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Inventor(s)	WELSH; Derrick

SAND-BASED THERMAL STORAGE APPARATUS

Abstract

A sand-based thermal storage apparatus, and a related system and method for heating a building are provided. The apparatus comprises an outer vessel, an inner vessel, a particulate heat storage material, and an electric heater. An annular interwall air space is defined between a wall of the outer vessel and a wall of the inner vessel, and surrounds the inner vessel. The interwall air space is in fluid communication with an outer vessel inlet and an outer vessel outlet. The particulate heat storage material comprises sand and is disposed in the inner vessel interior space and in contact with the inner vessel wall. At least part of the electric heater is embedded in the particulate heat storage material.

Inventors: **WELSH; Derrick (Dundas, CA)**

Applicant: **EVSAND INC.** (Dundas, CA)

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present application claims the benefit of and priority to U.S. Provisional Patent Application 63/554,655, filed Feb. 16, 2024, and titled "SAND-BASED THERMAL STORAGE APPARATUS", the contents of which are incorporated herein by reference in their entirety.

FIELD OF THE DISCLOSURE

[0002] The present disclosure relates to thermal storage apparatuses and related systems and methods for heating of buildings, and houses in particular.

BACKGROUND OF THE DISCLOSURE

[0003] In North America, the most common type of home heating system is a forced air furnace system that burns a fossil fuel (e.g., natural gas) to heat air and circulates the heated air through ductwork. Environmental concerns are motivating use of electrically powered heating systems (e.g., electric heat pumps and electric radiant heaters), but this has its own drawbacks. In many markets, electricity is sold to homeowners based on fluctuating time of use (TOU) price rates, and demand charges that depend on the consumer's peak power consumption rates. Concerns also exist about the ability of electrical grids to meet electricity demands for home heating, such as during prolonged periods of severe cold weather.

SUMMARY OF THE DISCLOSURE

[0004] It would be desirable for homeowners to be able to schedule electricity usage for heat generation in the most economical manner, and to store heat in the event of electricity supply failure. This requires a thermal storage apparatus to store generated heat and release the heat when desired. It would be preferable for such a heat storage apparatus to be economical, low maintenance, and conveniently retrofitted to ductwork of an existing forced air furnace system.

[0005] In one aspect, the present disclosure comprises an apparatus. The apparatus comprises an outer vessel, an inner vessel, a particulate heat storage material, and an electric heater. The outer vessel comprises an outer vessel wall that defines an outer vessel interior space, an outer vessel inlet, and an outer vessel outlet. The outer vessel inlet and the outer vessel outlet are spaced apart from each other in a longitudinal direction. The inner vessel extends in the longitudinal direction and comprises an inner vessel wall that defines an inner vessel interior space. The inner vessel is disposed in the outer vessel interior space with the inner vessel wall spaced apart from the outer vessel wall in a lateral direction transverse to the longitudinal direction to define an annular interwall air space. The interwall air space is between the outer vessel wall and the inner vessel wall, surrounds the inner vessel wall, and is in fluid communication with the outer vessel inlet and the outer vessel outlet. The particulate heat storage material comprises sand and is disposed in the inner vessel interior space and in contact with the inner vessel wall. At least part of the electric heater is embedded in the particulate heat storage material. Additional aspects of the apparatus are described herein.

[0006] In another aspect, the present disclosure comprises a system for heating a building. The building comprises a supply air duct terminating in a heat vent. The system further comprises an apparatus as described herein, wherein the outer vessel outlet is connected to the supply air duct to permit fluid communication from the interwall air space to the supply air duct via the outer vessel outlet. Additional aspects of the system are described herein.

[0007] In another aspect, the present disclosure comprises a method for heating a building. The method comprises supplying electrical energy to the electric heater of an apparatus as described herein to heat the particulate heat storage material; allowing the inner vessel wall to conduct heat from the particulate heat storage to the interwall air space; and operating a fan to flow air through the interwall air space from the outer vessel inlet to the outer vessel outlet. Additional aspects of the method are described herein.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] For a better understanding of the various embodiments described herein and to show more clearly how they may be carried into effect, reference will now be made, by way of example only, to the accompanying drawings in which:

[0009] FIG. **1** is an isometric view of an embodiment of a thermal storage apparatus of the present disclosure;

[0010] FIG. **2**A a top view of the apparatus of FIG. **1**;

[0011] FIG. **2**B is an elevation view of the apparatus of FIG. **2**;

[0012] FIG. **3**A is an isometric view of an outer vessel of the apparatus of FIG. **1**;

[0013] FIG. **3**B is an isometric view of an inner vessel of the apparatus of FIG. **1**;

[0014] FIG. **3**C is an isometric view of an electric heater of the apparatus of FIG. **1**;

[0015] FIG. **3**D is an isometric view of a plenum of the apparatus of FIG. **1**;

[0016] FIG. **4** is a functional block diagram of certain components of an embodiment of a thermal heating apparatus of the present disclosure;

[0017] FIG. **5** is a perspective view of a second embodiment of a thermal storage apparatus of the present disclosure;

[0018] FIG. **6** is a sectional elevation view of a third embodiment of a thermal storage apparatus of the present disclosure, with a schematic depiction of electrical components;

[0019] FIG. **7** is a sectional elevation view of a fourth embodiment of a thermal storage apparatus of the present disclosure, with a schematic depiction of electrical components; and

[0020] FIG. **8** is a flow chart of an embodiment of a method of operating a thermal storage apparatus of the present disclosure to heat a building and to regulate barometric pressure inside of the building.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE DISCLOSURE

Interpretation

[0021] For simplicity and clarity of illustration, where considered appropriate, reference numerals may be repeated among the Figures to indicate corresponding or analogous elements. In addition, numerous specific details are set forth in order to provide a thorough understanding of the embodiment or embodiments described herein. However, it will be understood by those of ordinary skill in the art that the embodiments described herein may be practiced without these specific details. In other instances, well-known methods, procedures and components have not been described in detail so as not to obscure the embodiments described herein. It should be understood at the outset that, although exemplary embodiments are illustrated in the figures and described below, the principles of the present disclosure may be implemented using any number of techniques, whether currently known or not. The present disclosure should in no way be limited to the exemplary implementations and techniques illustrated in the drawings and described below.

[0022] Unless otherwise explained, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure belongs.

[0023] Various terms used throughout the present description may be read and understood as follows, unless the context indicates otherwise: “or” as used throughout is inclusive, as though written “and/or”; singular articles and pronouns as used throughout include their plural forms, and vice versa; similarly, gendered pronouns include their counterpart pronouns so that pronouns

should not be understood as limiting anything described herein to use, implementation, performance, etc. by a single gender; “exemplary” should be understood as “illustrative” or “exemplifying” and not necessarily as “preferred” over other embodiments. Further definitions for terms may be set out herein; these may apply to prior and subsequent instances of those terms, as will be understood from a reading of the present description. It will also be noted that the use of the term “a” or “an” will be understood to denote “at least one” in all instances unless explicitly stated otherwise or unless it would be understood to be obvious that it must mean “one”. The phrase “at least one of” is understood to be one or more. The phrase “at least one of . . . and . . . ” is understood to mean at least one of the elements listed or a combination thereof, if not explicitly listed. For example, “at least one of A, B, and C” is understood to mean A alone or B alone or C alone or a combination of A and B or a combination of A and C or a combination of B and C or a combination of A, B, and C.
[0024] The term “comprising” and its derivatives, as used herein, are intended to be open ended terms that specify the presence of the stated features, elements, components, groups, integers, and/or steps, but do not exclude the presence of other unstated features, elements, components, groups, integers and/or steps. The foregoing also applies to words having similar meanings such as the terms, “including”, “having” and their derivatives. It will be understood that any embodiments described as “comprising” certain components may also “consist of” or “consist essentially of” these components, wherein “consisting of” has a closed-ended or restrictive meaning and “consisting essentially of” means including the components specified but excluding other components except for components added for a purpose other than achieving the technical effects described herein.
[0025] It will be understood that any component defined herein as being included may be explicitly excluded from the claimed invention by way of proviso or negative limitation, such as any specific component or method steps, whether implicitly or explicitly defined herein.
[0026] In addition, all ranges given herein include the end of the ranges and also any intermediate range points, whether explicitly stated or not.
[0027] Terms of degree such as “substantially”, “about” and “approximately” as used herein mean a reasonable amount of deviation of the modified term such that the end result is not significantly changed. These terms of degree should be construed as including a deviation of at least ±5% of the modified term if this deviation would not negate the meaning of the word it modifies.
[0028] The abbreviation, “e.g.” is derived from the Latin exempli gratia, and is used herein to indicate a non-limiting example. Thus, the abbreviation “e.g.” is synonymous with the term “for example.”
[0029] Modifications, additions, or omissions may be made to the systems, apparatuses, and methods described herein without departing from the scope of the disclosure. For example, the components of the systems and apparatuses may be integrated or separated. Moreover, the operations of the systems and apparatuses disclosed herein may be performed by more, fewer, or other components and the methods described may include more, fewer, or other steps. Additionally, steps may be performed in any suitable order. As used in this document, “each” refers to each member of a set or each member of a subset of a set.
[0030] As used in this document, “attached” in describing the relationship between two connected parts includes the case in which the two connected parts are “directly attached” with the two connected parts being in contact with each other, and the case in which the connected parts are “indirectly attached” and not in contact with each other, but connected by one or more intervening other part(s) between.
[0031] “Memory” refers to a non-transitory tangible computer-readable medium for storing information (e.g., data or data structures) in a format readable by a processor, and/or instructions (e.g., computer code or software programs or modules) that are readable and executable by a processor to implement an algorithm. The term “memory” includes a single device or a plurality of

physically discrete, operatively connected devices despite use of the term in the singular. Non-limiting types of memory include solid-state semiconductor, optical, magnetic, and magneto-optical computer readable media. Examples of memory technologies include optical discs such as compact discs (CD-ROMs) and digital versatile discs (DVDs), magnetic media such as floppy disks, magnetic tapes or cassettes, and solid state semiconductor random access memory (RAM) devices, read-only memory (ROM) devices, electrically erasable programmable read-only memory (EEPROM) devices, flash memory devices, memory chips and combinations of the foregoing. Memory may be non-volatile or volatile. Memory may be physically attached to a processor, or remote from a processor. Memory may be removable or non-removable from a system including a processor. Memory may be operatively connected to a processor in such as way as to be accessible by a processor. Instructions stored by a memory may be based on a plurality of programming and/or markup languages known in the art, with non-limiting examples including the C, C++, C#, Python™, MATLAB™, Java™, JavaScript™, Perl™, PHP™, SQL™, Visual Basic™, Hypertext Markup Language (HTML), Extensible Markup Language (XML), and combinations of the foregoing. Instructions stored by a memory may also be implemented by configuration settings for a fixed-function device, gate array or programmable logic device.
[0032] “Processor” refers to one or more electronic hardware devices that is/are capable of reading and executing instructions stored on a memory to perform operations on data, which may be stored on a memory or provided in a data signal. The term “processor” includes a single device or a plurality of physically discrete, operatively connected devices despite use of the term in the singular. The plurality of processors may be arrayed or distributed. Non-limiting examples of processors include integrated circuit semiconductor devices and/or processing circuit devices referred to as computers, servers or terminals having single or multi processor architectures, microprocessors, microcontrollers, microcontroller units (MCU), central processing units (CPU), field-programmable gate arrays (FPGA), application specific circuits (ASIC), digital signal processors, programmable logic controllers (PLC), and combinations of the foregoing.
[0033] Any method, application or module herein described may be implemented using computer readable/executable instructions that may be stored or otherwise held by a memory, and executed by a processor. Aspects of the present invention may be described with reference to flowchart illustrations and/or block diagrams of methods, apparatus (systems) and computer program products according to embodiments of the invention. It will be understood that each block of the flowchart illustrations and/or block diagrams, and combinations of blocks in the flowchart illustrations and/or block diagrams, can be implemented by computer program instructions. These computer program instructions may be provided to a processor, such that the processor, and a memory storing the instructions, which execute via the processor, collectively constitute a machine for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks.
[0034] The flowcharts and functional block diagrams in the figures illustrate the architecture, functionality, and operation of possible implementations of systems, methods and computer program products according to various embodiments of the present invention. In this regard, each block in the flowchart or block diagrams may represent a module, segment, or portion of code, which comprises one or more executable instructions for implementing the specified logical function(s). It should also be noted that, in some alternative implementations, the functions noted in the block may occur out of the order noted in the figures. For example, two blocks shown in succession may, in fact, be executed substantially concurrently, or the blocks may sometimes be executed in the reverse order, depending upon the functionality involved. It will also be noted that each block of the block diagrams and/or flowchart illustration, and combinations of blocks in the block diagrams and/or flowchart illustration, can be implemented by special purpose hardware-based systems that perform the specified functions or acts, or combinations of special purpose hardware and computer instructions.

[0035] The embodiments of the inventions described herein are exemplary (e.g., in terms of materials, shapes, dimensions, and constructional details) and do not limit by the claims appended hereto and any amendments made thereto. Persons skilled in the art will appreciate that there are yet more alternative implementations and modifications possible, and that the following examples are only illustrations of one or more implementations. The scope of the invention, therefore, is only to be limited by the claims appended hereto and any amendments made thereto.

Overview of Thermal Storage Apparatus

[0036] FIGS. **1** to **2**B show a perspective view (FIG. **1**), a top plan view (FIG. **2**A) and a side elevation view (FIG. **2**B) of an embodiment of a thermal storage apparatus **10** (hereinafter, simply, an “apparatus”). FIGS. **3**A to **3**D show components of the apparatus **10** of FIG. **1**. FIG. **4** shows a functional block diagram of some components of the apparatus **10** with lines between the components indicating operative connections, which may be implemented by wired connections and wired connection protocols (e.g., USB, Ethernet, etc.) and/or wireless connection protocols (e.g., WiFi™, Bluetooth™, etc.) as known in the art. FIGS. **5**, **6**, and **7**, show further embodiments of the apparatus **10**.

[0037] For convenient discussion, FIG. **1** shows the apparatus **10** in relation to a set of orthogonal reference x-, y- and z-axes. In the following discussion, the longitudinal direction refers to the direction coinciding with the direction of the z-axis, which may be the substantially vertical direction. The lateral direction refers to the direction transverse to the longitudinal direction, such as the directions coinciding with the x-axis or the y-axis, which may be substantially horizontal directions. It will be understood that the terms longitudinal direction and transverse direction are used herein in a relative sense, and do not limit the apparatus **10** to a particular orientation.

[0038] In general, the apparatus **10** includes an outer vessel **12**, an inner vessel **22**, a particulate heat storage material **38**, and an electric heater **40**. These and other components of the apparatus **10** are described below.

Outer Vessel, Inner Vessel, and Interwall Space

[0039] The outer vessel **12** is a structure that allows for through flow of air. The outer vessel **12** has an outer vessel wall that defines an outer vessel interior space. The outer vessel wall also defines an outer vessel inlet **14** that allows for flow of unheated air into the interwall air space **24** (as described below). The outer vessel wall also defines at least one outer vessel outlet **16** that allows for flow of heated air out of the interwall air space **24** (as described below). (It will be understood that the terms “unheated air” and “heated air” are used in a relative sense, and do not prescribe any particular temperature of the air). The outer vessel inlet **14** and the outer vessel outlet **16** are spaced apart from each other in the longitudinal direction (e.g., the vertical direction). In the embodiment of FIG. **1**, the outer vessel outlet **16** is disposed above the outer vessel inlet **14**, which may facilitate flow of heated air through the interwall air space **24** due to the tendency of heated air to rise within the outer vessel **12**. In the embodiment shown in FIG. **1**, the outer vessel inlet **14** is attached to an inlet conduit **18** which may be connected to a return air duct (not shown) of a building (e.g., a house). The outer vessel outlet **16** is attached via a plenum **30** to an outlet conduit **20** which may be connected to a supply air duct (not shown) of the building.

[0040] The inner vessel **22** is a structure that is used to contain the particulate heat storage material **38**. The inner vessel **22** extends in the longitudinal direction. The inner vessel **22** has an inner vessel wall that defines an inner vessel interior space that is used to store the particulate heat storage material **38**.

[0041] The inner vessel **22** is disposed in the outer vessel **12** interior space with the inner vessel wall spaced apart from the outer vessel wall in a lateral direction transverse to the longitudinal direction to define an annular interwall air space **24** between the outer vessel wall and the inner vessel wall. The interwall air space **24** surrounds the inner vessel wall and is in fluid communication with the outer vessel inlet **14** and the outer vessel outlet **16**. “Annular” as used herein, refers to the interwall air space **24** having a ring-shape in a cross-sectional plane in the lateral direction, but the ring-shape need not be circular. For example, the inner vessel **22** and the outer vessel **12** may both have a non-circular shape (e.g., rectangular or other polygonal shape) in a cross-sectional plane in lateral direction so as to define non-circular (e.g. a rectilinear or other polygonal) ring-shaped interwall air space **24** that surrounds the inner vessel wall, which is considered to be within the meaning of the term “annular” as used herein.

[0042] The outer vessel wall and the inner vessel wall may be made of a variety of suitable materials. In one embodiment, the outer vessel wall may have a layer of a thermally insulative material. In embodiments, the insulative material may comprise a mineral wool material (e.g., Rockwool™; Rockwool International) or another inorganic insulation material (e.g., fiberglass wool). The thermally insulative material helps to reduce heat loss from the heated air in the interwall air space **24** through the outer vessel wall. In one embodiment, the inner vessel wall may be made of a metallic material, such as steel. The metallic material may be selected to have a relatively high thermal conductivity to facilitate conduction of heat from the particulate heat storage material on the inside of the inner vessel wall to the air in the interwall air space **24** on the outside of the inner vessel wall.

[0043] The outer vessel **12** and the inner vessel **22** may have a variety of different shapes in different embodiments. In the embodiment shown in FIG. **1**, both the outer vessel wall and the inner wall vessel have a substantially cylindrical shape with a central axis extending in the longitudinal direction. In this embodiment, the central axes of the outer vessel **12** and the inner vessel **22** are collinear with each other so that the distance between the outer vessel wall and the inner vessel wall is substantially uniform in all lateral directions. In other embodiments, the outer vessel **12** and/or the inner vessel **22** may have other shapes such as an elliptical (oval) shape in a cross-sectional plane in the lateral direction, or an overall rectangular prismatic shape. In embodiments, the outer vessel **12** and the inner vessel **22** may have the same or similar shape (e.g., both are cylindrical in shape), or they may have different shapes (e.g., the outer vessel **12** is rectangular prismatic, and the inner vessel **22** is cylindrical). In embodiments, the outer vessel **12** may have a closeable opening (e.g., lidded opening) to access the inner vessel **22** disposed therein. In embodiments, the inner vessel **22** may have a closeable opening (e.g., a lidded opening) to allow for loading of the particulate heat storage material **38** therein at an installation site.

[0044] In embodiments, a proportion of a length of the inner vessel wall in the longitudinal direction to a distance between the outer vessel inlet **14** to the outer vessel outlet **16** in the longitudinal direction, expressed as a percentage, is at least 90 percent, 100 percent, or more. In the embodiment shown in FIG. **2**B, for example, the inner vessel wall is adjacent to the outer vessel inlet **14** and the outer vessel outlet **16** in the lateral direction the length of the inner vessel wall is greater than the distance between the outer vessel inlet **14** and the outer vessel outlet **16**. Accordingly, the air in the interwall air space **24** flows past the inner vessel wall along the entire path from the outer vessel inlet **14** to the outer vessel outlet **16**.

[0045] Referring to FIG. **2**, in this embodiment, the outer vessel inlet **14** is oriented to direct, into the interwall air space **24**, an air stream that is offset from a center of the outer vessel **12** in a cross-sectional plane in the lateral direction. The outer vessel outlet **16** is oriented to direct, out of the interwall air space **24**, an air stream that that is aligned with the longitudinal direction. As a result of this configuration, the air stream flows upwardly in a helical flow path, swirling circumferentially around the inner vessel **22** as the air stream flows from the outer vessel inlet **14** toward the outer vessel outlet **16**.

[0046] Referring to FIG. **1**, in this embodiment, the outer vessel **12** has an outer vessel outlet **16**, and an outer vessel auxiliary opening **17**. The outer vessel auxiliary opening **17** may act as a second outer vessel outlet or a fresh air intake, depending on the configuration of the recirculation valve **28**, as described below. Thus, the first outer vessel outlet **16** is oriented to direct, out of the interwall air space **24**, a first air stream in the longitudinal direction into a plenum **30** as described below. When the auxiliary outlet **17** is used as a second outer vessel outlet, the auxiliary outlet **17** is oriented to direct, out of the interwall air space **24**, a second air stream in the lateral direction and which may be offset from a center of the outer vessel **12**, which is then directed by the recirculation valve **28** to the recirculation conduit **26**.

Auxiliary Conduit, Recirculation Conduit and Valve

[0047] In the embodiment shown in FIG. **1**, the apparatus **10** comprises an auxiliary conduit **21** that provides fluid communication between the outer vessel auxiliary opening **17** and an auxiliary inlet **23** of the auxiliary conduit **21**. A recirculation conduit **26** branches from the auxiliary conduit **21** and permits fluid communication from the outer vessel auxiliary opening **17** to the outer vessel inlet **14**. A recirculation valve **28** (which may be generally referred to as a valve) is positioned to regulate air flow through the auxiliary conduit **21** either to the recirculation conduit **26** or from the auxiliary inlet **23**. In FIG. **1**, the recirculation valve **28** is shown symbolically by a hinged flapper valve member but may be implemented by a variety of different valve types. When the flapper valve member is in the raised open position (shown in solid line), the recirculation valve **28** permits heated air exiting the outer vessel auxiliary opening **17** to flow through the recirculation conduit **26** and into the interwall air space via the outer wall inlet **14**. When the recirculation valve **28** is in this configuration, the outer vessel auxiliary opening **17** may be considered to be a “second outer vessel outlet”. By opening the recirculation conduit **26**, the heated air is allowed to flow from the outer vessel auxiliary opening **17** to the outer vessel inlet **14**, and thereby preheat the unheated air before it enters the interwall air space **24**. This may result in air exiting the outer vessel outlet **16** being at a higher temperature than if the air entering the interwall air space **24** were not preheated in this manner.

[0048] Conversely, when the flapper valve member is in the lower closed position (shown in dashed line), the recirculation valve **28** prevents air from entering the recirculation conduit **26**. Instead, the recirculation valve **28** allows fresh air entering from the auxiliary inlet **23** to flow through auxiliary conduit **21** and the outer wall auxiliary opening **17** so that it can mix with heated air in the interwall air space **24** and the plenum **30** (as described below). For example, the auxiliary inlet **23** may be an inlet that is disposed outside of a house (e.g., on an exterior wall or a roof of a house) to allow for entry of fresh air.

[0049] In embodiments, the recirculation valve **28** is an electromechanically operated valve. The controller **46** (as described below) may activate the recirculation valve **28** based on a temperature measured by a thermal sensor **42** (as described below) and/or a pressure measurement by a barometric pressure sensor **43** (as described below). As a non-limiting example, the temperature measured by the thermal sensor **42** may be the temperature of air in a conduit upstream of the outer vessel inlet **14**, and the controller **46** may actuate the recirculation valve **28** to open the recirculation conduit **26** when the measured temperature is below a threshold temperature.

[0050] As another non-limiting example, the barometric pressure measured by the barometric pressure sensor **43** may be the pressure of air in the plenum **30** or another location of a building (e.g., a house). The controller **46** may actuate the recirculation valve **28** to close the recirculation conduit **26** to allow fresh air from the auxiliary inlet **32** to enter via the interwall air space **24** into the plenum **30** to increase the barometric pressure in the house when the measured barometric pressure is below a predefined threshold pressure. This may be useful for rebalancing pressure inside a well-sealed house that would not otherwise permit entry of sufficient make-up air to compensate for depressurization effects of ventilation devices (e.g., a bathroom fan, range hood, or dryer vent) or fuel-burning appliances (e.g., a natural gas furnace).

Plenum

[0051] In the embodiment shown in FIG. **1**, the apparatus **10** comprises a plenum **30** extending from the outer vessel outlet **16** to a plenum **30** outlet to establish fluid communication from the interwall air space **24** to the outlet duct. The plenum **30** allows cooler fresh air from the auxiliary inlet **23** to mix with heated air from the interwall air space **24** before the heated air is further distributed via outlet conduit **20**. A fan may be provided to draw a mixture of fresh air from auxiliary inlet and heated air from the interwall air space **24** into the plenum and through the outlet duct **20**.

Baffles in Interwall Air Space

[0052] In embodiments, the apparatus **10** further comprises at least one baffle **34** disposed in the interwall air space **24**, and attached to at least one of the outer vessel wall and the inner vessel wall. The baffles **34** may be used to direct flow of air through the interwall air space **24** in a circuitous manner and/or slow the flow of air through the interwall air space **24** so that the air is sufficiently heated by heat that is conducted from the particulate heat storage material **38** via the inner vessel wall. In the embodiment shown in FIG. **1**, the apparatus **10** has a plurality of baffles **34** that are spaced apart from each other in the longitudinal direction. Each of the baffles **34** is in the form of an annular baffle plate. The outer perimeter of the annular baffle plate is attached to the outer vessel wall. The annular baffle plate extends inwardly toward the inner vessel **22** so that there is no gap or only a small gap therebetween. Each baffle plate defines a baffle aperture **36** that allows fluid communication through the interwall air space **24** from the outer vessel inlet **14** to the outer vessel outlet **16**. The baffle apertures **36** of adjacent baffle plates are spaced apart from each other in the lateral direction. For example, as shown in FIG. **1**, adjacent baffle plates are rotated about a vertical axis with respect to each other by about 180 degrees so that their baffle apertures **36** are disposed on opposite sides of the inner vessel **22**. As a result of this configuration, the baffles **34** direct air flowing through interwall air space **24** from the outer vessel inlet **14** to the outer vessel outlet **16** in a helical-like path.

Particulate Heat Storage Material

[0053] The particulate heat storage material **38** is used to store the heat generated by the electric heater **40**. The particulate heat storage material **38** comprises sand. “Sand” as used herein refers to granular mineral particles having a diameter less than about 5 mm. As non-limiting example, sand may comprise have mineral particles with a diameter in the range of about 0.0625 mm to about 4.75 mm. The present disclosure is not limited by any particular mineral composition of the sand, with a non-limiting example including a mixture of silicon dioxide (quartz) and feldspars (e.g., sodium feldspar and/or potassium feldspar).

[0054] In some embodiments, the particulate heat storage material **38** may consist of sand, to the exclusion of other materials. In some embodiments, the particulate heat storage material **38** may comprise sand intermixed with other material(s). As a non-limiting example, the other material may comprise metallic particles (e.g., steel particles).

[0055] The present disclosure is not limited by a particular bulk density of sand. In some embodiments, the sand may be packed or compressed within the inner vessel **22** to a bulk density of at least 1500 kg/m3, more particular at least 1600 kg/m3, or even more particularly about 1650 kg/m3. Increasing the bulk density of the sand may increase the energy density of the sand, thus allowing for storage of greater heat energy for a given volume of sand.

[0056] The mass of the particulate heat storage material **38** may be selected depending on factors such as its heat capacity, and the amount of heat energy to be stored. The latter factor will depend on factors such as the size of the space to be heated by the apparatus, and the temperature differential between the expected temperature of the unheated air and the desired temperature of the heated air. In one embodiment, the mass of sand contained in the inner vessel **22** is about 150 kg, 180 kg, or 200 kg. For example, heating 180 kg of sand with a specific heat capacity of about 800/(kg K) by about 600° C. will result in the sand storing about 87×10{circumflex over ( )}6 J of heat energy.

Electric Heater

[0057] The electric heater **40** is a device that converts electrical energy to heat. In one embodiment, the electric heater **40** comprises a the resistive heating element **40** that generates heat by passage of electric current therethrough by the phenomenon of the Joule heating effect. In other embodiments, the electric heater **40** may convert electrical energy to heat in accordance with other principles of operation. At least part of the electric heater **40** is embedded in the particulate heat storage material **38**. In other words, the electric heater **40** is at least partially, and possibly fully, buried in the particulate heat storage material **38**, and in direct contact with the particulate heat storage material **38**, so that heat generated by the electric heater **40** conducts to the particulate heat storage material **38**. In embodiments, the electric heater **40** may have a variety of sizes and shapes (e.g., a wire or tube, a ribbon, a coil). In the embodiment shown in FIG. **1**, the electric heater **40** has a coil shape with a central axis that extends in the longitudinal direction so as to permit relatively even heating of the particulate heat storage material **38** contained in the cylindrical inner vessel **22**. The power density (i.e., heat flux per heated surface area) of the electric heater **40** may be selected to suit a particular application. In one embodiment, the power density of the electric heater **40** is sufficient so that it is operable to heat the particulate heat storage material **38** by at least about 800° C., or at least about 1000° C.

Thermal Sensor

[0058] Referring to FIG. **4**, in embodiments, the apparatus **10** may comprise a thermal sensor **42** to measure a temperature of a part of the apparatus **10**. The thermal sensor **42** may be implemented by a variety of known technologies for thermal sensors. A thermocouple, a thermistor, a resistance temperature detector (RTD) or a semi-conductor based thermal sensor are non-limiting examples of thermal sensors that may be suitable depending on the installation location of the thermal sensor **42** and the temperatures to which the thermal sensor **42** is exposed. In one embodiment, a first thermal sensor **42** in the form of a thermocouple may be positioned in the inner vessel **22** interior space to measure a temperature at or near a center of the mass of the particulate heat storage material **38**. A second thermal sensor **42** in the form of a thermocouple may be attached to the inner vessel wall to measure a temperature at or near the perimeter of the mass of the particulate heat storage material **38**. In addition or in the alternative, one or more thermal sensors **42** may be provided to measure temperatures at other locations inside or outside of a building (e.g., a house). These temperature measurements may be used by the controller **46** (as described below) to regulate the supply of electrical power to the electric heater **40**.

Barometric Pressure Sensor

[0059] Referring to FIG. **4**, in embodiments, the apparatus **10** may comprise a barometric pressure sensor **43** to measure a temperature of a part of the apparatus **10**. The barometric pressure sensor **43** may be implemented by a variety of known technologies for barometric pressure sensors. A microelectromechanical (MEMS)-based barometer, or a silicon-based piezoresistive pressure-sensing barometer that generates electronic signals depending on barometric pressure are non-limiting examples of barometric pressure sensors that may be suitable. As a non-limiting example, a barometric pressure sensor **43** may be installed within the plenum **30**, or at some location of a house that is situated remotely from the apparatus **10**. The barometric pressure measurements generated by one or more barometric pressure sensors **43** may be used by the controller **46** (as described below) to control the recirculation valve **28**, and/or used by the controller **46** (as described below) to control a switch **44** to regulate the supply of electrical power to the electric heater **40**.

Switch

[0060] Referring to FIG. **4**, in embodiments, the apparatus **10** may comprise a switch **44** (e.g. a relay switch) that is operable to regulate supply of electrical power from the power source connection **45** (e.g., the electrical circuit of a house) to the electric heater **40**. The controller **46** (as described below) may activate the switch **44** based at least on the temperature measured by the thermal sensor **42**. For example, the processor **48** of the controller **46** may control the switch **44** to supply or increase supply of electrical power to the electric heater **40** when the temperature measured by the thermal sensor **42** is at or below a lower threshold temperature. As another example, the processor **48** of the controller **46** may control the switch **44** to interrupt supply or decrease supply of electrical power to the electric heater **40** when the temperature measured by the thermal sensor **42** is at or above an upper threshold temperature.

[0061] The activation of the switch **44** by the controller **46** may based on factors that are additional or alternative to the temperature measured by the temperature sensor **42**. For example, the controller **46** may control the switch **44** based on the time of day. The controller **46** may comprise or be operatively connected to a computer clock. The controller **46** may control the switch **44** to control supply of electrical power to the electric heater **40** in accordance with predefined rules stored in the memory **50**, that are based on the time of day. For example, the controller **46** may control the switch **44** to supply electrical power to the electric heater **40** only during predefined times corresponding to off-peak hours (e.g., between 12 a.m. to 3 p.m., and from 10 p.m. to 12 a.m.) associated with lower time-of use electricity rates. Alternatively, the controller **46** may control the switch **44** to supply electrical power to the electric heater **40** during such off-peak hours in preference to peak hours associated with higher time-of-use electricity rates.

[0062] As another example, the controller **46** may control the switch **44** based on a prevailing electricity price rate. A predefined schedule of electricity price rates during a day may be stored in the memory **50** of the controller **46**. Alternatively, the controller **46** may be operatively connected to the internet or another communication network that allows the controller **46** to receive real-time time-of-use electricity price rates from a data source (e.g. a utility provider or regulator). The controller **46** may control the switch **44** to control supply of electrical power to the electric heater **40** in accordance with predefined rules stored in the memory **50**, that are based on the electricity price rate. For example, the controller **46** may control activation of the switch **44** to interrupt or decrease supply electrical power to the electrical heater **40** if the prevailing electricity price rate is at or above an upper threshold price. Conversely, the controller **46** may control activation of the switch **44** to supply or increase supply of electrical power to the electrical heater **40** if the prevailing electricity price rate is at or below a lower threshold price. In other words, the controller **46** may control the switch **44** to supply electrical power to the electric heater **40** during periods with lower electricity price rates in preference to periods with higher electricity price rates.

[0063] As another example, the controller **46** may control the switch **44** in accordance with a calculated amount of heat required over a time period, in excess of heat that is stored by the particulate heat storage material **38**. A first temperature sensor **42** may measure a first temperature at or near a center of the mass of the particulate heat storage material **38**. A second temperature sensor **42** may measure a second temperature outside of the house. The controller **46** may calculate a required amount of electrical energy that needs to be input to the electrical heater **40** to maintain a house at a predefined temperature or temperature range (e.g., at about 20° C.) over a time period. This calculation may be based on a predefined relationship (e.g., a mathematical function, or a lookup table) stored in the memory **50**, between the predefined temperature, the first temperature measurement and the second temperature measurement. The controller **46** may activate the switch **44** to control the supply of electrical power to the electric heater **40** based on the required amount of electrical energy. This may advantageously reduce the amount of electrical energy consumption, in comparison to a control algorithm that does not account for the amount of heat already stored by the particulate heat storage material **38**. In embodiments, the control of the switch **44** may also be based on aforementioned predefined rules based on the time of day and/or electricity price rates. For example, the controller **46** may implement an algorithm stored in the memory **50** to determine a schedule for activating the switch **44** to supply electrical energy to the electric heater **40** to maintain the temperature of the particulate heat storage material **38** to meet the required amount of heat over the time period. Optionally, the algorithm may use the time of day and/or electricity price rates as a constraint or constraint(s) on the schedule, or factors for optimizing the schedule to minimize the cost to supply electricity to the electric heater **40** over the time period. For example, the time period selected for calculating the required amount of heat may include both off-peak hours (associated with relatively low electricity pricing rates) and peak hours (associated with relatively high electricity pricing rates). If the heat already stored by the particulate heat storage material **38** (as indicated by the temperature of the particulate heat storage material **38**) is sufficient to satisfy the required amount of heat during the peak hours without supplying electrical energy to the electric heater **40** during the peak hours, then the controller **46** may determine a schedule that limits activating the switch **44**, if necessary, to supply electrical energy to the electric heater **40** to off-peak hours that precede or follow the peak hours. If the heat already stored by the particulate heat storage material **38** is insufficient to satisfy the required amount of heat during the peak hours, then the controller **46** may determine a schedule that activates the switch **44** to supply electrical energy to the electric heater **40** during peak hours (and possibly during off-peak hours), but limits the amount of electrical energy supplied during the peak hours to a minimum amount needed to meet the required amount of heat during the peak hours.

Controller

[0064] Referring to FIG. **4**, in embodiments, the apparatus **10** may comprise a controller **46**. The controller **46** includes at least one processor **48** and at least one memory **50**. The memory **50** is a non-transitory computer readable medium that stores control method instructions **52** that are executable by the processor **48** to control an operatively connected electromechanical recirculation valve **28** and/or the switch **44**, as discussed above, and/or a fan **58** as discussed below. The memory **50** storing the control method instructions **52** may be considered to be a computer-program product of the present disclosure.

[0065] FIG. **4** shows the processor **48** and the memory **50** by single functional blocks, but it will be understood that the processor **48** and the memory **50** may include a plurality of components or sub-components that are operatively connected to each other. For example, each of the processor **48** and the memory **50** may include a plurality of components that are physically discrete and remote from each other, but operatively connected together (e.g., by wire or wireless connections, and/or a communications network or protocols such as Wi-Fi, intranet or Internet protocols) in accordance with distributed computing techniques known in the art. For example, part of the processor **48** and memory **50** may be implemented by a microcontroller board programmed with firmware and forming part of a control panel, which is operatively connected to the thermal sensor **42**, the barometric pressure sensor **43**, the electromechanical recirculation valve **28**, the switch **44**, and/or the fan **58**. Another part of the processor **48** and memory **50** may be implemented by a personal computer device (e.g., a smartphone, a tablet computer, a desktop computer, or a laptop computer) running a software application that interfaces wirelessly with the microcontroller board.

[0066] The controller **46** may be operatively connected to a display device **54** (e.g., a display screen of the personal computing device) for displaying information relating to the control and operation of the controller **46** and the control methods implemented by the controller **46**. The processor **48** and memory **50** may also be operatively connected to a user input device **56** (e.g., a touch-sensitive display screen, a computer mouse, and/or a computer keyboard) for a user to provide information (e.g., threshold temperature values, threshold barometric pressure values, times of day corresponding to peak hours and off-peak hours of electricity price rates, and electricity price rates) relating to the control and operation of the controller **46** and the control methods implemented by the controller **46**. The processor **48** and memory **50** may also be operatively connected to a connection for a communication network **57** (e.g., a modem) to receive some or all of such information.

Second Embodiment With Fan and Filter

[0067] FIG. **5** shows an embodiment of the apparatus **10** similar to that shown in FIG. **1**. In this embodiment, the apparatus **10** further comprises an electrically powered fan **58** disposed externally of the outer vessel **12** on an inlet conduit **18** connected to the outer vessel inlet **14**. The fan **58** is operable to create an air flow from the outer vessel inlet **14** to the outer vessel outlet **16** via the interwall air space **24**. In this embodiment, the apparatus **10** also comprises a filter **60** positioned to filter air upstream of the outer vessel inlet **14**, by virtue of also being connected to the inlet conduit **18**, upstream of the fan **58**. The controller **46** (as described above) may activate the fan **58** based at least on the temperature measured by the thermal sensor **42** (as described above) or another thermal sensor. For example, in order to circulate air through the interwall air space **24** to heat a building, the processor **48** may activate the fan **58** when the temperature measured by the thermal sensor **42** is below or above a threshold temperature.

Third Embodiment With Tube Connecting Outer Vessel Inlet **14** and Outlet

[0068] FIG. **6** shows an embodiment of the apparatus **10** similar to that shown in FIG. **1**. In this embodiment, the apparatus **10** comprises a tube **62** extending from the outer vessel inlet **14**, via the interwall air space **24**, to the outer vessel outlet **16**, to permit fluid communication from the outer vessel inlet **14** to the outer vessel outlet **16** via the tube **62**. In this embodiment, the tube **62** has a coil shape wrapping around the inner vessel **22**, but in other embodiments, may have different configurations (e.g., a straight tube). The tube **62** may be used to convey air or a liquid, thus extending the use of the apparatus **10** to heat a liquid. For example, the tube **62** may be used to circulate heated water to a home water tank to substitute or supplement the heat generated by a burner of the home water tank, or to a water-based radiant heating system to substitute or supplement the heat generated by a boiler of the radiant heating system.

Fourth Embodiment With Tube Passing Through Particulate Heat Storage Material

[0069] FIG. **7** shows an embodiment of the apparatus **10** similar to that shown in FIG. **1**. In this embodiment, the apparatus **10** comprises a tube **62** extending through the outer vessel wall, the inner vessel wall and the particulate heat storage material **38**. In this embodiment, the tube **62** is straight, but in other embodiments, may have different configurations (e.g., a coil shape with a vertically oriented central axis). Like the embodiment shown in FIG. **6**, the tube **62** may be used to convey air or a liquid, thus extending the use of the apparatus **10** to heat a liquid.

Use and Operation

[0070] FIG. **8** is a flow chart of an embodiment of a method **100** of operating a thermal storage apparatus **10** of the present disclosure, which may be implemented by the controller **46** (as described above). It will be understood that the steps of the method **100** may be performed repeatedly and in real time. It will be understood that steps **108** and **110** may be performed concurrently or non-concurrently with steps **102** to **106**.

[0071] At step **102**, the controller **46** receives a temperature measurement from one or more thermal sensors **42**.

[0072] At step **104**, based on the temperature measurement, and/or other factors (e.g., a time of day, an electricity price rate), the controller **46** controls the switch **44** to increase or decrease supply of electrical power to the electric heater **40** to regulate the heating of the particulate heat storage material **38**. The inner vessel wall conducts heat from the heated particulate heat storage material **38** to the interwall air space **24**. The controller **46** may also control the recirculation valve **28** to regulate flow of air through the recirculation conduit **26** into the interwall air space **24**.

[0073] At step **106**, the fan **58** is operated to flow air through the interwall air space **24** from the outer vessel inlet **14** (which may be connected to a return air duct of a building) to the outer vessel outlet **16** (which may be connected to a supply air duct of a building). The fan **58** may be operated non-contemporaneously with supplying electrical energy to the electric heater **40**. For example, electricity may be supplied to the electric heater **40** for a period during a day (e.g., early morning) when electricity rates are lowest, or when electrical demand at a home is lowest. The heat generated by the electric heater **40** is stored in the particulate heat storage material **38**. While electricity is not being supplied to the electric heater **40**, the fan **58** may be operated intermittently during the day to circulate unheated air from a return air duct through the interwall air space **24** to the supply air duct of the building to heat the building, as needed. The amount of stored heat that is dissipated from the particulate heat storage material **38** will depend on the amount of air that is flowed through the interwall air space **24**.

[0074] At step **108**, the controller **46** receives a barometric pressure measurement from the barometric pressure sensor **43**. At step **110**, based on the barometric pressure measurement, the

controller **46** controls the recirculation valve **28** to allow fresh air from the auxiliary inlet **23** to flow into the interwall air space **24** via the auxiliary opening **17** of the outer vessel **12**. For example, the measured barometric pressure may indicate the barometric pressure inside a part of the house. If the measured barometric pressure is below a predefined threshold pressure, then the recirculation valve **28** may close the recirculation conduit **26** to allow fresh air from the auxiliary inlet **32** to enter into the plenum **30** to increase the barometric pressure in the house.
[0075] Although preferred embodiments of the invention have been described herein in detail, it will be understood by those skilled in the art that variations may be made thereto without departing from the spirit of the invention or the scope of the appended claims.
PARTS LIST
[0076] **10** apparatus [0077] **12** outer vessel [0078] **14** outer vessel inlet [0079] **16** outer vessel outlet [0080] **17** outer vessel auxiliary opening [0081] **18** inlet conduit [0082] **20** outlet conduit [0083] **21** auxiliary conduit [0084] **23** auxiliary inlet [0085] **22** inner vessel [0086] **24** interwall air space [0087] **26** recirculation conduit [0088] **28** recirculation valve [0089] **30** plenum [0090] **34** baffle [0091] **36** baffle aperture [0092] **38** particulate heat storage material [0093] **40** electric heater [0094] **42** thermal sensor [0095] **43** barometric pressure sensor [0096] **44** switch [0097] **45** power source connection [0098] **46** controller [0099] **48** processor [0100] **50** memory [0101] **52** control method instructions [0102] **54** display device [0103] **56** user input device [0104] **57** connection for communication network [0105] **58** fan [0106] **60** filter [0107] **62** tube [0108] **100-110** method, and steps thereof

Claims

1. An apparatus comprising: an outer vessel comprising an outer vessel wall that defines an outer vessel interior space, an outer vessel inlet, and an outer vessel outlet, wherein the outer vessel inlet and the outer vessel outlet are spaced apart from each other in a longitudinal direction; an inner vessel extending in the longitudinal direction and comprising an inner vessel wall that defines an inner vessel interior space, wherein the inner vessel is disposed in the outer vessel interior space with the inner vessel wall spaced apart from the outer vessel wall in a lateral direction transverse to the longitudinal direction to define an annular interwall air space between the outer vessel wall and the inner vessel wall that surrounds the inner vessel wall and is in fluid communication with the outer vessel inlet and the outer vessel outlet; a particulate heat storage material comprising sand and disposed in the inner vessel interior space and in contact with the inner vessel wall; and an electric heater, wherein at least part of the electric heater is embedded in the particulate heat storage material.
2-10. (canceled)
11. The apparatus of claim 1, wherein the outer vessel inlet is oriented to direct, into the interwall air space, an air stream that is offset from a center of the outer vessel in a cross-sectional plane in the lateral direction.
12-13. (canceled)
14. The apparatus of claim 1, wherein: the outer vessel outlet comprises a first outer vessel outlet and a second outer vessel outlet; the first outer vessel outlet is oriented to direct, out of the interwall air space, a first air stream in the longitudinal direction; and the second outer vessel outlet is oriented to direct, out of the interwall air space, a second air stream in the lateral direction.
15. The apparatus of claim 14, further comprising a recirculation conduit extending between the second outer vessel outlet and the outer vessel inlet to establish fluid communication from the second outer vessel outlet to the outer vessel inlet via the recirculation conduit.
16. (canceled)
17. The apparatus of claim **16**, wherein: the apparatus further comprises: a recirculation valve positioned to regulate air flow through the recirculation conduit, wherein the recirculation valve is

an electromechanically operated valve; a thermal sensor positioned to measure a temperature; and a controller comprising a processor and a memory comprising a non-transitory computer readable medium storing instructions executable by the processor to actuate the recirculation valve based on the temperature measured by the thermal sensor.

18. (canceled)

19. The apparatus of claim 1, wherein the outer vessel defines an auxiliary opening in fluid communication with the interwall air space to allow fresh air to enter the interwall air space and to mix with air in the interwall air space.

20. (canceled)

21. The apparatus of claim 1, wherein: the apparatus further comprises: a valve positioned to regulate air flow through the auxiliary opening, wherein the valve is an electromechanically operated valve; a barometric pressure sensor positioned to measure a barometric pressure; a controller comprising a processor and a memory comprising a non-transitory computer readable medium storing instructions executable by the processor to actuate the valve based on the barometric pressure measured by the barometric pressure sensor.

22. (canceled)

23. The apparatus of claim 1, further comprising at least one baffle disposed in the interwall air space, and attached to at least one of the outer vessel wall and the inner vessel wall, wherein the baffle defines a baffle aperture allowing fluid communication through the interwall air space from the outer vessel inlet to the outer vessel outlet.

24. (canceled)

25. The apparatus of claim 1, wherein the at least one baffle comprises a plurality of baffles that are spaced apart from each other in the longitudinal direction, and wherein the baffle aperture of a first one of the baffles and the baffle aperture of a second one of the baffles are spaced apart from each other in the lateral direction.

26. (canceled)

27. The apparatus of claim 1, wherein the particulate heat storage material consists of sand, and wherein the particulate heat storage material further comprises metallic particles mixed with the sand.

22-31. (canceled)

32. The apparatus of claim 1, further comprising: a thermal sensor positioned to measure a temperature of a part of the apparatus, or of a location inside or outside of a building; a switch operable to regulate supply of electrical power to the electric heater; and a controller comprising a processor and a memory comprising a non-transitory computer readable medium storing instructions executable by the processor to control the switch based at least on at least one of the temperature measured by the thermal sensor, a time of day, and an electricity price.

33-35. (canceled)

36. The apparatus of claim 1, wherein the apparatus further comprises an electrically powered fan operable to create an air flow from the outer vessel inlet to the outer vessel outlet via the interwall air space.

37-38. (canceled)

39. The apparatus of claim 1, further comprising a tube extending from the outer vessel inlet, via the interwall air space, to the outer vessel outlet, to permit fluid communication from the outer vessel inlet to the outer vessel outlet via the tube.

40. (canceled)

41. The apparatus of claim 1, further comprising a tube extending through the outer vessel wall, the inner vessel wall and the particulate heat storage material.

42. A system for heating a building comprising a supply air duct terminating in a heat vent, the system comprising the apparatus of claim 1, wherein the outer vessel outlet is connected to the supply air duct to permit fluid communication from the interwall air space to the supply air duct via the outer vessel outlet.

43. The system of claim 42, wherein the building comprises a return air duct, and wherein the outer vessel inlet is connected to the return air duct to permit fluid communication from the return air duct to the interwall air space via the outer vessel inlet.

44. A method for heating a building, the method comprising: supplying electrical energy to the electric heater of any apparatus of claim 1 to heat the particulate heat storage material; allowing the inner vessel wall to conduct heat from the particulate heat storage to the interwall air space; and operating a fan to flow air through the interwall air space from the outer vessel inlet to the outer vessel outlet.

45. The method of claim 44, wherein operating the fan is performed non-contemporaneously with supplying electrical energy to the electric heater.

46. The method of claim 44, wherein the outer vessel outlet is connected to a supply air duct of the building to permit fluid communication from the interwall air space the supply air duct via the outer vessel outlet.

47. The method of claim 44, wherein the outer vessel inlet is connected to a return air duct of the building to permit fluid communication from the return air duct to the interwall air space via the outer vessel inlet.