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(54) **PV WATER HEATER WITH ADAPTIVE CONTROL**

(76) Inventor: **Samuel L. Thomasson**, Gilbert, AZ (US)

Correspondence Address:
Paul F. Wille
6407 East Clinton St.
Scottsdale, AZ 85254 (US)

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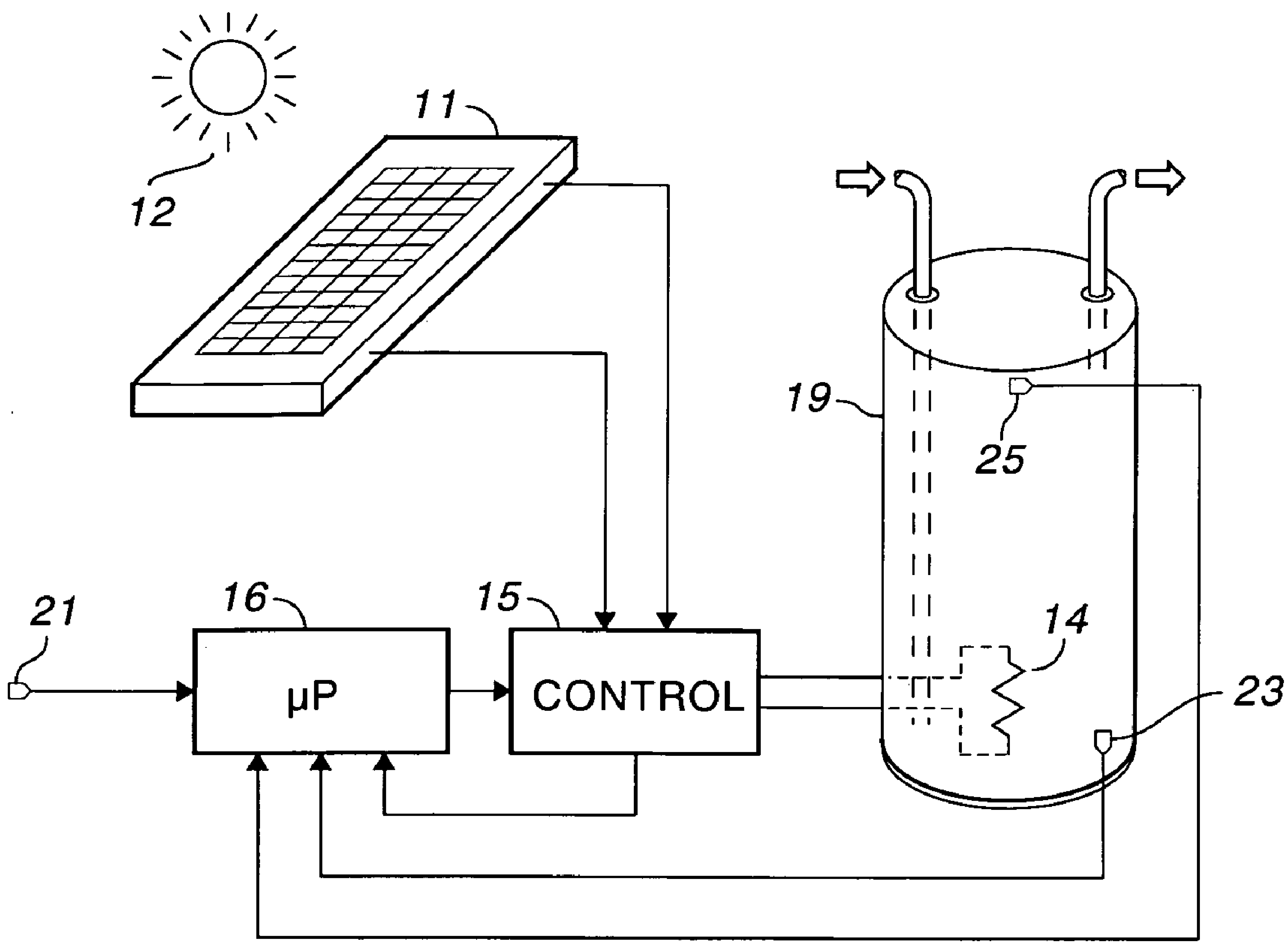
(57) **ABSTRACT**

A photovoltaic water heater includes a tank containing water and a heater element, a solar module, and a control circuit coupling the solar module to the heater element. One or more transducers in the system produce signals indicative of water usage. A microprocessor is programmed to produce a model of water usage from the signals and cause the heater element to heat water in accordance with the model.



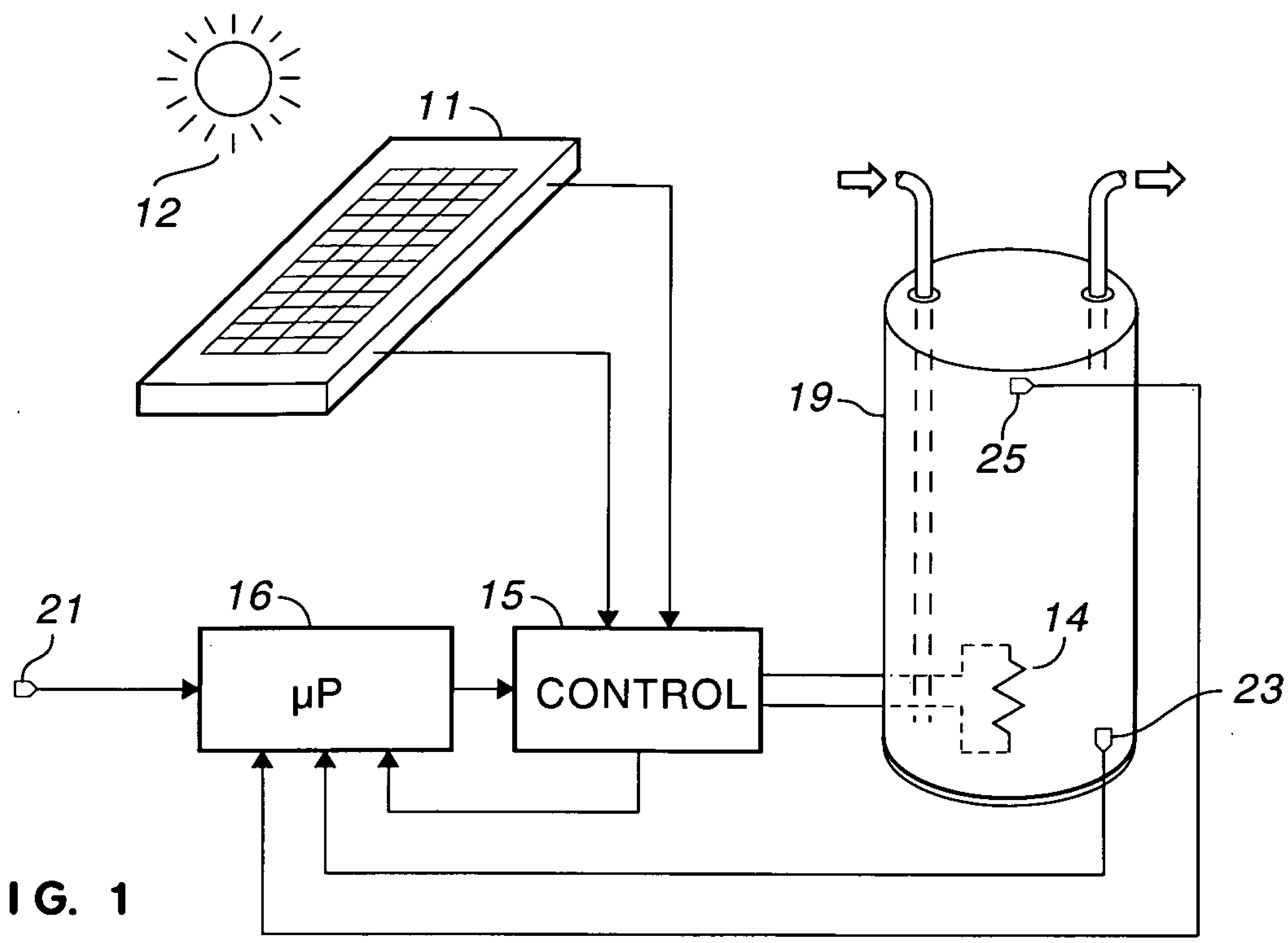

11
12
19
25
21
16
15
14
μP
CONTROL
23

FIG. 1

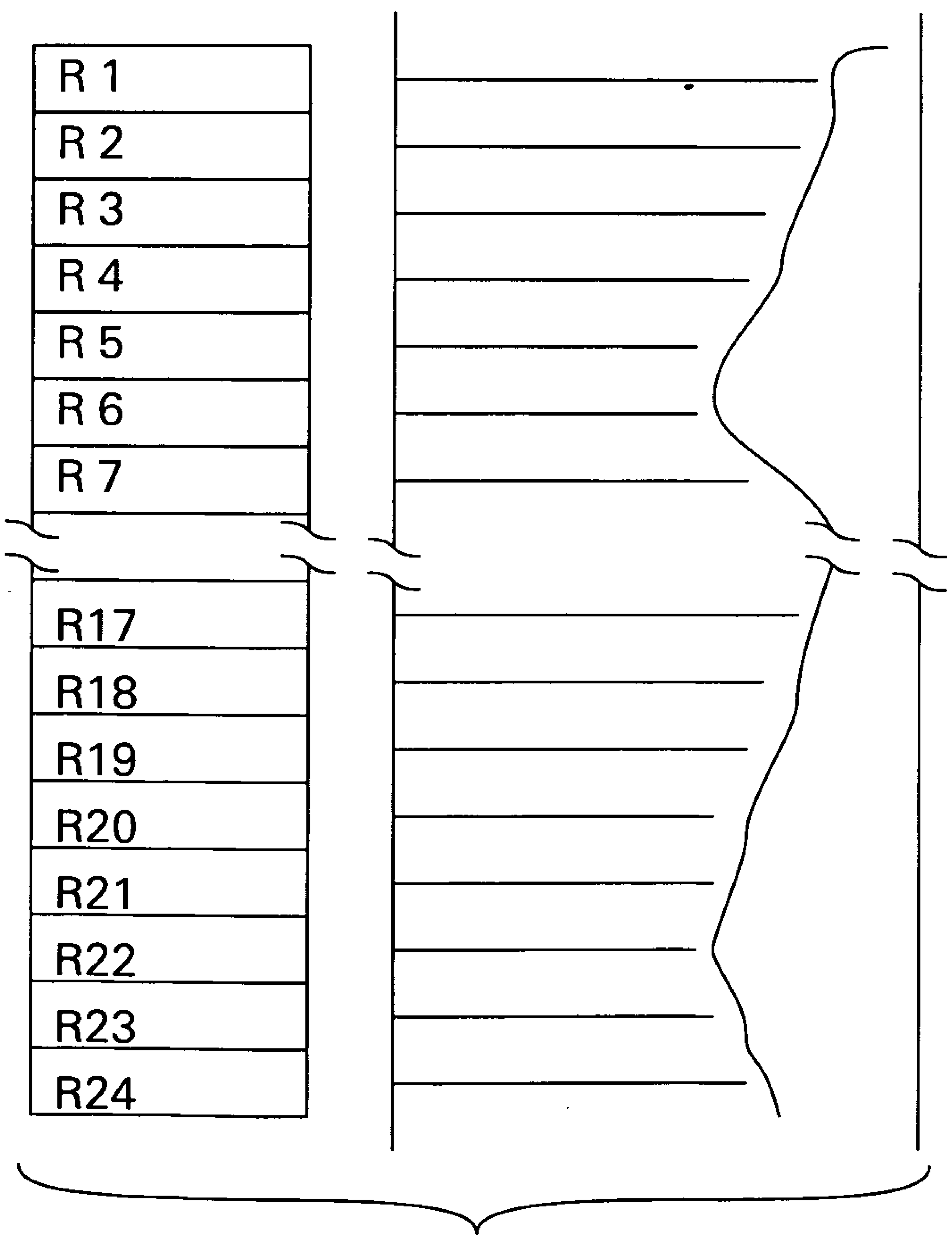

R 1
R 2
R 3
R 4
R 5
R 6
R 7
R17
R18
R19
R20
R21
R22
R23
R24

FIG. 2

PV WATER HEATER WITH ADAPTIVE CONTROL

FIELD OF THE INVENTION

[0001] This invention relates to solar powered water heaters and, in particular, to a water heater powered by electricity from a photovoltaic solar panel and controlled by a system that adapts to the consumption patterns of the user.

BACKGROUND OF THE INVENTION

[0002] The number of solar water heaters in use is less than one percent of the total number of water heaters. This is due to problems of durability, difficulty of installation, weight, and relatively high initial cost. Durability includes problems with freezing, leakage, pump failure, and hard (mineral bearing) water. Installation has often proved difficult, requiring roof penetrations for the plumbing that transports water to and from solar collectors (arrays of pipes containing water that is heated by the sun).

[0003] U.S. Pat. No. 5,293,447 (Fanney et al.) discloses a water heating system intended to avoid the problems associated with solar thermal water heaters. Photovoltaic modules generate direct current (DC) that is coupled directly (no conversion to alternating current) to resistive heating elements. The resistive heating elements replaced the standard heating elements in a conventional, electric water heater. A microprocessor controls a set of electrical relays that connect the photovoltaic module to the resistive heating elements in a manner that best matches the instantaneous operating characteristics of the photovoltaic modules.

[0004] Unlike other solar photovoltaic applications, a photovoltaic water heating system requires neither a battery for energy storage nor an inverter to convert the direct current from the photovoltaic module into alternating current (AC). The water tank acts as an energy storage device, bridging any mismatch between when solar heating is available and when the user needs hot water. The water tank can contain an AC heating element connected to an electric utility. Alternatively, a second water tank, heated by electricity, gas, or oil, can be connected downstream of the solar heated water tank. The AC heating element or the second water tank is to ensure an adequate hot water supply.

[0005] If the hot water in a water heater is not used for extended periods of time and is maintained at a set temperature, stand-by losses account for substantially all the energy consumed by the appliance. Most homes do not use a steady flow of hot water during the day with a single peak usage. Patterns of use vary from home to home, with each home having at least one period during which no hot water is used.

[0006] Presuming that standby losses are a small percentage of domestic hot water energy consumption, most currently available domestic solar thermal water heaters have two tanks. Cold supply water is preheated in a preheat tank connected between solar collectors and a conventional hot water heater.

[0007] A problem with most dual tank systems is that one cannot tell whether the hot water being drawn was heated in the solar preheat tank or in the conventional water heater. If a dual tank system is idle for extended periods of time, then it can experience the same standby losses as a conventional water heater alone. If the losses occur overnight and if peak usage is in the early morning hours, it is possible that a properly operating and otherwise efficiently designed two tank system will actually not provide any appreciable energy savings.

[0008] One solution to the problem of stand-by losses has been the use of an automatic timer to turn a water heater on and off in accordance with expected use. Common practice is to set such clock timers for generally accepted periods, e.g., off from midnight to 5:00 AM, and on the rest of the time. Thus, such timers are not very energy efficient because they generally require a water heating system to operate for long periods during the day when no hot water is needed, resulting in unnecessary energy consumption due to standby losses.

[0009] U.S. Pat. No. 4,568,821 (Boe) discloses apparatus for controlling a water heater in one of three modes, automatic preheat, timed preheat, and full use. In the automatic preheat mode, the water heater is cycled on automatically at a pre-selected hour for a pre-selected period of time every day. In the timed preheat mode, the water is heated for a selected period of time after being turned on by the user. In the full use mode, the water heater cycles as determined by the temperature of the water. As with any timer, efficiency depends upon the user accurately estimating periods of use and the estimates may not be accurate. Except for user initiation of a heating cycle, the operation is essentially timer or full. It is desired to provide greater flexibility and increased efficiency.

[0010] In view of the foregoing, it is therefore an object of the invention to provide an adaptive controller for PV water heaters.

[0011] Another object of the invention is to improve the efficiency of known PV water heaters.

[0012] A further object of the invention is to provide a PV water heater that does not require a second water storage tank.

SUMMARY OF THE INVENTION

[0013] The foregoing objects are achieved by this invention in which a photovoltaic water heater includes a microprocessor programmed to monitor water usage and adjust power to heater elements to provide hot water according to usage.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] A more complete understanding of the invention can be obtained by considering the following detailed description in conjunction with the accompanying drawings, in which:

[0015] FIG. **1** illustrates a preferred embodiment of an adaptive photovoltaic water heater constructed in accordance with a preferred embodiment of the invention; and

[0016] FIG. **2** is a chart illustrating the operation of the adaptive photovoltaic water heater illustrated in FIG. **1**.

DETAILED DESCRIPTION OF THE INVENTION

[0017] In the FIGURE, photoelectric solar module **11** converts photons from sun **12** into an electric current. The electric current is applied to heater element **14** by control circuit **15**. Heater element **14** converts the electric current to heat, thereby heating the water in tank **19**. Solar module **11** can be of any current or future design. The only constraint on the design is that heater element **14** be compatible with the voltage and current produced by module **11**.

[0018] Preferably, control circuit **15** uses pulse width modulation (PWM) to control power, thereby minimizing losses within control circuit **15**. Semiconductor or solid state switching is preferred to relays, although either can be used in control circuit **15** for varying the power supplied to heater element **14**. Heater element **14** includes one or more electrodes. If plural electrodes are used, then control circuit **15** can switch the electrodes in series or parallel combinations to provide the desired level of heating. Alternatively, PWM and switched electrodes can be used together to control the amount of power dissipated within tank **19**.

[0019] Control circuit **15** also provides feedback to microprocessor **16**, e.g. power level to heater element **14**, voltage and current data on solar module **11**.

[0020] Microprocessor **16** is preferably a single microcontroller chip having all necessary input/output (I/O), analog to digital (A/D) conversion, timing (including clock/calendar functions), and logic on a single chip. Alternately, separate devices for I/O, computation, conversion, and timing can be used.

[0021] Microprocessor **16** has several sense inputs, including photocell **21**, thermocouple **23**, and thermocouple **25**. Photocell **21** provides a signal representing the level of available sunlight. Thermocouple **23** produces a signal representing the temperature of the water at the bottom of tank **19**. Thermocouple **25** produces a signal representing the temperature of the water at the top of tank **19**. Other transducers could be used as well; e.g. to sense whether or not tank **19** contains water, at least above the height of heater element **14**, and to sense the flow of water to and from the tank.

[0022] In accordance with the invention, microprocessor **16** is programmed with initial conditions (default values), e.g. presuming that water consumption will occur mornings and evenings, and then monitors temperature to detect patterns of usage. The monitored data is then used to revise the model of water usage.

[0023] For example, as illustrated in FIG. **2**, microprocessor **16** includes plurality of registers. These registers store temperature data from the top of tank **19** and from the bottom of tank **19** as an indication of demand. A difference in temperature greater than a programmed amount is taken as an indication of water usage. A difference of less than that amount is just normal cooling. Actual temperatures are also monitored to prevent overheating.

[0024] As illustrated in FIG. **2**, each register corresponds to one hour of the day. In actual use, a greater number of registers would be used. Register R**1** corresponds to the hour from midnight to one in the morning. Register R**2** corresponds to the hour from one in the morning until two in the morning, and so on through register R**24**. As illustrated in FIG. **2**, water usage is greatest at approximately six o'clock in the morning and at ten o'clock at night.

[0025] Depending upon the size of tank **19**, microprocessor **16** initiates heating in anticipation of increased demand for hot water, e.g. fifteen minutes prior to demand increasing. A larger tank requires either more time or more power or both for heating to a given temperature. Power level is also determined in accordance with the magnitude of the demand.

[0026] If, for example, the user is a pilot flying at night, the peaks might move to ten o'clock in the morning and four o'clock in the morning. Pilots are generally absent for more than twenty-four hours and this is accommodated by using a greater number of registers. For example, a summer cabin might have water usage only on weekends. Seven sets of registers in memory would then be declared as storage registers for modeling a week of activity. All these variations are easily accommodated because the model is simply actual data in a plurality of registers.

[0027] Data can be accumulated for several days, in effect a running average, or the days can be stored in separate sets of registers and then analyzed for trends; e.g. comparing data from three or four consecutive Mondays at nine AM. At some point, current data is stored as a new set of default values and the process of accumulating data for a model begins again. In this way subtle changes, e.g. from summer to winter, are accommodated. "Accumulated" means data from register X is added to new data and the sum is then stored in register X.

[0028] The invention thus provides an adaptive controller for PV water heaters that does not require a second water storage tank, although one could be used if capacity demanded it. For example, available space or the layout of a building might dictate two smaller tanks instead of one big tank. Efficiency of known PV water heaters is improved in accordance with the invention by tailoring heating to usage in a way not previously known.

[0029] Having thus described the invention, it will be apparent to those of skill in the art that various modifications can be made within the scope of the invention. For example, instead of default values, the user could be requested, through a control panel to provide an estimate of the timing of water usage. Although temperature difference is used in the preferred embodiment for generating modeling data, data from other transducers could be used instead, e.g. one or more flow meters, or in addition to temperature data. Preferably, programmable memory, e.g. flash memory, is used for data storage. If temporary memory is used, i.e. memory that is erased by a power outage, at least the default values are stored in programmable memory.

What is claimed as the invention is:

1. In a photovoltaic water heater including a tank containing water and a heater element, a solar module, and a control circuit coupling the solar module to the heater element, the improvement comprising:

one or more transducers producing signals indicative of water usage;

a microprocessor programmed to produce a model of said water usage from said signals;

wherein said microprocessor is coupled to said control circuit for causing said heater element to heat water in accordance with said model.

2. The photovoltaic water heater as set forth in claim **1** wherein said one or more transducers includes a pair of temperature sensing transducers.

3. The photovoltaic water heater as set forth in claim **1** wherein said microprocessor is programmed to accumulate data taken at different times of day in different registers.

4. The photovoltaic water heater as set forth in claim **3** wherein accumulated data is made default data, thereby adapting the photovoltaic water heater to actual use.

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