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(54) **THERMOSTATS AND OPERATIONAL METHODS**

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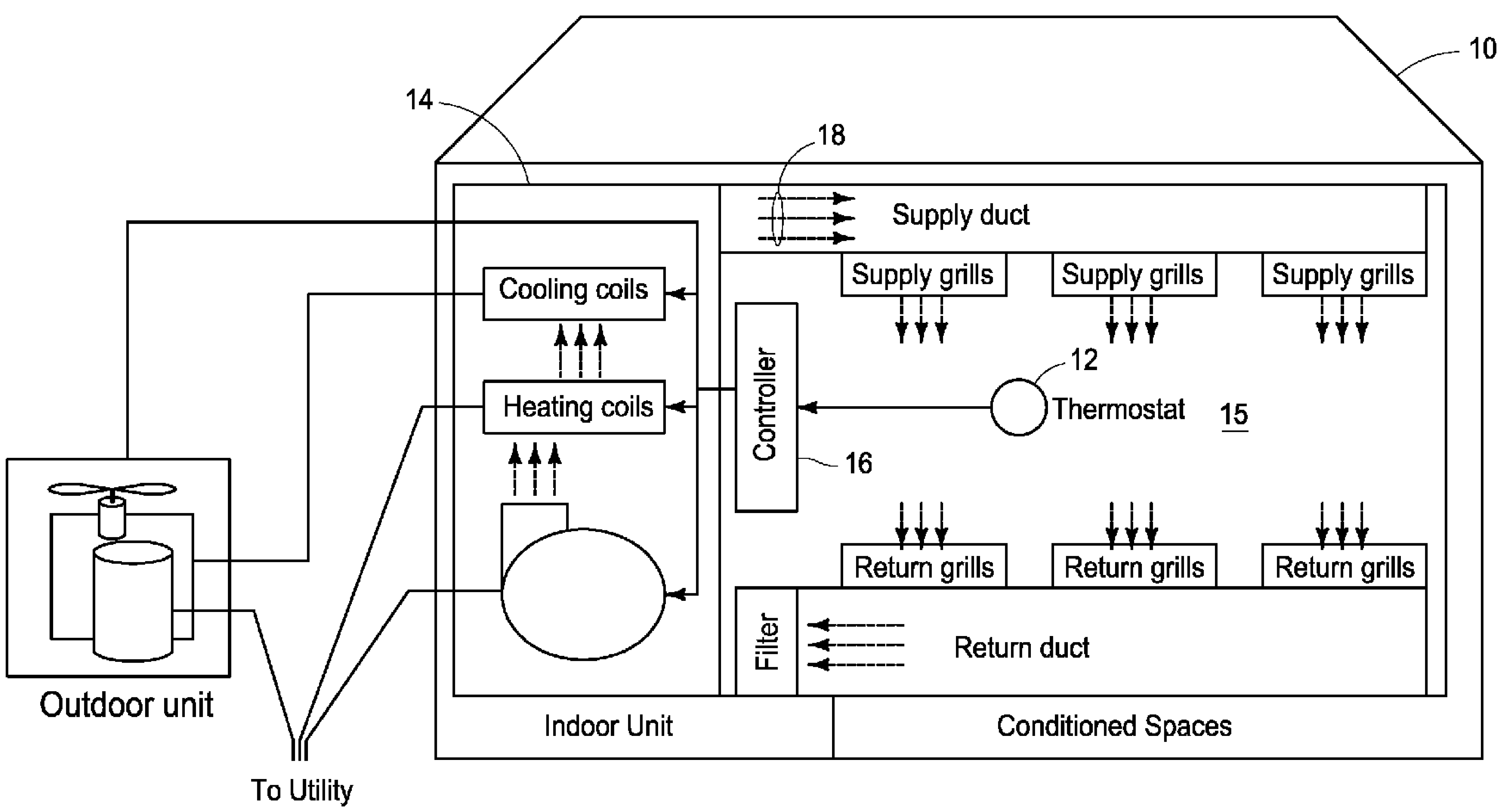
(57) **ABSTRACT**

Thermostats and operational methods are described. According to one aspect, a thermostat includes an interface configured to receive a control signal, wherein the control signal comprises fast components and slow components, and the fast components change at an increased rate compared with slow components of the control signal, control circuitry including a fast response controller configured to use the fast components of the control signal to generate a fast temperature offset, a slow response controller configured to use the slow components of the control signal to generate a slow temperature offset, and wherein the control circuitry is configured to use the fast temperature offset and the slow temperature offset to control a conditioning apparatus to at least one of heat and cool a conditioned area at a plurality of moments in time.



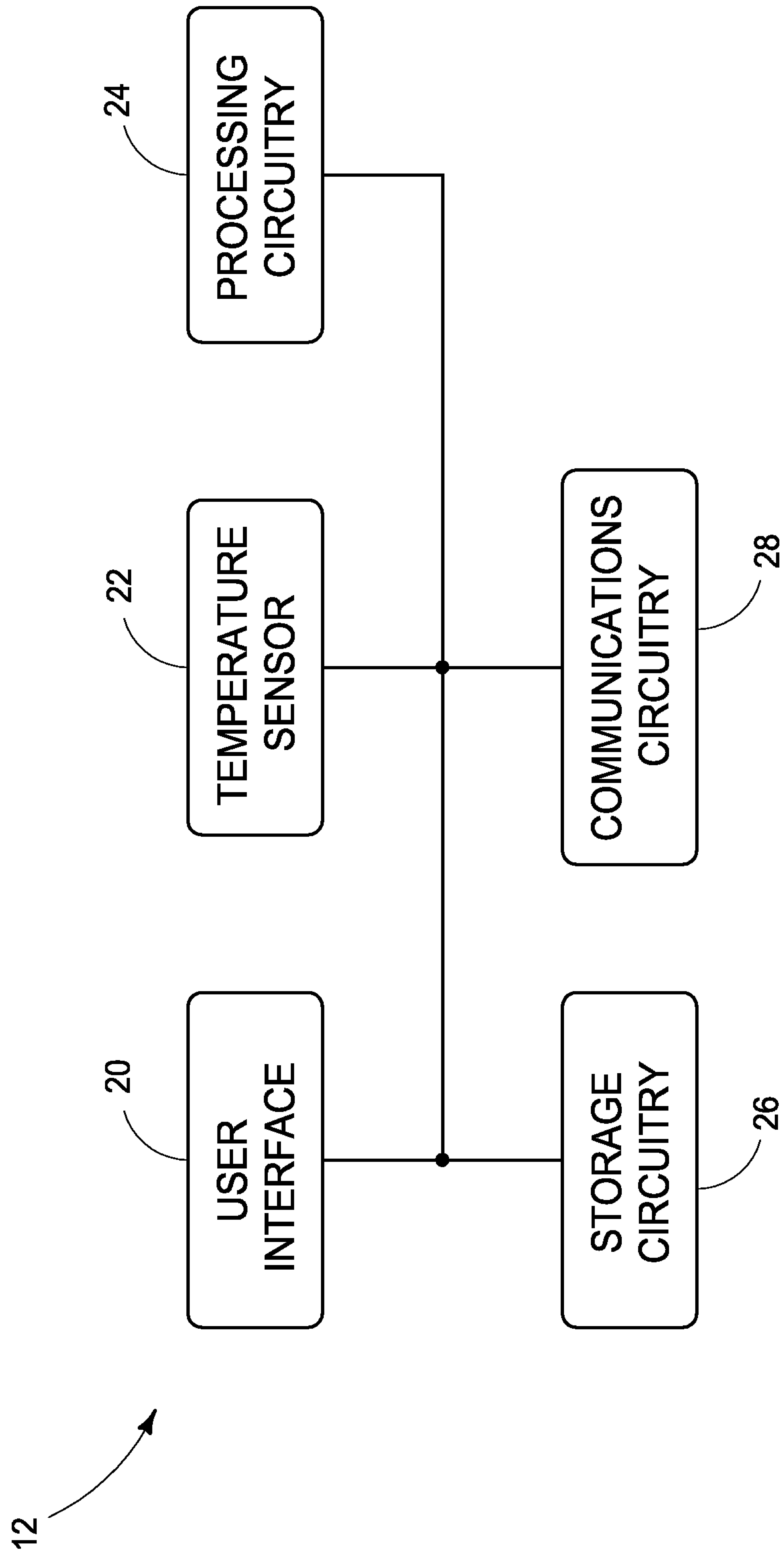

12
20
USER INTERFACE
22
TEMPERATURE SENSOR
24
PROCESSING CIRCUITRY
26
STORAGE CIRCUITRY
28
COMMUNICATIONS CIRCUITRY

FIG. 1

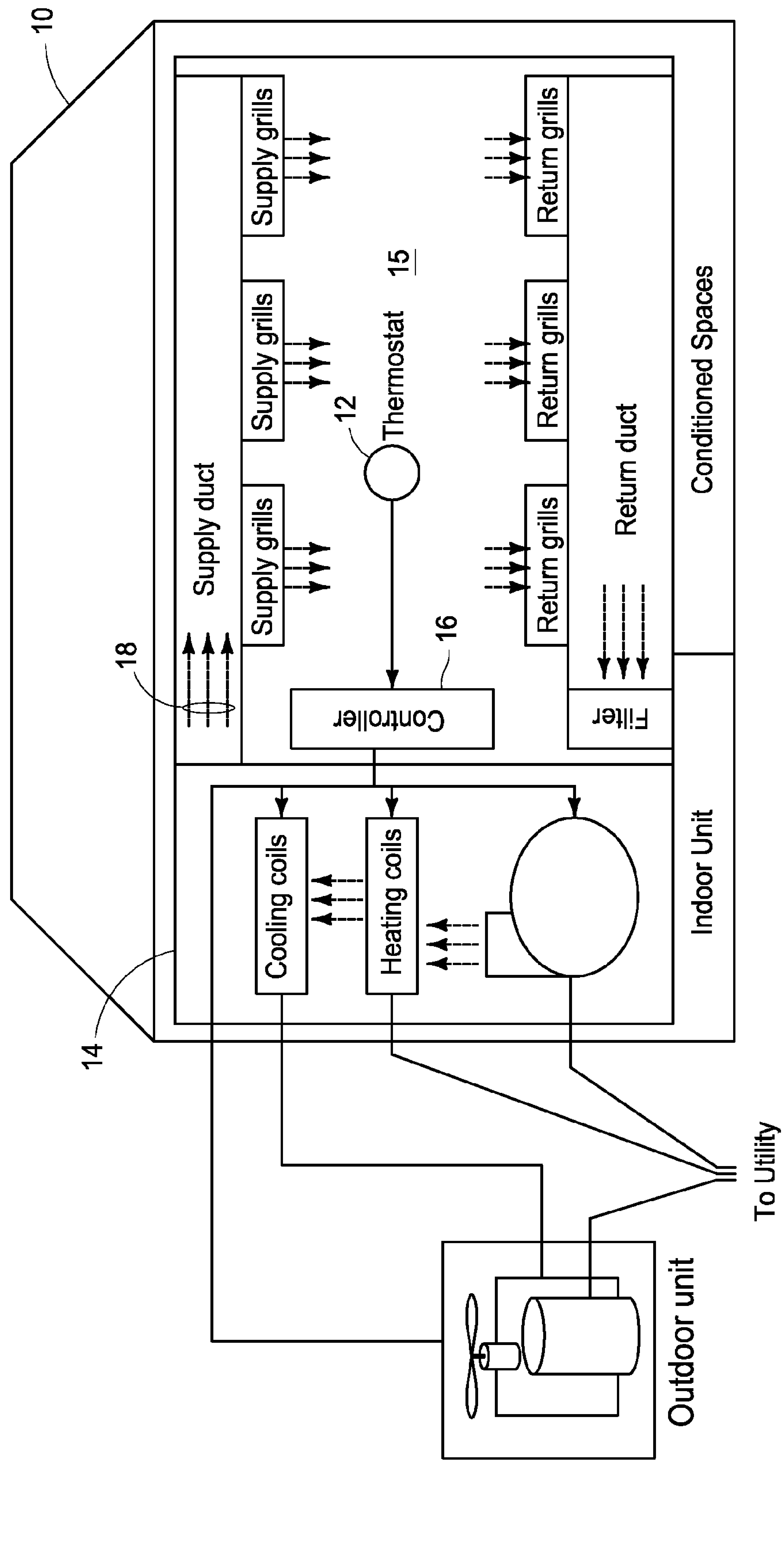

10
18
Supply duct
Supply grills
Supply grills
Supply grills
12
Thermostat
15
16
Controller
Return grills
Return grills
Return grills
Return duct
Filter
Conditioned Spaces
Cooling coils
Heating coils
Indoor Unit
14
To Utility
Outdoor unit

FIG. 2

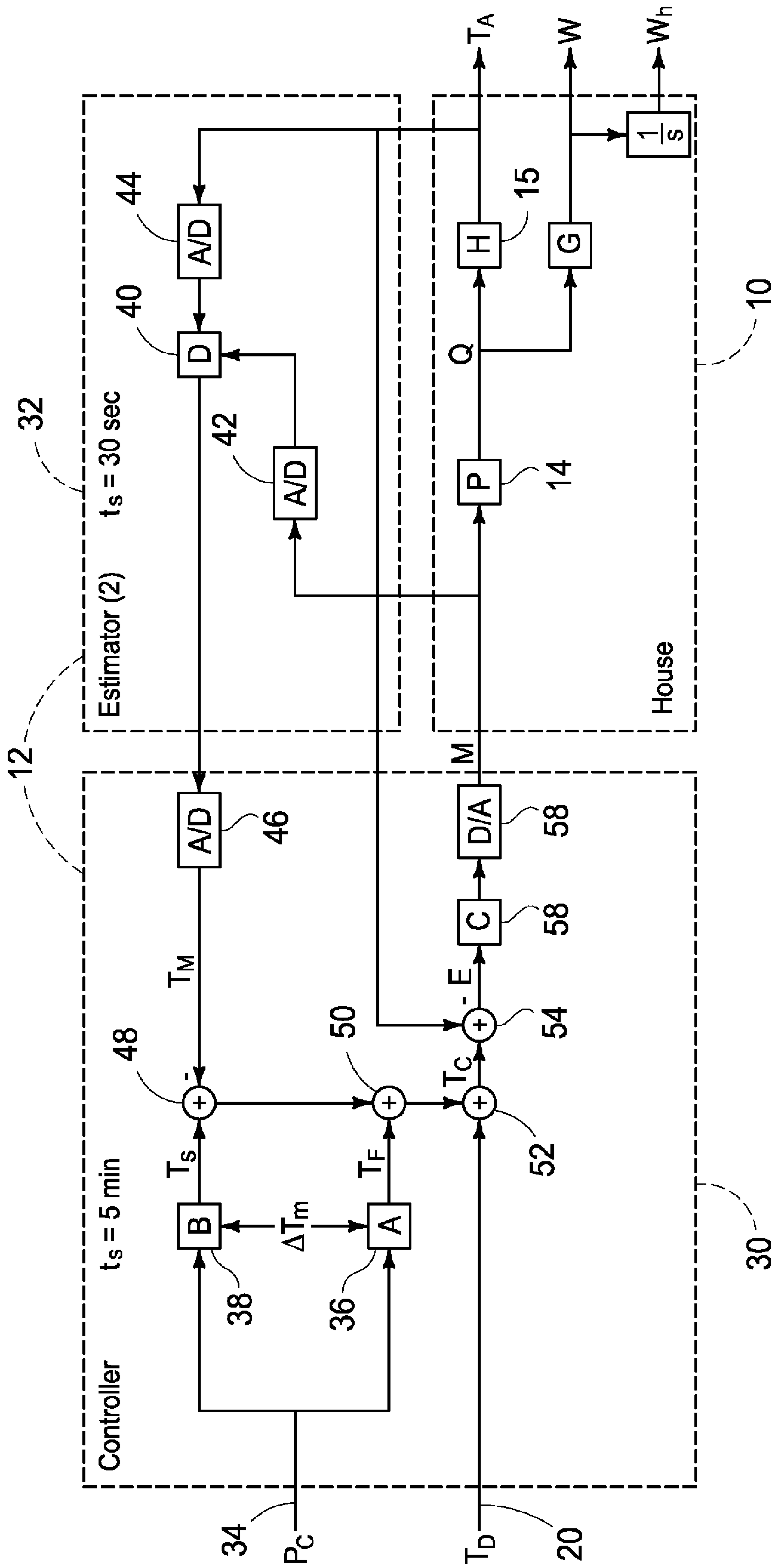

Controller
t_S = 5 min
Estimator (2)
t_S = 30 sec
House
A/D
D
A/D
A/D
B
A
ΔT_m
T_S
T_F
T_M
T_C
- E
C
D/A
M
P
Q
H
G
1/s
T_A
W
W_h
P_C
T_D
10
12
14
15
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FIG. 3

THERMOSTATS AND OPERATIONAL METHODS

RELATED PATENT DATA

[0001] This application claims priority to and the benefit of U.S. Provisional Patent Application Serial No. 62/028,736 filed Jul. 24, 2014, titled "Next Generation Transactive Thermostat", and also claims priority to and the benefit of U.S. Provisional Patent Application Ser. No. 62/086,953 filed Dec. 3, 2014, titled "Thermostat for Real-Time Price Demand Response Using Discrete-Time Control and Zero Deadband", the disclosures of which are incorporated herein by reference.

STATEMENT AS TO RIGHTS TO INVENTIONS MADE UNDER FEDERALLY-SPONSORED RESEARCH AND DEVELOPMENT

[0002] This invention was made with Government support under Contract DE-AC0576RLO1830 awarded by the U.S. Department of Energy. The Government has certain rights in the invention.

TECHNICAL FIELD

[0003] This disclosure relates to thermostats and associated operational methods.

BACKGROUND OF THE DISCLOSURE

[0004] Thermostatically controlled electrical loads can provide valuable energy storage and are prime candidates for fast acting demand response (DR) that can be used to mitigate highly variable renewable power generation and limited availability of ramping resources. However, when some conventional thermostats are retrofitted for real-time price demand response control, significant control errors can arise, particularly in the form of dispatch control drift.

[0005] At least some aspects of the disclosure are directed towards thermostats and associated operational methods which overcome at least some of the shortcomings of conventional thermostats.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] Example embodiments of the disclosure are described below with reference to the following accompanying drawings.

[0007] FIG. **1** is an illustrative representation of a house according to one embodiment.

[0008] FIG. **2** is a functional block diagram of a thermostat according to one embodiment.

[0009] FIG. **3** is a functional block diagram of a thermostat and house according to one embodiment.

DETAILED DESCRIPTION OF THE DISCLOSURE

[0010] This disclosure is submitted in furtherance of the constitutional purposes of the U.S. Patent Laws "to promote the progress of science and useful arts" (Article 1, Section 8).

[0011] At least some embodiments of the disclosure are directed to thermostats and associated operational methods which may be used to implement demand response control strategies in example implementations. In a more specific example, the thermostats attempt to distribute electrical loads evenly throughout the day, and in the presence of peak loads upon the electrical grid of a utility.

[0012] Referring to FIG. **1**, example embodiments herein are discussed with respect to an implementation of a thermostat 12 within a residential house **10**. Thermostat **12** controls operational modes of a conditioning apparatus **14**, such as a heat pump, to provide either heated or cooled air **18** to heat or cool a conditioned area **15** of house **10**. Thermostat **12** applies control signals to a controller **16** of conditioning apparatus **14** to control the operational modes of the conditioning apparatus **14**. Other thermostatic end-use loads can be controlled using thermostat **12** in other implementations.

[0013] In one embodiment, thermostat **12** is used in demand response control strategies of electrical utilities as mentioned above. Demand response is increasingly regarded as an important resource for electricity interconnections in industrialized economies. Demand response provides both economic and technical benefits that far outweigh their costs, and demand response plays an important role in mitigating both the market power of electricity suppliers and the intermittency of renewable generation. Numerous thermostats **12** may be used in numerous houses **10** to implement demand response control strategies in but one example application of use.

[0014] Thermostat **12** is transactive and receives a control signal from an external source in some of the disclosed embodiments. An electrical utility, or other source, may provide the control signal to thermostats **12** implemented with the houses **10** in one embodiment. The control signal is used to implement demand response control strategies in one embodiment. The control signal may be communicated via any appropriate communications method, such via as the Internet, wired, and/or wireless communications and is used by thermostat **12** to control conditioning apparatus **14** as discussed below.

[0015] In one embodiment, the control signal is indicative of price of electrical energy which is supplied to house **10** and conditioning apparatus **14**. The control signal changes as a result of changes in price of the electrical energy in one embodiment. For example, the control signal changes as a result of changes in supply and demand of electrical energy at different moments in time. The control signal may be calculated from the intersection of supply and demand curves of the electrical energy in one implementation, and the control signal changes due to changes in the supply and demand of the electrical energy at different moments in time. In one embodiment, updates to the control signal are provided to the thermostat **12** at predefined moments in time, such as every five minutes in one example.

[0016] The control signal comprises fast and slow components which correspond to changes of the control signal at different rates. For example, fast components refer to changes of the control signal which are less than an hour and slow components refer to changes of the control signal which are greater than an hour. In one specific embodiment, the fast components correspond to short term price signals emanating from distribution capacity or ancillary service markets and the slow components correspond to long term price signals from bulk energy markets.

[0017] As mentioned above, the control signal is used to implement demand response control strategies in one embodiment. Additional details regarding demand response, thermostat **12**, control signals and other related aspects are discussed in a thesis by Chassin, David P., New Residential Thermostat for Transactive Systems, University of Victoria, Victoria, BC, December **14**, **2014**, the teachings of which are incorporated herein by reference. Furthermore, additional details regarding use of control signals to control operations of thermostat **12** and conditioning apparatus **14** are discussed below with respect to FIG. **3**.

[0018] Referring to FIG. **2**, one embodiment of circuitry of thermostat **12** is shown. In the illustrated example embodiment, thermostat **12** includes a user interface **20**, a temperature sensor **22**, processing circuitry **24**, storage circuitry **26**, and communications circuitry **28**. Other embodiments are possible including more, less and/or alternative components.

[0019] User interface **20** is configured to interact with a user including conveying data to a user (e.g., current temperature, temperature set points, operational mode, program cycles for wake/sleep/away/home) as well as receiving inputs from the user, for example, selecting the operational modes, such as heat, cool, and off.

[0020] In one embodiment, processing circuitry **24** is arranged to process data, control data access and storage, issue commands, and control other desired operations. In one more specific embodiment, processing circuitry **24** is configured to perform the operations of the thermostat controller and state estimator discussed below with respect to FIG. **3**.

[0021] Processing circuitry **24** comprises circuitry configured to implement desired programming provided by appropriate computer-readable storage media in at least one embodiment. For example, the processing circuitry **24** may be implemented as one or more processor(s) and/or other structure configured to execute executable instructions including, for example, software and/or firmware instructions. Other example embodiments of processing circuitry **24** include hardware logic, PGA, FPGA, ASIC, state machines, and/or other structures alone or in combination with one or more processor(s). These examples of processing circuitry **24** are for illustration and other configurations are possible. Processing circuitry **24** may also be referred to as control circuitry which is configured to implement operations of thermostat **12** discussed below with respect to FIG. **3**.

[0022] Storage circuitry **26** is configured to store programming such as executable code or instructions (e.g., software and/or firmware), electronic data, databases, image data, or other digital information and may include computer-readable storage media. At least some embodiments or aspects described herein may be implemented using programming stored within one or more computer-readable storage medium of storage circuitry **26** and configured to control appropriate processing circuitry **14**.

[0023] The computer-readable storage medium may be embodied in one or more articles of manufacture which can contain, store, or maintain programming, data and/or digital information for use by or in connection with an instruction execution system including processing circuitry **24** in one embodiment. For example, computer-readable storage media may be non-transitory and include any one of physical media such as electronic, magnetic, optical, electromagnetic, infrared or semiconductor media. Some more specific examples of computer-readable storage media include, but are not limited to, a portable magnetic computer diskette, such as a floppy diskette, a zip disk, a hard drive, random access memory, read only memory, flash memory, cache memory, and/or other configurations capable of storing programming, data, or other digital information.

[0024] Communications circuitry **28** is arranged to implement communications of thermostat **12** with respect to external devices and/or networks (not shown). For example, communications interface **28** may be arranged to communicate information bi-directionally with respect to thermostat **12**. Communications interface **28** may be implemented as a network interface card (NIC), serial or parallel connection, USB port, Firewire interface, Ethernet port, flash memory interface, or any other suitable arrangement for implementing communications of thermostat **12**. In one embodiment, communications circuitry **28** outputs control signals which control the operational modes of conditioning apparatus **14**. In addition, communications circuitry **28** may receive control signals, from external of the thermostat **12**, and which may include control signals which are indicative of the price of electrical energy supplied to house **10** in at least one embodiment.

[0025] Referring to FIG. **3**, operations of one embodiment of thermostat **12** are described. Thermostat **12** includes plural subsystems including a thermostat controller **30** and a state estimator **32** in the depicted example embodiment. The thermostat controller **30** is configured to control operations of conditioning apparatus **14** to at least one of heat and cool a conditioned area **15** of house **10**. State estimator **32** is configured to provide information regarding a mass temperature of the conditioned area **15**.

[0026] In one embodiment, the thermostat controller **30** and state estimator **32** are discrete-time control subsystems which are implemented using processing circuitry **24** described above. Processing circuitry **24** implementing the operations of thermostat controller **30** and state estimator **32** may also be referred to as control circuitry.

[0027] Thermostat controller **30** operates to implement changes to the operational mode of conditioning apparatus **14** at a plurality of discrete moments in time which are predefined according to a discrete, finite interval or period in one embodiment. The state estimator **32** operates to sample the data from the house **10** (e.g., the operational mode M of the conditioning apparatus and the air temperature T_A) and provide data which is indicative of the mass temperature of the conditioned area **15** to controller **30** at discrete moments in time defined according to a common interval or period in one embodiment.

[0028] The sampling frequency of the state estimator **32** is faster than the frequency used by thermostat controller **30** to make changes to the operational mode of conditioning apparatus **14** in one embodiment. For example, the state estimator **32** may operate at a frequency which is 10 times faster than the operational frequency of the thermostat controller **30** (e.g., the sampling rate of state estimator **32** may be i_s=30 seconds while thermostat controller **30** operates to access updates to the control signal and change the operational mode of conditioning apparatus **14** at a rate i_s=5 minutes in one embodiment).

[0029] Thermostat controller **30** receives a control signal P_c via an interface **34** of communications circuitry **28**, for example, from a utility which supplies electrical energy to house **10** or other appropriate source. The source of the control signal provides changes or updates to the control signal at discrete moments in time, such as every five minutes, in one embodiment. In one more specific embodiment, thermostat controller **30** makes changes to the operational mode of the conditioning apparatus **14** at discrete moments in time which are synchronized with the updates to the control signal.

[0030] In addition to the control signal, thermostat controller **30** also receives a desired temperature set point T_D of conditioned area **15**, for example, via user interface **20** as set by the occupant of the house **10**.

[0031] In one embodiment, the control signal is filtered to separate the signal into components with time-constants that correspond to the building mass response of the conditioned area of the house (long or slow-term response) and components with time-constants that correspond to the air's response of the conditioned area of the house (short or fast-term response), denoted as slow response and fast response components, respectively. The fast components change at an increased rate compared with the slow components. In one embodiment, the thermostat controller **30** controls the long-term response of the house using the slow components independently of control of the short-term response of the house using the fast components.

[0032] The control signal P_c received by the thermostat **12** is provided to a fast response controller **36** and a slow response controller **38** in the illustrated embodiment. Fast and slow response controllers **36**, **38** are configured to relate or convert changes in price information to changes in temperature in one embodiment. For example, fast and slow response controllers **36**, **38** process respective fast and slow components of the control signal to generate to respective fast and slow temperature offsets in one embodiment. The fast and slow temperature offsets are used to adjust the desired temperature set point selected by the user based upon the control signal, which may include price information as set forth in the following continuing discussion.

[0033] One embodiment of fast controller **36** calculates a fast temperature offset T_F according to the following:

$$T_F = \frac{F_H(P_C) - P_A}{K} \qquad (1)$$

where P_A is the expected price of electricity (e.g., an average price of electrical energy supplied to the house over the previous 24 hours), P_C is the most recently-received price of the electrical energy, F_H is a high-pass filter with a cut-off frequency corresponding to approximately 1 hour (i.e., about 3600^{-1} Hz) to pass only fast components and filter the slow components of the control signal, and a demand response control gain or comfort gain $K=P_D$/delta T_m where P_D is the standard deviation of the price of the electrical energy and delta T_m is the occupant's maximum allowed temperature deviation from the desired temperature set point (e.g., 2° F.). Delta T_m may also be equal to $k/(T_m-T_D)$ where k is a comfort setting which is selected by the occupant and which is indicative of a customer preference of comfort with respect to temperature (e.g., from 0 for maximum comfort to >100 for maximum savings in one embodiment), T_D is the desired air temperature set point of the conditioned area of the house selected by the occupant, and T_m is the minimum or maximum allowed air indoor temperature, which is selected based upon whether the air temperature of the conditioned area of the house is above or below the desired temperature set point. When the indoor air temperature of the house is below the desired temperature set point, the minimum allowed indoor air temperature is used for T_m, and when the indoor air temperature of the house is above the desired temperature set point, the maximum allowed indoor air temperature is used for T_m.

[0034] One embodiment of the slow response controller **38** operates similarly to the fast response controller **36** but a low-pass filter F_L is utilized instead of F_H to calculate a slow temperature offset T_s. The low-pass filter has the same cut-off frequency as the fast response controller **36** but only passes slow components with frequencies lower than about 3600^{-1} Hz and filters the fast components in the described embodiment.

[0035] One embodiment of slow controller **38** calculates a slow temperature offset T_s according to the following:

$$T_S = \frac{F_L(P_C) - P_A}{K} \qquad (2)$$

[0036] State estimator subsystem **32** is configured to use the operational mode (M) of the conditioning apparatus **14** and the indoor air temperature of the conditioned area of the house T_A, which may be measured, to estimate the mass temperature T_M of the conditioned area **15** of the house **10**. A simple observer/state estimator **33** of subsystem **32** may be implemented using standard control theory in one embodiment since the transfer function between air temperature and mass temperature is a first-order system. Additional details regarding one implementation of state estimator subsystem **32** are discussed in Shengwei Wang and Xinhua Xu, "Parameter Estimation of Internal Thermal Mass of Building Dynamic Models using Genetic Algorithm", Energy Conversion and Management 47, 2005, pages 1927-1941, the teachings of which are incorporated herein by reference.

[0037] House **10** is a continuous subsystem and plural analog-to-digital converters **40**, **42** provide digitized data of the mode of conditioning apparatus **14** and the measured indoor air temperature of the conditioned area **15** of the house **10** for use in the discrete state estimator subsystem **32** in the illustrated embodiment. The output of state estimator subsystem **32** is indicative of the mass temperature T_M of the house **10** and is applied to an analog-to-digital converter **46** which provides digitized data of the mass temperature T_M for use within the thermostat controller subsystem **30**. In one embodiment, the different values of the mass temperature T_M are provided at a rate i_s=30 seconds.

[0038] The control circuitry of the thermostat **12** implementing the thermostat controller subsystem **30** is configured to use the fast and slow temperature offsets to control operation of conditioning apparatus **14** to heat and cool the conditioned area **15** of the house **15** at different discrete moments in time. In one more specific embodiment, thermostat controller **30** is configured to determine a difference **48** between the slow temperature offset T_s and mass temperature T_M. The determined difference is added **50** to the fast temperature offset T_F to provide a combined temperature offset which is added **52** to the desired temperature set point T_D of conditioned area **15** to provide an adjusted temperature set point T_C. The adjusted temperature set point T_c implements demand response control operations and is the new temperature set point which is desired to be controlled to in consideration of the price of the electrical energy which is supplied to the house **10** in the described embodiment.

[0039] An error E corresponding to the difference between the adjusted temperature set point T_c and the measured air temperature T_A of the conditioned area **15** is applied to mode controller **56** which uses the determined error to control the operational mode of conditioning apparatus **14**.

[0040] In one embodiment, mode controller **56** may have two set points, one for heating and one for cooling. The mode controller **56** may also operate in an automatic mode to automatically choose heating or cooling based on the temperature set points in at least one embodiment. In another embodiment, the user selects heating or cooling and the mode controller **56** controls whether the conditioning apparatus **14** is on or off at different moments in time. In addition, the mode controller **56** may support occupancy schedules to allow occupants to assign different set points for specific hours of the day and days of the week.

[0041] If the error E which is applied to mode controller **56** is negative, the air temperature T_A is greater than expected and mode controller **56** outputs a mode control signal M which is equal to −1 to instruct the conditioning apparatus **14** to be in the "on" operational mode to cool the conditioned area **15**. If the error E is zero, the air temperature T_A is at the expected temperature and mode controller **56** outputs a mode control signal M which is equal to 0 to instruct the conditioning apparatus **14** to be in the "off" operational mode to cool the conditioned area **15**. If the error E is positive, the air temperature T_A is less than expected and mode controller **56** outputs a mode control signal M which is equal to 1 to instruct the conditioning apparatus **14** to be in the "on" operational mode to heat the conditioned area **15**. In some embodiments, the mode controller outputs a mode control signal M which is equal to 2 to instruct the conditioning apparatus **14** to be in the supplemental or emergency heating mode.

[0042] As mentioned above, the error E is used to change the operational mode of the conditioning apparatus **14** at discrete moments in time, for example, according to a common interval or period, such as every 5 minutes in the described embodiment. In addition, the operational mode selected by the mode controller **56** at the beginning of a given interval is maintained for the entire interval in one embodiment. This controlling the change of operational mode at such discrete moments in time and maintaining the same operational mode during the entire interval prevents quick cycling of the conditioning apparatus **14** between different operational modes.

[0043] In particular, in one embodiment, the length of time of the interval or period between the discrete moments in time when changes to the operational mode are allowed be made may be greater than a minimum runtime of the conditioning apparatus (e.g., air conditioners and heat-pumps may have minimum runtime requirements to allow for pressure equalization before the next start to reduce motor wear and tear that occurs during compressor start-up with non-zero vapor backpressure). The selection of the length of the interval to be greater than the minimum runtime of the conditioning apparatus **14** in combination with the maintenance of the conditioning apparatus in the same operational mode during the length of the entire interval according to one embodiment assures that the conditioning apparatus **14** is operated appropriately and does not cycle too quickly.

[0044] In addition, this discrete control by thermostat controller **30** according to one embodiment enables control of the operational mode of the conditioning apparatus **14** with zero deadband and changes to the operational mode of the conditioning apparatus **14** may be made without hysteresis. For example, some conventional analog and digital thermostats change the operational mode after the actual temperature of a conditioned area exceeds a set point by an amount which equal to the deadband to reduce quick cycling. However, in the presently-described embodiment, changes are made to the operational mode by the thermostat controller **30** at defined moments in time based upon adjusted temperature set point T_C and the measured air temperature T_A and not due to changes in temperature in excess of a deadband.

[0045] In one embodiment, changes to the operational mode of the conditioning apparatus (e.g., every 5 minutes) are synchronized in time with the reception of updates to the control signal (e.g., every 5 minutes). Furthermore, although changes to the operational mode of the conditioning apparatus **14** are made at discrete moments in time defined by an interval, the operational mode may remain the same before and after individual discrete moments in time without a change if the error does not indicate that changes to the operational mode should be made.

[0046] The output of mode controller **56** is applied to digital-to-analog converter **58** and the digitized output M controls the operational mode of conditioning apparatus **14**. The converter **58** operates as a zero order sample/hold circuit in the illustrated embodiment which holds a constant output for the duration of an interval and which makes the discrete input from the mode controller **56** at the beginning of an interval appear as a continuous signal throughout the respective interval.

[0047] The control signal M is applied to the conditioning apparatus **14** to control the operational mode of conditioning apparatus **14** to heat or cool the conditioned area **15**. Element G of FIG. **3** corresponds to the coil, compressor and fan of conditioning apparatus **14** and the amount of power (W) and energy (W_h) to generate the heat Q which is applied to the conditioned area **15** may also be determined and output.

[0048] As discussed herein, some embodiments of the thermostat have minimal or zero deadband (hysteresis) which reduces aggregate load drift (reduces differences between measured load and cleared load) while maintaining satisfactory control of temperature of the conditioned area. Furthermore, consumers may configure the thermostat with different comfort preferences for different occupancy modes such as home, away, wake, sleep, etc. in one implementation. The disclosed thermostats provide energy shifting (reduce or increase in load) and cost savings based upon the control signal and provide an energy demand elasticity of an entire residential load between 10%-25% for air conditioning (heating or cooling) during peak times in some embodiments. Further elasticity is provided if the thermostats are used with other thermostatic end-use loads, such as refrigerators, freezers, water heaters, dish washers, clothes washers, and dryers.

[0049] Furthermore, at least some embodiments of the thermostats provide demand response in real-time distribution capacity auction systems. The disclosed thermostats may be implemented in arrangements to provide demand response which is one of the most cost-effective intermittency mitigation resources available to grid operators. At least some embodiments of the thermostat provide benefits of transactive systems, which implement demand response based on price of electricity (or other control), including environmental benefits associated with increased integration of renewable resources.

[0050] In compliance with the statute, the invention has been described in language more or less specific as to structural and methodical features. It is to be understood, however, that the invention is not limited to the specific features shown and described, since the means herein disclosed comprise preferred forms of putting the invention into effect. The invention is, therefore, claimed in any of its forms or modifications within the proper scope of the appended aspects appropriately interpreted in accordance with the doctrine of equivalents.

[0051] Further, aspects herein have been presented for guidance in construction and/or operation of illustrative embodiments of the disclosure. Applicant(s) hereof consider these described illustrative embodiments to also include, disclose and describe further inventive aspects in addition to those explicitly disclosed. For example, the additional inventive aspects may include less, more and/or alternative features than those described in the illustrative embodiments. In more specific examples, Applicants consider the disclosure to include, disclose and describe methods which include less, more and/or alternative steps than those methods explicitly disclosed as well as apparatus which includes less, more and/or alternative structure than the explicitly disclosed structure.

What is claimed is:

1. A thermostat comprising:

an interface configured to receive a control signal, wherein the control signal comprises fast components and slow components, and the fast components change at an increased rate compared with the slow components of the control signal;

control circuitry comprising:

a fast response controller configured to use the fast components of the control signal to generate a fast temperature offset;

a slow response controller configured to use the slow components of the control signal to generate a slow temperature offset; and

wherein the control circuitry is configured to use the fast temperature offset and the slow temperature offset to control a conditioning apparatus to at least one of heat and cool a conditioned area at a plurality of moments in time.

2. The thermostat of claim **1** wherein the fast response controller is configured to filter the slow components of the control signal and the slow response controller is configured to filter the fast components of the control signal.

3. The thermostat of claim **1** wherein the control circuitry is configured to use a comfort setting of a customer which is indicative of a customer preference of comfort with respect to temperature to generate the fast and slow temperature offsets.

4. The thermostat of claim **1** wherein the control circuitry is configured to use a mass temperature of the conditioned area, a desired temperature set point of the conditioned area, and an air temperature of the conditioned area to control the operation of the conditioning apparatus to at least one of heat and cool the conditioned area.

5. The thermostat of claim **4** wherein the control circuitry is configured to:

determine a first difference between the slow temperature offset and a mass temperature of the conditioned area;

add the first difference to the fast temperature offset to provide a combined temperature offset;

add the combined temperature offset to the desired temperature set point of the conditioned area to provide an adjusted temperature set point;

determine a second difference between the adjusted temperature set point and the air temperature of the conditioned area; and

use the second difference to control the conditioning apparatus.

6. The thermostat of claim **1** wherein the control signal is indicative of price of electrical energy which is supplied to the conditioning apparatus.

7. The thermostat of claim **6** wherein the control signal changes as a result of changes in the price of electrical energy which is supplied to the conditioning apparatus.

8. The thermostat of claim **1** wherein the control circuitry is configured to control operation of the conditioning apparatus in different operational modes at different discrete moments in time to at least one of heat and cool the conditioned area.

9. The thermostat of claim **8** wherein the control circuitry is configured to use the fast and slow temperature offsets to determine that a change of the conditioning apparatus from a first operational mode to a second operational mode is appropriate, and to control the conditioning apparatus to change from the first operational mode to the second operational mode with zero deadband and without hysteresis.

10. The thermostat of claim **1** wherein the control circuity comprises discrete control circuitry configured to change an operational mode of the conditioning apparatus only at a plurality of discrete moments in time.

11. The thermostat of claim **10** wherein the control circuity is configured to change the operational mode at the discrete moments in time which are defined by an interval.

12. The thermostat of claim **11** wherein the control circuitry is configured to maintain the conditioning apparatus in the same operational mode for an entirety of the interval.

13. The thermostat of claim **11** wherein the discrete moments in time correspond to updates in the price signal at different moments in time.

14. The thermostat of claim **11** wherein the mass temperature information is generated by a state estimator which samples the air temperature of the conditioned area at an increased rate compared with the rate of the discrete moments in time defined by the interval.

15. The thermostat of claim **11** wherein the interval is greater than a minimum runtime of the conditioning apparatus.

16. The thermostat of claim **1** wherein the fast and slow response controllers are configured to use a maximum allowed temperature deviation from a desired temperature set point of the conditioned area to generate the fast and slow temperature offsets.

* * * * *