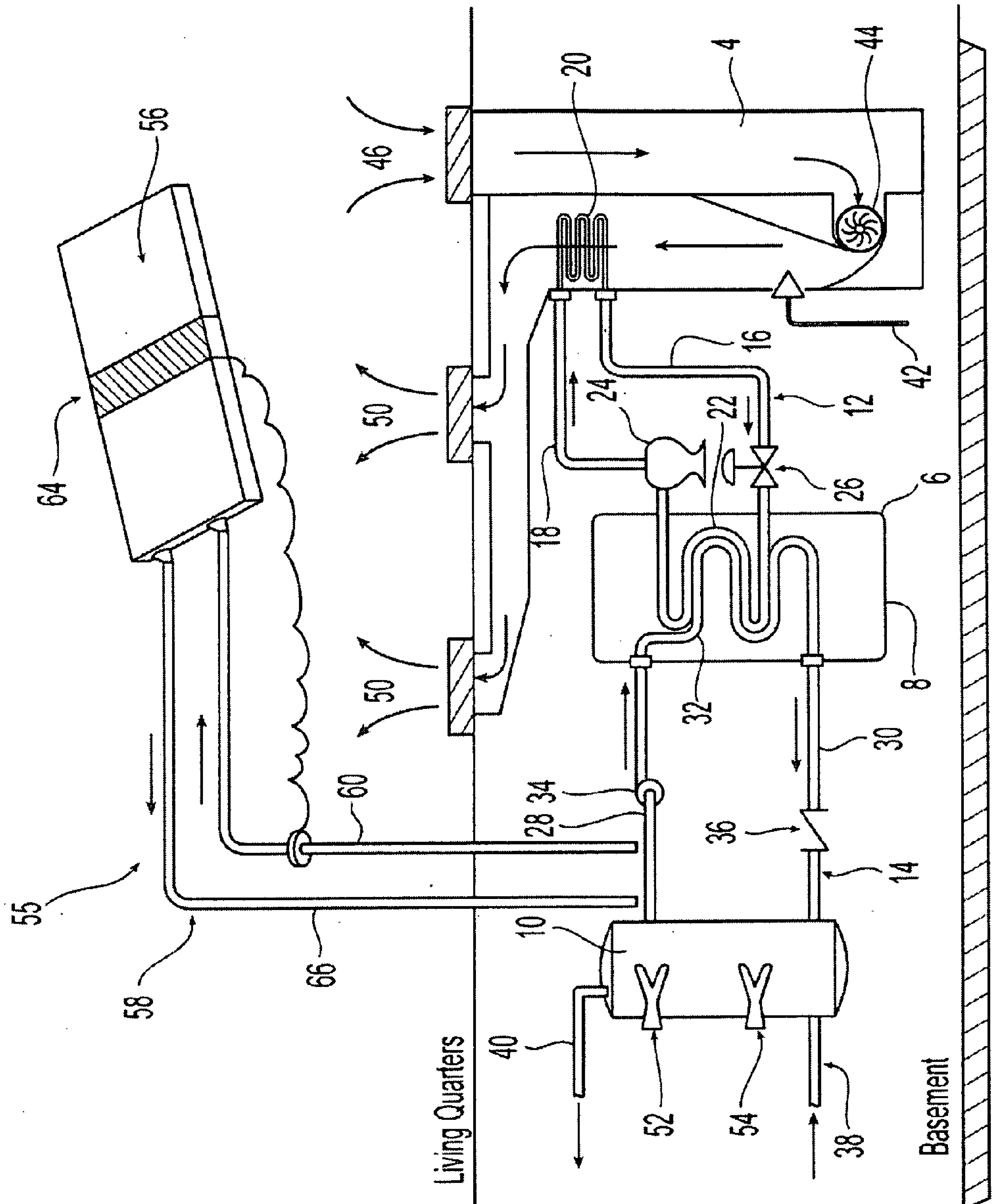
Fig. 1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58
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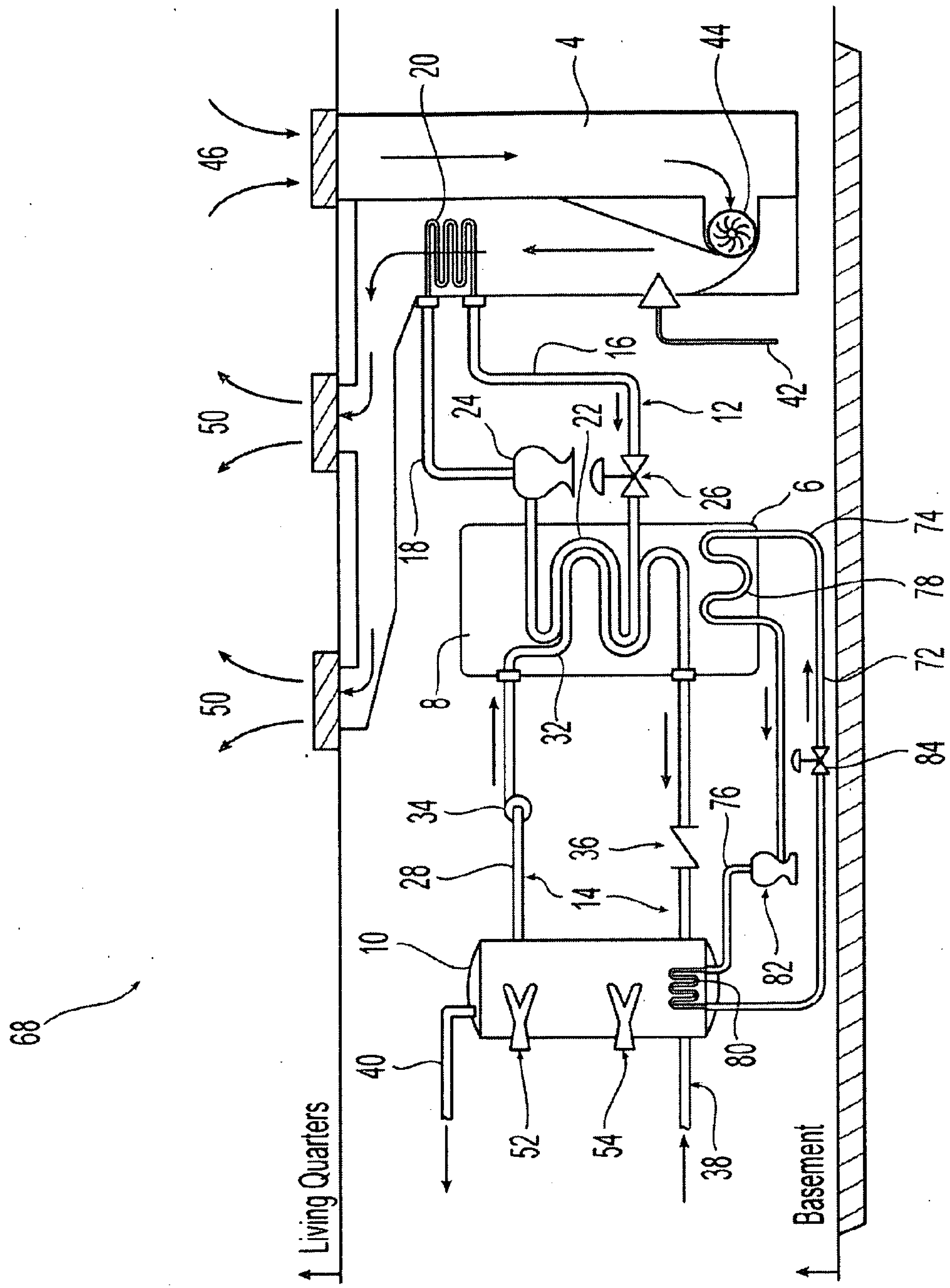
38
Living Quarters
Basement

Fig. 2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Basement
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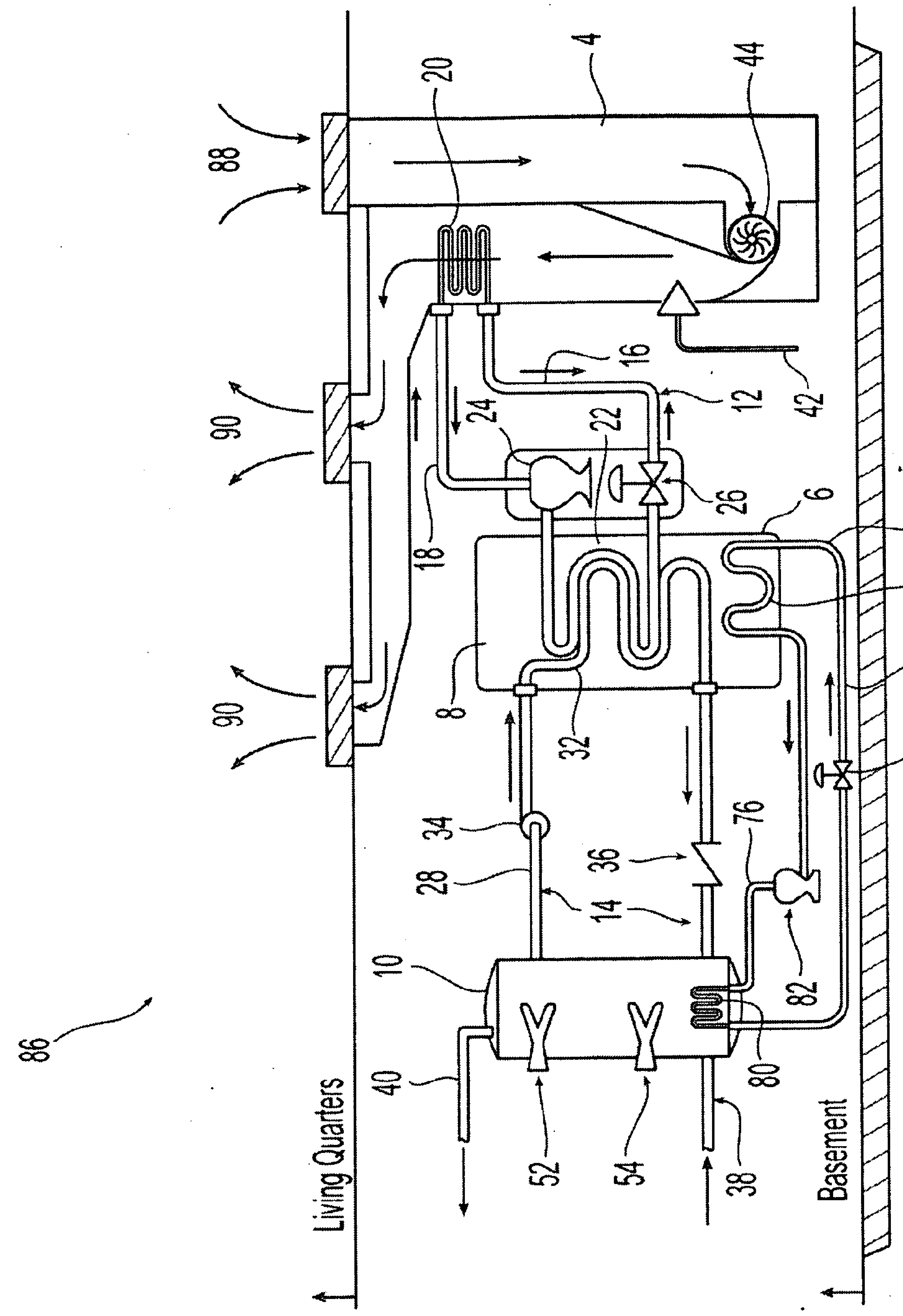
Fig. 3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Basement
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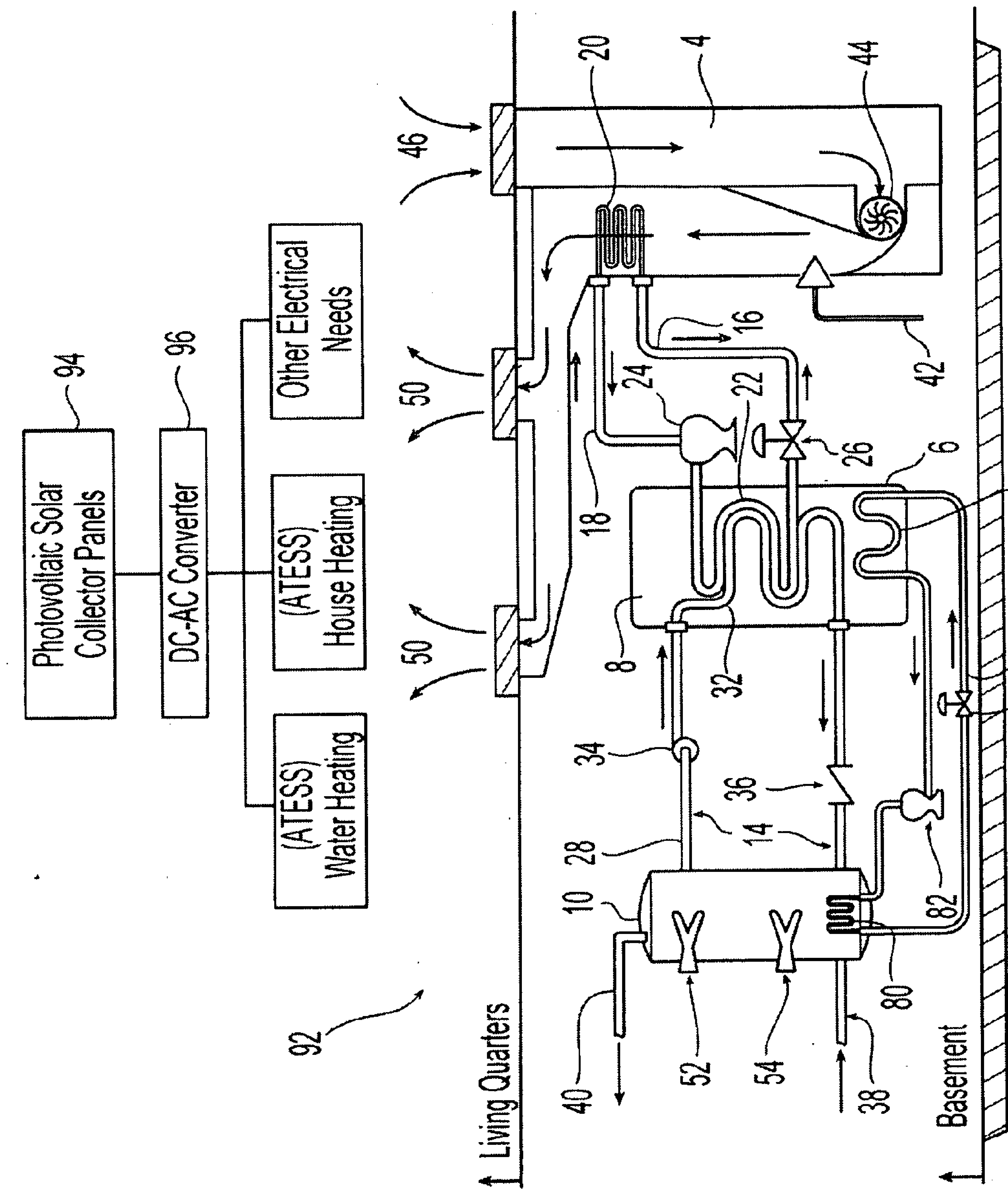
Fig. 4



Photovoltaic Solar Collector Panels
DC-AC Converter
(ATESS) Water Heating
(ATESS) House Heating
Other Electrical Needs
Living Quarters
Basement
94
96
92
46
50
50
20
4
44
16
42
24
22
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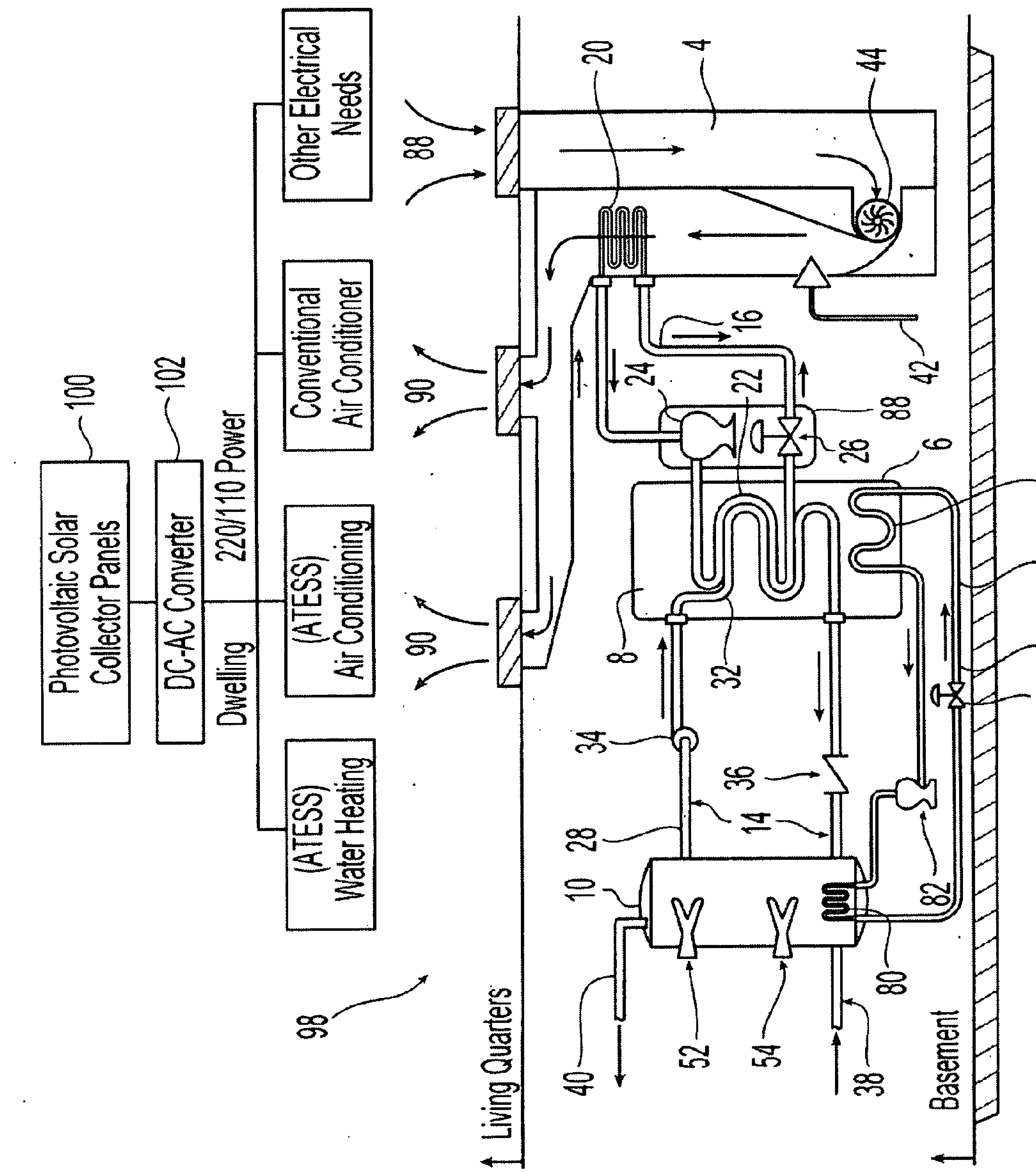
Fig. 5


Photovoltaic Solar Collector Panels
100
DC-AC Converter
102
Dwelling
220/110 Power
(ATESS) Water Heating
(ATESS) Air Conditioning
Conventional Air Conditioner
Other Electrical Needs
98
90
90
88
Living Quarters
Basement
40
52
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38
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Fig. 6

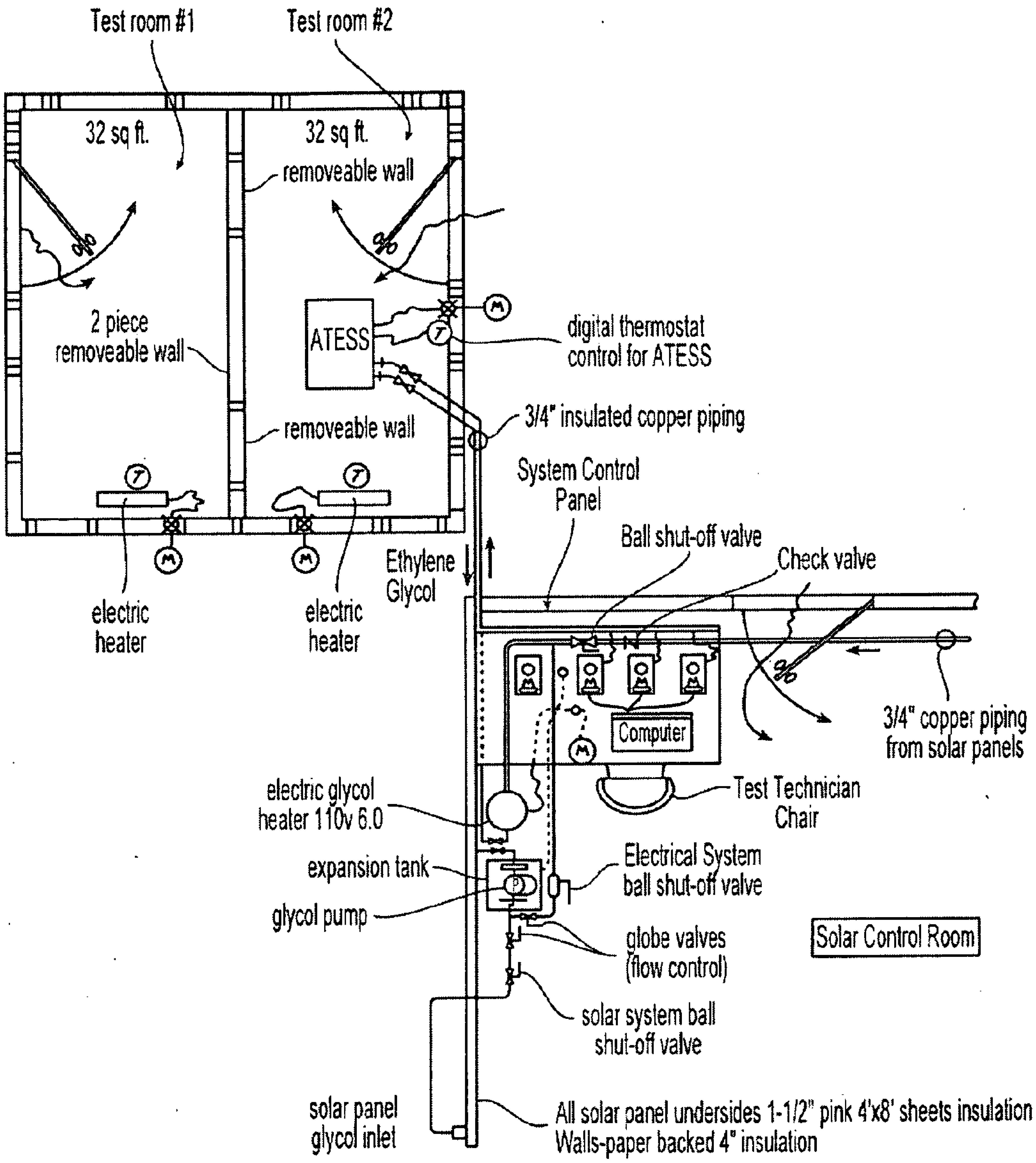

Test room #1
Test room #2
32 sq ft.
32 sq ft.
removeable wall
2 piece
removeable wall
ATESS
digital thermostat
control for ATESS
removeable wall
3/4" insulated copper piping
System Control
Panel
Ball shut-off valve
Check valve
Ethylene
Glycol
electric
heater
electric
heater
Computer
3/4" copper piping
from solar panels
Test Technician
Chair
electric glycol
heater 110v 6.0
expansion tank
glycol pump
Electrical System
ball shut-off valve
globe valves
(flow control)
Solar Control Room
solar system ball
shut-off valve
solar panel
glycol inlet
All solar panel undersides 1-1/2" pink 4'x8' sheets insulation
Walls-paper backed 4" insulation

Fig. 7

(ATESS Heating System) Test Results (BTU)																		
								ATESS Heating System										
Temp of Outside Air °F		Day	Heat to Room #1	Heat to Room #2		Main Heating System		Evening Off Peak Electric to TESM		Day Solar Electric to TESM		Heat Pump Compression TESM		Motor Loss & Extra Room Heat Demand		ATESS Controls	
Max	Min																
-	-	1	15,940	15,700	=	15,700	+	0	+	0	+	0	+	0	+	0	
-	-	2	14,440	14,790	=	14,790	+	0	+	0	+	0	+	0	+	0	
-	-	3	15,220	15,100	=	15,100	+	0	+	0	+	0	+	0	+	0	
-	-	4	13,690	15,319	=	0	+	4,729	+	4,729	+	2,931	+	1,742	+	1,186	15,317
41	32	5	12,770	15,865	=	0	+	5,120	+	5,120	+	3,174	+	1,265	+	1,186	15,865
36	31	6	14,070	17,165	=	0	+	5,564	+	5,564	+	3,449	+	1,402	+	1,186	17,165
35	30	7	15,060	19,549	=	0	+	5,275	+	5,275	+	3,270	+	4,543	+	1,186	19,549
37	29	8	16,940	18,126	=	0	+	5,086	+	5,086	+	3,153	+	3,615	+	1,186	18,126
37	24	9	15,710	18,123	=	0	+	5,462	+	5,462	+	3,386	+	2,627	+	1,186	18,123
43	26	10	14,340	16,685	=	0	+	5,462	+	5,462	+	3,386	+	1,189	+	1,186	16,685
47	26	11	15,220	19,275	=	0	+	5,581	+	5,581	+	3,400	+	3,527	+	1,186	19,275
27	13	12	20,351	21,887	=	0	+	5,618	+	5,618	+	3,483	+	5,982	+	1,186	21,887
23	12	13	20,368	23,079	=	0	+	5,778	+	5,778	+	3,582	+	6,755	+	1,186	23,079
38	24	14	15,996	19,675	=	0	+	5,976	+	5,976	+	3,701	+	2,832	+	1,186	19,671

Fig. 8

Optimum Day Test Results															
						ATESS Heating System									
Hour	Heat to Duplex Room #1 (BTU)	Heat to Duplex Room #2 (BTU)		Main Heating System (BTU)		Evening Off Peak Electric to TESM (BTU)		Day Solar Electric to TESM (BTU)		Heat Pump Compression TESM		Motor Loss & Extra Room Heat Demand		ATESS Controls	
1	597	706	=	0	+	0	+	0	+	141	+	60	+	49	
2	597	706	=	0	+	0	+	0	+	141	+	60	+	49	
3	597	706	=	0	+	0	+	0	+	141	+	60	+	49	
4	597	706	=	0	+	0	+	0	+	141	+	60	+	49	
5	597	706	=	0	+	0	+	0	+	141	+	60	+	49	
6	597	706	=	0	+	1,366	+	0	+	141	+	60	+	49	
7	597	706	=	0	+	1,366	+	0	+	141	+	60	+	49	
8	597	706	=	0	+	1,366	+	0	+	141	+	60	+	49	
9	597	706	=	0	+	1,366	+	0	+	141	+	60	+	49	
10	597	706	=	0	+	0	+	0	+	141	+	60	+	49	
11	597	706	=	0	+	0	+	0	+	141	+	60	+	49	
12	597	706	=	0	+	0	+	0	+	141	+	60	+	49	
13	597	706	=	0	+	0	+	0	+	141	+	60	+	49	
14	597	706	=	0	+	0	+	0	+	141	+	60	+	49	
15	597	706	=	0	+	0	+	0	+	141	+	60	+	49	
16	597	706	=	0	+	0	+	0	+	141	+	60	+	49	
17	597	706	=	0	+	0	+	0	+	141	+	60	+	49	
18	597	706	=	0	+	0	+	0	+	141	+	60	+	49	
19	597	706	=	0	+	0	+	1,366	+	141	+	60	+	49	
20	597	706	=	0	+	0	+	1,366	+	141	+	60	+	49	
21	597	706	=	0	+	0	+	1,366	+	141	+	60	+	49	
22	597	706	=	0	+	0	+	1,366	+	141	+	60	+	49	
23	597	706	=	0	+	0	+	0	+	141	+	60	+	49	
24	597	706	=	0	+	0	+	0	+	141	+	60	+	49	
Total	14,328	16,944		0		5,464		5,464		3,384		1,440		1,176	16,928

Fig. 9

(ATESS) Test Results (BTU per Day)

	Heat Required BTU/Per Day	(ATESS) Night Off Peak Electricity & Daytime Solar		
		Evening Off Peak Elec Heat to TESM	Daytime Solar Elec Heat to TESM	Heat Pump Comp and Motor Loss
Test Site 32sq ft	14,328	5,464	5,464	4,824
Residence 1600sq ft (ratio 50:1)	716,400	273,200	273,200	170,000

Fig. 10A

Global Warming Effects in an Annual 125 Day Heating Season

References:	BTU/Gallon	Gallons/Heating Season	Carbon Emmissions	CO2 Emmissions
Fuel Oil	148,000	711	3831lbs	14,060lbs
LPG	91,600	1,150	2927lbs	10,742lbs
ATESS	N/A	N/A	0lbs	0lbs

Fig. 10C

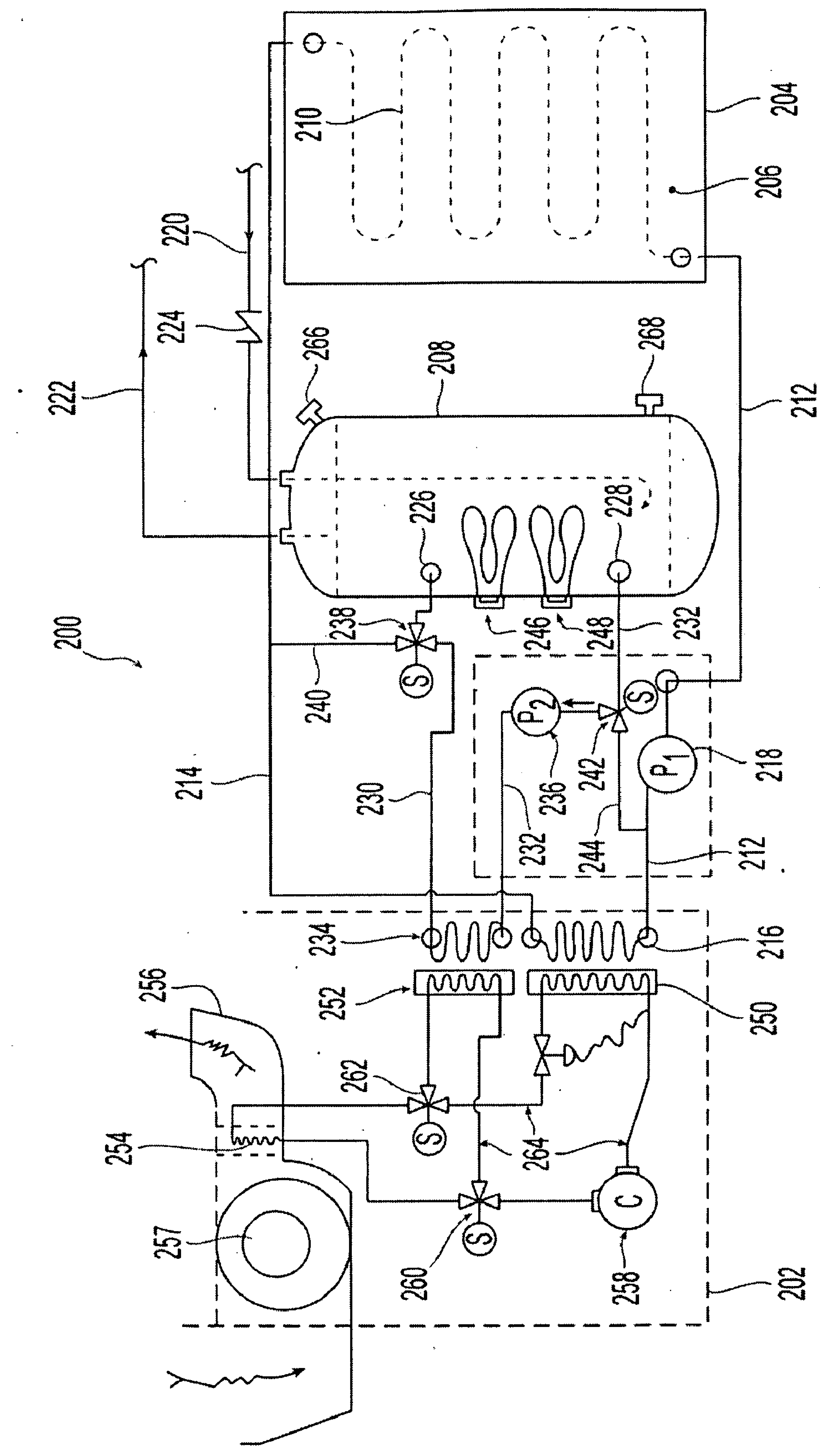
Limited Energy Sources

Conventional Heating Fuel Source	Conventional System Energy Source	(ATESS) (1) Night Off Peak Electricity & Daytime Solar: Evening Off Peak Elec Heat to TESM $0.03/KWH	Daytime Solar Elec Heat to TESM $0.00/KWH	Heat Pump Comp and Motor Loss $0.12/KWH	Winter Annual Heating Costs $$ Per Year: Conventional Heating Systems	ATESS Heating System
Fuel Oil @ $2.55/gal 85% Combustion eff.	5.69 gpd 14.51 $/day	80 kwhrs 2.40 $/day	80 kwhrs 0 $/day	49.8 kwhrs 5.98 $/day	$1,813	$1,048
LPG @ $1.86/gal 85% Combustion eff.	9.2 gpd 15.46 $/day	80 kwhrs 2.40 $/day	80 kwhrs 0 $/day	49.8 kwhrs 5.98 $/day	$1,932	$1,048

Conventional Heating Fuel Source	Conventional System Energy Source	(ATESS) (2) Night Off Peak Electricity Only: Evening Off Peak Elec Heat to TESM $0.03/KWH	Daytime Solar Elec Heat to TESM $0.00/KWH	Heat Pump Comp and Motor Loss $0.12/KWH	Winter Annual Heating Costs $$ Per Year: Conventional Heating Systems	ATESS Heating System
Fuel Oil @ $2.55/gal 85% Combustion eff.	5.69 gpd 14.51 $/day	160 kwhrs 4.80 $/day	0 kwhrs 0 $/day	49.8 kwhrs 5.98 $/day	$1,813	$1,348
LPG @ $1.86/gal 85% Combustion eff.	9.2 gpd 15.46 $/day	160 kwhrs 4.80 $/day	0 kwhrs 0 $/day	49.8 kwhrs 5.98 $/day	$1,932	$1,348

Conventional Heating Fuel Source	Conventional System Energy Source	(ATESS) (3) Daytime Solar Energy Only: Evening Off Peak Elec Heat to TESM $0.03/KWH	Daytime Solar Elec Heat to TESM $0.00/KWH	Heat Pump Comp and Motor Loss $0.12/KWH	Winter Annual Heating Costs $$ Per Year: Conventional Heating Systems	ATESS Heating System
Fuel Oil @ $2.55/gal 85% Combustion eff.	5.69 gpd 14.51 $/day	0 kwhrs 0 $/day	160 kwhrs 0 $/day	49.8 kwhrs 5.98 $/day	$1,813	$748
LPG @ $1.86/gal 85% Combustion eff.	9.2 gpd 15.46 $/day	0 kwhrs 0 $/day	160 kwhrs 0 $/day	49.8 kwhrs 5.98 $/day	$1,932	$748

Fig. 10B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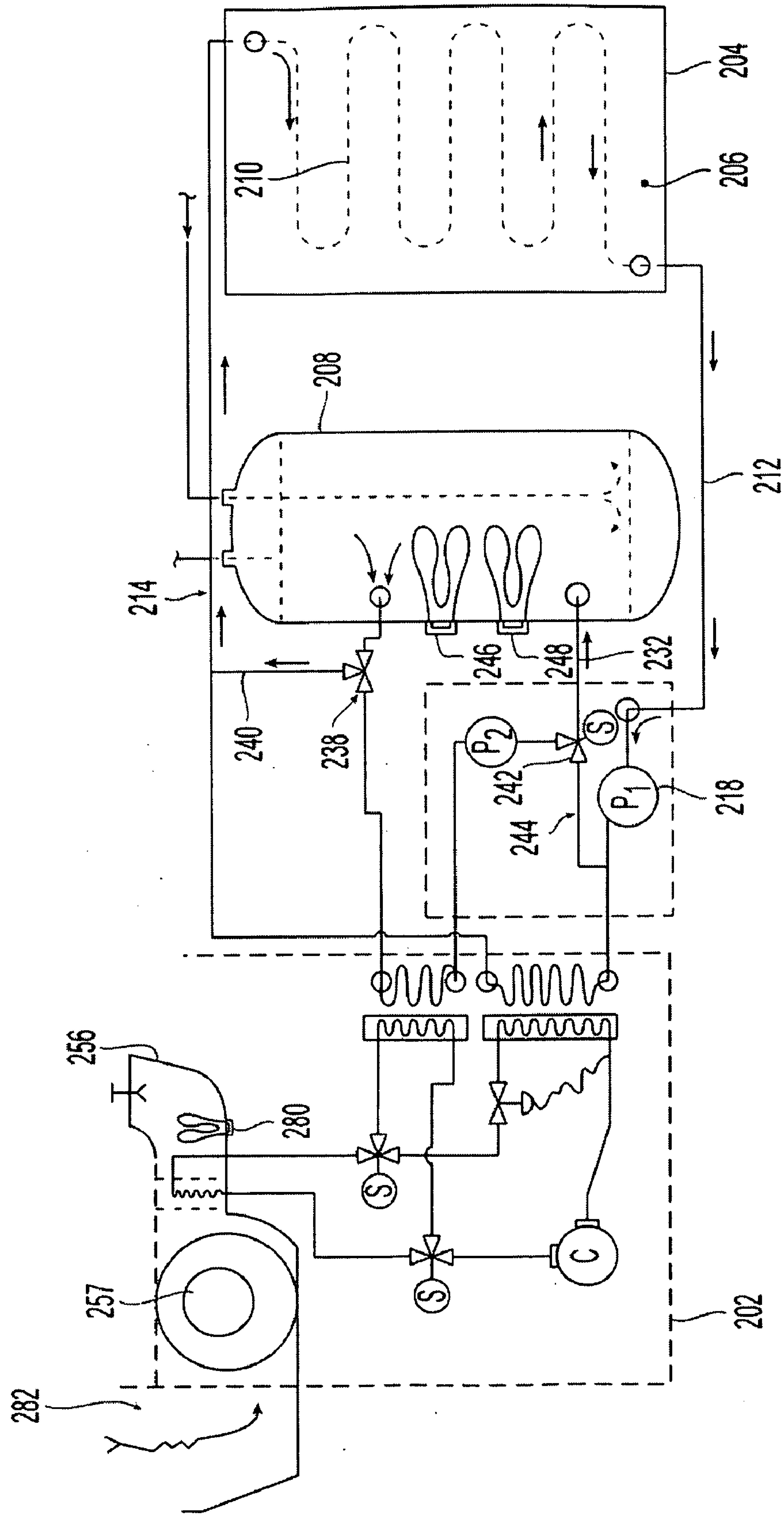
P1
P2
C

Fig. 11



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P_1
P_2
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Fig. 12

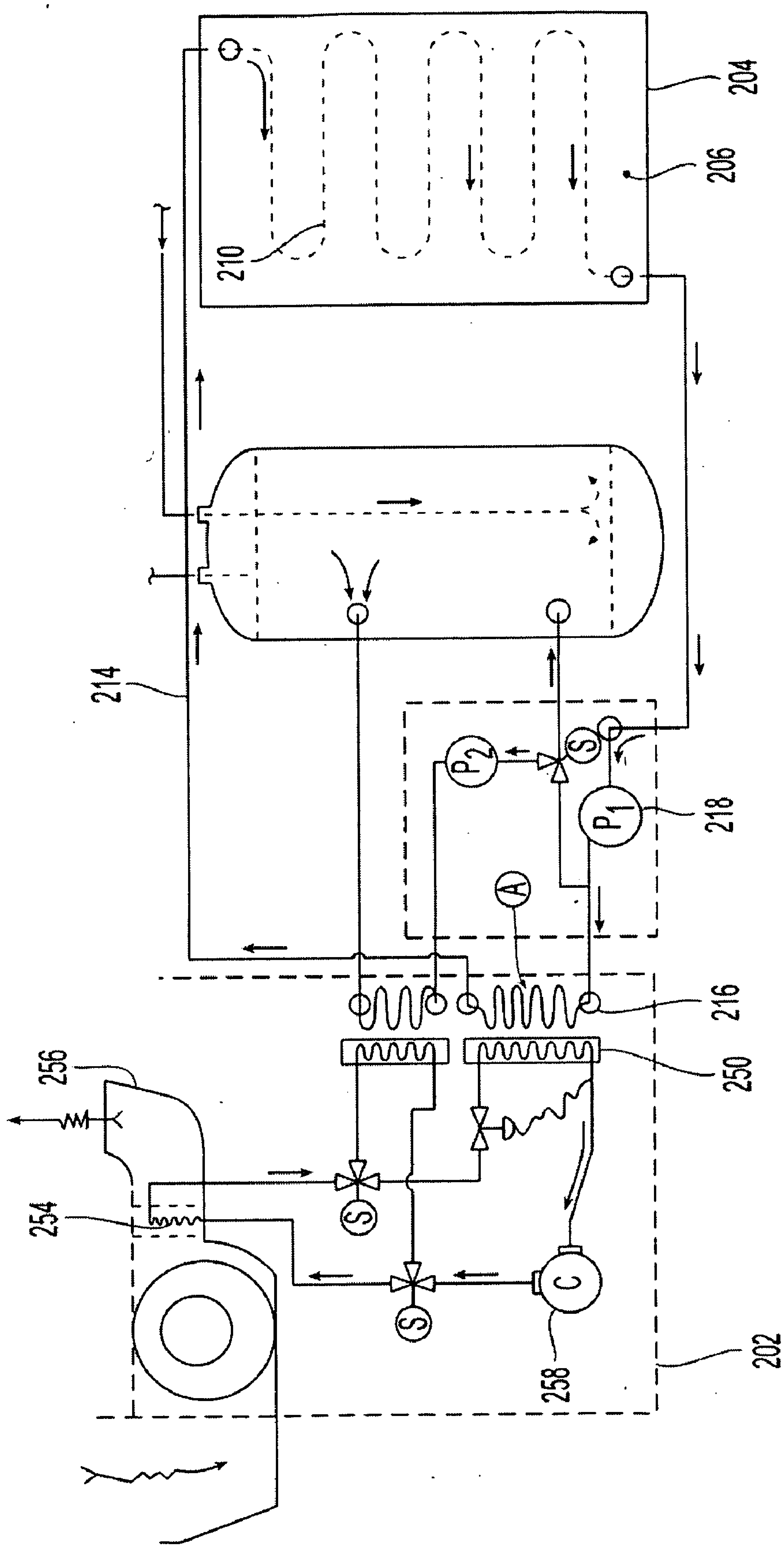
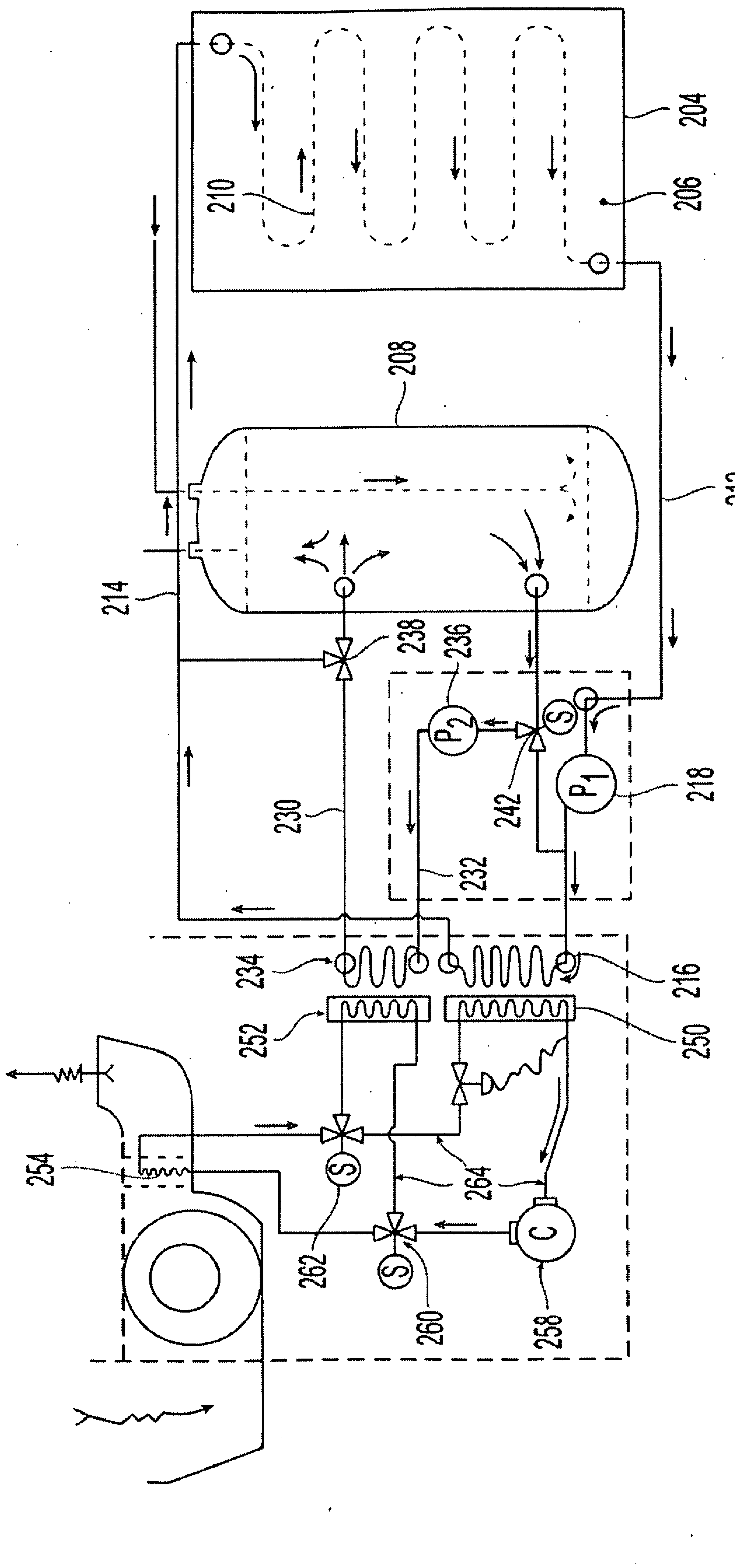


Fig. 13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S
260
S
C
258

Fig. 14

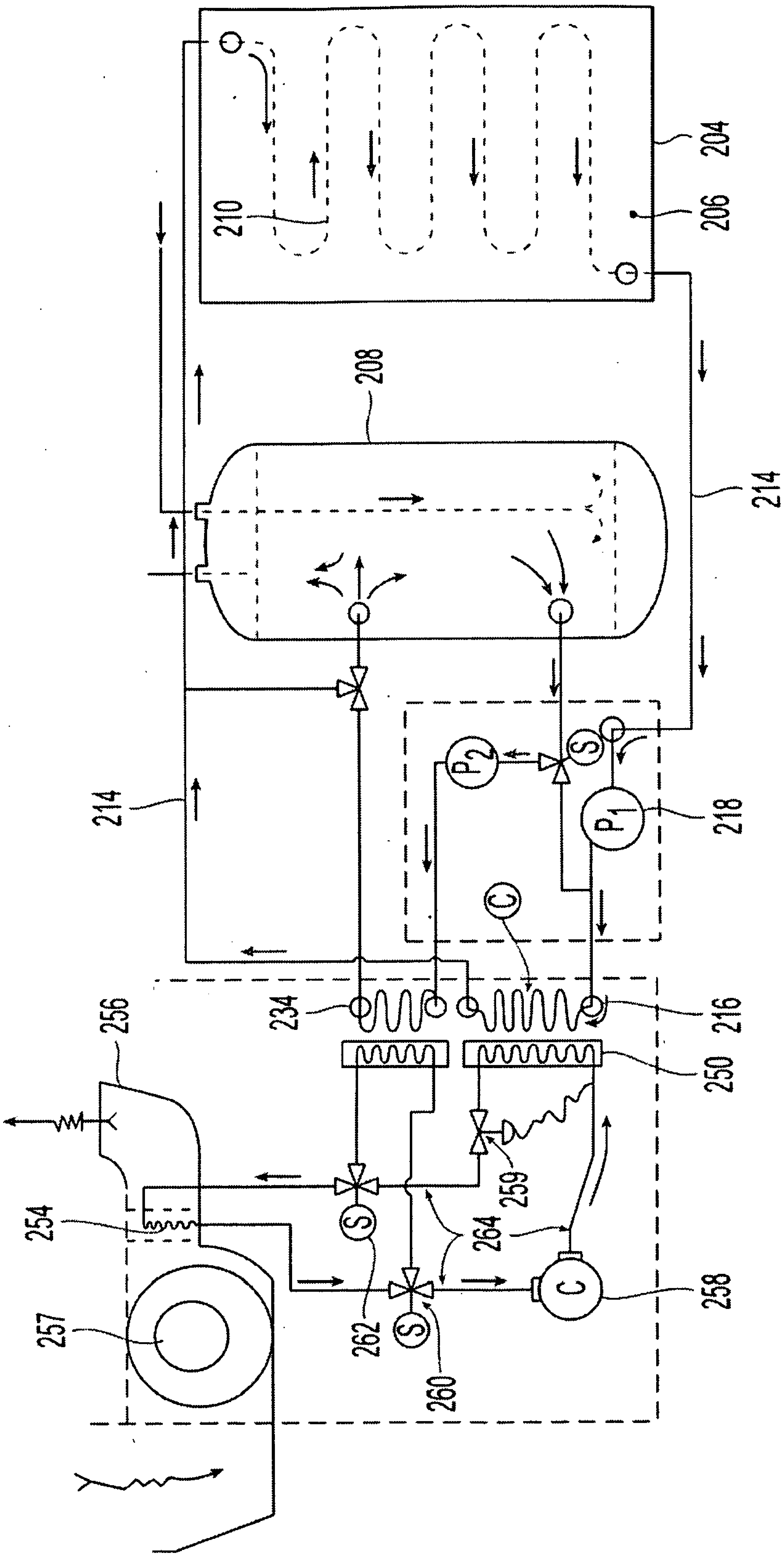
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Fig. 15

ACTIVE THERMAL ENERGY STORAGE SYSTEM AND TANK FOR USE THEREIN

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation-in-part of co-pending U.S. non-provisional patent application Ser. No. 12/212,822, filed Sep. 18, 2008, which is a continuation of U.S. non-provisional patent application Ser. No. 11/818,401, filed Jun. 13, 2007, now U.S. Pat. No. 7,441,558, which is a non-provisional of U.S. provisional patent application Ser. No. 60/852,844, filed Oct. 19, 2006, the entirety of which applications are incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The invention relates to a system for heating and cooling of residential and commercial building spaces and hot water systems, and more particularly to an active heat transfer system used for use in efficiently controlling air and water temperature in commercial buildings and residences.

BACKGROUND OF THE INVENTION

[0003] The electrical energy generation and distribution networks in the United States are currently stressed to the limit by peak demands during daytime hours. Quite expectedly, the demands of the industrial sector, commercial and residential air conditioning and water heating are highest during the daytime hours. During the off peak, late evening and night time hours, the opposite is true, and there normally is excess electrical power available which is not needed in the local power grid.

[0004] Using nationwide transmission power lines, the power generation and distribution grid is used to transfer excess power to other grids that require it. This is a form of load leveling that is aimed at maintaining the coal, oil or nuclear power generation plants at a level, constant, load. The problem with such a load leveling scheme is that costs are high, due to the costs of transmission and line losses inherent in cross-country transmission to other power grids.

[0005] Further, large coal, oil and nuclear power generation plants operate most efficiently when running at full capacity. Due to the short time of peak demand large generation facilities are not scaled to peak demand. Smaller generation units are started up to meet the extra needs of peak demand. This allows the large generation units to run at full capacity for most of the day. These smaller generation units are significantly more costly and polluting than their larger counterparts.

[0006] It would be advantageous to provide a system that enables local off-peak utilization of the excess power from the local grid, thus reducing costs associated with peak production, pollution associated with that peak production, and also reducing costs associated with transmission of excess power over long distances.

SUMMARY OF THE INVENTION

[0007] A system is disclosed for storing excess local grid power produced during off peak hours (e.g., night, holidays, etc.), for use in heating/cooling systems in residential and commercial buildings during peak (e.g., daytime) periods. An active thermal energy storage system (hereinafter referred to as "ATESS") is disclosed for storing this excess local grid off peak power in a thermal energy storage material, such as that described in U.S. Pat. No. 3,976,584 to Leifer, and for using the stored energy to control air and water temperatures in residential dwelling and/or commercial buildings during peak energy periods. It will be appreciated, however, that the ATESS may be used to provide energy for heating/cooling at any time during a 24 hour day, and not just during the peak energy periods.

[0008] The ATESS facilitates the use of off peak excess electrical energy, thus reducing the need for oil and natural gas systems that are typically used for air and hot water heating in residential dwellings or commercial buildings. Thus, the invention relates to the active transfer of thermal heat energy obtained from any of a variety of natural energy sources (e.g., solar, electrical, wind, gas, oil, etc.) to a thermal energy storage material, such as one of the materials described in U.S. Pat. No. 3,976,584 to Leifer, the entire contents of which patent is incorporated herein. The thermal energy storage material may be contained in an appropriate tank or storage vessel (which will be described in greater detail below). The energy stored in the thermal energy storage material may be transferred by an active heat transfer system (e.g., a heat pump) to any of a variety of locations within a residential home or commercial building as needed for air and/or water heating at any time during a 24 hour day.

[0009] The ATESS operates on the principal of collecting limited available input energy from any and all sources (e.g., solar, electricity, wind, oil, gas) and storing that energy in a thermal energy storage material until needed later. The energy stored in the thermal energy storage material may be removed by a heat transfer system (e.g., heat pump) to control the temperature of residential homes or commercial buildings, thus providing the heat energy requirements at any time during a 24 hour day. Hot water or other liquid heating needs can be met by use of a dual integrated or separate heat transfer (e.g., heat pump) system which can transfer the stored energy from the energy storage material as needed for such purpose.

[0010] In one example, systems exist for collecting solar energy from the sun's radiation only during the limited day time hours for use in home air or water heating needs. However, such systems can only provide this energy when the sun is available. During the evening hours or on cloudy days the residential dwelling and/or commercial building air and/or water heating energy needs must be obtained from or supplemented by other available sources of energy, such as oil, natural gas, wind or electrical energy. Thus, alternative sources of energy are required in order to satisfy the full 24 hours of energy needs. The ATESS functions to receive solar energy during daylight hours, and to store that energy in a thermal energy storage material for use at any time during a 24 hour period. Stored energy is then transferred to the area of need by an active heat transfer (e.g., heat pump) system. In this way, the ATESS can make solar energy available 24 hours a day, thus reducing the need for oil or natural gas for residential dwelling and/or commercial building heating and/or water heating energy needs.

[0011] Currently residential dwellings and/or commercial buildings use air-conditioning powered by electricity to remove heat from the air inside the dwellings and\or buildings. Electrical energy is required to remove the heat energy from the inside air to make it comfortable for human occupancy during hot humid days and nights. The ATESS can be configured so that the active heat transfer system (e.g., heat pump) removes heat from the air inside a building, and stores it in the thermal energy storage material. This stored waste heat, which is normally rejected to the outside atmosphere by typical air conditioning units, can then be used to heat the water used in the residential dwellings and/or commercial buildings. It can also be used to provide night time heating needs, as appropriate.

[0012] The ATESS will reduce markedly the daytime peak power electric demands on the electrical power grid and the electric generating equipment of the local power companies. The ATESS enables more efficient local use of energy from the local power grid, thus reducing or eliminating the need for oil and natural gas. Concurrent reductions in the emission of carbon dioxide and other pollutants, normally associated with energy production from oil or natural gas, would also be achieved from residences.

[0013] A thermal energy storage system is disclosed, comprising a first tank for holding a quantity of water, a second tank having a quantity of thermal energy storage material disposed therein, the thermal energy storage material comprising a substantially solid clathrate having a melting point above 32 degrees Fahrenheit (F), and a latent heat of fusion approaching that of water, and recirculation piping connecting the first and second tanks. The recirculation piping may be in fluid communication with an inner volume of said first tank, the recirculation piping further comprising a heating coil disposed within the second tank. Thusly arranged, heated water disposed in said first tank at a first time may be movable within said recirculation piping, and through said heating coil, to transfer heat from the heated water to the thermal energy storage material disposed within the second tank. Furthermore, cool water disposed in said first tank at a second time is movable within said recirculation piping, and through said heating coil, to transfer heat from said thermal energy storage material disposed within the second tank to the cool water.

[0014] A thermal energy storage system is disclosed, comprising a hot water tank for holding a quantity of water, a storage tank having a quantity of thermal energy storage material disposed therein, the thermal energy storage material comprising a substantially solid clathrate having a melting point above 32 degrees Fahrenheit (F), and a piping loop connecting the hot water tank and the storage tank. The piping loop may be in fluid communication with an inner volume of said hot water tank, the piping loop further comprising a heating coil disposed within the storage tank. When a quantity of water in said hot water tank has a temperature greater than a temperature of said thermal energy storage material, said water is movable within said piping loop and heating coil to transfer heat from the water to the thermal energy storage material. When said quantity of water in said hot water tank has a temperature less than a temperature of said thermal energy storage material, said water is movable within said piping loop and heating coil to transfer heat from the thermal energy storage material to the water.

[0015] A thermal energy storage system, comprising a first tank, a second tank, and an air distribution system. The first tank may have a quantity of water disposed therein. The second tank may have a quantity of thermal energy storage material disposed therein. The thermal energy storage material may comprise a phase change material having a melting point above 32 degrees Fahrenheit (F), and a latent heat of fusion approaching that of water. The first and second tanks may be connected by a recirculation loop for moving said water from said first tank through a first coil disposed within said second tank to transfer energy between said water and said thermal energy storage material. Said second tank and said air distribution system may be connected by an air conditioning loop for moving a first heat transfer fluid from a second coil disposed in said second tank to a third coil disposed in said air conditioning system to transfer energy between said thermal energy storage material and air passed over said third coil.

[0016] A thermal energy storage system is disclosed, comprising a first tank, a second tank, and a hot water radiator circulation system. The first tank may have a quantity of water disposed therein. The second tank may have a quantity of thermal energy storage material disposed therein, the thermal energy storage material comprising a phase change material having a melting point above 32 degrees Fahrenheit (F), and a latent heat of fusion approaching that of water. The first and second tanks may be connected by a recirculation loop for moving said water from said first tank through a first coil disposed within said second tank to transfer energy between said water and said thermal energy storage material. The second tank and the hot water radiator circulation system may be connected by loop for moving a first heat transfer fluid from a second coil disposed in said second tank to a water coil disposed in said hot water radiator circulation system to transfer energy between said thermal energy storage material and water passed over said water coil.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] FIG. **1** shows the ATESS installed in a dwelling that has an oil or natural gas hot air furnace system;

[0018] FIG. **2** shows the ATESS installed in a dwelling having an oil or natural gas hot air furnace system supplemented with solar water heating collector panels;

[0019] FIG. **3** shows the ATESS installed in a dwelling having an oil or natural gas hot air furnace system and has a separate water heating system (heat pump);

[0020] FIG. **4** shows the ATESS installed in a dwelling having an oil or natural gas hot air furnace system and has a separate water heating system (heat pump), and which further comprises a dual control system for use as an air conditioner;

[0021] FIG. **5** shows the ATESS described in FIG. **3** with photovoltaic solar collection panels for cold winter weather operation; and

[0022] FIG. **6** shows the ATESS described in FIG. **4** with photovoltaic solar collection panels for hot summer weather operation;

[0023] FIG. **7** is a schematic an arrangement of an ATESS test facility used to test system and thermal energy storage material efficacy;

[0024] FIG. **8** is a tabular representation of the results of a 14 day test of the ATESS;

[0025] FIG. **9** is a tabular representation of the performance of the ATESS on an hourly basis throughout a 24-hour day;

[0026] FIGS. **10**A-C are tabular representations of daily fuel oil and LPG (liquid propane gas) consumption for a residential home, including a comparison of the annual winter heating costs for fuel oil, LPG, and the ATESS heating system using off peak electric and daytime solar, all off peak electricity, and all daytime solar;

[0027] FIG. **11** shows an alternative arrangement of the ATESS installed in a dwelling having an oil or natural gas hot air furnace system; and

[0028] FIGS. **12-15** illustrate four exemplary modes of operation of the ATESS of FIG. **11**.

DETAILED DESCRIPTION

[0029] As previously noted, there are many sources of energy (e.g., solar, electrical, oil, gas, wind, etc.) which may be available for collection only during limited time periods during a 24 hour day. This is in contrast to the electrical, heating or cooling power needs associated with a residential or commercial building, which may vary during any given 24 hour period. The disclosed ATESS accommodates such limited availability of these energy sources and provides a steady source of energy, as needed, throughout a 24 hour period.

[0030] Referring to FIG. **1**, the ATESS **1** is shown installed in the basement area **2** of a dwelling having an oil or natural gas hot air furnace system **4**. The ATESS **1** may comprise a storage tank **6** containing a quantity of thermal energy storage material **8**, a hot water storage tank **10** for heating and distribution of hot water through the residence, and a connection **12** between the storage tank **6** and the furnace system **4** to allow the transfer of heat between the thermal energy storage material **8** and the furnace system **4**. A connection **14** will also be provided between the hot water tank **10** and the storage tank **6** to allow the transfer of heat between the thermal energy storage material **8** contained in the storage tank **6** and the hot water from the hot water tank **10**.

[0031] The connection **12** between the storage tank **6** and the furnace system **4** may comprise fluid supply and return piping **16**, **18** which connect to opposite ends of a condenser coil **20** located within the furnace system **4**. Likewise, the supply and return piping **16**, **18** connect to opposite ends of an evaporator coil **22** located within the storage tank **6**. The supply and return piping **16**, **18** and condenser and evaporator coils **20**, **22** thus form a closed loop for the movement of a heat transfer fluid between the furnace system **4** and the thermal energy storage material tank **6**. The flow rate of the heat transfer fluid may be controlled by operation of a compressor **24** located in the return piping **18**, and a control valve **26** located in the supply piping **16**.

[0032] Likewise, the connection **14** between the thermal energy storage material tank **6** and the hot water tank **10** may comprise supply **28** and return **30** piping connected to a heating coil **32** disposed within the storage tank **6**. Water is pumped through the supply and return piping **28**, **30** by a circulation pump **34** located in the supply piping line. A check valve **36** disposed within the discharge piping protects against backflow of water through the return piping when the pump **34** is turned off. The hot water tank **10** may further have a cold water supply line **38** for providing a constant source of water to the tank **10** for heating, and a hot water discharge line **40** for distributing the heated water throughout the residence.

[0033] The hot water tank **10** may further have one or more electrical resistance heaters **52**, **54** to heat the water in the tank to a desired temperature using building electricity.

[0034] In operation, the water in the hot water tank **10** is heated to a desired temperature using one or more of the resistance heaters **52**, **54**. The heated water may then be pumped through the supply and return piping **28**, **30** to heat the thermal energy storage material **8** contained in the thermal energy storage material tank **6**. This heat transfer can occur until a desired amount of energy is contained in the thermal energy storage material **8**.

[0035] Thereafter, the energy contained in the thermal energy storage material **8** can be transferred to the air **46** of the furnace system **4** via the fluid supply and return lines **16**, **18**. The heat transfer fluid contained in these lines may be warmed as it passes through the evaporator coil **22** and compressor **24**. Energy contained in the heat transfer fluid is then transferred to the recirculating air **46** via the condenser coil **20**, providing warm air **50** to be returned to the living space.

[0036] The energy in the thermal energy storage material **8** can also be used to transfer energy back to the water in the hot water tank **10**, via the supply and return piping **28**, **30** and recirculation pump **24**. Thus, during off-peak periods (e.g., night time) the hot water system is used to transfer heat to the thermal energy storage material **8**, allowing the storage of large quantities of heat during an otherwise light energy loading period. Thereafter, during peak loading periods (e.g., daytime), the heat can be transferred back to the hot water tank or to the furnace, as needed to heat the building air and/or water.

[0037] In addition to the condenser coil **20** arrangement, the furnace system **4** may comprises a traditional fuel supply **42**, and a furnace air circulation fan **44** for drawing cold air **46** from the living space **48**. The fan **44** causes the cold air **46** to flow over the condensing coil **20**, and then circulates the heated air **50** throughout the living space **48**. In one embodiment, where the living space thermostat is set to about 70 degrees F., the cold air **46** is at a temperature of about 65 degrees F., and the hot air **50** is at a temperature of about 75 degrees F.

[0038] One appropriate thermal energy storage material is that described in U.S. Pat. No. 3,976,584 to Leifer, the entire contents of which is incorporated by reference herein. The Leifer patent describes a clathrate material that is stable at atmospheric temperature and pressure, has a melting point higher than 32 degrees F., and has a relatively high specific heat and heat of fusion. Such a material absorbs heat until its temperature rises to its melting point. Because of its high heat of fusion, the thermal storage material can absorb a large quantity of heat per unit mass, making it a highly efficient means of energy storage. This is but one possible material that may be used as the thermal energy storage material **8**, and other materials have properties that are expected to make them desirable for use as the thermal energy storage material **8**. For example, materials such as imidazole, imidazolium chloride, derivatives of pyrrole, such as 2-acetyl pyrrole or tetra methylpyrrole, or other like compounds may be suitable for use as thermal energy storage material **8**. The results of testing of certain of these thermal energy storage materials are discussed in relation to FIGS. **8-10**C. Materials other than those specifically tested and/or identified may be suitable as well, as will be appreciated by one of ordinary skill in the art.

[0039] The tank **6** employed to hold the thermal energy storage material will preferably be made of a material that is non-reacting when exposed to the particular thermal energy storage material **8** used in the ATESS. Thus, in one embodiment the tank **6** may be made from polyethylene material. Alternatively, the tank **6** may be made from glass or non-reacting material or may be provided with a glass or other non-reacting material lining such as polypropylene, fiberglass or Teflon.

[0040] Like the tank interior, the external surfaces of lines **22**, **32** that run within the tank should also be non-reactive when exposed to the particular thermal energy storage material **8** contained in the tank **6**. For embodiments in which lines **22**, **32** comprise copper piping or tubing, the external surfaces may be coated with an acrylic paint and wrapped with a polymer wrap to prevent reaction between the thermal energy storage material **8** and the copper material. As an alternative to the polymer wrap, a paraffin material may be used as a coating over the acrylic coat. Paraffin is expected to work well where the operating temperature of the thermal energy storage material **8** is less than about 140 degrees F., since the melting point of paraffin is about 162-177 degrees F. As a further alternative, lines **22**, **32** could be made from a polymer material, such as polyethylene (e.g., PEX tubing), polypropylene, fiberglass or Teflon. Additionally, polymer coated metal tubing may be used.

[0041] The tank **6** and its connections should be sealed from the atmosphere to prevent the evaporation of water from the thermal energy storage material **8** during operation. Large-scale evaporation may cause undesirable changes in the thermal properties. Alternatively, evaporation may be compensated for by providing a level measurement scheme for the tank **6** so that additional water can be added to the thermal energy storage material **8** when a minimum acceptable tank level is detected. Examples of suitable level measurement schemes may comprise a visual line-type indicator, as well as automated level detection systems. Additionally, in response to a low-level indication, supplemental water may be added manually by the user, or via an automated load leveling system.

[0042] Lines **22**, **32** should be arranged within the tank **6** to serve the entire height of the tank (i.e., they should run almost to the bottom of the tank **6**) to avoid solid spots within the material during operation. The lines **22**, **32** can have a U-shaped configuration, or they may be coiled. It will be appreciated that the tubing configuration within the tank is not limited to U-shapes and coils, and that other appropriate shapes for lines **23**, **32** may also be used.

[0043] In one embodiment, the surplus 220 Volt [V] off-peak electrical energy, which is only available for about eleven hours in the evening, provides the thermal energy for heating the home and hot water needs over a 24 hour day by maintaining all of the water in the hot water tank **10** at about 120 degrees F. The 120 F hot water is circulated into a tube heating coil **32** installed in the tank **6** used for storing the thermal energy storage material **8**, thus transferring heat energy to the material **8** (solid to liquid) at a constant 77 degrees F. melting point for storage. When the dwelling thermostat demands more heat, the ATESS compressor **24** and the furnace air circulation fan **44** starts. The refrigerant control valve **26** provides a 40 degrees F. vaporized refrigerant to the evaporator coil **22** which absorbs heat from the 77 degrees F. thermal energy storage material. The compressor **24** elevates the refrigerant temperature to 120 degrees F. to the condensing coil **20**, which transfers the heat required at all times during a 24 hour day to the circulating furnace air **46** for home heating. It is noted that this temperature scenario applies where the living space temperature (i.e., the thermostat set temperature) is 70 degrees F. Thus, where cooler or warmer living space temperatures are desired, the system operating temperatures will adjust accordingly.

[0044] Referring to FIG. **2**, an ATESS **55** is shown installed in a dwelling having an oil or natural gas hot air furnace system **4** similar to that described in relation to FIG. **1**. In the FIG. **2** system, the energy from the furnace system **4** is supplemented with energy provided by one or more solar water heating collector panels **56**. In the illustrated embodiment, a solar panel circulating water loop **58** is integrated into the hot water return piping **30** so that water from the hot water tank **10** can be circulated through the solar energy collector panel **56**. A solar panel supply line **60** connects to the hot water return piping **30** between the check valve **36** and the hot water tank **10** to draw water from the tank **10** and/or the output from the heating coil **32**. A solar panel circulation pump **62** is disposed in the supply line **60** to provide the motive circulation force for the water. The pumped water passes through the internal passages (not shown) within the solar panel **56**, and is heated by the direct energy of the sun. The energy produced by a photovoltaic collector portion **64** of the solar panel **56** is used to power pump **62**. The heated water then passes to a return line **66** which directs the water back to the hot water tank **10**. The heated water can then be passed through the supply and return piping **28**, **30** using recirculation pump **34** so that the heat from the water is transferred to the thermal energy storage material **8** in the tank **6**. It will be appreciated that the solar panel **56** may be used to supplement the heat provided by the electrical resistance heaters **52**, **54**, or on days of particularly direct sunlight, may be used alone to heat the water in the hot water tank.

[0045] The energy provided to the thermal energy storage material **8** is thereafter available for use to heat the recirculated air **46** of the furnace, or to heat the hot water contained in the hot water tank **10**.

[0046] The remainder of the system **55**, including the storage tank **6**, thermal energy storage material **8**, and the connections between the storage tank **6**, the hot water tank **10** and the furnace system **4** may all be the same as described in relation to the system **1** of FIG. **1**.

[0047] In one embodiment, solar energy collected during sunny days as well as surplus off-peak electrical energy provided to the electrical resistance heaters **52**, **54** (which, again, may only be available for about eleven hours in the evenings,) provides the thermal energy to heat the home and hot water needs throughout a 24 hour day by maintaining all the water in the hot water tank **10** at about 120 degrees F. The 120 degree F. hot water is circulated into the tube heating coil **32** installed in the thermal energy storage material tank **6**, transferring heat energy to the thermal energy storage material **8** (solid to liquid) at a constant 77 degree F. melting point for storage. When the dwelling thermostat demands more heat, the ATESS compressor **24** and the furnace air circulation fan **44** start. The refrigerant control valve **26** provides a 40 degree F. vaporized refrigerant to the evaporator coil **22** which absorbs heat from the 77 degree F. thermal energy storage material **8**. The compressor **24** elevates the refrigerant temperature to 120 degrees F. to the condensing coil **20**, which transfers the heat required at any time during a 24 hour day, to the circulating furnace air **46** for home heating.

[0048] Referring to FIG. **3**, an ATESS **68** is installed in a dwelling having an oil or natural gas hot air furnace system **4** as well as a separate water heating system (i.e., a heat pump), **72**. The system of FIG. **3** has substantially the same piping, components, and interconnections as described in relation to the system of FIG. **1**, but also includes a heat pump system **72** that enables supplemental heating of the water in the hot water tank **10** to accommodate high volume hot water needs during the day and/or night.

[0049] Thus, the ATESS **68** of FIG. **3** comprises a furnace system **4**, thermal energy storage material tank **6**, hot water tank **10**, and all related piping and fluid management components described in relation to FIG. **1**. As with the systems described in relation to FIGS. **1** and **2**, the ATESS **68** heats the thermal energy storage material **8** during off-peak hours by circulating hot water from the hot water tank **10** through the heating coil **32** in the storage tank **6**.

[0050] The ATESS **68** further comprises an additional closed heating loop **72** having fluid supply **74** and return **76** piping in communication with respective evaporator and condenser coils **78**, **80** located within the thermal energy storage material tank **6** and the hot water tank **10**. A compressor **82** is located in the supply line **74** and provides the motive force for moving the heat transfer fluid (contained within the piping **74**, **76**) between the heat transfer coils **78**, **80** in the respective tanks **6**, **10**, thereby transferring heat from the thermal energy storage material **8** to the hot water located in the hot water tank **10**. A control valve **84** is located within the return piping **76** to control the flow rate of the heat transfer fluid, thus controlling the amount of heat transferred between the thermal energy storage material **8** and the water in the hot water tank **10**.

[0051] As with the previously described embodiments, the surplus 220 V off-peak electrical energy, which is only available for about eleven hours during the evening, provides the thermal energy to heat the home and hot water over a 24 hour day by maintaining all the water in the hot water tank **10** at about 120 degrees F. The 120 degree F. hot water (heated by the resistance heaters **52**, **54**) is circulated into a heating coil **32** installed in the thermal energy storage material tank **6**, thus transferring heat energy to the thermal energy storage material (changing it from solid to liquid) at a constant 77 degrees F. melting point for storage. When the dwelling thermostat demands more heat, the ATESS compressor **24** and the furnace air circulation fan **44** starts. The refrigerant control valve **26** provides a 40 degrees F. vaporized refrigerant to the evaporator coil **22** which absorbs heat from the 77 degree F. thermal energy storage material **8**. The compressor **24** elevates the refrigerant temperature to 120 degrees F. to the condensing coil **20**, which transfers the heat required at all times of a 24 hour day, to the circulating furnace air for home heating. The heat pump system **72** is operable to heat water in the hot water tank **10** at any time of the day, using the stored heat in the thermal energy storage material **8**.

[0052] Referring to FIG. **4**, ATESS system **86** is installed in a dwelling having an oil or natural gas hot air furnace system **4**, and which has a separate water heating system (i.e., a heat pump) **78** similar to that described in relation to the ATESS of FIG. **3**. In the embodiment of FIG. **4**, however, the ATESS **86** is configured with a control system **87** that may reverse the functions of the components to enable the ATESS **86** to heat or cool the house as desired. Thus, on hot, humid summer days, the ATESS **86** removes heat from the house circulating air **88**, and stores that heat in the thermal energy storage material **8** for heating water for home use or home heating. The cooled air **90** is then recirculated through the dwelling.

[0053] The ATESS **86** of FIG. **4** comprises a furnace system **4**, thermal energy storage material tank **6**, hot water tank **10**, as well as all related piping and fluid management components described in relation to FIG. **3**. As noted, the ATESS **86** further comprises a control system **87** operable to reverse the flow of heat transfer fluid between the storage tank **6** and the coil **20** of the furnace system **4**. This flow reversal may be implemented by providing an appropriate piping arrangement for redirecting the flow of the heat transfer fluid according to a desired series of valve settings. Thus, in a "heating" setting, the flow of heat transfer fluid would be through lines **16** and **18** in the direction of arrows "A," and would be functional for heating the dwelling air **88**. In the "cooling" setting, the flow of heat transfer fluid would be through lines **16** and **18** in the direction of arrows "B," and would be functional for cooling the dwelling air **88**. Suitable electronics may be provided to automatically actuate and control the direction and flow rate of the heat transfer fluid through lines **16** and **18**.

[0054] Where the system **86** is used for cooling the dwelling air **88**, particularly during the hot summer months in southern portions of the northern hemisphere, an outdoor evaporator coil and fan may be provided in communication with the heat transfer storage material **8**. This arrangement may be of advantage where the thermal energy storage material **8** has met its maximum capacity for storage of rejected air conditioning heat, since it provides a path for rejecting excess heat to the outdoors.

[0055] In an alternative embodiment, in lieu of a special piping arrangement for redirecting flow, compressor **24** could be a reversible compressor, and control valve **26** could be of a design that provides a desired degree of flow control regardless of the direction of flow past the seat. Additionally, in lieu of control valve **26** a pair of control valves could be provided, one for controlling refrigerant flow rate when heat is needed in winter or on cool summer evenings, and a second to control refrigerant flow if heat needs to be removed from the dwelling in the summer. Suitable known control electronics may be provided to enable automatic selection of a flow direction.

[0056] As with the previously-described embodiments, the ATESS **86** of FIG. **4** operates to store energy in the thermal energy storage material **8** during periods in which such storage is most efficient. In one embodiment, energy removed from the hot air **88** of the living space is transferred to the storage material **8** via the compressor **24**, control valve **26** and piping **16**, **18** arrangement previously described. The stored energy may then be used to heat water (in a manner previously described) immediately or at a later time, or to heat the air circulated through the furnace system **4** at a later time, as needed.

[0057] Referring to FIG. **5**, ATESS system **92** has substantially the same piping and components as the system **68** described in relation to FIG. **3**, and further comprises one or more photovoltaic solar collection panels **94** to provide additional water and air heating for cold weather operation, such as in winter. The one or more solar collection panels **94**, employing known photovoltaic principles, may produce direct current (DC) electricity, which may then converted to alternating current (AC) electricity by a suitable AC/DC converter **96**. The resulting AC electricity may then be connected to the appropriate home or building power supply circuits. A step-up or step down converter (not shown) may also be required to match the home or building power supply circuit. The electricity from the solar panels **94** may be provided directly to the resistance heaters **52**, **54** that provide thermal energy to the water contained in the hot water tank **10**. This energy may then be transferred to the thermal energy storage material via lines **28**, **30** and heating coil **32**, in a manner previously described in relation to the systems of FIGS. **1-4**.

[0058] The system of FIG. **5** is particularly well suited to use in cold weather regions. Thus, when the cold weather season arrives, the available daytime solar power generated by the solar collection panels **94** may be used to heat water in the hot water tank for house use, and also to store the (now converted) electrical energy in the thermal energy storage material **8** using ATESS **92**. The ATESS **92**, in a manner similar or identical to that described in relation to FIG. **3**, may then be used to heat the home and to meet hot water needs during any portion of a 24 hour day. The off-peak surplus electric power would be back-up energy during cloudy or limited sunny days for the net thermal energy needed to heat the residential dwelling or commercial building and/or water.

[0059] Referring to FIG. **6**, ATESS system **98** has substantially the same piping and components as the ATESS **86** described in relation to FIG. **4**, and further comprises one or more photovoltaic solar collection panels **100** for hot summer weather operation. The one or more solar collecting panels **100** using known photovoltaic principals, may generate direct current (DC) electricity, which may then be converted to alternating current (AC) using a voltage converter **102**, thus enabling connection with the home or building electric power supply. When the hot, humid, weather season arrives, the electric power generated by the solar collection panels **100** may be used to operate the conventional air conditioning system, which operates in conjunction with the reversible ATESS **86** system described in relation to FIG. **4** to cool the air **88** in the living space.

[0060] A storage tank **6** for use in a typical dwelling may be approximately 400 gallons in volume, and may contain an energy storage material such as that described in U.S. Pat. No. 3,976,584 to Leifer. Other appropriate thermal energy storage materials may be tetra iso-amyl ammonium fluoride. $38H_20$, tetra n-butyl ammonium fluoride. $18H_20$ (Clathrate Materials). Additionally, the following Non-Clathrate Materials may also be used: imidazole, imidazolium chloride, derivatives of pyrrole, such as 2-acetyl pyrrole or tetra methylpyrrole, or other like compounds. The heating coils **22**, **32**, **78** may be made of corrosion resistant materials suitable for carrying approximately 120 degree F. water in operation. The total heat stored in the approximate 400 gallons of thermal heat storage material would heat a home of approximately 1600 square feet of living space maintaining a temperature of approximately 70 degrees F. in the most northern latitudes of the United States daily throughout the year. The heat stored in the approximate 400 gallon tank **6** of thermal energy storage material **8** for heating the home would also heat water in an approximate 60 gallon insulated hot water tank **10** to a desired 115 degrees F. to 120 degrees P temperature for normal family hot water usage.

[0061] The ATESS may be provided with an appropriate computer control system for controlling the heat pump system **72**, furnace system **4**, recirculation pumps **34**, **62** compressor **24**, control valve **26**, and resistance beaters **52**, **54** to enable the ATESS to perform as desired to compliment the oil or natural gas heating system and/or water heating system needs of a commercial or residential building. The control system would also control the dwelling heat transfer (i.e., heat pump) system as a dual system to remove heat from the air circulating in the furnace duct system during the hot and humid summer days, and to that heat in the thermal energy storage material stored in the storage tank **6**. The system may be used in conjunction with a conventional electric powered air conditioning system during the hot-humid summer months.

[0062] It will also be appreciated that the ATESS may be integrated into a mobile platform to aid in the transport of perishable commodities such as orange juice and the like. Thus, the ATESS may be sized and configured for installation in railroad cars, trucks, planes, container/cargo ships or other transportation platforms. In one example, the ATESS may be combined with solar panels or fuel oil to reduce oil consumption in ocean going passenger ships.

[0063] Further, the ATESS may be used as part of a system for reducing the energy consumption required for any of a variety of industrial processes that require substantial energy, such as soup making, and the like.

[0064] In yet another embodiment, the ATESS may be used to advantage in applications such as commercial/personal ice skating or hockey rinks.

[0065] Advantages

[0066] The Northeast area of the United States has the larger number of homes and commercial buildings heated by oil and liquefied natural gas (LPG). Due to the lack of major natural gas pipelines serving the area, liquefied natural gas is imported through major seaports in the Northeast by huge tankers from foreign countries, which could be a terrorist threat to the security of our seaports. The conversion to ATESS of homes and commercial buildings to electric off peak power or solar energy would eliminate these shipments and the associated threats to our seaports.

[0067] The United States currently imports approximately 40% of its domestic oil needs from foreign countries. The ATESS system can substantially reduce or eliminate the need for foreign oil.

[0068] ATESS can also reduce the need to heat residential dwellings or commercial buildings with oil and natural gas. ATESS can reduce daytime peak electric power demands during hot and humid weather.

[0069] ATESS can store solar thermal energy available during the daytime for use during day or night for energy needs of residential dwellings or commercial buildings.

[0070] ATESS, if widely used in residential dwellings and commercial buildings, will allow electric power generation networks to practice load leveling between peak daytime and surplus off-peak night time electric power demands.

[0071] Laboratory Test Results for Various Thermal Energy Storage Materials

[0072] The inventors have conducted laboratory tests to determine the melting point, heat of fusion and safe operating temperature range of several materials considered suitable for use as thermal energy storage material **8**. The results of the inventors' tests are shown in Table 1 below. In addition to the specific clathrate material the inventors used in their tests, other potentially useful clathrate materials exist and are noted herein. These materials include: tetra iso-amyl ammonium fluoride $38H_2O$, which has a melting point of 88 degrees F., and tetra n-butyl ammonium fluoride $18H_2O$, which has a melting point of 98.6 degrees F. It should be noted that some of the other thermal energy storage materials identified in Table 1 below have melting points much greater than 77 degrees F. The use of these higher melting point materials in any one of the previously described ATMSS systems may preclude the need for a heat pump system **72**.

TABLE 1

Physico-Chemical Results of Potential Tested Thermal Energy Storage Materials

Materials	Melting Point (degrees F.)	Heat of Fusion (BTU/lbs)	% Heat of Fusion of Water (%)	Safe Operating Range (degrees F.)
TESM 1[1]	77	108	75%	77-140
Imidazole	194	75	52%	194-320

TABLE 1-continued

Physico-Chemical Results of Potential Tested Thermal Energy Storage Materials				
Materials	Melting Point (degrees F.)	Heat of Fusion (BTU/lbs)	% Heat of Fusion of Water (%)	Safe Operating Range (degrees F.)
Imidazolium Chloride	320	60	42%	320-375
2-Acetylpyrrole	195	77	54%	195-260

Note that the "Safe Operating Range" indicated in Table 1 represents, for each TESM, a temperature range between the melting point of the TESM and a point approximately 5-20 degrees F. below the decomposition temperature of the particular TESM.
[1]"TESM 1" was $(n\text{-}C_4H_9)4NF32.8H_2O$

[0073] Test Site Results

[0074] Referring to FIG. **7**, a test site building was constructed as a horizontal duplex, with each room (Rooms #1 and #2) being approximately 32 square feet. Room #1 was heated conventionally, while Room #2 was heated using the ATESS. The inventors used 40 lbs of Thermal Energy Storage Material (TESM) 8, which in this case was $(n\text{-}C_4H_9)$ 4NF $32.8H_2O$, and which will be referred to hereinafter as "TESM **1**." The TESM **1** was contained in TESM **1** tank **6**. For the purposes of the test, the tank **6** was a 5 gallon polyethylene tank. Internal piping was copper, coated with acrylic coating and wrapped with a polymer film. The tank **6** connections were sealed from the atmosphere using tape to prevent evaporation. The 40 lbs. of TESM **1** stored heat energy from two (2) limited sources in these tests. Source 1 was evening off peak electricity and Source 2 was daytime solar energy. The solar heat collection system worked well, but due to the lack of sunny days during, the test, the inventors simulated the daytime solar heat by using metered daytime electric power. Both sources were limited to four (4) hours per cycle for the tests. The ATESS in Room #2 was a scaled down version of the ATESS previously described in relation to FIG. **2**.

[0075] FIG. **8** shows the results of 14 days of testing. Days 1, 2, and 3 were conducted to determine the heat required to maintain a consistent temperature in Rooms #1 and #2. The results of these tests show the heat required to maintain the same temperature in Rooms #1 and #2 are essentially the same.

[0076] FIG. **8** also shows test days #4 through #14 which were conducted using only the ATESS heating system as a primary heat source for Room #2. Test days #4 and #5 were not considered in the results because those days used 3.0 and 3.5 hour heating cycles to transfer heat to the TESM, and these shorter cycle times were deemed not to be long enough for transfer of an adequate amount of heat to TESM **1** for storage during the tests. The remaining test days (#6 to #14) used four (4) hour TESM heating cycles. The results show that ATESS heating system works very well to maintain the temperature in Room #2 at a nominal 70 degrees F. (temperature actually ranged from about 68-71 degrees F.) without the use of any conventional additional heat from fuel oil or gas. During the December and January tests, the outside air temperature fluctuated from a low of 12 degrees F. to a high of 47 degrees F.

[0077] FIG. **9** shows the performance of the ATESS heating system hour by hour during a 24-hour day. The results in FIG. **9** were compiled for an optimum day (i.e., one close to the mean of test days 6-14) using the ATESS. The results show energy from two (2), limited sources (i.e., evening off peak electricity and daytime solar) being distributed as needed to test Room #2 in order to maintain a desired temperature. Some heat from the ATESS control system, compressor motor losses, and heat of compression from the compressor were also added to Room #2. The limited source energy from non-peak electric and solar was stored in the TESM **1** during the limited 4 hour cycles and then distributed to Room 2 by the ATESS heat pump system. The heat needed to maintain 70 degrees F. in Room 2 was controlled by the thermostat of the ATESS system.

[0078] The results tabulated in FIGS. **8** and **9** show heat pump inefficiencies of our system design which can be substantially improved by an experienced heating and ventilation equipment manufacturer. For example, the ATESS system prototype heat pump evaporator coil comprised single diameter copper tubing. An experienced HVAC engineer could design an evaporator coil having a varied diameter in order to maintain a constant evaporator refrigerant temperature of approximately 40 degrees F. across the entire coil. Additionally, the prototype heat pump system had less than optimal electric compressor motor efficiency, which may be improved greatly in large system designs using either AC or DC electric power. Additionally, modern control systems applied to a large-scale ATESS would use little electric power as compared to the prototype system. The ATESS heating system inefficiency is indicated in FIGS. **8** and **9** as extra heat added to room #2 ("Motor Loss and Extra Room Heat Demand") to maintain the desired temperature.

[0079] The inventors consider that to install an operational. ATESS into a full size residential home having 1600 sq ft. of living area would require a 50:1 scale up to replicate the results shown at the test site. FIGS. **10**A-C show the daily fuel oil and LPG (liquid propane gas) consumption for such a residential home. In addition, FIGS. **10**A-C shows a comparison of the annual winter heating costs for: a) fuel oil, b) LPG, and c) the ATESS heating system using: 1) off peak electric and daytime solar, 2) all off peak electricity, and 3) all daytime solar.

[0080] The results indicate a substantial cost savings can be achieved through use of the ATESS. For example, the annual cost for fuel oil using a 125 day annual winter heating cycle is estimated to be about $1,813, while the annual cost for LPG also using a 125 day annual winter heating cycle is estimated to be $1,932. (These estimated costs where calculated using estimates of $2.55/gallon of fuel oil and $1.86/gallon of LPG.) By comparison, the annual heating cost using the ATESS for the 125 day annual winter heating cycle with: 1) off peak electric and daytime solar is estimated to be about $1,048; 2) all off peak electric is estimated to be about $1,348; and 3) all daytime solar is estimated to be about $748. Thus, it can be seen that there would be a considerable savings with the use of the ATESS as compared to conventional heating methods. This savings can be increased by adding accessories to heat water.

[0081] For example, during hot summer months, heat may be removed from the dwelling space (via air conditioning) and stored in the TESM. Appropriate piping and pumping equipment (e.g., items **72**, **83** in FIG. **4**) may be added to the ATESS to allow transfer of this stored heat from the TESM **8** to the hot water in the hot water tank **10** to maintain a desired temperature (e.g., 125 degrees F.). Heating the hot water in this manner may eliminate or reduce the need to use expensive daytime electric, fuel oil or LPG.

[0082] FIGS. **10**A-C further show the gallons per day of fuel oil and LPG as well as the total annual costs for a 125 day winter heating season.

[0083] In addition to the aforementioned cost savings, the use of the ATESS may also result in substantial reductions in pollutants emitted to the atmosphere as compared to conventional heating systems. For example, the burning of fuel oil (for the annual heating season) emits to the atmosphere 3,831 lbs of carbon and 14,060 lbs of CO_2 per residence (again assuming a 1600 square foot living space). The burning of LPG emits 2,927 lbs of carbon and 10,742 lbs of CO_2, for the same size living space. The ATESS, by contrast, emits no carbon or CO_2 to the atmosphere from the residences. These results are clearly shown at the bottom of FIG. **10**C.

[0084] Referring now to FIG. **11**, an alternative arrangement for the ATESS **200** is shown installed in dwelling having a heating, ventilation and cooling (HVAC) system **202**. As with the previous embodiments, the ATESS **200** may comprise a storage tank **204** containing a quantity of thermal energy storage material **206**, a hot water storage tank **208** for heating and distribution of hot water through the residence, and connections between the storage tank **204** and the HVAC system **202** to allow the transfer of heat between the thermal energy storage material **206** and the HVAC system **202**. Connections may also be provided between the hot water tank **208** and the storage tank **204** to allow the transfer of heat between the thermal energy storage material **206** contained in the storage tank **204** and the water in the hot water tank **208**.

[0085] The storage tank **204** and the thermal energy storage material **206** used with the ATESS **200** of FIG. **11** may be the same as the storage tank **6** and the thermal energy storage material **8** described in relation to the ATESS **1** of FIGS. **1-10**.

[0086] As can be seen in FIG. **11**, one difference between the ATESS **200** of FIG. **11** and the ATESS **1** of FIGS. **1-10** is that the storage tank **204** does not have an evaporator coil (i.e., coil **22** in FIG. **1**) disposed inside the tank This arrangement protects the TESM from overheating by assure that the 140 F deterioration limit of the TESM will not be reached during normal operation of the system.

[0087] The storage tank **204** does have a connection to the HVAC system **202**, comprising a fluid loop **210** located within the tank **204**, fluid supply and return piping **212**, **214** which connect to opposite ends of a first coil **216** located within the HVAC system **202**. A first pump **218** located within the supply piping **212** is controllable to circulate fluid within the loop to transfer energy between the thermal energy storage material **206** and the HVAC system **202**. The first pump **218** may be a variable speed pump that enables precise control of the flow rate of the fluid within the loop. Although the system has been described as using water as the circulated "fluid," it will be appreciated that other fluids may be used depending upon the application of the system. For example, ethylene glycol, mineral oil, Dow-Therm and the like can be used as the circulated fluid where the ATESS **200** will not be used for providing hot water service (e.g., tap, cooking, or cleaning uses) to the building in which the system is installed.

[0088] As an additional measure of protection against exceeding the deterioration limit of the thermal energy storage material **206**, the storage tank **204** may have a temperature sensor. This temperature sensor may be operable to signal the shutdown of the first pump **218**, and to signal the HVAC system **202** to remove heat from the dwelling air and to exhaust the heat to the outside of the dwelling. It will be appreciated that one or more temperature sensors may also be provided to measure the temperature of the fluid within the supply piping **212**.

[0089] The hot water tank **208** may have an inlet connection **220** for receiving fill water from a city water or other appropriate water supply connection, and an outlet connection **222** for providing heated water for home hot water uses. The inlet connection **220** may have a check valve **224** disposed therein to prevent backflow from the tank to the water supply line. The hot water tank **208** also may be connected to the HVAC system **202** to enable the transfer of energy between the tank and the HVAC system. This connection may comprise first and second tank connections **226**, **228**, and first and second fluid loop piping legs **230**, **232** which connect to opposite ends of a second coil **234** located within the HVAC system **202**. A second pump **236** located within the second fluid loop piping leg **232** is controllable to circulate water within the loop to transfer energy between the hot water tank **208** and the HVAC system **202**. The second pump **236** may be a variable speed pump that enables precise control of the flow rate of the water within the piping legs **230**, **232**.

[0090] The hot water tank **208** and the storage tank **204** may also be connected to enable the selective transfer of energy between the thermal energy storage material **206** in the storage tank **204** and the water in the hot water tank **208**. To this end, a first three-way valve **238** may be disposed within the first fluid loop piping leg **230**. The first three-way valve **238** may be operable to allow flow through the first fluid loop piping leg **230** to provide flow from the hot water tank **208** to the coil **234** located within the HVAC system **202**. The first three-way valve **238** may also be provided with a first circulation leg **240** that connects an outlet port of the valve **238** to the fluid return piping **214** of the storage tank **204** to enable circulation of water between the hot water tank **208** and the storage tank **204**. Similarly, a second three-way valve **242** may be disposed in second fluid piping leg **232**, and may be operable to allow flow through the second fluid loop piping leg **232** to provide flow between the hot water tank **208** and the coil **216** located within in the HVAC system **202**. The second three-way valve **242** may also be provided with a second circulation leg **244** that connects an outlet port of the valve **242** to fluid supply piping **212** of the storage tank **204** to enable the circulation of water between the hot water tank **208** and the storage tank **204**. In the illustrated embodiment, the first and second three-way valves are solenoid valves that may be remotely or locally operable using a manual or automated control system.

[0091] The hot water tank **208** may additionally have one or more electrical resistance heaters **246**, **248** to heat the water in the tank to a desired temperature using building electricity.

[0092] Energy may be transferred between the HVAC system, the storage tank **204**, and the hot water tank **208** via a plurality of coil sets. Specifically a first coil set **250** is positioned in thermal communication with first coil **216**, while a second coil set **252** is positioned in thermal communication with second coil **234**. A third coil set **254** is positioned within a supply duct **256** of the HVAC system **202** to heat or cool air being provided to the living spaces via fan **257**. A compressor **258** with associated piping and valves is provided for transferring energy: (1) from the first or second coil sets **250**, **252** to the third coil set **254**, or (2) from the third coil set **254** to the first or second coil set **250**, **252**. In this way, energy can be transferred between the air in the supply duct **256** and the hot water tank **208** or the storage tank **204**.

[0093] It will be appreciated that although the coil pairs **216/250**, **234/252** are shown as being separate and discrete coils, that they will often constitute opposing heat transfer paths within a single fluid-to-fluid heat exchanger. Likewise, third coil set **254** will often constitute a fluid-to-air heat exchanger.

[0094] First and second HVAC three-way valves **260**, **262** may be provided in the compressor piping **264** to facilitate selectable circulation between: (a) the first coil set **250** and the third coil set **254**, or (b) the second coil set **252** and the third coil set **254**. In one embodiment, the HVAC three-way valves **260**, **262** comprise solenoid actuated valves to enable automatic or manual remote control of the system.

[0095] In practical use, the thermal energy storage material **206** may be delivered in liquid form by an over the road tanker from a chemical plant where it is manufacture. A special self-sealing fill nozzle **266** may be provided near the top of the tank **204**. This fill nozzle **266** may allows speedy filling and sealing, thus minimizing evaporation of the thermal energy storage material. Likewise, the tank **204** may have a low level drain nozzle **268** with a drain valve installed near the bottom of the tank so that an over the road tanker can pump the thermal energy storage material **206** out of the storage tank **204** and transport it to a local distributor service center to be recrystallized and reused.

[0096] As disclosed, the ATESS **200** has a multiplicity of operating configurations that result in a highly flexible energy storage and transfer system. Referring now to FIGS. **12-15**, several exemplary modes of operation of the ATESS **200** will now be described in detail. Specifically, Mode 1, described in relation to FIG. **12**, shows an exemplary configuration of the ATESS **200** as an off-peak heating system during the Winter season. Mode 2, described in relation to FIG. **13**, shows an exemplary configuration of the ATESS **200** for use during the peak heating cycle, again during the Winter season. Mode 3, described in relation to FIG. **14**, is for use of the ATESS in a water heating cycle, for all seasons. Mode 4, described in relation to FIG. **15**, is for use of the ATESS as part of a renewable energy cycle, for warn weather seasons.

[0097] Off-Peak Heating System (Winter Season)

[0098] Referring to FIG. **12**, in this mode, the storage of "off-peak" (eleven hours) surplus electric energy is supplied first to the hot water tank **208** via the electric resistor heating elements **246**, **248** controlled by a timer. First pump **218** circulates approximately 125° F. water from the hot water tank **208** to the storage tank **204** via a loop comprising first three-way valve **238**, first circulation leg **240**, fluid return piping **214**, fluid loop **210**, fluid supply piping **212**, second circulation leg **244**, second three-way valve **242** and second fluid loop piping leg **232**. The heat from the "off peak" surplus electricity is transferred through the fluid loop **210** for storage in the thermal energy storage material **206**. The cooled water (i.e., from the outlet of fluid loop **210**) than is circulated back to the hot water tank **208** for further addition of heat to be stored in the thermal energy storage material for the remainder of the limited "off-peak" 8 hour time period. The water in the hot water tank **208** is available for use during the "off-peak" period and is ready for the early morning part of "peak" activities at 8 am.

[0099] The HVAC system **202** may not operate during the "off peak" hours for space heating or water heating. Space heating is provided by electric resistance heater element **280** in the ductwork **256** where cool return air **282** is circulated by the variable speed fan **257** in the heat pump unit housing. This electric duct resistance heating element **280** is available again by timer for automatic actuation during this "off peak" period.

[0100] The "off-peak" heat stored in the thermal energy storage material for water and space heating is then charged to the dwelling owner by the electric utility server at the base low cost rates. When the "off-peak" timer shuts off all electric power to the ATESS **200**, the system controls would automatically switch to Mode 2, to be described next.

[0101] Peak Heating Cycle—Winter Season

[0102] Referring to FIG. **13**, in the Peak Heating Cycle mode mode, the "peak" period (eleven hours) space heating is provided by the "off peak" electric heat stored in the thermal energy storage material that was stored in the storage tank during the "off peak" hours.

[0103] The first pump **218** pumps warm water heated by the 77° F.-115° F. thermal energy storage material **206** through the first coil **216**, which transfers the "off-peak" stored electric energy to the first coil set **250** in the HVAC system **202**. The compressor **258** transfers the heat as a high pressure refrigerant to the third coil set **254** in the supply air ductwork **256**, which heats the air provided to the living space. The hot air circulated to the living space will control the space heating temperature at 70 F. The cooled refrigerant from the third coil set **254** is then returned to the first coil set **250** to remove more heat from the first coil **216** in which water heated via the thermal energy storage material **206** is being circulated.

[0104] The first pump **218** circulates cooled water through return line **214** back to the storage tank **204** to remove more heat from the "off-peak" electric energy stored in the thermal energy storage material to provide space heating as previously described. It is contemplated that water heating may be needed during the active "peak" daytime hours, at which time the system operate in Mode 3, to be discussed next.

[0105] Water Heating Cycle—All Seasons

[0106] Referring to FIG. **14**, in the Water Heating Cycle mode, the peak water heating:period (9:00 a.m. to 11:00 p.m.) water heating is provided by "off peak" electric or summer "renewable energy" obtained from air conditioning heat stored in the thermal energy storage material **206** stored in the storage tank **204**.

[0107] The first pump **218** circulates warm water heated by the 77° F.-115° F. thermal energy storage material via **212** through first coil **216** and then back to the storage tank via the fluid return piping **214** and fluid loop **210**, in the process transferring heat from first coil **216** to the fluid in the first coil set **250**. This transfers the "off-peak" stored electric energy charged to the thermal energy storage material **206** to the fluid in the first coil set **250**. The compressor **258** and first and second HVAC three-way valves **260**, **262** transfer this heat received via first coil set **250** as a high pressure refrigerant to the second coil set **252**. The hot second coil set **252** then interfaces with second coil **234** associated with the first pump **218**. The second pump **236** circulates relatively cool water from the bottom of the hot water tank **208** through second coil **234** to heat the water using heat gained from the second coil set **252**, thus maintaining the hot water temperature for dwelling use of 125° F. or as desired.

[0108] The modes of operation described thus far mainly address cold weather needs. During the hot summer weather, air conditioning of living spaces often is of prime importance. The summer air cooling needs are provided by conventional air conditioning units which reject the heated air to the outdoors. During any day in which air conditioning is required, the ATESS "Renewable Energy Cycle," Mode 4, can be put into operation, as will be described next.

[0109] Renewable Energy Cycle—Warm Weather Seasons

[0110] Referring to FIG. **15**, when operating in this mode, the high peak cooling period (4:00 pm-6:00 pm) summer water heating needs will be provided using air conditioning heat normally rejected to the outdoors. This may be accomplished by operating in the "renewable energy cycle" mode using the ATESS system **200** like an air conditioner and storing this renewable energy in the thermal energy storage material **206**.

[0111] The HVAC system **202** is engaged in the cooling mode by reversal of the compressor **258**, the expansion control valve **259**, first coil set **250** and the third coil set **254** from that of the winter heating mode. The third coil set **254** disposed in the supply air duct **256** helps to maintain the cooling space temperature at 76° F. The normally rejected air conditioned heat energy is transferred from the third coil set **254** to the first coil set **250**. This heat is then transferred to the cool circulating water flowing through first coil **216**. The first pump **218** transfers the now-heated circulating water via the fluid return piping **214** and fluid loop **210** to the thermal energy storage material **206** for storage. This stored heat, which is wasted with typical systems, is then used to heat dwelling water stored in the hot water tank **208** as described in the previous mode.

SUMMARY

[0112] The inventors have shown that using the disclosed ATESS heating system as a compliment or a primary heating system:

[0113] (1) Substantially reduces the need for fuel oil and/or liquid petroleum gas (LPG) for heating homes or industrial buildings.

[0114] (2) Substantially reduces both carbon and carbon dioxide (CO_2) emissions which contributes to global warming.

[0115] (3) Substantially reduces the need to transport surplus generated off peak electrical power from local grids, because it can be stored in the TESM for use at anytime during a 24-hour day.

[0116] (4) ATESS heating systems allow for the use of solar energy obtained during daylight hours and stored in the TESM for use anytime during a 24-hour day.

[0117] (5) ATESS heating systems, would transition home heating systems to electric as their primary energy source. This would reduce the country's dependence on foreign oil and LPG, thereby improving homeland security.

[0118] Although the invention has been described in terms of exemplary embodiments it will be apparent to those skilled in the art that various changes and modifications can be made thereto without departing from the spirit and scope of the invention.

1. A tank for storing a thermal energy storage material, comprising:

an outer shell and an inner surface, the inner surface defining a volume for accepting a quantity of thermal energy storage material;

heat exchange piping disposed within the volume for transferring heat between the thermal energy storage material and a fluid disposed within the heat exchange piping;

fill and drain connections;

wherein the fill and drain connections seal the volume from the outside atmosphere to prevent evaporation of the thermal energy storage material contained therein; and

wherein the inner surface of the tank and the outer surfaces of the heat exchange piping comprise a non-reactive material.

2. The tank of claim **1**, wherein the heat exchange piping comprises a polymer material or a metal material having an outer polymer layer.

3. The tank of claim **1**, wherein the inner surface of the tank comprises a material selected from the list consisting of polyethylene, glass polypropylene, fiberglass and Teflon.

4. The tank of claim **1**, wherein the heat exchange piping comprises copper or other high heat transfer material coated with an acrylic layer or other non-reactive coating material.

5. The tank of claim **1**, further comprising a level measurement system for providing an indication of a level of the thermal energy storage material disposed within the tank.

6. The tank of claim **1**, wherein the level measurement system comprises a visual indicator or an automated level detection system.

7. The tank of claim **6**, further comprising an automatic load leveling system that automatically adds a quantity of water in response to a predetermined low level reading from the level measurement system.

8. The tank of claim **1**, wherein the heat exchange piping is arranged within the tank in a configuration selected from the list consisting of U-shaped and coiled.

9. The tank of claim **1**, further comprising an electric resistance heater or other energy source for heating the thermal energy storage material.

10. The tank of claim **1**, further comprising a removable lid that provides access to the volume.

11. A thermal energy storage system comprising:

a water tank for holding a quantity of water;

a storage tank having a quantity of thermal energy storage material disposed therein, the thermal energy storage material comprising a substantially solid material having a melting point above 32 degrees Fahrenheit (F) and a latent heat of fusion approaching that of water;

a first circulation loop comprising a first loop section disposed within the second tank and a second loop section in thermal communication with a first coil of a heating, ventilating and air conditioning (HVAC) system, the first circulation loop further having a first pump for circulating water between the first and second loop sections;

a second circulation loop comprising a first connection to the water tank, a third loop section in thermal communication with a second coil of the HVAC system, a second connection to the water tank, and a second pump for circulating water between the water tank and the third loop section; and

third circulation loop piping connecting the water tank and the storage tank, the third circulation loop having first and second valves disposed therein, the first and second valves being operable to provide selective fluid communication between the third circulation loop and the first and second circulation loops.

12. The system of claim **11**, wherein the system has a first configuration in which the first and second valves are aligned so that the first pump circulates water between the third circulation loop piping and portions of the first and second circulation loop to transfer heat from the water in the water tank to the thermal energy storage material disposed within the storage tank.

13. The system of claim **11**, wherein the system has a second configuration in which the first and second valves are aligned so that the first pump circulates water within the first circulation loop to transfer heat from the first coil of the HVAC system to the thermal energy storage material in the storage tank.

14. The system of claim **1**, wherein the system has a third configuration in which the first and second valves are aligned so that the first pump circulates water within the first circulation loop to transfer heat from thermal energy storage material to the first coil of the HVAC system, and the second pump circulates water within the second circulation loop to transfer heat from the thermal energy storage material to the second coil of the HVAC system.

15. The system of claim **11**, wherein the HVAC system further comprises a compressor, first and second HVAC valves, an HVAC piping loop, and a third coil disposed in a ventilation duct for transferring energy between air in the ventilation duct and the third coil.

16. The system of claim **15**, wherein the first and second HVAC valves are selectively operable to form a first HVAC loop between the first coil and the third coil, and a second HVAC loop between the second coil and the third coil.

17. The system of claim **16**, wherein said compressor is a reversible compressor.

18. The system of claim **15**, further comprising a temperature sensor associated with the storage tank, wherein when the temperature sensor senses that the temperature of the TESM exceeds a predetermined temperature limit, the temperature sensor is operable to send a signal which causes the first pump to be turned off and the HVAC system to be turned on.

19. The system of claim **11**, wherein the first and second pumps are variable speed pumps.

20. The system of claim **11**, wherein the first and second valves are three-way solenoid valves.

21. The system of claim **10**, wherein the first coil and the second loop section of the first recirculation loop comprise a first heat exchanger, and the second coil and the third loop section of the second recirculation loop comprise a second heat exchanger.

22. The system of claim **10**, wherein the thermal energy storage material is selected from the list consisting of clathrate, imidazole, imidazolium chloride and a derivative of pyrrole.

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