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(54) **PREFABRICATED INSULATED THERMAL ENERGY STORAGE ENCLOSURE**

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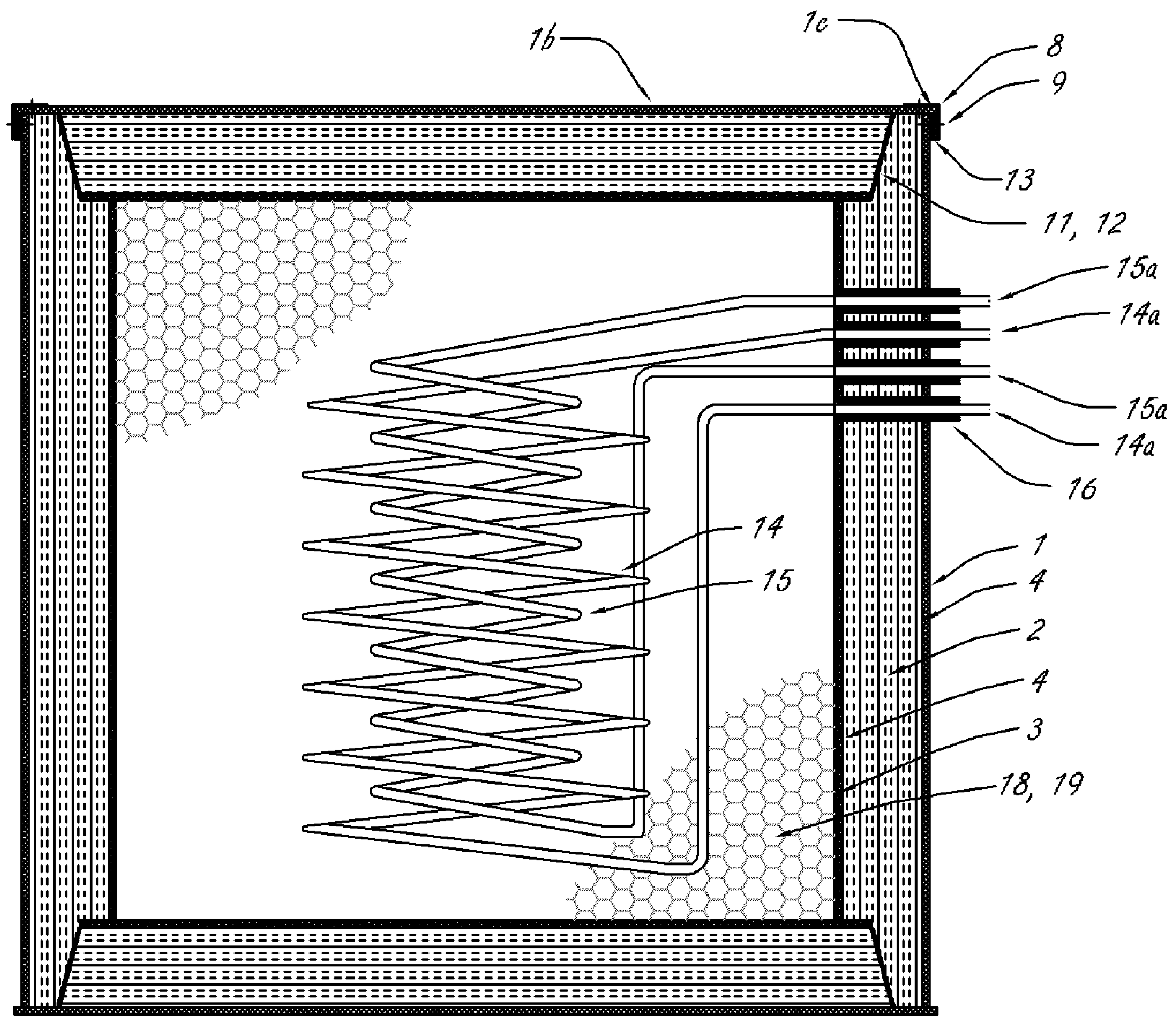
(57) **ABSTRACT**

A thermally insulated enclosure manufactured in pre-assembled or kit form, and constructed of prefabricated insulated sandwich panels, or structural insulated sandwich panels in some embodiments, rated for relatively high operating temperatures and designed for the storage of thermal energy in solid phase particulate storage medium or media at up to 125 deg C. and possibly higher. Said energy storage medium or media will typically be sand, gravel, or other powder or granulated material, or combination thereof, and optionally some proportion of phase change material. Said insulated enclosure is designed to accommodate a variety of heat transfer device designs in storing solar energy and off-peak-generated electric energy. The primary applications for the invention are expected to be in domestic hot water heating, space heating, and process heating, however in addition the thermal energy retained in the enclosure can also be used in powering the refrigeration cycle in some space cooling systems.



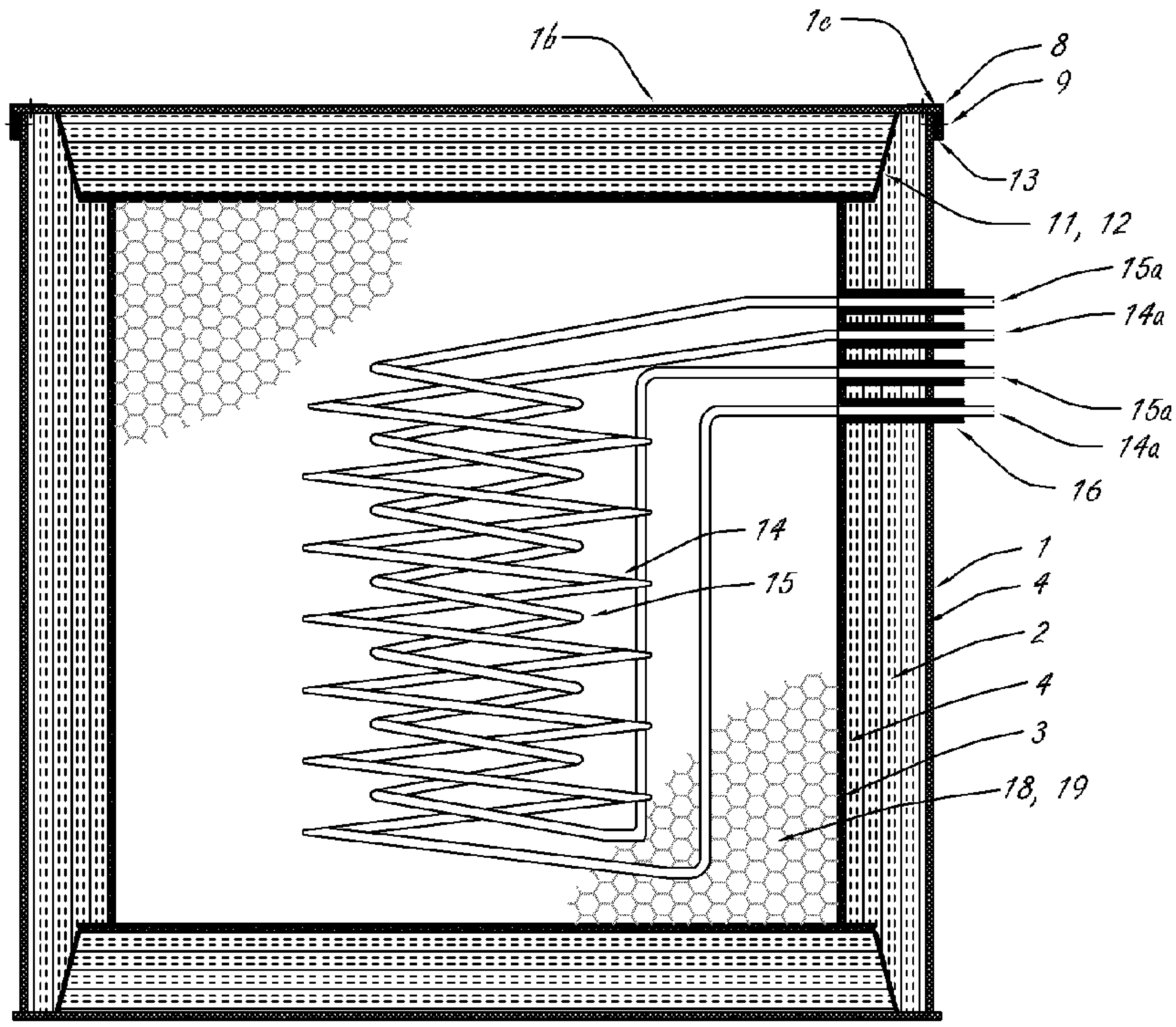


Fig 1

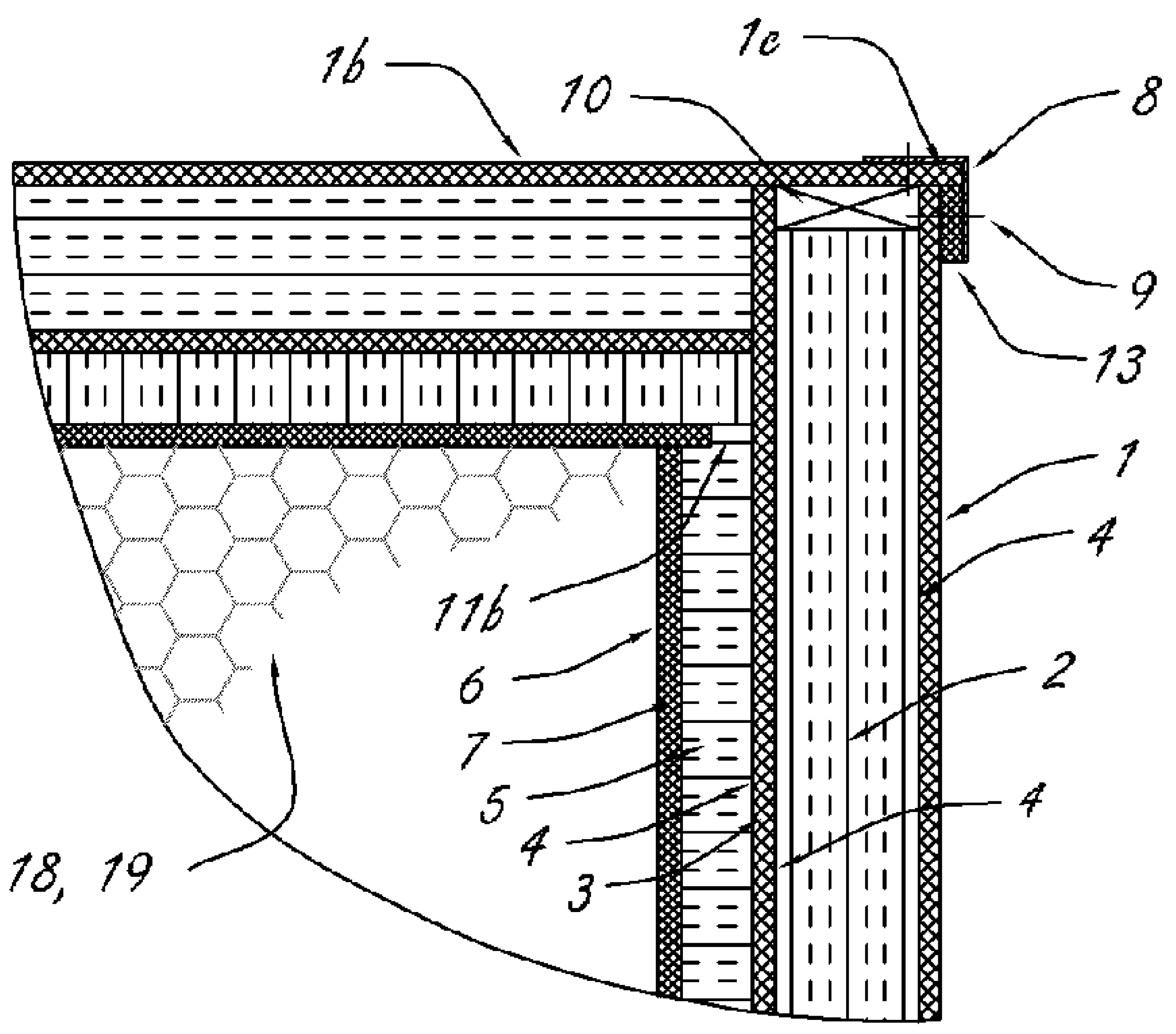


Fig 4

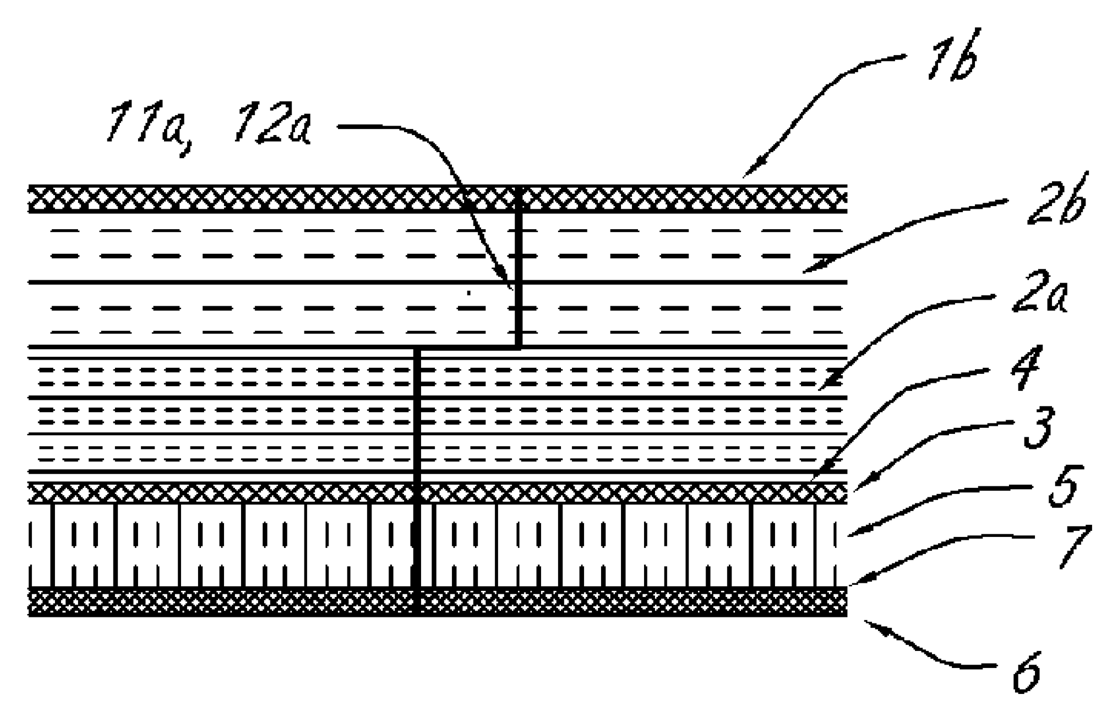


Fig 5

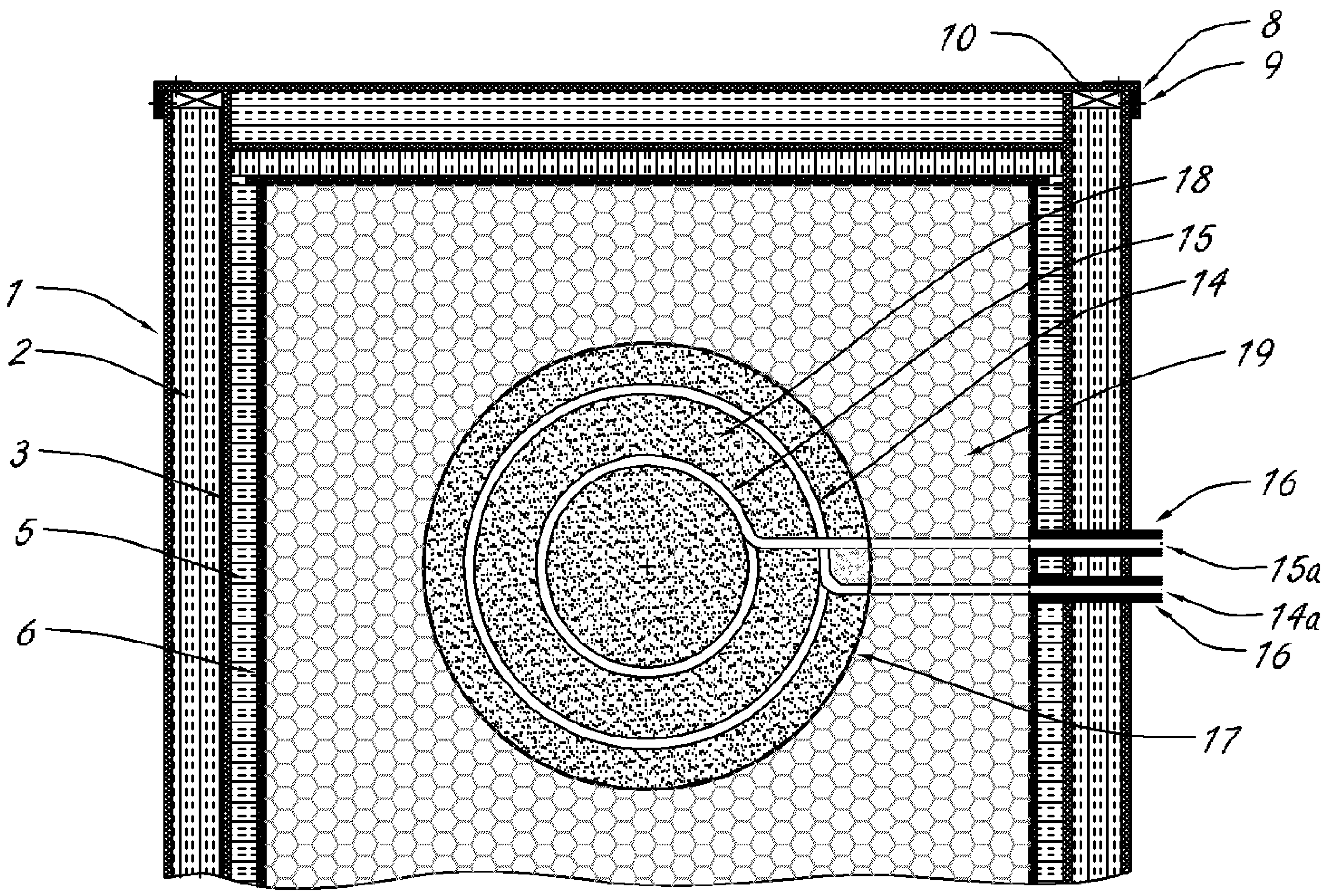

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Fig 2

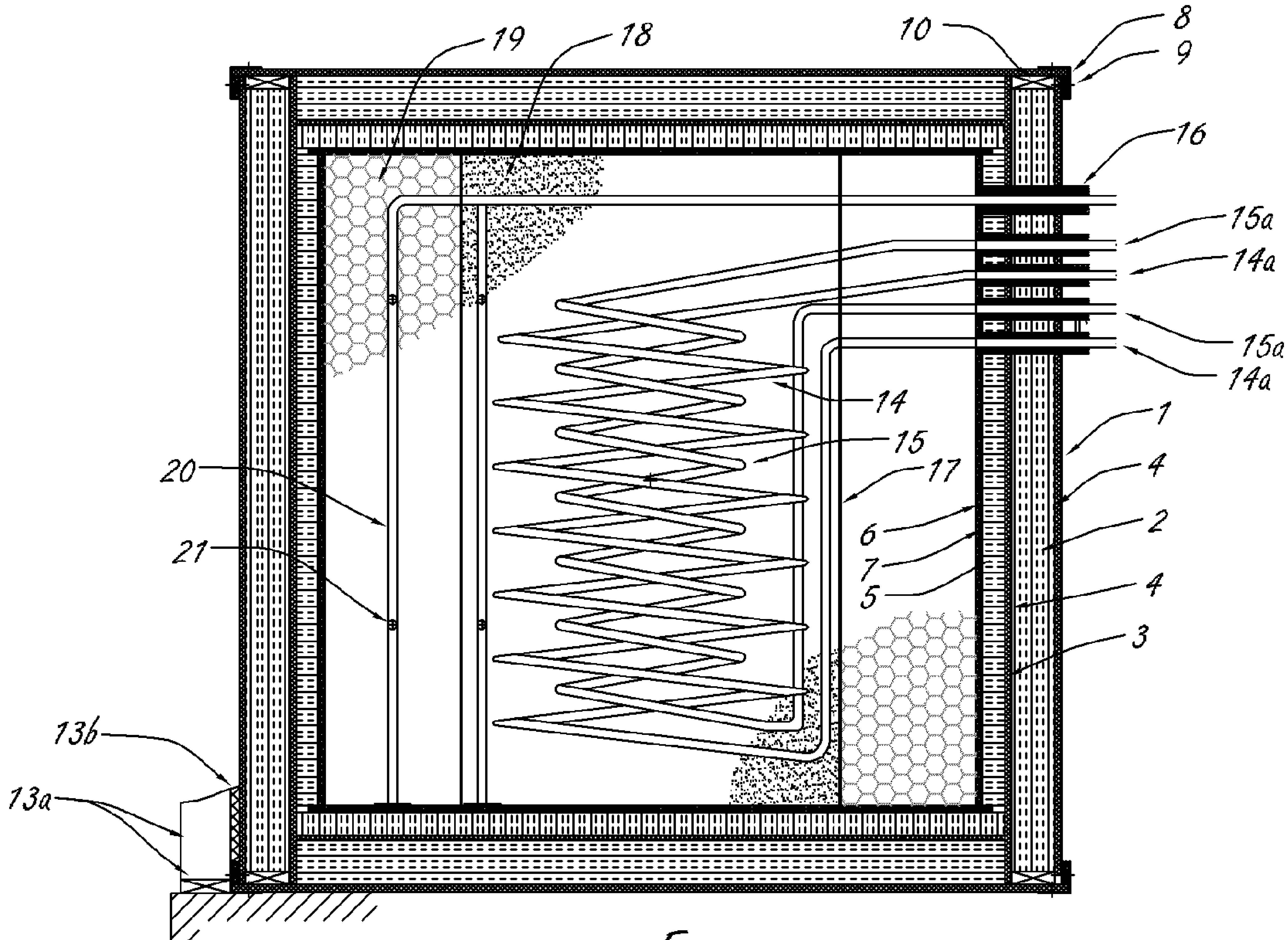
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Fig 3

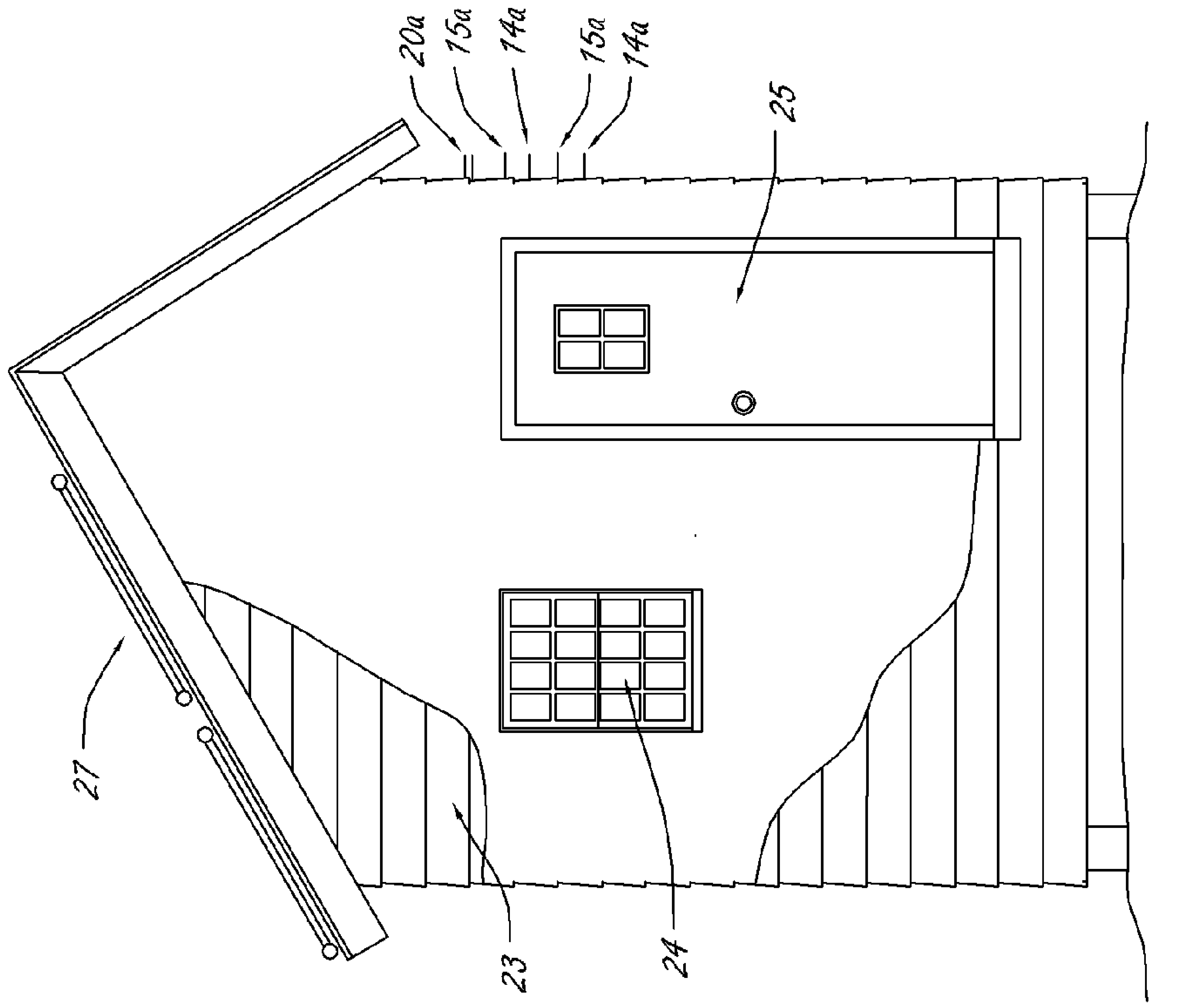
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Fig 7

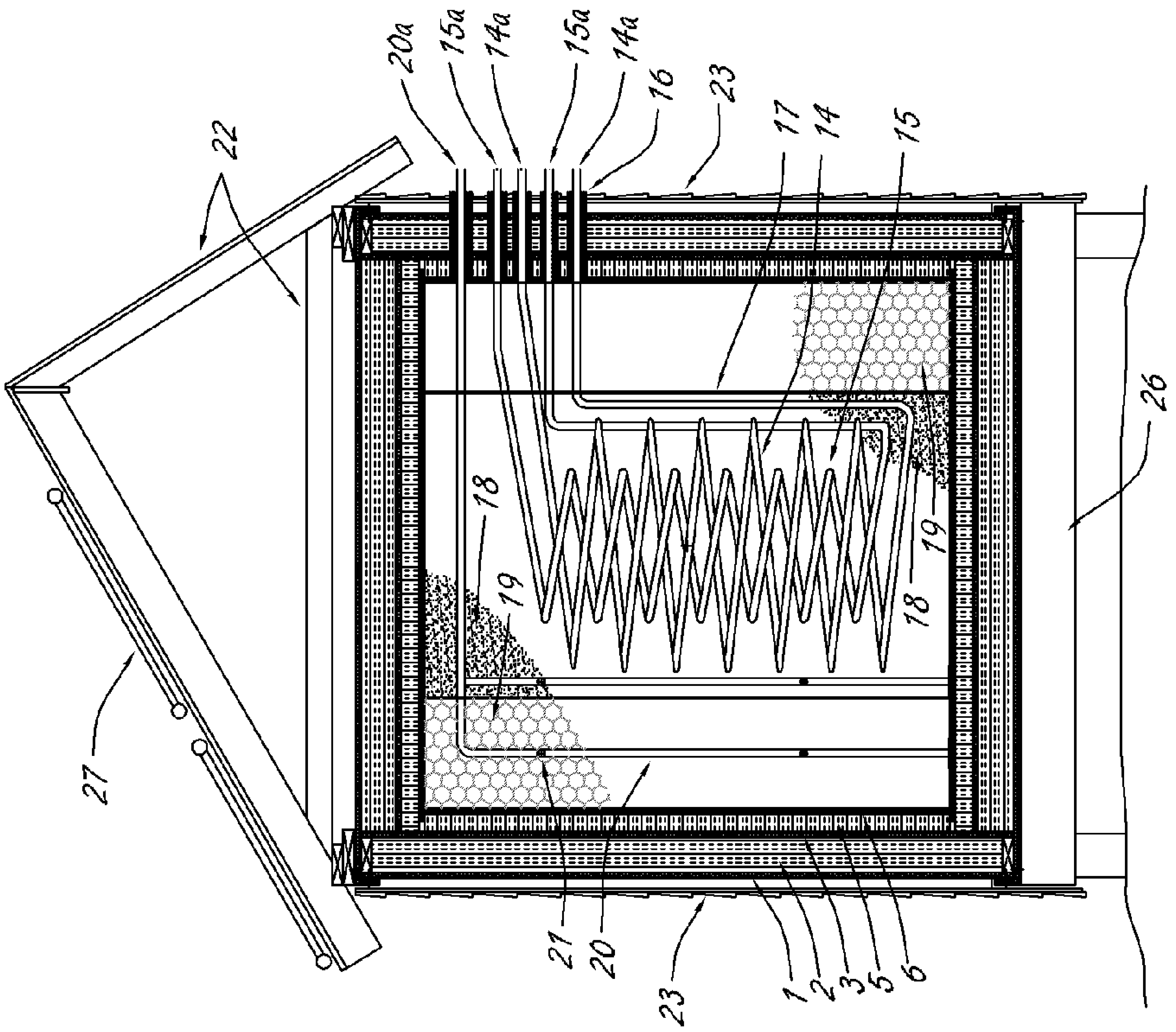
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Fig 6

PREFABRICATED INSULATED THERMAL ENERGY STORAGE ENCLOSURE

TECHNICAL FIELD

[0001] This disclosure relates generally to enclosures for the storage of thermal energy, and more specifically to such enclosures utilizing solid phase storage medium or media as opposed to a liquid phase storage medium. Said enclosures are constructed of prefabricated insulated sandwich panel assemblies forming the walls, floor and roof sections, suitable for manufacture as pre-assembled units and/or in kit form, with varying options in terms of ancillary components, such as internal heat transfer coils as described herein.

BACKGROUND ART

[0002] It is generally known that storage of thermal energy for later release and transfer to a structure, process or other entity requiring heat can be a useful and cost efficient undertaking. This concept is often used, for example, in active solar heating systems, commonly in residential, institutional, and commercial installations for domestic water heating or space heating. Other examples are process systems requiring thermal energy in commercial and industrial settings, and in heating water in swimming pools and similar facilities.

[0003] The benefits of such systems are in a reduction in the consumption of traditional non-renewable energy resources such as fossil fuels, in direct energy cost savings, or as an aid in enabling the deferral of construction of new capital-intensive electric generating facilities through the increased use of off-peak generation, an advantage that also benefits the consumer in the form of lower power rates.

[0004] It is commonly accepted that the need for more efficient use of renewable energy sources, such as solar power, and better utilization of non-renewable energy resources, as in off-peak electrical generation, will continue to grow as traditional fossil fuel resources are further depleted.

[0005] Storage of thermal energy for later release, as described above, is often achieved through the use of storage tanks containing a medium of water, brine, or other liquids, or in a storage medium of earth, rocks or other solid materials, all provided with some means of transferring said energy into, and recovery from, the energy storage medium. In some cases phase change materials (PCMs) are used to take advantage of the latent heat of fusion capacity available in such materials.

[0006] A number of previous patents have been issued for apparatuses that focus on the storage of thermal energy, however there are distinct and significant differences in the processes and apparatuses described in those patents in accomplishing this objective from those of the current invention, as summarized hereinafter.

[0007] Firstly, those patents generally identify solar as the sole energy source of interest, as opposed to one or both of solar and electrical as per the current invention.

[0008] Some previous patents, namely Can. 1,040,953 (Atkinson, issued Oct. 24, 1978) and Can. 1,020,828 (Strickland et al, issued Nov. 15, 1977) provide for thermal energy storage in an enclosure, both utilizing rocks as the storage medium, but also focus on the novelty of the means of the actual collection of said energy. The apparatuses defined by said patents are not particularly well-suited to the utilization of state-of-the-art but conventional solar collectors, for instance, as the means of energy collection. Also, retrieval of the stored thermal energy is by air circulation, which has practical limitations in many applications. In addition, and of significance with respect to the current invention, the ease and practicality of construction of said enclosures are not prime considerations in these patents, as with the current invention.

[0009] Other existing patents, namely Can. 1,108,879 (Balch, issued Sep. 15, 1981), and Can. 1,082,545 (Yaun, issued Jul. 29, 1980) are for systems and apparatuses in which the energy storage is achieved through utilization of ground mass in buried systems. These typically rely on relatively complex processes and apparatuses in storing and retrieving the thermal energy. By their nature they are typically intended for larger scale energy storage than that generally intended with the current invention.

[0010] Still other previous patents, namely Can. 1,206,106 (Hofius and Moses, issued Jun. 17, 1986), and Can. 1,160,923 (Stice, issued Jan. 24, 1984), focus primarily on the containers for retention of a thermal energy storage medium, and manufacturing of the same. Said patents offer distinctly different approaches to thermal energy storage requiring more highly specialized processes in the manufacturing of the inventive containers in comparison to those required with the current invention, and also are tailored to the use of PCMs as the primary energy storage media. As noted heretofore, PCMs do have one advantage over the particulate solid materials proposed herein, but they also typically have some disadvantages, including relatively high costs and the potentially problematic trait of experiencing relatively significant magnitudes of expansion and contraction in passing through the phase change temperature, a trait that must be physically accommodated in the apparatuses of the energy storage method employed. The inventive containers of the aforementioned patents that hold the PCMs also collect the solar energy directly, and are not particularly well-suited to the utilization of high efficiency conventional solar collectors, or off-peak electrical generation as sources for said energy, as proposed in the current invention.

[0011] The most common method of providing thermal energy storage in active solar systems in residential, commercial, institutional, and industrial settings, has been through single or multiple storage tanks containing water as the energy storage medium. Although water is known to have higher specific and volumetric heat capacities than most solid phase materials, and can thus store greater quantities of heat per given mass and volume respectively, concerns related to the risks of storing relatively large quantities of water can, for a variety of reasons, effectively impose fixed capacity limits on thermal storage systems using that medium.

[0012] Concerns over leakage of the contained liquid in these storage tanks typically increase with increasing storage volume, and also with increasing operating temperatures due to safety considerations of potential human contact exposure. If additional thermal energy storage is desired beyond that achievable at a given operating pressure, it is necessary to increase said pressure of the storage tank or tanks, thereby further increasing safety concerns related to the accidental release of steam. Furthermore, storage of thermal energy in water storage tanks with the water retained for some time within a relatively moderate temperature range of between 20° and 50° C. (68°-122° F.) can lead to the spread of micro-organisms responsible for legionnaire's disease, (ref. OSHA Technical Manual, Section 3, Chapter 7, Legionnaire's Disease—updated effective Jun. 24, 2008) resulting in increased risk to individuals exposed to said water.

[0013] Thermal storage capacity limitations of water tanks as discussed above can impose restrictions on the capabilities of potential installations, such as in restricting residential and institutional solar heating systems to the supply of domestic hot water (DHW) alone, rather than being supportive to the design of said systems to also provide supplemental thermal energy for space heating.

[0014] Where some form of solid phase thermal storage medium is used, rather than liquid phase, enclosures have not been available in an economical prefabricated form that facilitates construction and satisfies economic viability requirements to the extent being proposed in the current invention. Because of the relatively high temperatures that can be attained in thermal storage systems in some energy collection processes, specialized knowledge of material characteristics and specific design and construction details appropriate for a suitable enclosure are required. Such specialized knowledge requirements can thereby constrain potential constructors not trained in the art, resulting in the need for specialists in the field, and potentially leading to higher costs than can be justified in many situations. Alternately, defective designs and unsatisfactory performance can also result.

[0015] Accordingly there is a need in the art for a pre-engineered prefabricated enclosure, for use with solid phase thermal energy storage media that is economical, of adequate strength, highly thermally insulated, able to withstand the exposure temperatures to which it is subjected, and with the required thermal storage capacity and means of heat transfer, such as appropriately configured heat transfer coils of electrical wiring or piping design, with all components in a form that can be readily assembled by persons without specialized knowledge of the process and material characteristics required in the construction of said enclosure and ancillaries. Said heat transfer coils should be in a form suitable for connection to standard state of the art energy recovery systems, such as solar-based or electric, with the latter typically being in conjunction with an off-peak generation purchase agreement.

[0016] The enclosure should be of a design that can be varied in size to cover a range of thermal energy storage capacities and applications. The enclosure should be adaptable to either interior or exterior installations, with the latter being in a form suitable for mounting of solar collectors on the roof of said enclosure if advantageous in a solar-based system, and also one that satisfies the aesthetic requirements of the installation. This latter consideration, namely aesthetics, can be significant in establishing an embodiment of the thermal energy storage enclosure as the preferred alternative in an outside setting to other energy-saving and/or cost-saving options that may be available, but that may not offer as great an economic advantage through reduced energy costs.

DISCLOSURE OF INVENTION

[0017] The present invention is a prefabricated insulated enclosure for the storage of thermal energy in solid phase particulate storage medium or media (PTESM) at temperatures up to 125 deg C. and possibly higher, that provides a practical alternative to a single or multiple water storage tank(s) typically used for this application, such as in solar-heated DHW and space heating installations, and also as an alternative to other methods and enclosures that utilize a solid phase storage medium, but that lack the innovations and advantages featured in the current invention. The PTESM used to fill the enclosure can be sand, gravel, or other powder or granulated material, or, as described later in this section, a combination of particulate media grades, with the different grades separated by a cylindrical metallic structural partition, thereby benefiting the heat transfer processes involved due to specific properties characteristic of each grade as discussed hereinafter. In addition, it is also possible to incorporate PCMs as a portion of the PTESM used, thereby benefiting from latent heat capacity of the PCMs in addition to the sensible heat capacity of the PTESM. The inventive enclosure is adaptable to both interior installations, and exterior installations with appropriate weather protection elements added to the enclosure as further described hereinafter.

[0018] The inventive enclosure is constructed of a set of panel-type envelope components forming the two side walls, two end walls, roof and floor. Said envelope panel components are designed as prefabricated composite "sandwich" type assemblies with rigid facing panels and a core of sheet or board-type insulation, or alternately, a foamed-in-place type of insulation. In one embodiment of the current invention, these components are bonded to each other to act compositely in providing flexural and shear strength in resisting the lateral loading imposed on the walls by the PTESM, as well as gravity loading, both due to the weight of the PTESM and other interior components as further described hereinafter, and also of external environmental loading in the instances of exterior installations of the inventive enclosure. Said external environmental loadings are discussed further hereinafter. This design concept for said embodiment of the sandwich panel is similar to that employed in structural insulated panels, commonly known as SIPs, as used in the exterior envelope construction of some buildings.

[0019] The aforementioned sandwich panel envelope components have the thermal insulative resistance required to restrict heat loss from the PTESM to acceptable values, as determined though economic analyses that generally consider the following; cost savings though reduced purchase requirements of conventional energy, enclosure and system construction and installation costs, and calculated rates of thermal energy loss though enclosure envelope components. Maximum anticipated exposure temperature from contact with the heated PTESM impacts on the aforementioned materials used for said sandwich panel construction, namely, the interior facing panels, combination structural and insulative core, and bonding adhesive(s). Given that the panels for the inventive enclosure combine the structural characteristics of the aforementioned SIP panels along with a high temperature resistance necessitated by the relatively high temperature potentially attainable in the storage medium, the said panels for the inventive enclosure shall hereinafter be referred to as HTSIP ("high temperature structural insulated panel") as an abbreviated form of identification.

[0020] In a second embodiment of this invention the flexural and shear strength requirements of the wall sections of the insulative enclosure are provided by external structural framing against which the sandwich wall panels are braced. Similarly, the floor panel can be provided with additional structural support in the form of a prefabricated but conventional floor framing assembly, or alternately, a base slab, typically of concrete construction. Depending on the height of wall, span of the floor, and weight and lateral loading characteristics of the PTESM, it may not otherwise be economically practical to provide the strength required to the floor as in an HTSIP type assembly. In these cases the non-structural sandwich panels shall hereinafter be referred to as

HTSANIP ("high temperature sandwich insulated panel") as an abbreviated form of identification.

[0021] In another embodiment of the invention the insulative core of said sandwich panels are constructed of multiple bonded layers of different insulative materials such that adequate structural and thermal performance is provided by the core in achieving the required structural performance of said sandwich panels. Less costly materials can then be used where maximum temperature resistance requirements through the thickness of said insulative core are reduced as a result of the temperature gradient that naturally occurs through the sandwich panel assemblies with increasing distance from the aforementioned and heated PTESM

[0022] In yet another embodiment of the current invention additional sandwich panel layered components, comprising a high temperature insulative layer and high temperature protective liner panel in contact with the PTESM, are bonded to the prefabricated insulated sandwich panel assemblies of the walls, floor and roof of the enclosure, thereby providing added protection against deterioration in the structural and/or thermal performance of the sandwich panel assemblies as a result of the aforementioned temperature gradient, and thus avoiding similar deterioration in the structural and/or thermal performance of the enclosure as a whole assembly.

[0023] In yet another embodiment of the current invention the enclosure is provided with two separate prefabricated internal heat transfer systems, with the "input" system consisting of one or more heat transfer coils to transfer the thermal energy from the energy source to the PTESM in the inventive enclosure, and the "output" system consisting of one or more heat transfer coils to transfer said stored energy to the end use application, or in some cases to one or more intermediate energy transfer devices, such as an inside water tank with relatively small thermal storage capacity in comparison to the inventive enclosure.

[0024] Said "input" heat transfer systems can be one of a range of alternative designs, namely in the form of piping for containment of liquid as the heat transfer medium, ducting for containment of hot air as the heat transfer medium, or electric resistance wiring. Said "output" heat transfer systems are generally in the form of piping for containment of liquid as the heat transfer medium. Where the heat transfer system type is in the form of piping, external fins attached to said piping may be provided to improve the efficiency of energy transfer to or from the PTESM. Configuration and construction of these heat transfer system elements are designed to facilitate the placement of the PTESM with minimal risk of damage to said elements during the process of filling the inventive enclosure with said medium (media), and also to preferentially transfer heat from storage areas of higher temperature of said medium (media) within the inventive enclosure rather than from storage areas of lower temperature of said medium (media). In one embodiment of the invention the aforementioned prefabricated structural sandwich panel assemblies are provided with insulative sleeves (**16**) at the locations where the aforementioned piping, wiring, and ducting of the associated aforementioned thermal energy transfer device(s) penetrate said sandwich panels, thus providing protection to portions of the insulative core that may otherwise be damaged if exposed to direct contact with the heated inlets and outlets of the heat transfer devices.

[0025] In another embodiment of the invention the enclosure is provided with one or more heretofore identified cylindrical metallic fabrication(s) extending vertically between the interior faces of the floor and roof sandwich panels of the inventive enclosure to allow separation of different PTESM grades, thereby providing additional benefits as summarized below;

[0026] The separation of PTESM grades as noted better optimizes the use of the different performance characteristics of the storage media both inside and outside the barrier created by said cylindrical fabrication(s). A preferred grade of PTESM for placement inside the confines of said cylindrical fabrication(s) is one such that a balance is provided in the cost of the medium and in reducing the potential for damage to the heat transfer coils positioned within said fabrication(s) during the PTESM filling process, or during the removal of the PTESM in the event servicing of said coils is required, while still providing adequate heat transfer capabilities, such as with sand. A preferred grade of PTESM for placement outside the confines of said cylindrical fabrication(s) is one, different from the aforementioned "inside" grade, such that a balance is provided in the cost of the medium and in maximizing both heat transfer efficiency and thermal energy storage capacity, such as with gravel.

[0027] Servicing and removal of the heat transfer coils positioned within said cylindrical fabrication(s) is facilitated through the ability to remove just the PTESM material within said fabrication(s) by suction or other process, and leaving undisturbed the PTESM material occupying the space between said cylindrical fabrication(s) and the inside faces of the enclosure.

[0028] In another embodiment of the invention the enclosure is provided with conduit propitiously positioned within the interior space to accommodate wiring and temperature sensor devices for the purpose of recording process data and providing data to the process control system employed in managing the heat transfer processes involved.

[0029] The inventive enclosure can be pre-assembled, or made available in kit form, with the previously described HTSIP and/or HTSANIP components prefabricated for ready assembly in a location remote from the area of said fabrication. In various embodiments of the invention, the other heretofore-described ancillary components can be included in said kit.

[0030] Although the inventive enclosure is suitable for use in a variety of environments, including residential, institutional, commercial and industrial, the anticipated highest demand is in residential applications, and more specifically, in active solar heating systems, for either DHW heating or space heating, or both combined. In such solar heating systems, the PTESM in the enclosure is heated by conventional solar collectors, with temperature regulation by a compatible conventional control system as typically used in solar heating systems employing storage tanks for containment of water or other liquids as the means of storing the thermal energy. The PTESM is able to take greater advantage of the higher temperature capabilities of some designs of collectors, such as "vacuum tube-" or "evacuated tube"-type solar collectors, in comparison to what is practical in the storage of water in conventional hot water storage tanks. In addition to heating applications, the enclosure is also able to provide thermal energy in powering the refrigeration cycle by means of thermally-driven coolers in space cooling systems.

[0031] A number of parameters in the design of the inventive enclosure and aforementioned ancillary components can be varied and thus accordingly impact thermal energy storage capacity and efficiency. These parameters include overall enclosure size and thermal insulative resistance of the HTSIP envelope, thermal characteristics of the PTESM, and design specifications of the internal heat transfer coils.

[0032] In numerous applications, such as in solar-based residential combined DHW and space heating systems, significantly greater thermal energy storage capacity is typically achievable with the inventive enclosure than with traditional water tank storage. To illustrate this point, the theoretical thermal energy storage capacities of typical configurations in each of the two storage systems were calculated.

[0033] Interior measurements of the inventive enclosure were taken as 1800 mm×2400 mm×1800 mm for comparison to a 760 litre (**200** US gal) water storage tank, generally considered a "large" tank for a residential system, and one more likely to be used for combined DHW and space heating rather than just DHW alone, a more common configuration. The PTESM for the inventive enclosure was assumed to be silica sand with a specific heat value of 1,280 kJ/m^3 K, in comparison to water, with a comparable value of 4,180 kJ/m^3 K. Maximum operating temperatures of 125° C. and 90° C. were assumed for the inventive enclosure and storage tank respectively, in consideration of the higher temperature capabilities typically achievable with the PTESM in the inventive enclosure. A common reference ambient temperature of 35° C. was assumed as the minimum useful temperature for heating purposes. Based on the foregoing parameters and including an allowance for reduced thermal storage capacity due to the space occupied within the inventive enclosure by heat transfer coils and other peripherals, the theoretical thermal energy storage capacities were determined to be 866 MJ (240 kw-hr) and 170 MJ (47 kw-hr) for the inventive enclosure and water storage tank respectively relative to the base thermal energy content at the assumed common ambient temperature in the two sample systems as described.

[0034] Obviously the difference in thermal energy storage capacities would be even greater for a smaller water storage tank more typical for this application, particularly in a residential system. Such a difference may influence the decision regarding degree of conversion to a more environmentally sensitive energy system; potentially even to the extent it could be determined not to proceed with the conversion in the first place. As previously noted, the size of the inventive enclosure and associated volume of PTESM can be varied over a wide range with minimal increased risk resulting from the increased thermal storage capacities, in contrast to the situation with water storage based systems, as discussed heretofore, and further hereinafter.

[0035] The enclosure is adaptable to either an interior or exterior site installation. In an exterior installation, the basic inventive enclosure structure is typically protected from weather elements by means of conventional roof and wall sheathing and other conventional cover materials. In the case of the enclosure being constructed of HTSIP elements, as heretofore defined, the said enclosure also forms the base structural element in resisting the additional imposed design loadings of an environmental nature. Aesthetic requirements can be met in those instances through the selection of appropriate cover materials and trim elements, including facade-style window and door elements, and by tailoring the shape of the visible "building" as desired, thereby providing an appearance that is complementary to the site and adjoining buildings.

[0036] An additional benefit of an exterior setting for a solar energy installation utilizing the inventive enclosure as noted above is that of the roof providing a convenient and preferential location for solar collector mounting that is more-readily accessible than is often typically the case, in turn allowing for improved access for inspection and maintenance of said collectors, along with the possibility of adjusting the orientation of said roof to maximize the solar radiation collection efficiency of said collectors.

[0037] The invention provides several advantages over existing hot water storage systems in many potential applications;

- **[0038]** As discussed heretofore, thermal energy storage capacity can be more easily varied over a larger range thereby increasing the potential for greater storage for periods of darkness and low solar radiation, thereby yielding increased savings through greater reductions in conventional energy costs.
- **[0039]** The concern over liquid spillage of the storage medium is eliminated, other than the potential risk of a smaller amount of PCM if used as replacement for some fraction of the PTESM. Although in those systems employing liquid-type solar collector systems, process fluids at high temperatures still exist in the heat transfer piping systems and in possible auxiliary equipment, such as an optional intermediate small energy transfer tank that can be used in the heat exchange system serving the end-use application, the total volume of hot fluids is significantly reduced. When the inventive system is used in conjunction with off-peak electrical generation, concern over liquid spillage is limited to just that of the circulating liquid type heat recovery system employed in the recovery of thermal energy from the PTESM of the inventive enclosure.
- **[0040]** Higher insulation levels can more easily be provided for with the inventive enclosure in comparison to that practically achievable with conventional hot water storage tank installations.
- **[0041]** The maximum temperature of the storage medium can typically be increased in comparison to water-based storage, although it is recognized that this advantage is offset to some degree by the lower specific heat capacity of many potential common medium materials, such as sand, in comparison to water.

[0042] In addition to the aforementioned advantages over alternative existing designs, the inventive enclosure incorporates other features that increase the practicality of the form of thermal energy storage it affords to many potential users of said energy as follows:

- **[0043]** The invention can be readily retrofitted to existing houses. As heretofore noted, the enclosure can be installed in either an interior or exterior setting. In further variations of site selection options, it can be located inside an existing or proposed building that is outside the main residence, such as a detached garage structure, with the connective piping to the end use structure typically insulated and routed through burial in a trench or in some other effective manner.
- **[0044]** The enclosure can accommodate a range of PTESM materials. Sand and gravel are considered the most economical relative to initial cost, however other materials may prove to be more cost effective taking into consideration thermal capacity and alternative energy costs. As previously noted one alternative to further

increase storage capacity for a given enclosure is in the use of PCMs as a replacement fraction of the PTESM mass.

[0045] The prefabricated nature of the construction, including the integral and appropriately-configured heat transfer system assemblies, utilizing materials specifically selected to meet necessary thermal, structural, and aesthetic requirements, along with the other advantages afforded by the inventive enclosure, as heretofore outlined, in satisfying the energy demands of the heating and/or cooling system(s) of the end use application are considered key elements in the novelty of the invention. The enclosure system thus has considerably greater practicality, including economic viability, for construction by the typical end-user, either with assistance from a contractor, or as a "do it yourself" project, than the alternative of attempting to construct a system utilizing similar concepts but without the benefit of the engineering design or prefabrication of required components

[0046] Other advantages and features of the invention will become more apparent from the following description and the accompanying drawings which are illustrative of preferred embodiments of the invention claimed herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0047] Drawings which illustrate embodiments of the invention and included herein are as follows;

[0048] FIG. **1** is a sectional view taken at a vertical plane through the basic embodiment of the invention with a single grade of core insulation (**2**) and depicting heretofore described "input" heat transfer coil (**14**) and "output" heat transfer coil (**15**) in schematic form along with the insulative sleeves (**16**) of the penetrations of the supply and return piping (**14***a*, **15***a*) for said heat transfer coils where penetrating the HTSIP or HTSANIP of the enclosure wall

[0049] FIG. **2** is a sectional view taken at a horizontal plane through another embodiment of the current invention with a dual grade of core insulation (**2**, **5**) in the heretofore described HHTSIP, and depicting heretofore described "input" and "output" heat transfer coils in schematic form, with the heretofore described metallic cylindrical fabrication (**17**) and two different and isolated grades of PTESM (**18**, **19**)

[0050] FIG. **3** is a sectional view through the same embodiment of the current invention as in FIG. **2** above but with the view taken at a vertical plane through the invention.

[0051] FIG. **4** is a sectional view through an abutting corner of vertical and horizontal HHTSIP panels illustrating the dual grade nature of core insulations (**2**, **5**), and the thermal break detail (**11***b*) heretofore described at said corner.

[0052] FIG. **5** is a sectional view at the junction of connecting side edges of abutting HHTSIP panels illustrating the thermal break detail (**11***a*) heretofore described at said junction, and also depicting the embodiment of said panel where two grades of insulation (**2***a*, **2***b*) are bonded to form a structural core such that adequate structural and thermal performance is provided by the core in achieving the required structural performance of said sandwich panels as a whole, but permitting less costly insulative material to be used where maximum temperature resistance requirements through the thickness of said insulative core are reduced as heretofore described.

[0053] FIG. **6** is a sectional view taken at a vertical plane through an embodiment of the current invention as in FIG. **3** above but depicting the installation in an exterior location with weatherproofing additions to the inventive enclosure, and in this embodiment depicting separate external structural floor support (**26**) as heretofore described as a possible preferred or required element.

[0054] FIG. **7** is an elevation view depicting the installation of the inventive enclosure in an exterior location as in FIG. **6** but with the inventive enclosure hidden by standard "outbuilding" type features such as wall siding (**23**), roof structure and facade style window (**24**) and door (**25**) elements, in satisfying additional aesthetic preferences, in addition to contributing to the weather resistant functionality of said building.

[0055] The basic embodiment of the previously-defined HTSIP assembly as illustrated in FIG. **1** consists of a minimum of three layers, namely an outside facing panel (**1**), a middle insulative core (**2**), and an interior liner panel (**3**). The layers are bonded together with adhesive (**4**) with the strength required to allow the layered assembly to act compositely in resisting the imposed structural loadings as heretofore described. In another embodiment of the current invention the insulative core is self-bonding to the facing panels, as in the case of a foamed-in-place polyurethane grade insulation, and said adhesive is thereby not required. It is critical that the composite assembly maintains adequate strength at the maximum exposure temperatures anticipated at each interface and depth throughout the thickness of the assembly. The most severe (ie highest) exposure temperature occurs at the interface of the PTESM and the interior liner panel (**3**), and decreases through the thickness of the various layers in the HTSIPs of the inventive enclosure to a minimum at the exterior surface of the outside facing (**1**).

[0056] The interior facing (**3**) can be a rigid panel such as fiber-reinforced cement board, or other panel product with adequate strength properties at the higher temperatures anticipated from exposure to the heated PTESM. The insulating core (**2**) can be one of a variety of products that provides the desired combination of mechanical and insulative properties at the maximum design operating temperature, such as polyisocyanurate foam and cellular glass rigid insulations. The exterior facing (**1**) can be a rigid panel such as plywood, or other engineered wood product, fiber-reinforced cement board, or other similar product with adequate mechanical properties. This embodiment of the HTSIP shall hereinafter be identified as the basic HTSIP.

[0057] In one embodiment of the current invention, per FIGS. **2**-**6**, where dictated by the maximum operating temperature in the PTESM, the basic HTSIP assembly described above (**1**, **2**, **3**, **4**) is provided with additional protection against said temperature consisting of an additional layer of high-temperature-resistant insulation (**5**), such as cellular glass or mineral fiber type and a separate high temperature liner panel (**6**) in direct contact with the PTESM (**19**). These additional layers are bonded together with suitable high temperature adhesive (**7**), and to the internal facing panel of said basic HTSIP with heretofore described adhesive (**4**). In this embodiment of the current invention it is possible that the rigid structural panel thereby positioned in the interior of the sandwich panel assembly (**3**), and provided with the additional thermal protection heretofore described, can in some cases be a wood-based product such as plywood or OSB whereby required strength properties are maintained at the maximum anticipated operating temperature at that location in the assembly. As heretofore noted, it is also possible that depending on the temperature gradient though the thickness of said embodiment of the sandwich panel assembly, a polystyrene or other grade of insulation with lower maximum operating temperature capability but also less costly grade can be used as the structural core element (**2**), or as the outer layer (**2***b*) in a bonded multi-layer structural core in the heretofore described HTSIP assembly and contributing to the strength requirements of said panel. This bonded multi-layer structural core (**2***a*, **2***b*) is illustrated in the embodiment depicted in FIG. **5**. This structural sandwich panel assembly with even higher temperature resistance then becomes another embodiment of the HTSIP assembly, and is hereinafter identified as HHTSIP (Higher High Temperature SIP).

[0058] The panels are connected along their edges using structural angle sections (**8**) predrilled at pre-determined spacings and fastened to adjoining panels along their edges with conventional screw type fasteners (**9**) of the design size and strength required to resist the loading imposed by the PTESM. In some embodiments of the current invention a wood spacer (**10**) is installed along the edges of the panel assembly to further stabilize this connection when required

[0059] An important feature of the edge detail of the HTSIP assembly, as shown by FIG. **1**, is that the edge of the foam core is shaped (**11**) to minimize thermal bridging though the thickness of the panel assemblies in this connecting corner region of abutting panels of the inventive enclosure. As further security in maintaining this thermal break and guarding against thermal energy loss at said connecting areas, a strip of high temperature blanket-type insulation (**12**) in the range of 3 mm thick is inserted in said corner region during the assembly process of the inventive enclosure.

[0060] Similar to the low thermal bridging objective of the HTSIP assembly detail referenced above, a thermal break is also incorporated in the HHTSIP assembly (**11***b*) as illustrated in FIG. **4** in the layer of high-temperature insulation (**5**) as a means of reducing the maximum temperature exposure to the basic HTSIP assembly component of the HHTSIP assembly heretofore described.

[0061] In addition to the construction measures adopted at connecting corner regions heretofore described, in some embodiments of the inventive enclosure, as illustrated in FIGS. **1** and **4**, the outer panel facing (**1***b*) of the horizontal roof HTSIP or HHTSIP is extended beyond the outermost contact edge of the outer vertical panel facing of the side wall (**1**), with said extension (**1***c*) being in the range of 10 mm. In these embodiments, a horizontal spacer strip (**13**), typically of wood or plastic material, is installed against the top and bottom edges of the vertical HTSIPs and secured by the aforementioned structural angle sections (**8**) and attendant securing fasteners (**9**) to maintain the necessary relative positioning of the roof and floor panels with the vertical wall panels of the inventive enclosure. These design details aid in the assurance of full load bearing in the transmittal of gravity loading through the roof panel (**1***b*) to said vertical panels of the inventive enclosure. The security of this load transfer detail becomes even more critical when the inventive enclosure is installed outdoors, with said enclosure providing the structural support in resisting additional loading to that of a typical indoor installation, namely the dead loads of the external roof construction and any solar collector units and associated framing mounted on said roof, and live loads imposed by snow and wind as pertinent to the geographic region of the enclosure installation.

[0062] Where the size of the inventive enclosure is such that multiple HTSIP or HHTSIP panels are required for one or more sets of opposite faces of the enclosure, an edge detail (**11***a*) similar to that of FIG. **5** is provided to minimize thermal bridging through connecting side edges of abutting panels. As heretofore noted in the case of the corner edge junctures of the inventive enclosure, a strip of high temperature blanket type insulation (**12***a*) in the range of 3 mm thick is also inserted in the joint of said connecting side edges as added insurance against thermal bridging.

[0063] As heretofore noted, in one embodiment of the current invention, the flexural and shear strength requirements of the HTSANIP wall sections of the inventive enclosure are provided by external structural framing (**13***a*) against which the sandwich wall panels are braced, as illustrated in FIG. **3**. Said framing can be conventional construction, as in the use of lumber components, with the loading from the inventive enclosure transferred from said sandwich wall panels by some standard structural element as a filler panel (**13***b*) possessing sufficient compressive rigidity.

[0064] In one embodiment of the current invention input and output heat transfer coils (**14**, **15**) are selectively positioned and spaced to optimize heat transfer into and from the PTESM. In the embodiments shown in FIGS. **1**, **2**, **3** and **6**, said heat transfer coils are shown schematically as coiled piping, however the input heat transfer coil(s) (**14**) can alternately be ductwork or electric resistance wiring as heretofore noted. Said heat transfer coil piping, ductwork or electric resistance wiring penetrate the inventive enclosure walls in heretofore described insulative sleeves (**16**) terminating at ends (**14***a*) for input heat transfer coil(s) and ends (**15***a*) for output heat transfer coil(s), with said terminations suitable for connection to the process system services external to the inventive enclosure. Said insulative sleeves (**16**) serve to minimize heat loss from the inventive enclosure, and as with the HTSIP or HHTSIP assembly previously described, thereby maintain adequate performance at the maximum design exposure temperature anticipated.

[0065] As heretofore noted in this section, in one embodiment of the current invention one or more metallic cylindrical fabrication(s) (**17**) is provided to allow the use of two separate grades of PTESM, typically a finer grade, such as sand (**18**), within the boundary of said fabrication(s), and a coarser grade, such as gravel (**19**), outside the boundary of said fabrication(s).

[0066] In another embodiment of this invention, one or more roof HTSIP or HHTSIP assembly(ies) is designed to be removable to facilitate access to the aforementioned heat transfer coils for servicing without the dismantling of the entire inventive enclosure thereby minimizing the amount of PTESM to be removed. In this case the adjacent roof and wall HTSIPs or HHTSIPs that remain in position adjacent to the temporarily removed panel(s), and reinforced as required, provide the necessary stiffness and strength in maintaining the overall dimensions and structural integrity of the enclosure under the applied loadings that remain during said servicing procedure.

[0067] In another embodiment of the current invention, heretofore mentioned conduits (**20**) are positioned within the enclosure to accommodate wiring and enable the secure embedment of temperature sensor devices within the PTESM (**18**, **19**) and within the insulative layers of the envelope of the inventive enclosure itself (**2**, **5**) if desired, for the purpose of recording operating data and providing data to the process control system that manages the heat transfer processes involved. Fittings (**21**) are installed in said conduit at the embedment locations for said sensors, as shown in FIGS. **3**

and **6**. Said conduits penetrate the walls of the inventive enclosure in insulative sleeves similar to those heretofore described for heat transfer device enclosure wall penetrations (**16**), with end terminations (**20***a*) compatible with exterior data collection and control system wiring.

[0068] As heretofore indicated, when installed outside, the inventive enclosure is protected from the environmental elements by a weather resistant envelope, consisting of a roof structure (**22**), siding and associated strapping (**23**), and with windows (**24**) and doors (**25**) of a facade nature, all contributing to the presentation of desired appearance in the form of a site-compatible "outbuilding" as illustrated in FIGS. **6** and **7**. In the embodiment depicted in said figures a separate external structural floor support frame (**26**) as heretofore described is depicted in place under the HHTSANIP floor panel assembly. Where the energy source is solar, exposed roof space thus provided can serve as a preferred area for mounting of solar collectors (**27**). The roof structure in such construction can be made asymmetrical as shown schematically in said figures to preferentially increase space available to said collectors in a solar heating system. Maximizing solar exposure for said collectors can thereby be achieved though combination of this expanded roof surface and the selective orientation of said roof surface. In this embodiment the inventive enclosure is designed as the structural core of the structure in withstanding the additional environmental loadings imposed in an exterior setting, as a means of eliminating the need for additional structural elements and their associated costs, thus contributing to the economic viability of the inventive enclosure-based energy storage system. As heretofore noted, other embodiments of the current invention achieving similar functionality of the energy storage process are achievable using HTSANIP panels in which exterior structural framing is employed to resist the interior loading imposed by the PTESM and also exterior loading on the structure from environmental effects.

[0069] As will be apparent to those skilled in the art in light of the foregoing disclosure, many modifications to the invention described herein are possible without departing from the spirit and scope thereof. Accordingly, the scope of the current invention is to be construed in accordance with the substance of the claims as defined in that section of the current application.

BEST MODE FOR CARRYING OUT THE INVENTION

[0070] Construction of the inventive HTSIP and HTSANIP enclosure panels as heretofore described is accomplished using methods essentially as employed in the construction of sandwich panels, including structural insulated panels, such as are typically used in the envelope construction of some buildings. These methods include assembly of the sandwich panel layers, including the insulative core sheet(s) and facings, and typically either using adhesives and possibly heat in joining said components under pressure, or in the utilization of a self-bonding grade of insulation, as in the case of a foamed-in-place urethane grade. The general methods employed in this process are thus well practiced and understood, except that the various component materials must be specifically selected for anticipated maximum design temperatures and loadings, and other details such as connections and penetrations require consideration of the end use application for the current invention. It is significant that the maximum design temperatures are typically greater than those encountered in said building envelope applications. In the case of the HHTSIP panels as heretofore noted, the basic procedure remains similar except that an additional insulative layer is introduced to the sandwich panel assembly as a means of further increasing it's maximum operating temperature capability.

[0071] Also as heretofore noted the inventive enclosure with attendant ancillary components can be pre-assembled to various stages of completion, or the various components prefabricated in a centralized manufacturing facility suitable for final assembly in the field.

INDUSTRIAL APPLICABILITY

[0072] As heretofore noted, the inventive enclosure and associated ancillary components have many potential applications where thermal energy is required, whether that be in residential, commercial, institutional or industrial applications. It is anticipated however that the most widely targeted application will be for space heating systems and DHW heating systems in single- and multi-residential, institutional and light commercial situations and also for heating the water of swimming pools and similar facilities. Also as noted heretofore, the energy source most widely anticipated to be utilized with the inventive enclosure applications is solar, although said enclosure is also suitable for use in storage of thermal energy from an electrical source, generally in off-peak generation/time-of-use applications. In addition however the thermal energy retained in the enclosure can also be used in powering the refrigeration cycle by means of thermally-driven coolers in space cooling systems.

1. A prefabricated enclosure for storing thermal energy from an external energy source of solar radiation or electricity, or a combination of the two, with said storage to be in a particulate solid phase thermal energy storage medium or media (PTESM) (**18**, **19**), with said enclosure comprising prefabricated insulated panel assemblies for the floor, walls and roof, with said assemblies fabricated as structural insulated sandwich panels with rigid facings (**1**, **3**) and insulative core (**2**), with said facings and core being layers of said panel assemblies and bonded together at their contact surfaces and designed to act compositely in resisting the gravity and lateral loading imposed by the aforementioned PTESM over its anticipated operating temperature range, or alternately with said insulative core being a foamed-in-place grade of insulation such as is possible with polyurethane foam and such that said foam self-adheres to said facings with the required adhesive strength, and with the four edges of said panel assemblies prepared in a manner to minimize thermal bridging through such edge connections (**11**, **12**, **11***a* **12***a*), and with panel corner edge brackets and attendant fasteners (**8**, **9**) being of the necessary structural strength to connect said insulated sandwich panels to each other in a manner that maintains the structural integrity of said enclosure under all anticipated loadings, and with said enclosure suitable for the installation in its interior of one or more thermal energy input transfer device(s) to transfer thermal energy from said external source to said PTESM and one or more thermal energy output transfer device(s) being in the form of coil(s) of piping design (**14**), with or without heat transfer fins to transfer thermal energy from said PTESM either directly or indirectly to the "end use" application of said stored energy, with said end use being for one or a combination of domestic hot water heating, space heating, swimming pool or similar use heating, or in powering the refrigeration cycle by means of thermally-driven coolers in space cooling systems.

2. A prefabricated enclosure for storing thermal energy as in claim **1** with said insulative core of said sandwich panels to consist of multiple bonded layers of different insulative materials such that adequate structural and thermal performance is provided by the core in achieving the required structural performance of said sandwich panels as a whole thereby permitting less costly materials to be used where maximum temperature resistance requirements through the thickness of said insulative core is reduced as a result of the temperature gradient that naturally occurs through said sandwich panel assemblies with increasing distance from the aforementioned and heated said PTESM

3. A prefabricated enclosure for storing thermal energy as in claim **1**, with solar radiation being the sole aforementioned external energy source and with the aforementioned thermal energy transfer devices provided with the enclosure, and the thermal energy input transfer device(s) being in the form of coil(s) of piping design (**14**), with or without heat transfer fins, and with input piping to said device(s) being suitable for attachment to the outlet piping from external solar collectors that form part of the energy collection system of said solar energy source.

4. A prefabricated enclosure for storing thermal energy as in claim **1**, with electrical energy being the sole aforementioned external energy source and with the aforementioned thermal energy transfer devices provided with the enclosure, and the thermal energy input transfer device(s) being in the form of electrical resistance wiring.

5. A prefabricated enclosure for storing thermal energy as in claim **1**, with solar radiation and electrical energy being the aforementioned external energy sources with the aforementioned thermal energy transfer devices provided with the enclosure, and the thermal energy input transfer device(s) being in the form of coil(s) of piping design (**14**), with or without heat transfer fins and also in the form of electrical resistance wiring, such that the aforementioned PTESM can be heated by a combination of external energy sources of solar radiation and electrical energy.

6. A prefabricated enclosure for storing thermal energy as in claim **1**, and with the aforementioned thermal energy transfer devices provided with the enclosure, and the thermal energy input transfer device(s) being in the form of hot air ducting.

7. A prefabricated enclosure for storing thermal energy as in claim **2** with the aforementioned prefabricated structural sandwich panel assemblies all provided with insulative sleeves (**16**) at the locations where the aforementioned piping, wiring, and ducting of the associated aforementioned thermal energy transfer device(s) penetrate said sandwich panels.

8. A thermal energy storage enclosure as in claim **1** with the aforementioned prefabricated structural sandwich panel assemblies, panel assembly corner edge brackets, and fasteners, and some or all of the aforementioned internal heat transfer devices with aforementioned associated insulative sleeves all provided in kit form ready for assembly.

9. A thermal energy storage enclosure as in claim **1**, but where the aforementioned sandwich wall panel assemblies are not required to act compositely in resisting flexural or shearing stresses resulting from the lateral loading imposed by the aforementioned PTESM over the anticipated temperature range of said PTESM, but rather are braced against external framing (**13***a*) that provides those strength requirements.

10. A thermal energy storage enclosure as in claim **1**, but where the aforementioned sandwich floor panels are not required to act compositely in resisting applied flexural or shearing stresses resulting from the gravity loading imposed by the aforementioned PTESM over the anticipated temperature range of said storage medium but rather are braced against external framing (**26**) or other structural floor construction as in a structural concrete slab that provides those strength requirements.

11. A thermal energy storage enclosure as in claim **1**, with the aforementioned PTESM being sand or other relatively fine particulate-sized granular matter with the option of achieving increased energy storage capacity provided by some fraction of the volume of said PTESM being displaced by a phase change material.

12. A thermal energy storage enclosure as in claim **1**, with the aforementioned PTESM being gravel or other graded and relatively coarser particulate-sized material with the option of achieving increased energy storage capacity provided by some fraction of the volume of said PTESM being displaced by a phase change material.

13. A thermal energy storage enclosure as in claim **1**, with the aforementioned PTESM being both sand and gravel or aforementioned alternatives with the two grades of said PTESM being separated from each other by one or more metallic cylindrical fabrication(s) extending between the interior facings of the aforementioned floor and roof sandwich panels of said enclosure with the main heat transfer portions in coil form of the aforementioned heat transfer devices installed inside said cylindrical fabrication(s) and said sand grade or said alternative of said PTESM being placed inside said cylindrical fabrication(s) thereby reducing the possibility of damage to said main portions of heat transfer devices during the filling process of said PTESM, and said gravel grade or said alternative of said PTESM being placed outside said cylindrical fabrication(s) with said separation of grades of PTESM thereby allowing the selective removal of said sand grade or said alternative of said PTESM thereby facilitating access to and possible removal of any said heat transfer devices installed within said fabrication(s) for service and/or replacement and said separation of grades of PTESM also yielding benefits from improved thermal energy storage characteristics of said gravel grade or said alternative of PTESM relative to said sand grade or said alternative of PTESM yet also yielding the benefits of selected use of the sand grade or said alternative PTESM as heretofore described.

14. A thermal energy storage enclosure as in claim **13** with some fraction of one or both of the aforementioned grades of PTESM being displaced by a phase change material as a means of achieving increased thermal energy storage capacity.

15. A thermal energy storage enclosure as in claim **1** in which provisions are made in the structural design of said enclosure to allow the temporary removal of specific aforementioned prefabricated sandwich roof panel assembly(ies) while maintaining the structural integrity of the overall enclosure structure either through the addition of temporary structural reinforcing elements or the installation of permanent reinforcing elements to adjacent panel assemblies, or a combination of these two methods, with said provisions being made to facilitate the selective removal by means of vacuum or other process the portion of the aforementioned PTESM residing within the aforementioned metallic cylindrical fabrication(s) and encasing the aforementioned heat transfer devices, thereby facilitating access to and possible removal of said heat transfer devices installed within said cylindrical fabrication(s) for service and/or replacement of said heat transfer devices without necessitating the removal of the remainder of said PTESM.

16. A thermal energy storage enclosure as in claim **1** with a network of prefabricated conduit to accommodate wiring and temperature sensor devices, with said conduit propitiously positioned within the interior space of said enclosure or provided in kit form for installation during the assembly process of said enclosure, thereby allowing said sensor devices to be securely installed at predetermined locations in the aforementioned PTESM for the purpose of providing data to a process control system that manages the heat transfer processes involved.

17. Thermal energy storage enclosure as in claim **1** wherein additional sandwich panel layered components, comprising a high temperature insulative layer (**5**) and high temperature protective liner panel (**6**), with the latter being in intimate contact with the aforementioned PTESM, are bonded to the aforementioned prefabricated insulated sandwich panel assemblies of the walls, floor and roof of said enclosure to provide added protection against deterioration in the structural and/or thermal performance of said sandwich panel assemblies and hence similar deterioration in the structural and/or thermal performance of said enclosure as a whole assembly, due to upper temperature extremes reached in the aforementioned PTESM that would otherwise cause a reduction in the strength and/or insulative properties of the structural layers and adhesive comprising said insulated sandwich panel assemblies.

18. Thermal energy storage enclosure as in claim **1** whereby said enclosure is installed in an exterior setting and wherein the design and specifications, or actual materials for roof framing (**22**) and weatherproofing components for the roof and for the walls of said enclosure are provided, with said weatherproofing components comprising conventional roof and wall sheathing (**22**, **23**) and conventional roof coverings, resulting in a conventional "outbuilding" appearance, but with said energy storage enclosure forming the underlying structural form in resisting the additional imposed design loadings of an environmental nature, including wind, snow and seismic loading, and with additional aesthetic requirements met by tailoring the shape of the visible said outbuilding structure, and incorporating trim elements, including facade-style window (**24**) and door (**25**) elements in providing an appearance that is complementary to the site and adjoining buildings.

19. Thermal energy storage enclosure in an exterior setting as in claim **18** wherein the aforementioned sandwich wall panel assemblies of said enclosure are not required to act compositely in resisting applied compression forces in the axis of the facing panels, or flexural or shearing stresses resulting from the lateral loading imposed by both the aforementioned PTESM over the anticipated temperature range of said PTESM and from aforementioned design loadings of an environmental nature, but rather whereby said sandwich wall panel assemblies are braced against external framing (**13***a*) that provides those strength requirements, with said external framing also serving as the base structural form for attachment of aforementioned wall sheathing and roof framing as required for the aforementioned outbuilding construction.

20. Thermal energy storage enclosure in an exterior setting as in claim **18** wherein the external energy source is solar, and the roof of the aforementioned enclosure outbuilding is used as a base structural form for mounting associated solar collectors (**27**), and furthermore, as a means of increasing space for said collectors, the roof structure in said outbuilding can be made asymmetrical to preferentially increase space available to said solar collectors.

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