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(54) HEAT PUMP USING PHASE CHANGE MATERIALS

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(57) ABSTRACT

The present invention is directed toward compositions of phase change materials derived from fats and oils, and the utilization of such phase change materials in heating, venting, and air conditioning (HVAC) systems. More particularly, the utilization of such phase change materials in a heat pump or air conditioner to significantly increase the efficiency of heat exchange with the surrounding environment. Various embodiments are disclosed including energy storage devices having phase change materials encapsulated between sheets of material to reduce stresses associated with freezing and thawing of the phase change material. A preferred heat pump apparatus utilizes the phase change material in the evaporator, and a smart fan mode of operation to circulate outside air through the evaporator based on approach temperature rather than compressor operation.

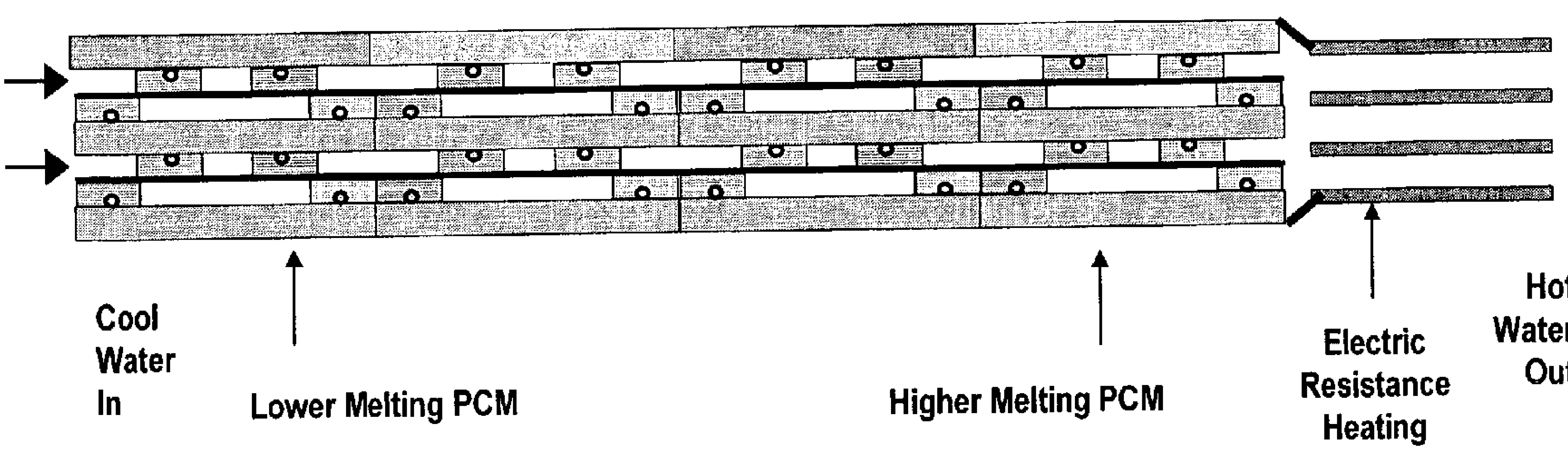


Fig. 1.

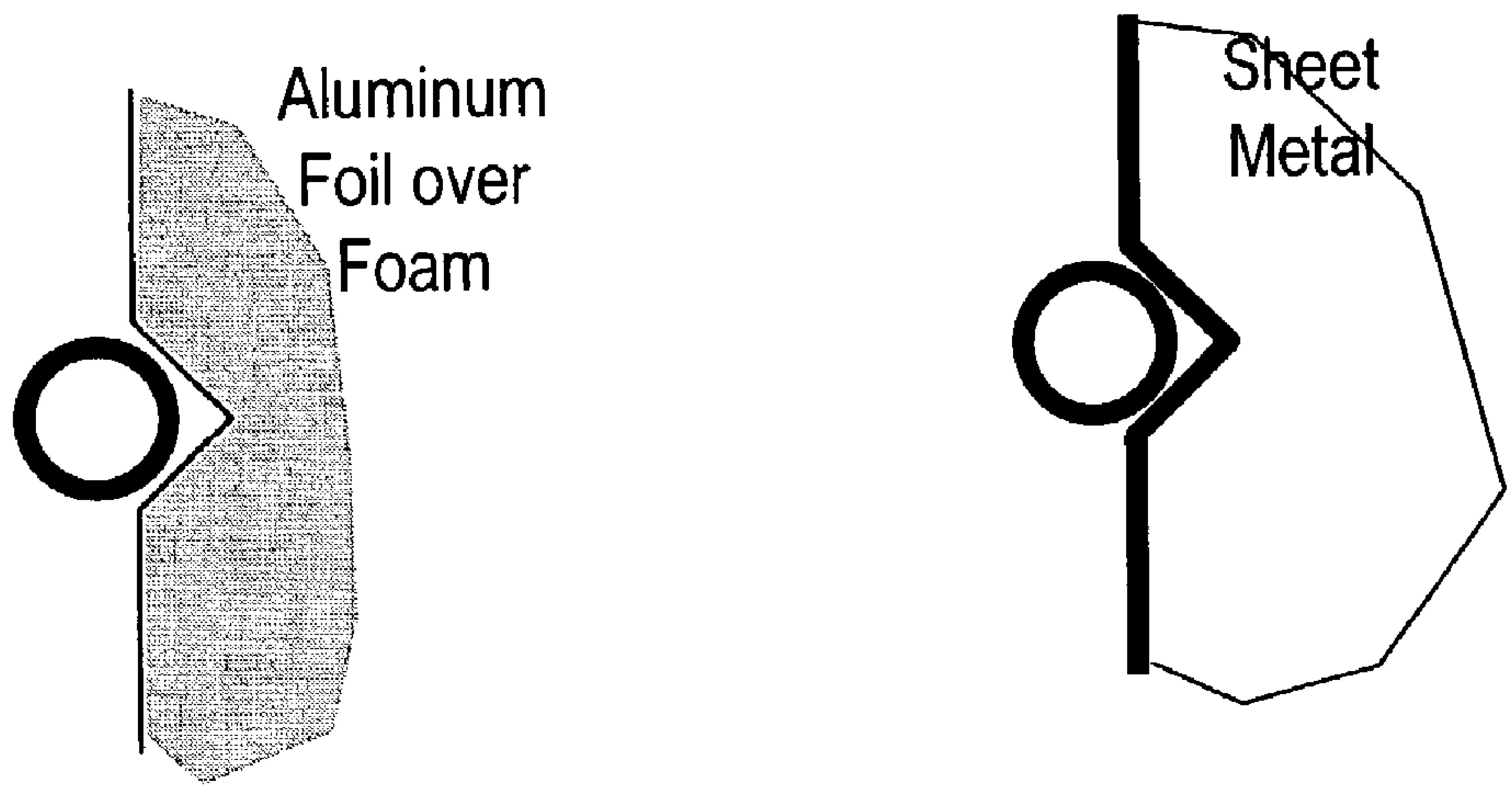

Aluminum
Foil over
Foam
Sheet
Metal

Fig. 2.

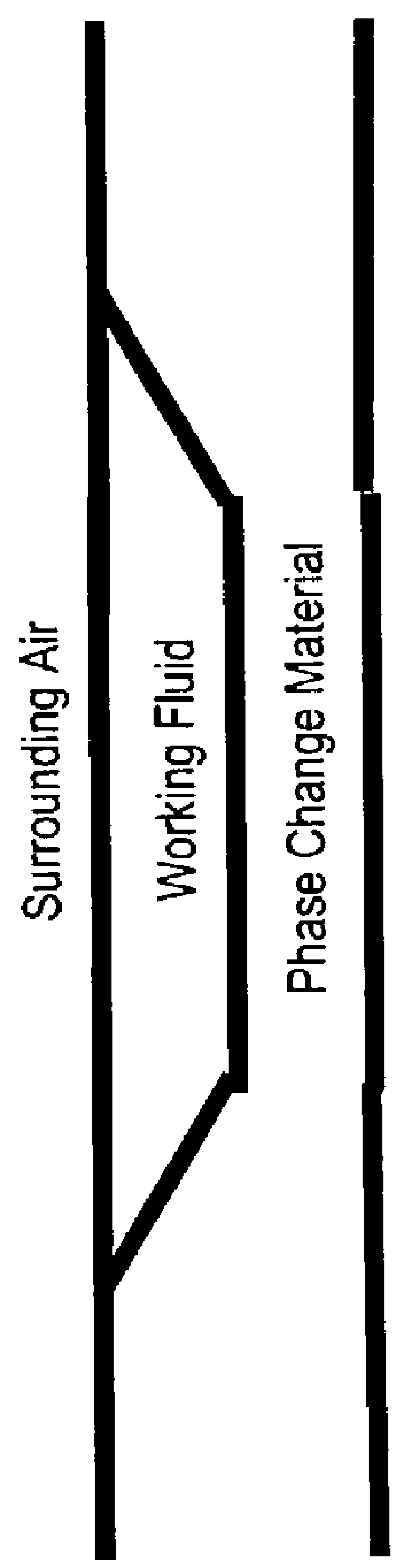

Surrounding Air
Working Fluid
Phase Change Material

Fig. 3.

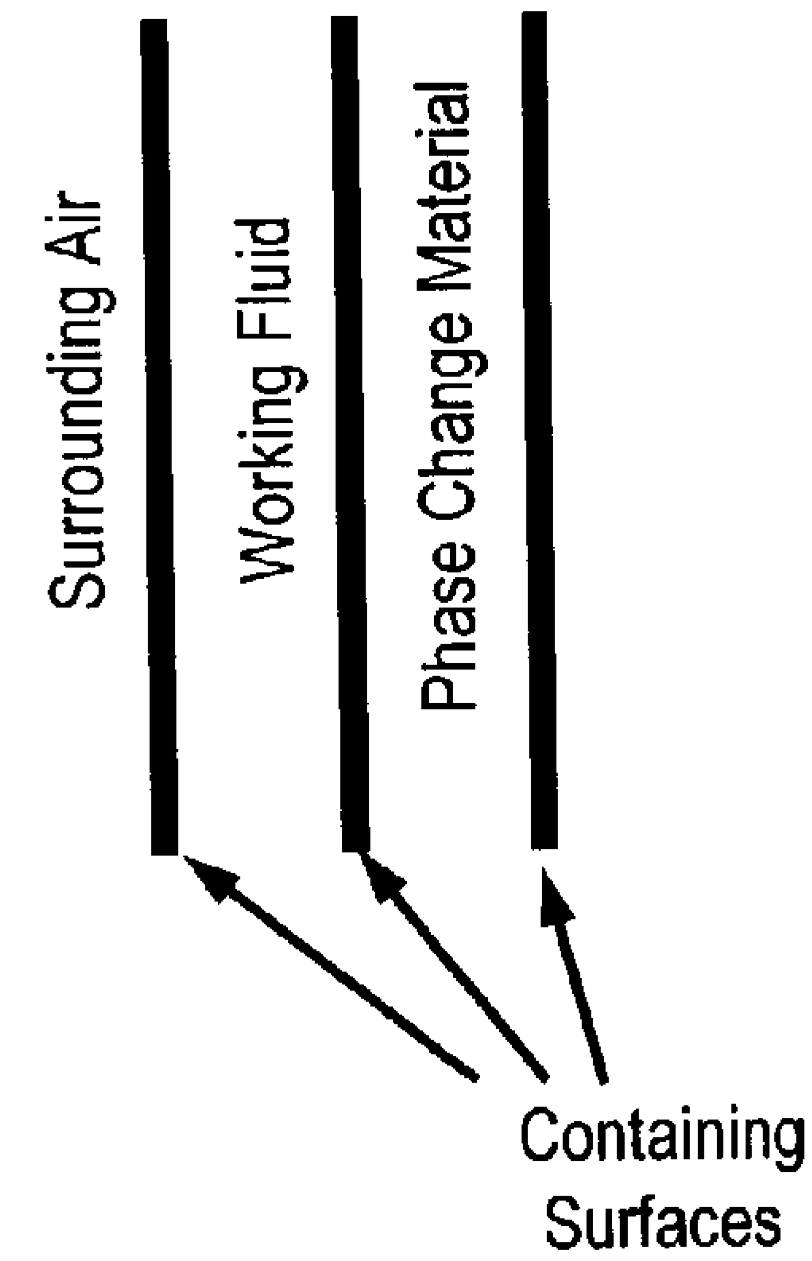

Surrounding Air
Working Fluid
Phase Change Material
Containing
Surfaces

Fig. 4.

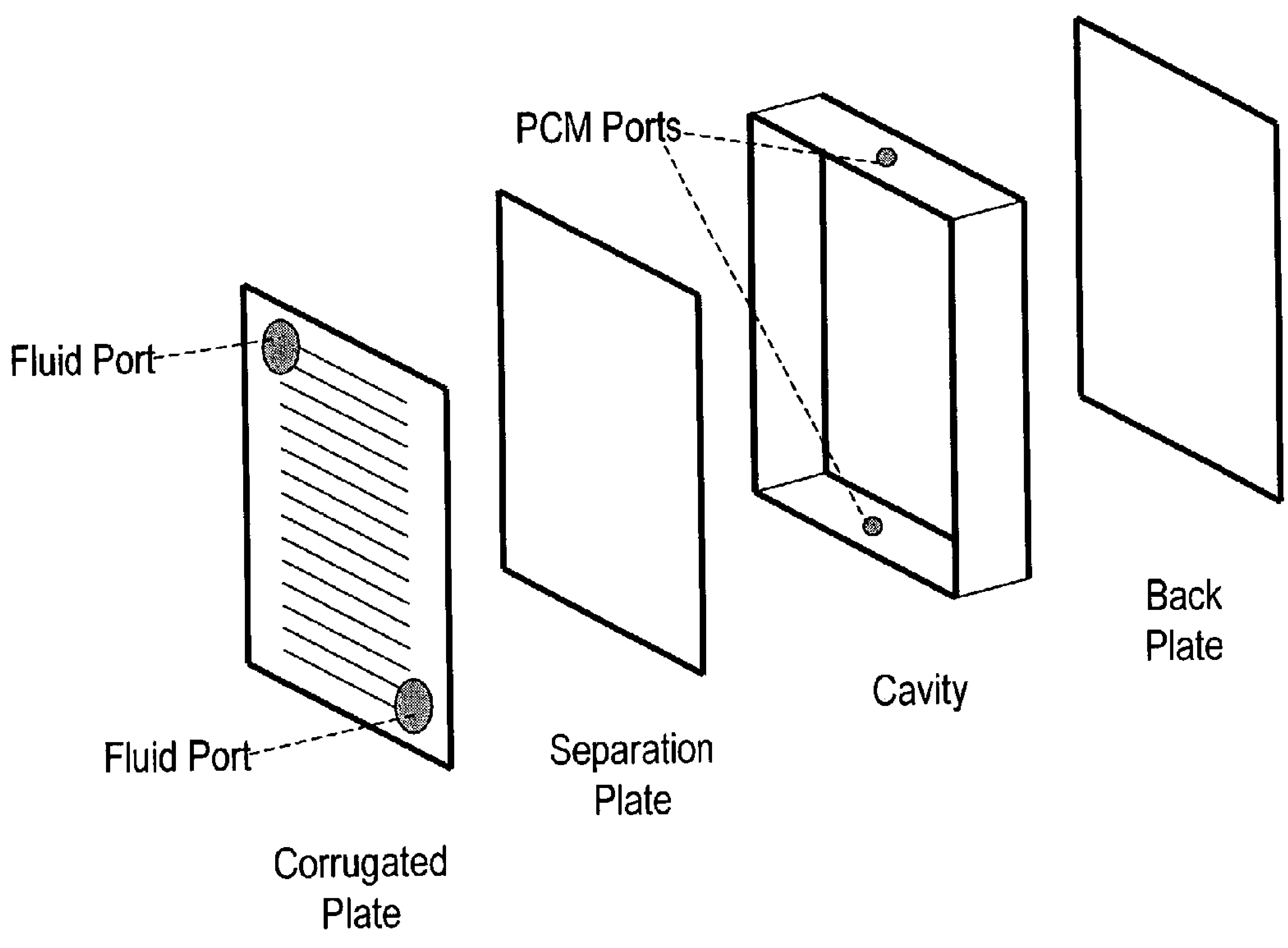

PCM Ports
Fluid Port
Fluid Port
Corrugated
Plate
Separation
Plate
Cavity
Back
Plate

Fig. 5.

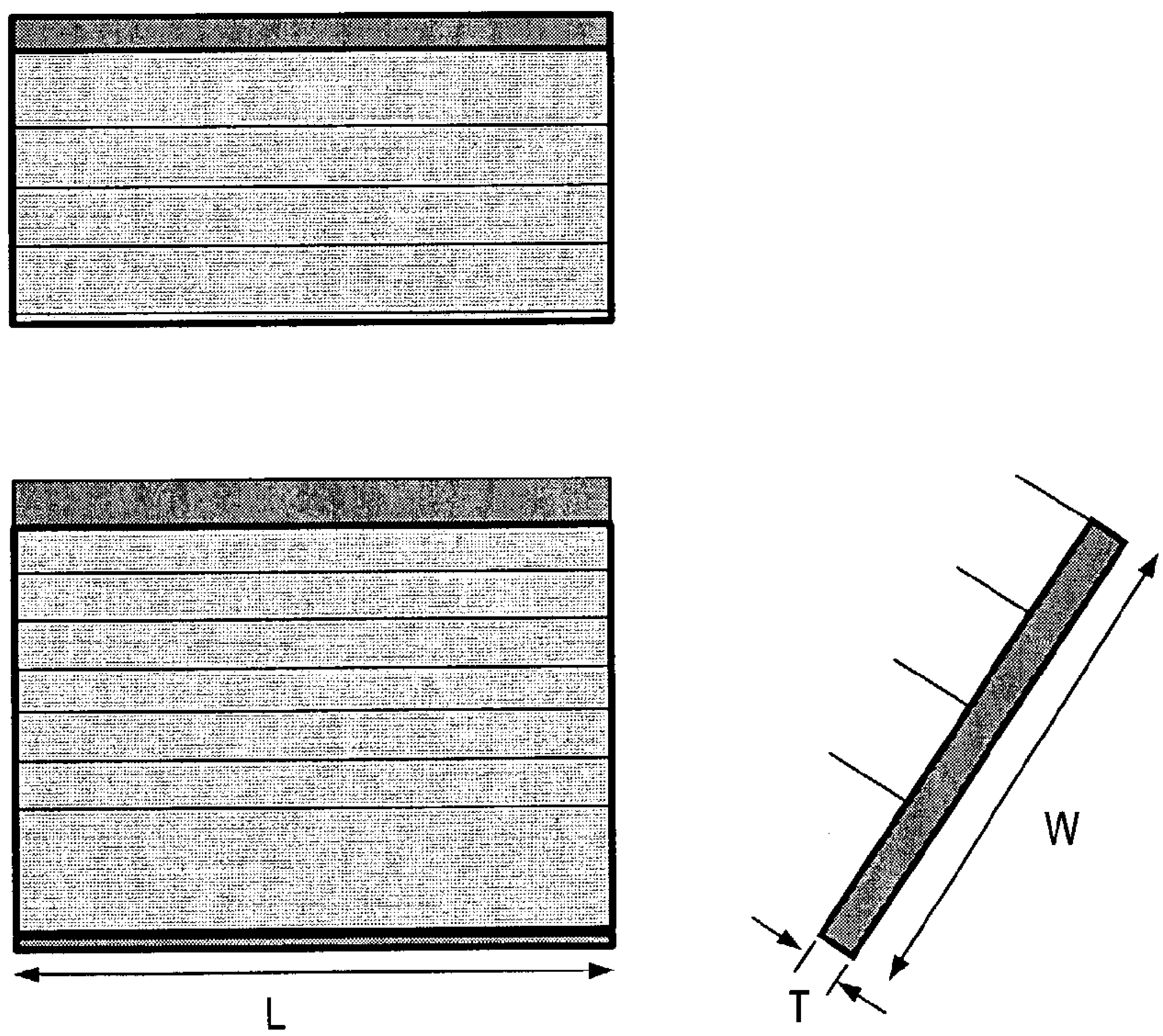


Fig. 7.

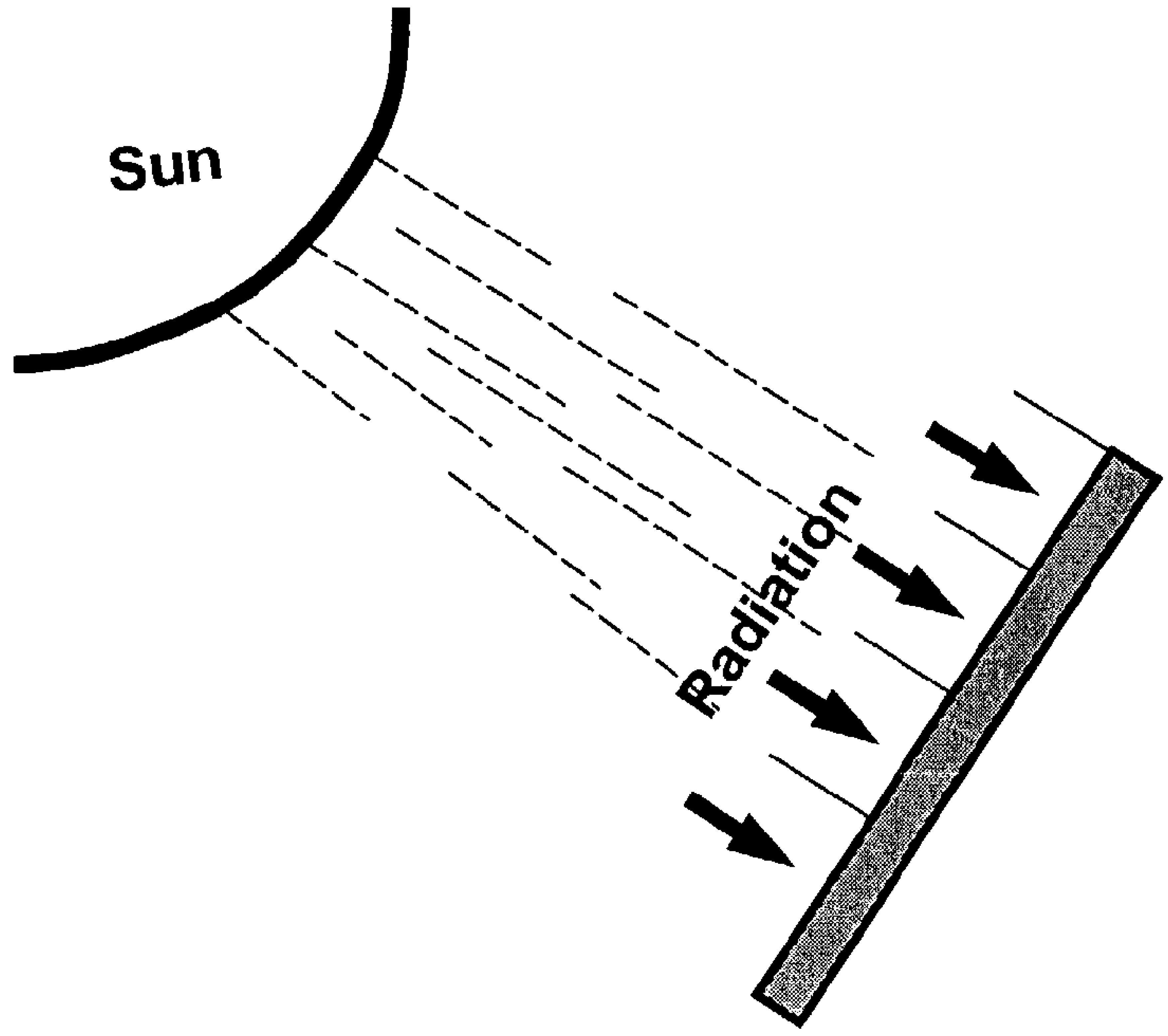


Fig. 8.

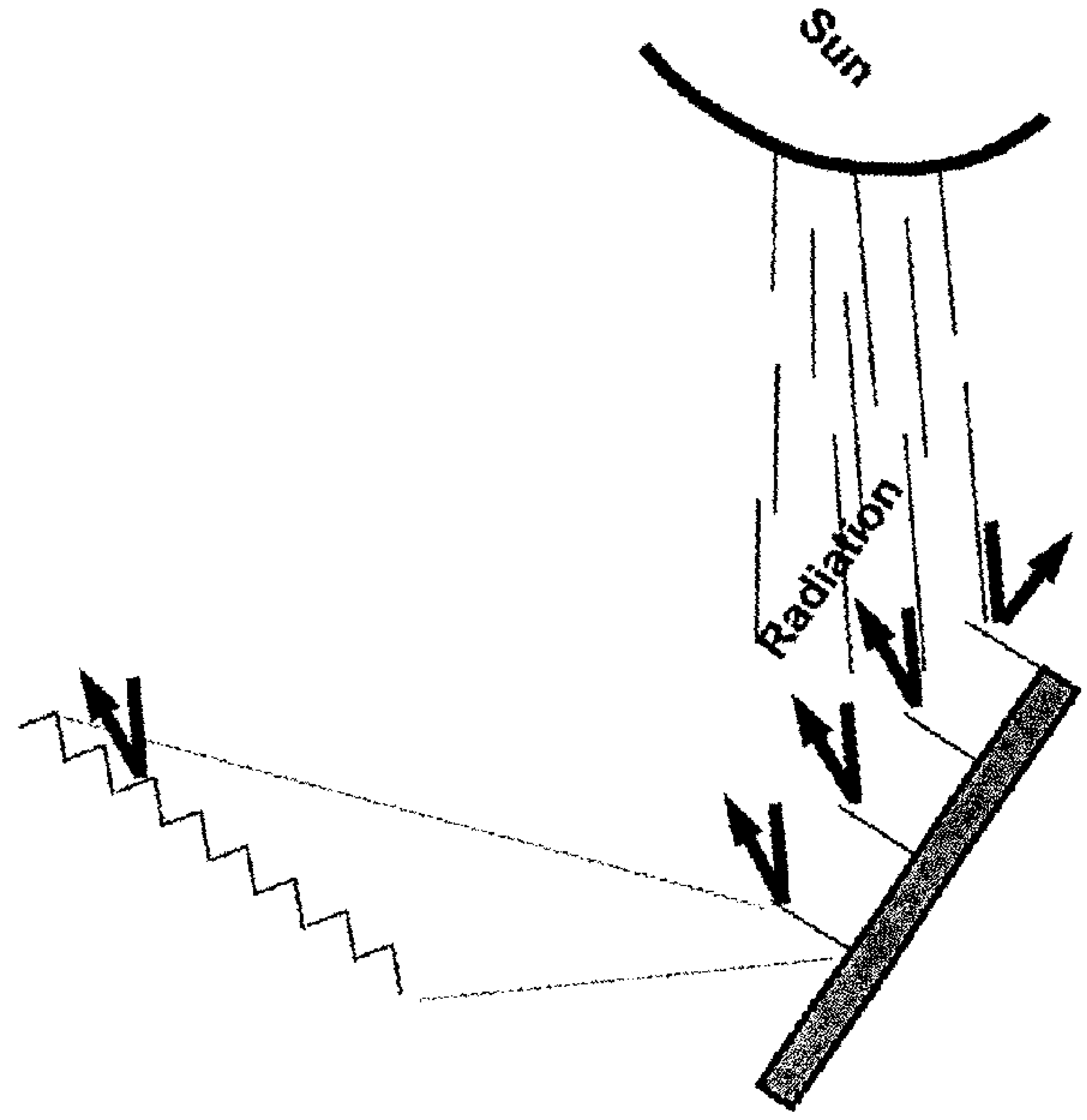

Sun
Radiation

Fig. 6.

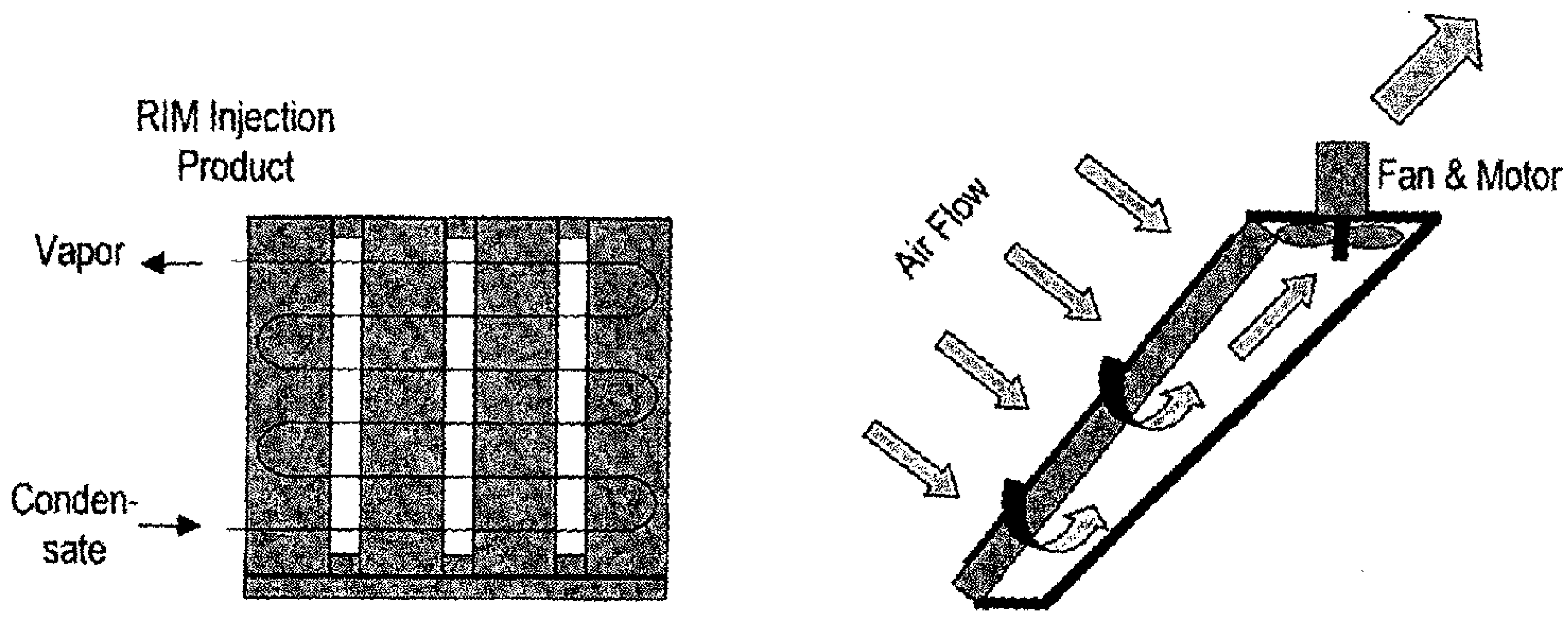
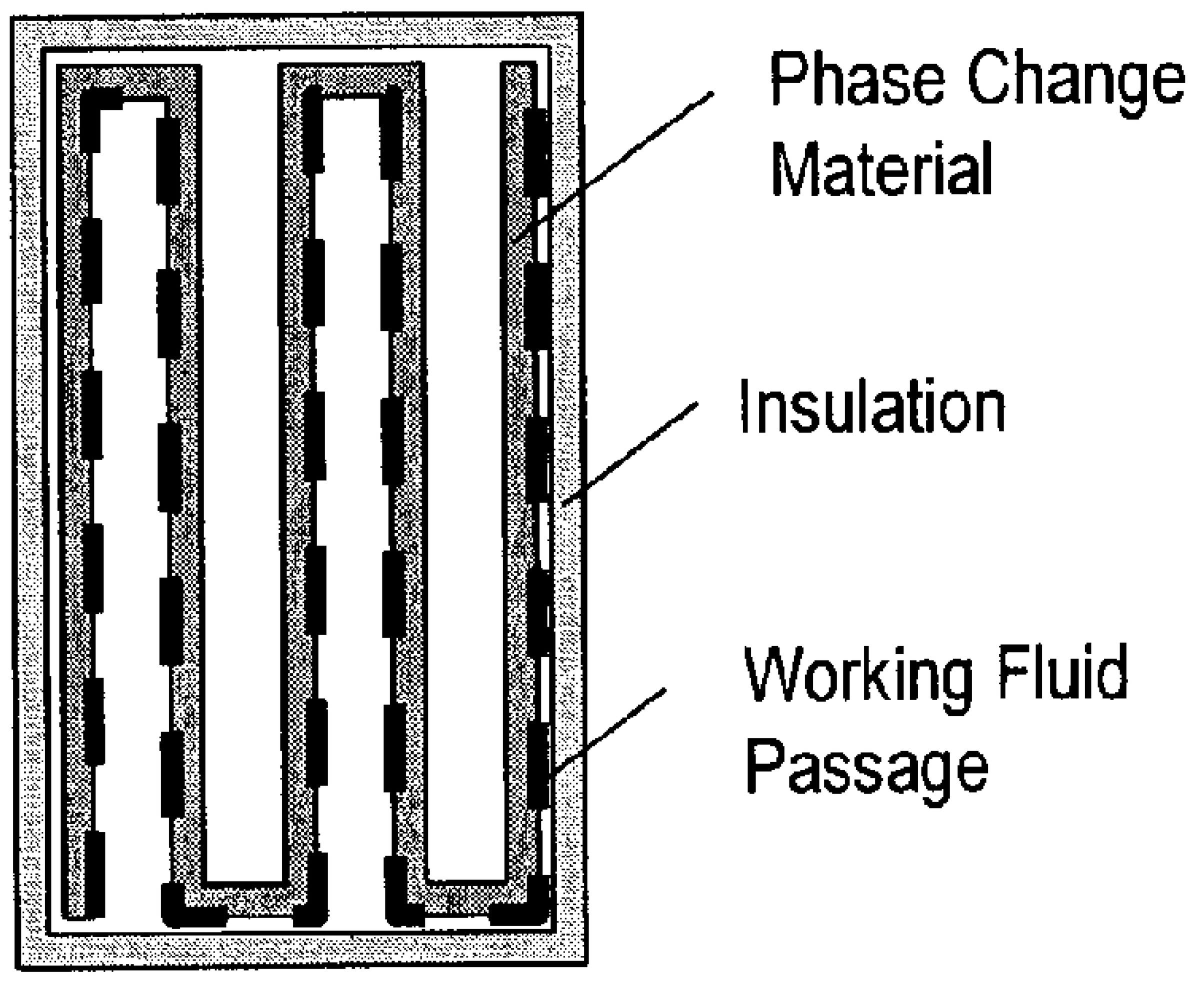
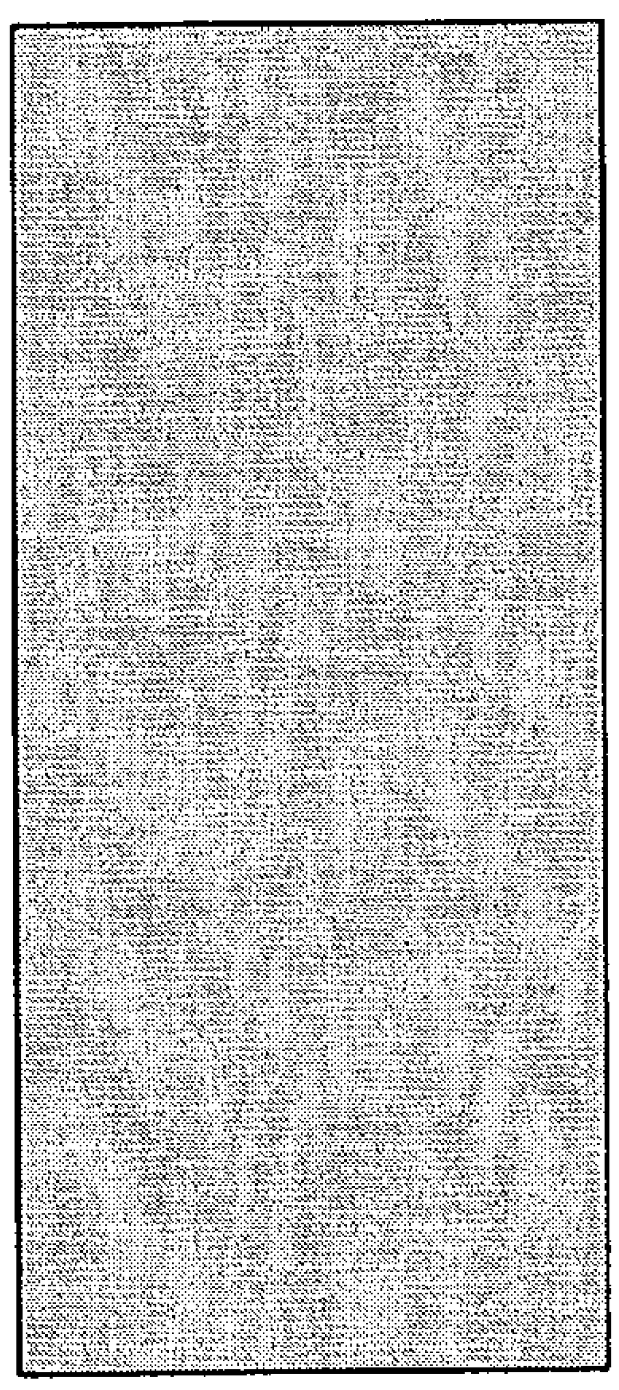

RIM Injection
Product
Vapor
Conden-
sate
Air Flow
Fan & Motor

Fig. 9.

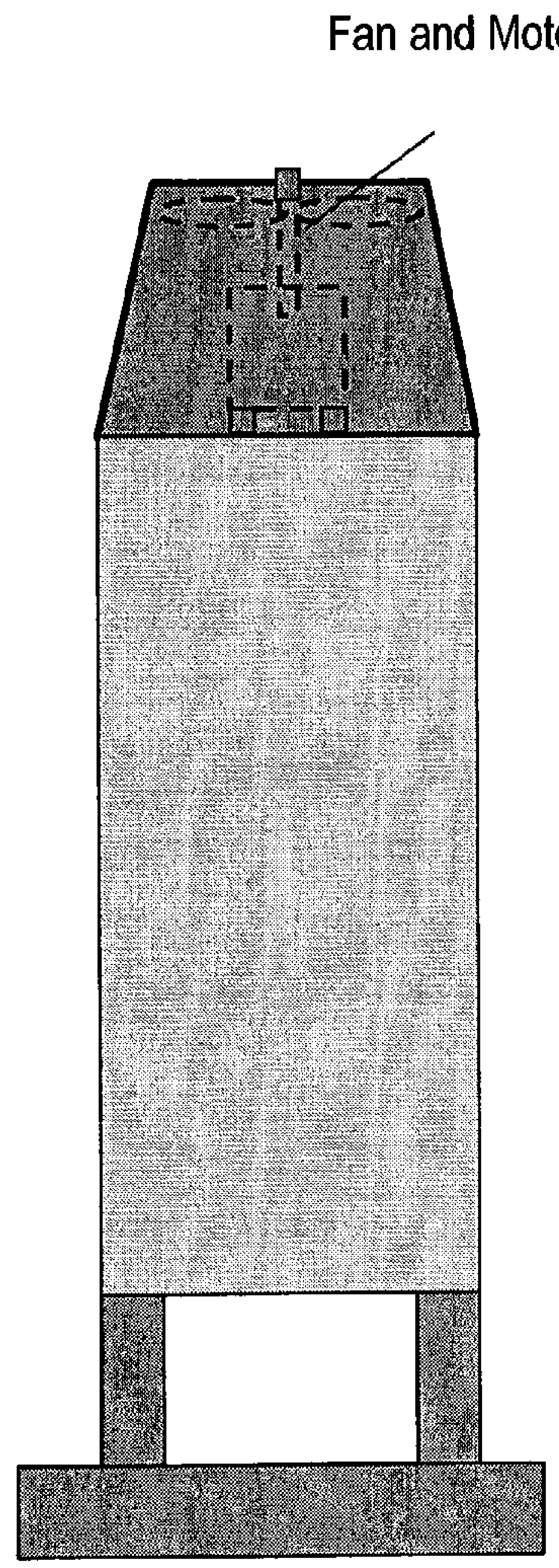
Top View



Side View



HEAT TRANSFER DEVICE NOT SHOWING FAN



HEAT TRANSFER DEVICE SHOWING FAN AND STAND

Fig. 10.

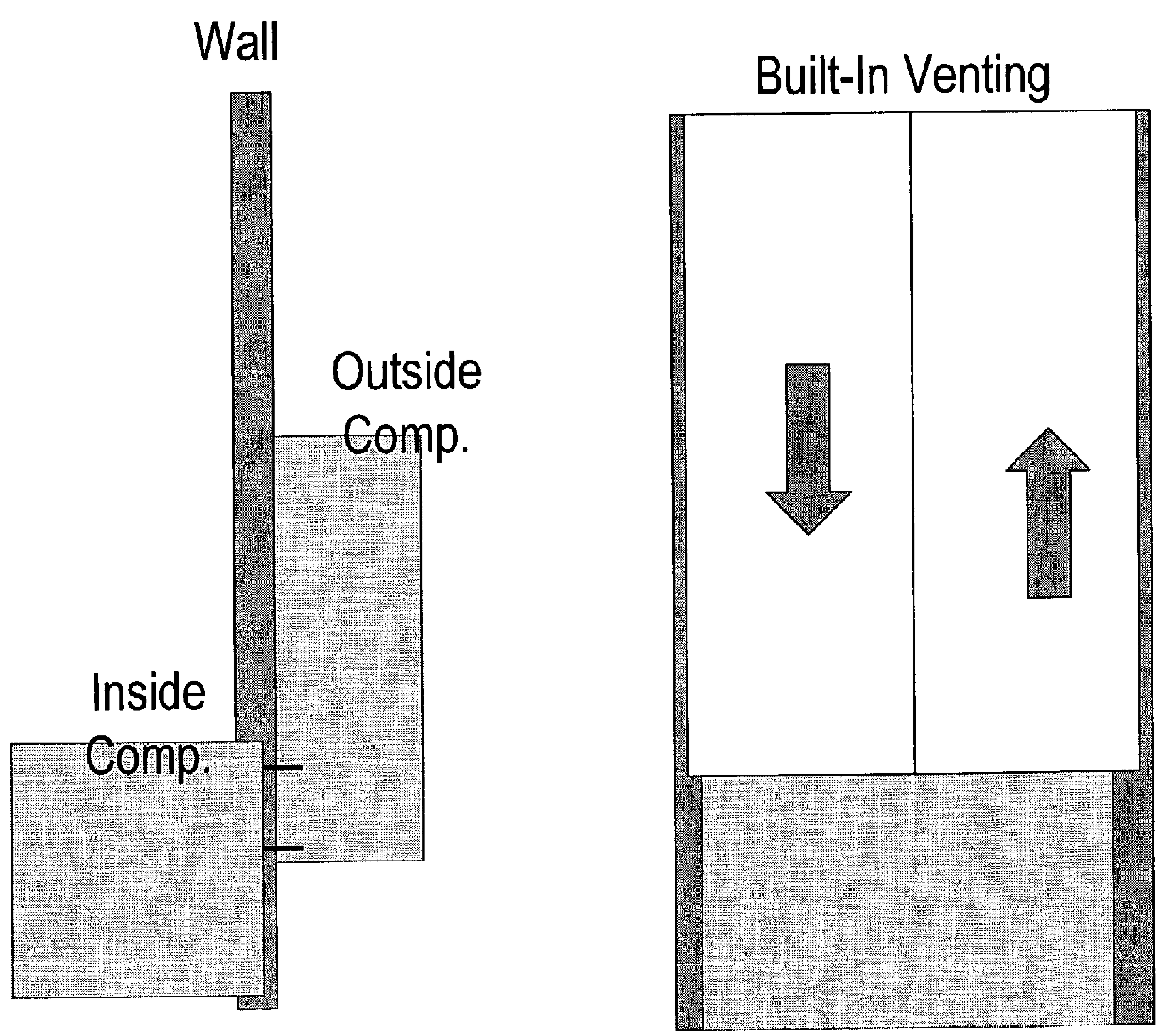


Fig. 11

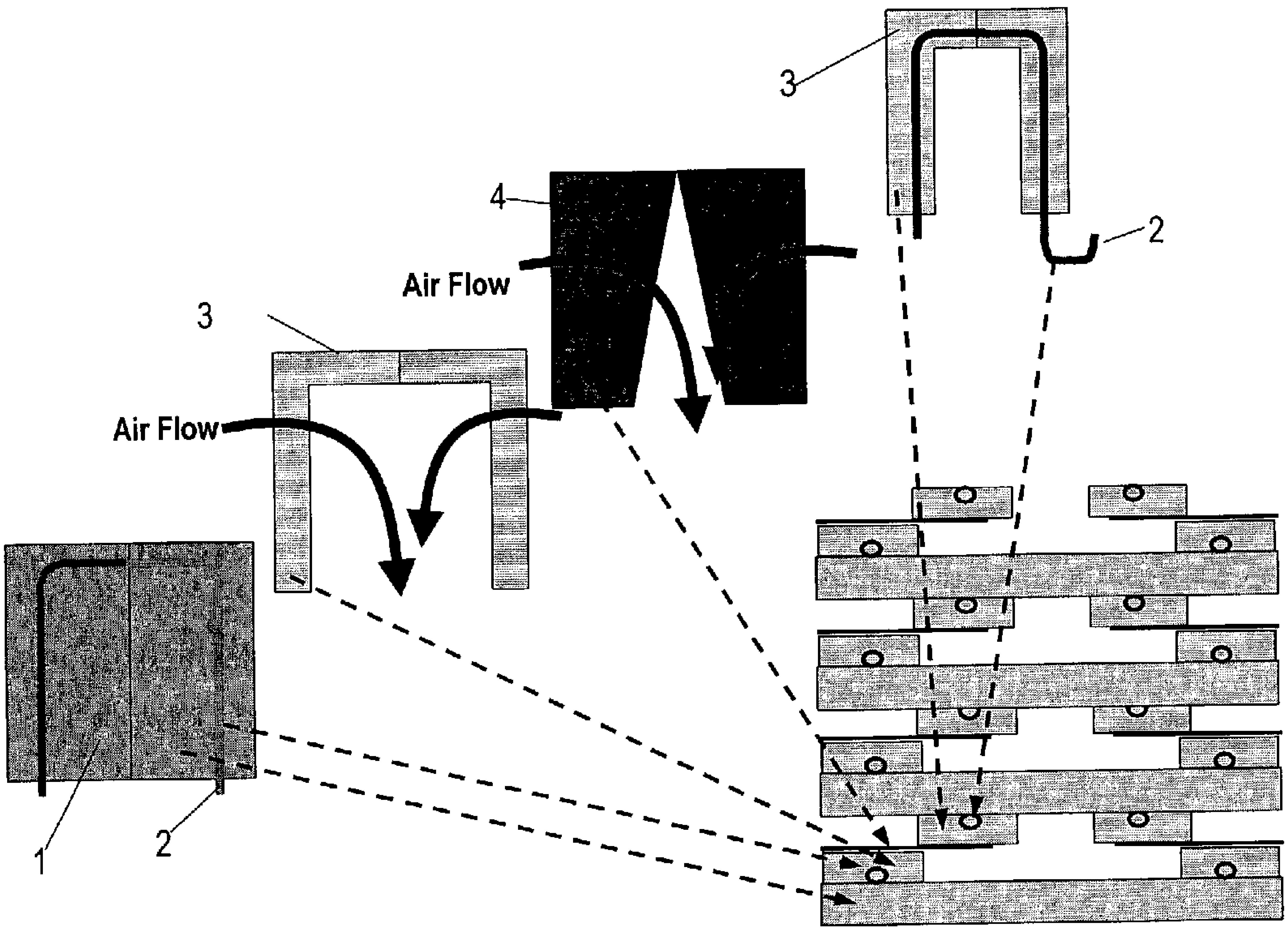

3
4
2
Air Flow
3
Air Flow
1
2

Fig. 12

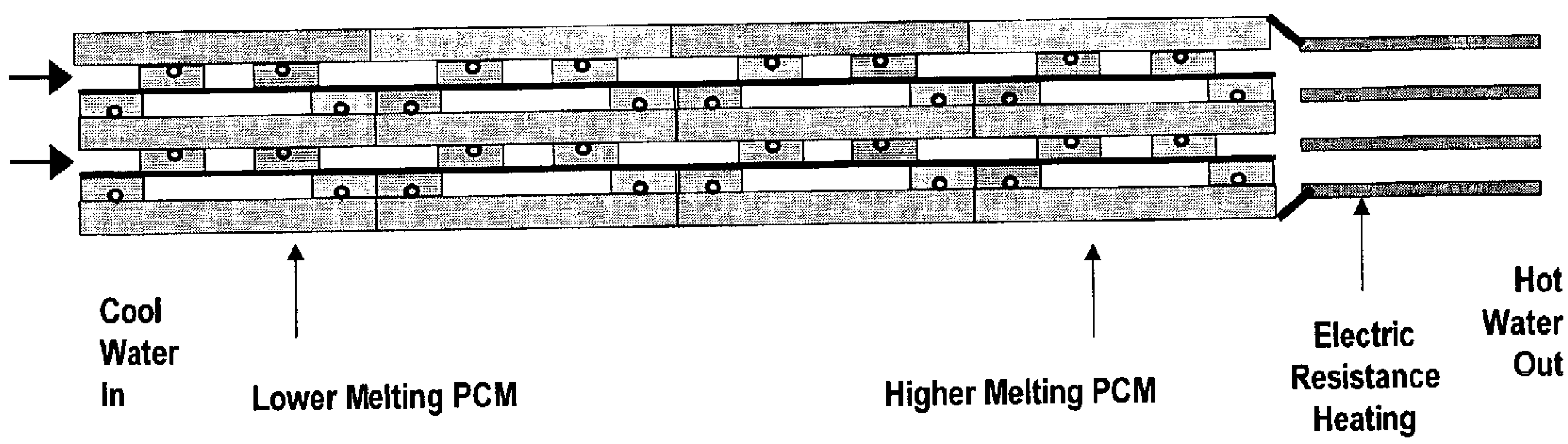

Cool
Water
In
Lower Melting PCM
Higher Melting PCM
Electric
Resistance
Heating
Hot
Water
Out

Fig. 13

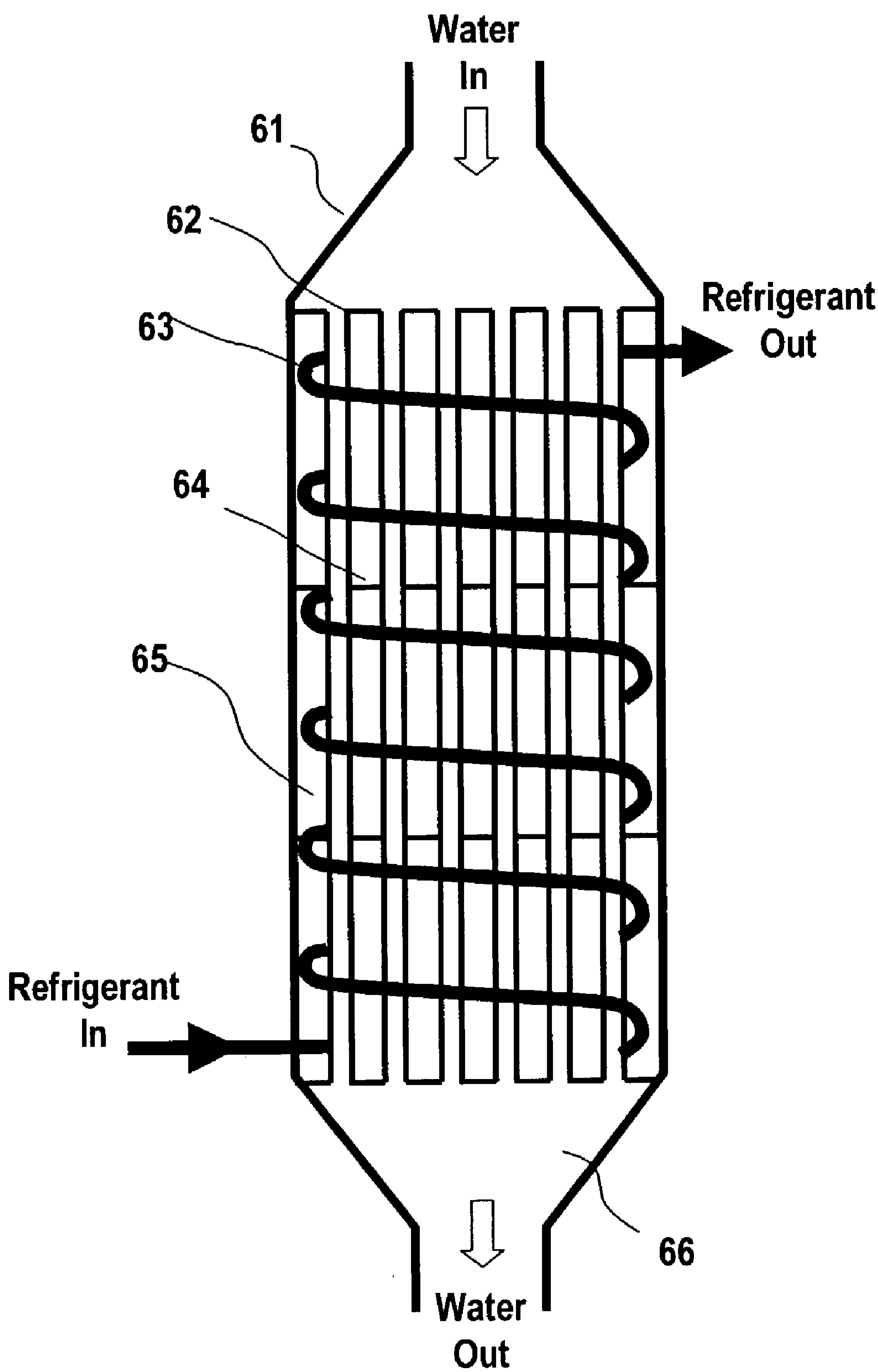

Water
In
61
62
63
Refrigerant
Out
64
65
Refrigerant
In
66
Water
Out

Fig. 14

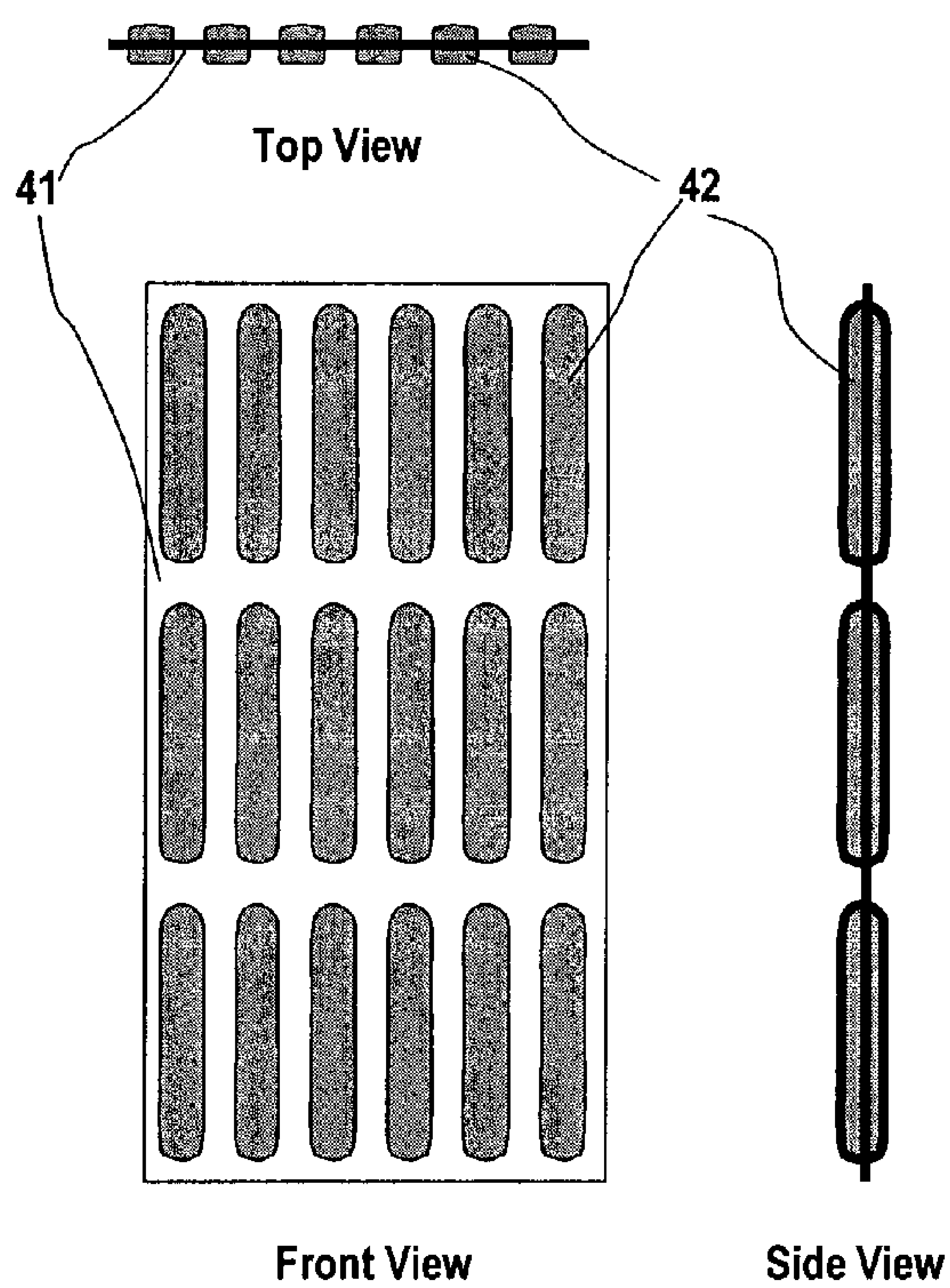

Top View
41
42
Front View
Side View

Fig. 15

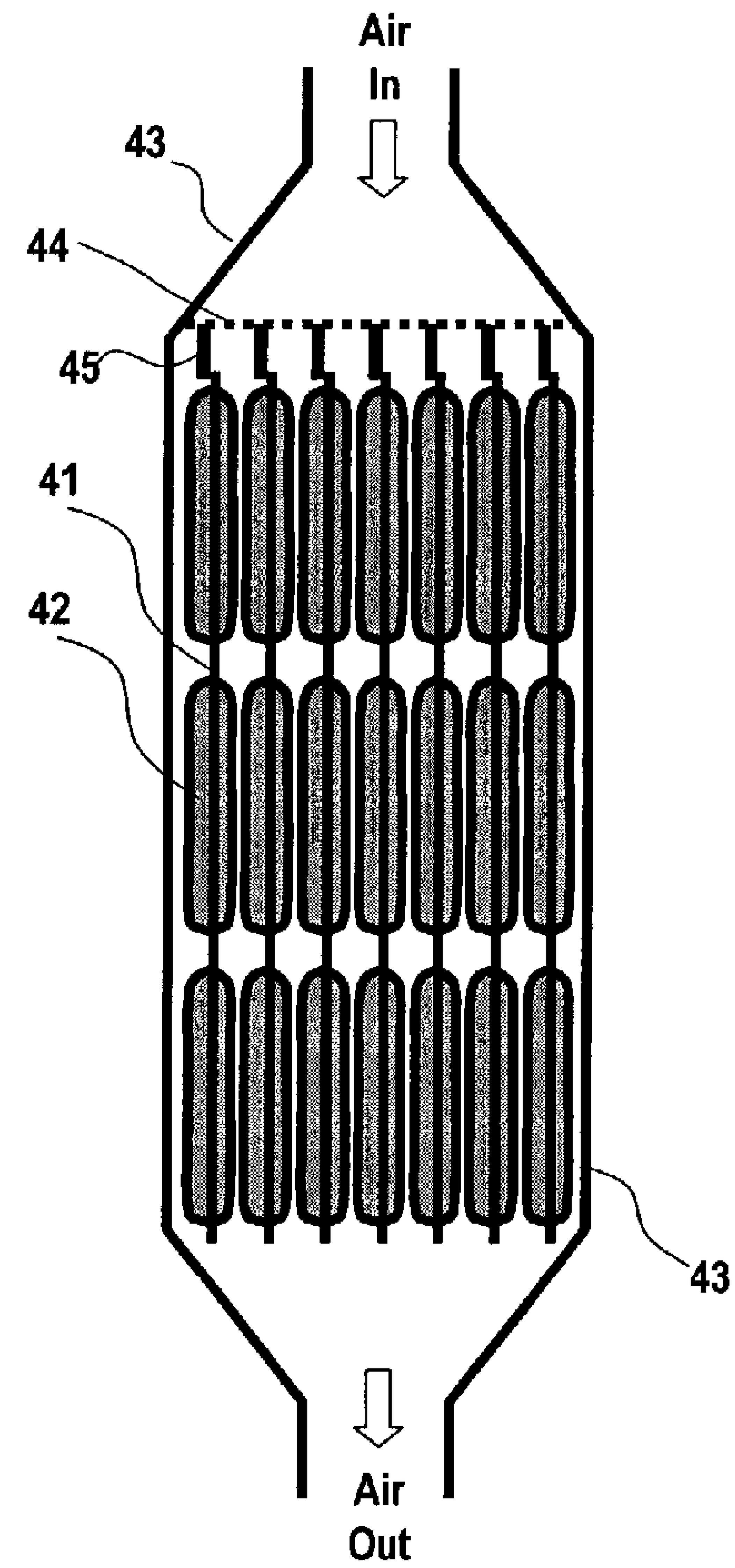
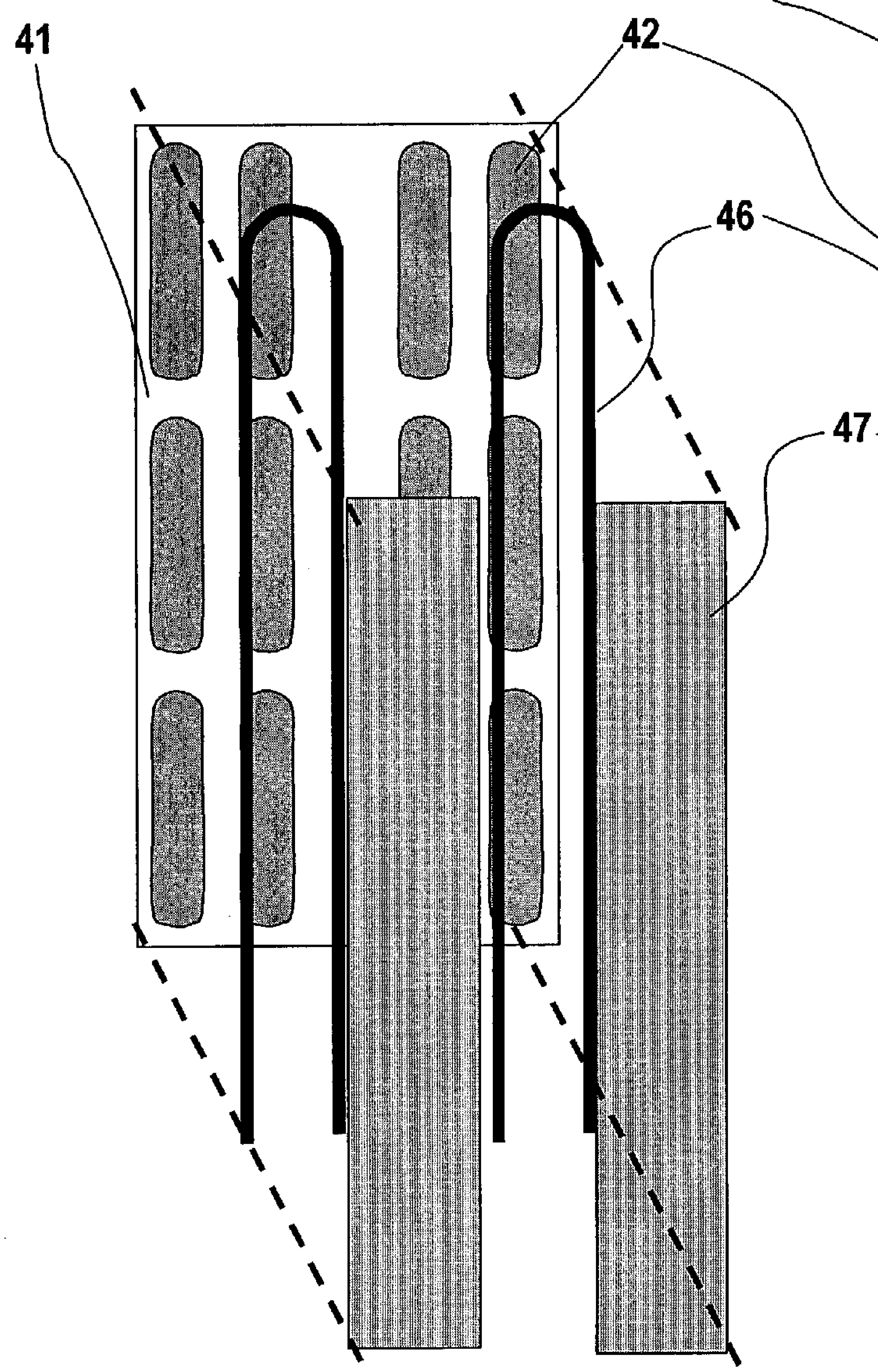
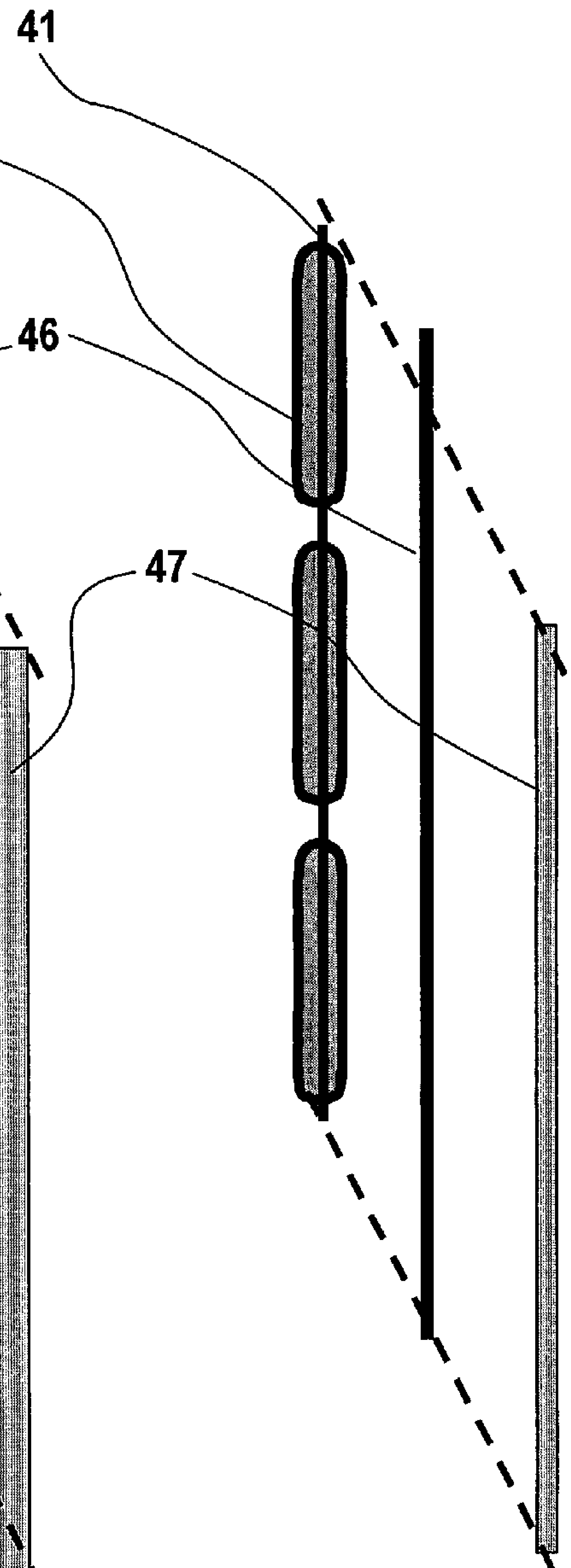

Air
In
43
44
45
41
42
43
Air
Out

Fig. 16



Front View Expansion

Fig. 17



Side View Expansion

Fig. 18

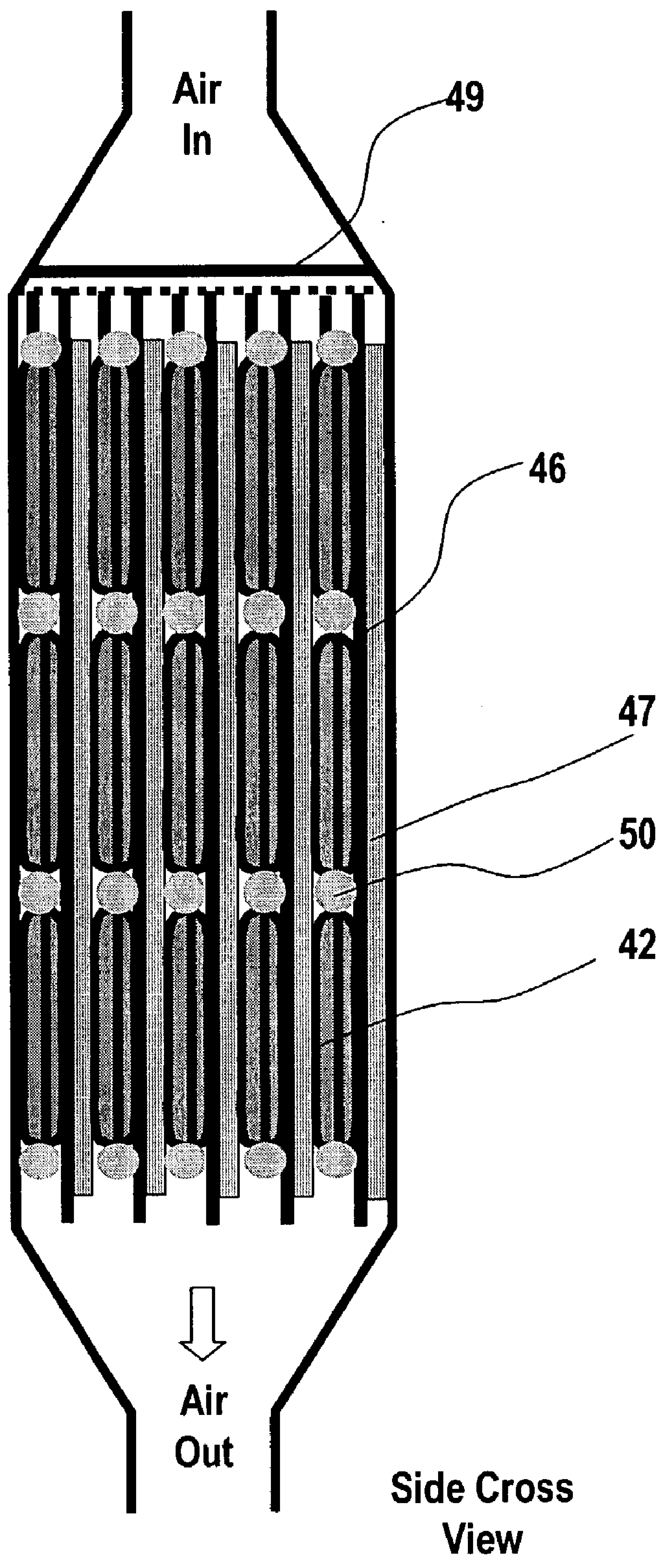


Fig. 19

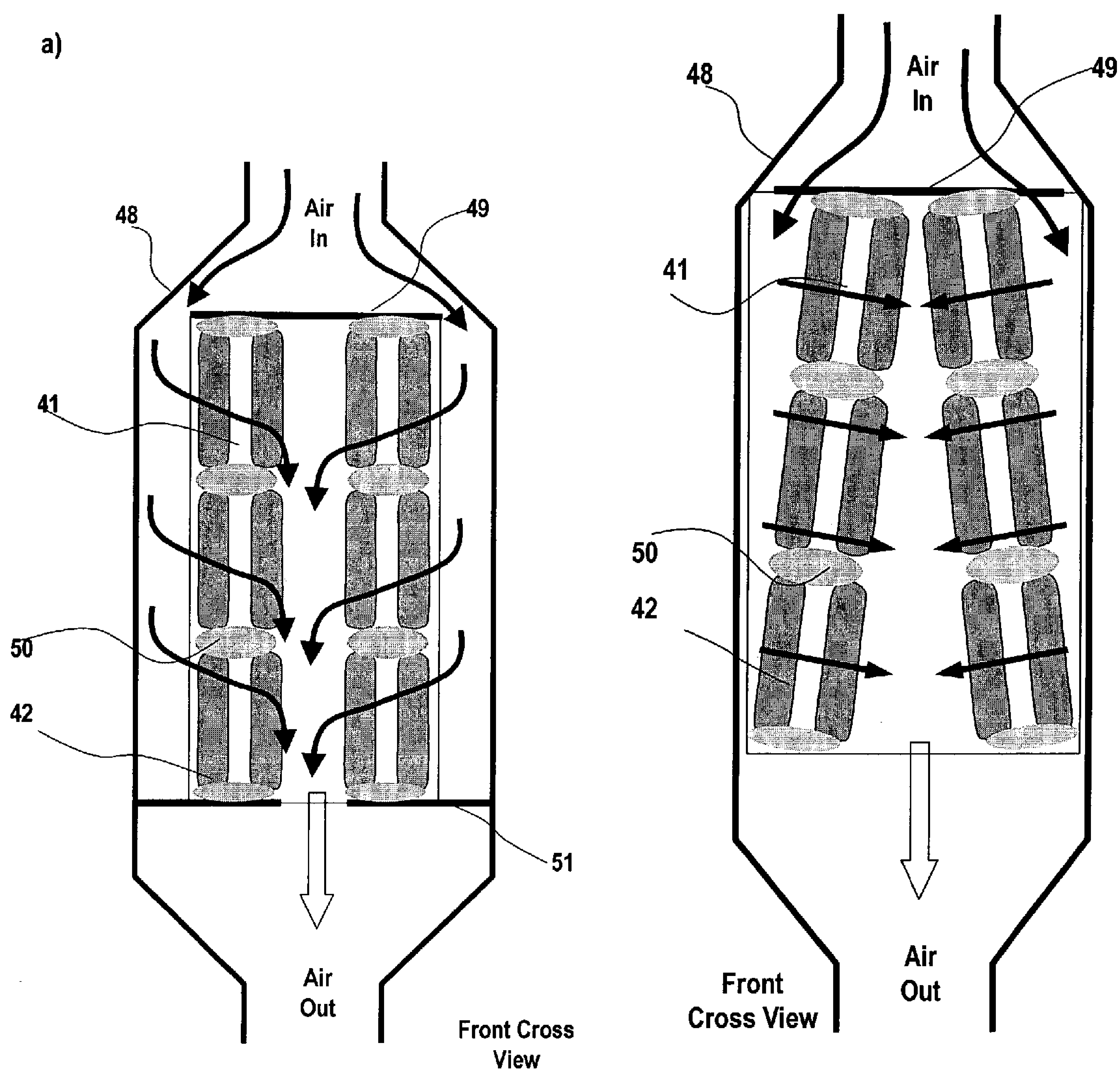
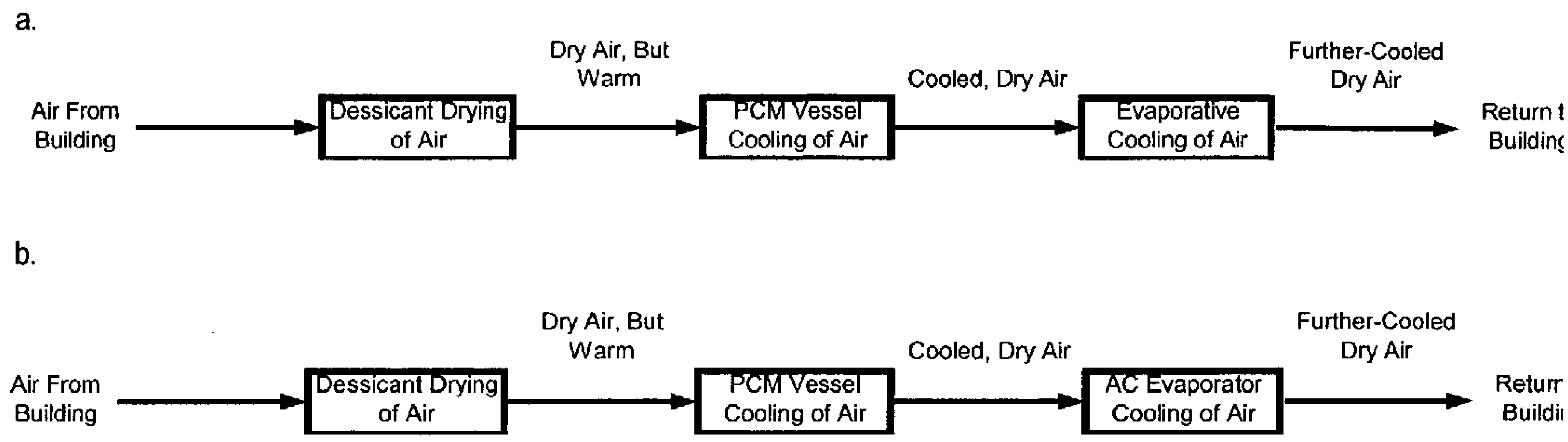
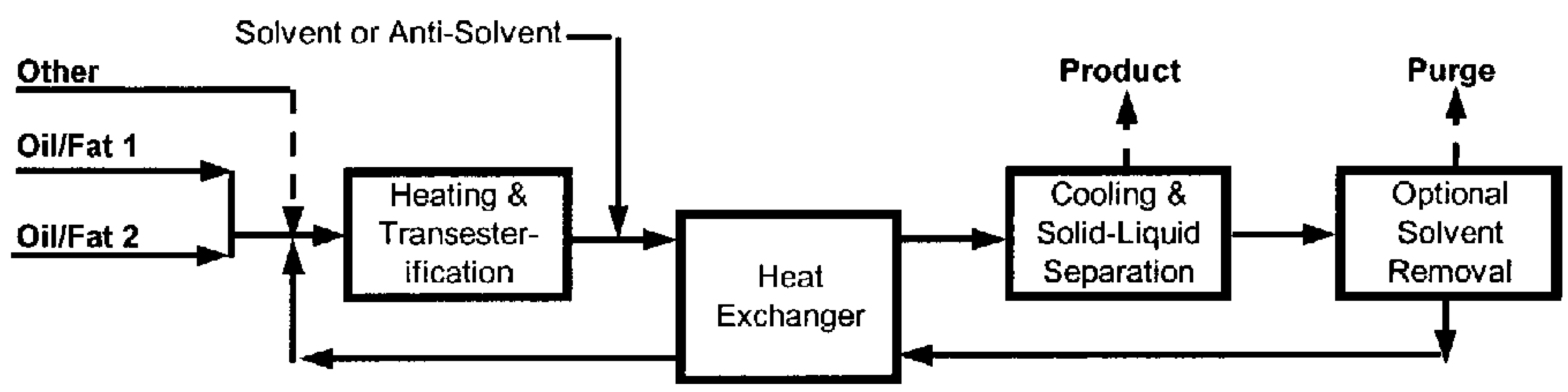

a)
Air
In
48
49
41
50
42
51
Air
Out
Front Cross
View
b)
Air
In
48
49
41
50
42
Front
Cross View
Air
Out

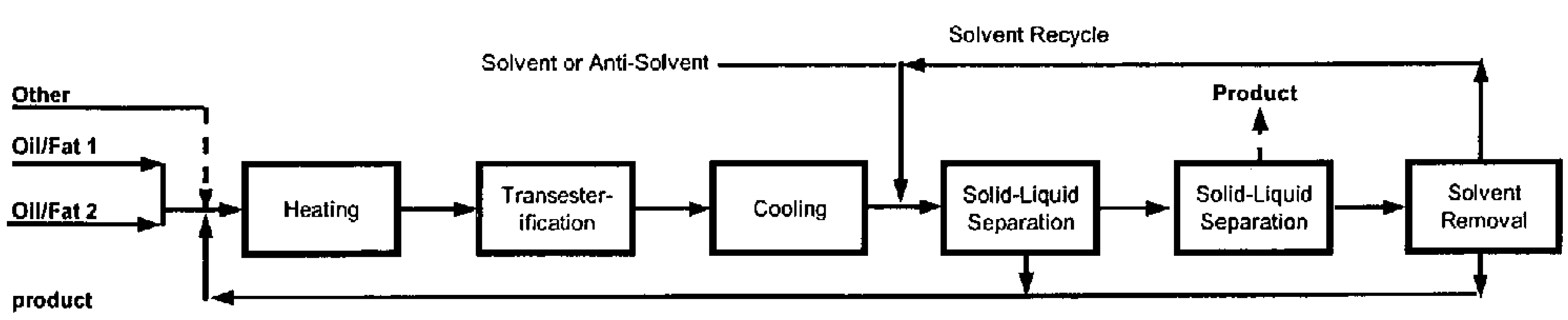
Fig. 20





- - - indicates stream is optional, depending on mode of operation
Oil/Fat 1 preferably beef tallow
Oil/Fat 2 preferably soybean oil, rapeseed oil, or yellow grease
Trans-Est Cat. preferably calcium carbonate

Fig. 21



- - - indicates stream is optional, depending on mode of operation
Oil/Fat 1 preferably beef tallow
Oil/Fat 2 preferably soybean oil, rapeseed oil, or yellow grease
Trans-Est Cat. preferably calcium carbonate

Fig. 22

HEAT PUMP USING PHASE CHANGE MATERIALS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is a Continuation-In-Part of U.S. patent application Ser. No. 09/945,682, filed Sep. 5, 2001, now pending, and claims priority of the following U.S. Provisional Patent Applications: Serial No. 60/351,506, filed Jan. 28, 2002; Serial No. 60/364,466, filed Mar. 18, 2002; Serial No. 60/410,325, filed Sep. 13, 2002; and Serial No. 60/426,595 filed Nov. 18, 2002.

BACKGROUND OF THE INVENTION

[0002] 1. Field of Invention

[0003] This invention relates generally to phase change materials and apparatus utilizing phase change materials and, more particularly, to phase change materials produced from fats and oils, and HVAC apparatus utilizing phase change materials, including heat pumps.

[0004] 2. Description of Prior Art

[0005] The present invention relates to phase change material (PCM) chemicals used in PCM devices to store or remove thermal energy. Applications include (1) walls, flooring, and tank devices used to moderate climates in buildings (2) food storage coolers or other types of coolers, (3) devices used to keep food warm, and (4) essentially any device used to keep a substance at a relatively constant temperature between −20° C. and 150° C. More specifically, this invention is directed toward a composition of PCM chemicals largely comprised of fatty acid derivatives, a method for producing these PCM chemicals, and a method for using these PCM chemicals.

[0006] The term "phase change material" or PCM is known in the science as that class of materials that uses phase changes to absorb or release heat at a relatively constant temperature. Typically the phase changes are fusion (or melting) with an associated latent heat.

[0007] Advantages of PCM in climate control include:

[0008] 1. Eliminating need of air conditioner or heater requirements during substantial portions of the year.

[0009] 2. Shift electricity usage from prime time to non-prime time.

[0010] 3. Reducing the size of air conditioners needed to provide cooling requirement.

[0011] 4. Substantially expanding regions in which heat pumps are practical for heating in wintertime.

[0012] Commonly used PCMs include hydrated salts, eutectic salts, and paraffins. Similar prior art on use of phase change materials with the outside units of heat pumps has not been located.

SUMMARY OF INVENTION

[0013] The present invention is directed toward a composition of phase change material and method for high yields of phase change materials from fats and oils, the use of phase change materials in the area of heating, venting, and air conditioning (HVAC) systems. Another aspect of the present invention is an improvement on that component of a heat pump or air conditioner that exchanges heat with the surrounding environment. More specifically, a heat pump or air conditioning coil that is designed to maximize the intake of solar energy onto the coil. Similar technology for high yields of products from fats and oils has not been located.

BRIEF DESCRIPTIONS OF DRAWINGS

[0014] **FIG. 1** is a schematic illustration showing two methods of integrating the tubing of a heat pump coil onto a surface.

[0015] **FIG. 2** is a schematic drawing illustrating a method of integrating the tubing of a heat pump coil with phase change material wherein part of the surface in contact with air contacts the phase change material and part of the surface in contact with air contacts the working fluid.

[0016] **FIG. 3** is a schematic drawing illustrating a method of integrating the tubing of a heat pump coil with phase change material.

[0017] **FIG. 4** is an exploded isometric view of a solar coil comprised of two heat transfer plates, a cavity, and a back plate wherein the heat pump fluid flows between the two plates and the cavity is filled with a phase change material.

[0018] **FIG. 5** is a side view, top view, and front view of preferred heat pump coil.

[0019] **FIG. 6** is a schematic drawing illustrating methods of integrating the tubing of a heat pump coil onto a surface by RIM attachment of the tubing to a panel with air channels through cavity, and a perspective view showing the path of air flow directed through the panel with a fan.

[0020] **FIG. 7** is a schematic drawing illustrating how the shield does not block sunlight during winter and with the sun low to the southern horizon (Northern hemisphere application).

[0021] **FIG. 8** is a schematic drawing illustrating how the shield blocks and reflects sunlight during summer and with the sun low to high in the sky (Northern hemisphere application).

[0022] **FIG. 9** is a schematic drawing illustrating an outside heat transfer device for a heat pump with a fan controlling air flow and insulation preventing heat flow when the fan is off.

[0023] **FIG. 10** is a schematic drawing illustrating a modulated central air unit for easy house installation.

[0024] **FIG. 11** is a schematic drawing illustrating an evaporator/condenser design using thin rectangular PCM containers.

[0025] **FIG. 12** is a schematic drawing illustrating a hot water heater using PCM as a stored source of heat to provide sufficient capacity to heat rapid flow of water.

[0026] **FIG. 13** is a schematic drawing illustrating a tube and shell configuration using segregated PCM chemicals and a refrigerant coil to heat water.

[0027] **FIG. 14** is a schematic drawing illustrating a laminated pouch array using two sheets to encapsulate the PCM chemical.

[0028] **FIG. 15** is a schematic drawing illustrating a vessel configuration for hanging laminated pouch arrays.

[0029] **FIG. 16** is a schematic expanded front view of a laminated pouch array embodiment with a refrigerant tube and packing sheet to provide **3**-way heat transfer.

[0030] **FIG. 17** is a schematic expanded side view of the laminated pouch array embodiment with a refrigerant tube and packing sheet to provide **3**-way heat transfer.

[0031] **FIG. 18**. is a schematic side view in cross section of a vessel containing the laminated pouch array embodiment with a refrigerant tube and packing sheet to provide **3**-way heat transfer.

[0032] **FIG. 19***a* is a schematic front view in cross section of the vessel containing the laminated pouch array embodiment with a refrigerant tube and packing sheet to provide **3**-way heat transfer illustrating the air flow pattern forcing air to enter on the sides of the hanging laminated pouch array.

[0033] **FIG. 19***b* is a schematic front view in cross section of the vessel containing the laminated pouch array embodiment showing the pouches arranged to provide even air flow.

[0034] **FIG. 20***a* and **FIG. 20***b* are block air flow diagrams of systems using PCM to enhance the performance of desiccant with evaporative cooling follow-up, and with AC cooling follow-up, respectively.

[0035] **FIG. 21** is a block flow diagram of a process for producing PCM chemicals from fats and oils using reversible reaction and a solid-liquid separation process.

[0036] **FIG. 22** is a block flow diagram of a process for producing PCM chemicals from fats and oils using two solid-liquid separation processes.

DESCRIPTION OF PREFERRED EMBODIMENTS

[0037] Three-Way Heat Transfer Embodiment

[0038] The improved heat transfer devices in accordance with the present invention may serve as either the evaporator or condenser of a heat pump, and alternative embodiments, as described hereinafter are effective for replacing conventional hot water heaters. The present apparatus and method incorporates a phase change material into the heat transfer device such that efficient heat transfer occurs between; a) air and the working fluid of the heat pump, b) the phase change material and the working fluid of the heat pump, and c) air and the phase change material. A significant advantage of the present invention over other apparatus and methods of the prior art is that all three heat transfer processes (a, b, and c) occur efficiently and in one integrated device. Incorporation of the phase change material into the evaporator or condenser can improve efficiency, extend heat pump operation into colder temperatures where it would otherwise not be the preferred option, and reduce the needs for deicing the heat pump evaporator.

[0039] The improved heat transfer device contains a passage for the flow of a heat pump fluid (also referred to as working fluid) such that heat transfer occurs through the surface of at least part of that passage. **FIG. 1** and **FIG. 2** illustrate alternative configurations for this heat transfer means—the working fluid is the fluid of the heat pump or refrigerant cycle.

[0040] Heat transfer to or from the passage is through a surface preferably comprised of metal or polymer or two or more surfaces in contact so as to function as a single surface for heat transfer. The inside of this surface is defined as being in contact with the working fluid (such as a FREON refrigerant). 10% to 90% of the outside of this surface contacts a gas comprised primarily of air, and 10% to 90% of the outside of this surface contacts a phase change material. More preferably, 30% to 80% of the surface outer side contacts air, and 20% to 70% of the surface outer side contacts a phase change material. Most preferably, 50 to 70% of the surface outer side contacts air, and 30% to 50% of the surface outer side contacts a phase change material.

[0041] In this embodiment, a heat pump uses a PCM chemical to improve the efficiency for heating a building, the heat pump includes a condenser that functionally releases thermal energy into a building, a compressor that compresses a working fluid, an evaporator that takes in thermal energy, and a fan that directs air through the evaporator. The evaporator includes at least one conduit for flow of said working fluid through the evaporator, at least one sealed cavity containing a PCM chemical, and at least one air path through which surrounding air can flow. At least 10% of the cumulative area of the outer perimeter(s) of the conduit(s) is (are) functionally in direct contact with the PMC chemical. Here, "functionally in direct contact" means that the outside (working fluid is inside) of the conduit wall is in direct contact with the PCM chemical or the conduit wall is in direct contact with the PCM chemical container.

[0042] The amount of phase change material in the heat transfer device is greater than the amount of working fluid in the heat transfer device. The ratio of phase change material mass to working fluid mass is greater than 10, more preferably greater than 25, and most preferably about 100. The total volume of phase change material is preferably between 1 and 500 gallons and more preferably between 10 and 100 gallons for every 2500 square feet of space being heated by the heat pump. The ratio decrease for larger, commercial buildings.

[0043] The phase change material is itself isolated from surrounding air in a cavity that would generally be considered a passage or container, and the volume of this cavity is greater than volume of the working fluid passage per the mass ratios previously specified. Consistent with heat pump operation, the working fluid passage allows the working fluid to flow through the heat transfer device. The working fluid flow is typically caused by a pump or compressor (not shown in the diagrams).

[0044] The phase change material is contained within the heat transfer device and does not leave the heat transfer device during normal operation. Air flows through the heat transfer device to facilitate heat transfer. Air flow is caused by a blower, a fan, or natural convection cause by wind or solar heating/expansion of air.

[0045] By way of example, **FIG. 1** illustrates an embodiment in which the working fluid passage is a tube. The tube is attached to the phase change material's containing surface. About 50% of the outer tube circumference is in contact with air and about 50% of the outer circumference is in contact with a phase change material. The phase change material may be either a continuous phase or an encapsulated phase. Sheet metal is depicted in **FIG. 1**, by way of example, as a means to contain the phase change material. The surface of the sheet metal extends beyond contact with the working fluid tube to include contact with air therein providing efficient heat transfer between the air and the phase change material.

[0046] Three-Way Heat Transfer Device

[0047] The embodiment of **FIG. 1** illustrates the use of tubes for flow of the working fluid. Here, two surfaces separate the working fluid from the phase change material. In these embodiments the two metal surfaces are at least in part in close contact so as to function as one thicker wall having relatively high thermal conductivity. The first illustration of **FIG. 1** illustrates the use of a tube next to a thin sheet of thermally conductive material such as aluminum foil. Subsequently, the foil contains and protects a phase change material that in the bulk is not fluid. An example of a phase change material that in bulk is not fluid is a polymer undergoing a glass transition at the temperature of interest. Another example of a phase change material that in bulk is not fluid is a solid-liquid transition phase change material that is encapsulated in a polymer such as epoxy resin. The second illustration of **FIG. 1** is a tube connected to a rigid sheet that is thermally conductive. An example of such a sheet is sheet metal. Here, the sheet serves three purposes: (1) it contains the phase change material and (2) it acts as a fin to increase the heat transfer area of the tube, and (3) it increases the surface available to absorb the radiant energy of sunlight or enthalpy of air.

[0048] By way of example, **FIG. 2** illustrates an embodiment in which the working fluid passage is a conduit formed by two sheets. One sheet separates the working fluid from the air. Another sheet separates the working fluid from the phase change material. The two sheets are welded, brazed, or otherwise continuously joined so as to form a passage for the working fluid. About 50% of the outer tube circumference is in contact with air and about 50% of the outer circumference is in contact with a phase change material. Sheets extend to fully contain the phase change material and provide a heat transfer area between the phase change material and surrounding air. Methods known in the science can be used to identify the material and thickness of the sheet to provide both heat transfer and structure. Metals containing varying amounts of copper, iron, and zinc are commonly used for similar applications requiring both efficient heat transfer and structure, but the embodiments of this invention are not limited to a particular material of construction.

[0049] **FIGS. 3, 4** and **5** further illustrate examples of various embodiments of the invention. The example embodiment of **FIG. 5** allows orientation to absorb solar radiation during the winter months. The rectangular configuration is represented by a length (L), width (W), and thickness (T) as illustrated by **FIG. 5**. The preferred size of the device is such that the thickness is less than 20% of the length. More preferably, the thickness is less than 10% of the length. In a more absolute sense, the length is preferably between 1 and 30 feet. More preferably, the length is between 2 and 15 feet. Most preferably, the length is between 3 and 10 feet. As compared to conventional heat pump coils, conventional coils are typically arranged in a cylindrical or box pattern surrounding a fan.

[0050] The back face of the cavity of **FIGS. 3, 4**, and **5** are primarily containing walls that optionally exchange heat with air. The front face of the cavity is that face contains the integrated working fluid passage and in **FIG. 5** is positioned to receive incidental sunlight. The working fluid is separated from the surrounding air by an air-side wall. In this embodiment, the working fluid flows through a tube, or alternatively, it flows generally between two plates.

[0051] In the embodiment of **FIG. 4, a** corrugated plate separates the air from the working fluid, a second separation plate separates the working fluid from the phase change material, and a back plate contains the phase change material. An enlarged cavity is optionally created by a perimeter around the cavity that increases the space between the separation plate and back plate. The corrugated plate forces spaces between the separation plate and the corrugated plate to allow flow by the working fluid. Ports at the upper and lower end of the corrugated plate allow the working fluid to be introduced and removed. Optional ports in the phase change material cavity allow the phase change material to be introduced or removed from the cavity. The plates are fastened by methods known in the science to create a seal on the perimeters and to provide structural reinforcement as necessary along the large flat surfaces.

[0052] **FIGS. 2 and 3** illustrate in greater detail the separation of the working fluid from air and from the phase change material.

[0053] Methods known in the art are used to configure the heat transfer fluid passage so as to allow evaporation or condensation consistent with proper heat pump operation, and to enhance the configurations to improve heat transfer with the air adjacent to the working fluid passage and adjacent to the surface that contains the phase change material. A conductive packing in the cavity increases heat transfer throughout the phase change material.

[0054] The heat transfer embodiments may be used to transfer heat to/from outside air (for example, as an evaporator for a heat pump) or to/from inside air (for example, as a condenser for a heat pump). It should be understood that the heat transfer embodiments are not limited to heat pumps. For example, the heat transfer embodiments may be used with air conditioners.

[0055] Performance benefits in air conditioning can be achieved by using two evaporators, one containing a phase change material and one not containing a phase change material. Flow of working fluid to the heat transfer device-(evaporator) may be controlled by a valve where, in an example of an air conditioner evaporator, flow to the heat transfer device during the night time stores coolness in the phase change material while during the day time flow is diverted to a second evaporator that does not contain a phase change material. In this alternative embodiment, load shifting is achieved by having return air contact that heat transfer device containing the phase change material prior to contacting the heat transfer device that does not contain the phase change material.

[0056] As previously indicated, the heat transfer device of this invention is designed to provide efficient heat transfer between a) air and the working fluid of the heat pump, b) the phase change material and the working fluid of the heat pump, and c) air and the phase change material. In addition, the heat transfer must be controllable. Heat transfer with the working fluid is controlled by controlling the flow of working fluid to the heat transfer device. When working fluid flow stops (such as when the compressor is switched off), the working fluid will approach the temperature of the air. Independent control of heat transfer between the phase change material and air requires an auxiliary control means.

[**0057**] The heat transfer device is generally designed such that when air flows through the device, heat is readily transferred between the working fluid and air, and when air does not flow through the device the phase change material is insulated from heat transfer between the phase change material and air. Methods known in the art incorporating baffles and ducts to direct air flow and insulation to enclose the heat transfer device can generally be used to achieve these desired heat flow characteristics. Heat transfer between surrounding air and the heat transfer device is thus controlled by controlling the air flow through the device.

[**0058**] By way of example, **FIG. 6** illustrates an alternative embodiment for integrating a fan with the heat transfer device. **FIG. 6** illustrates how the generally rectangular embodiment of **FIG. 4** and **FIG. 1** can be incorporated with a fan. The overall rectangular embodiment is comprised of a series of smaller rectangular embodiments with gaps between the smaller rectangular embodiments to facilitate air flow. A fan pulls or pushes air through these gaps. Ducting of air between the generally rectangular embodiment and the fan is such to allow good integration of the generally rectangular embodiment with its location. The embodiment of **FIG. 6** illustrates this ducting where the generally rectangular embodiment is oriented at a different angle than the surface where it is mounted. The preferred method for manufacturing the embodiment of **FIG. 6** is by reaction injection molding. When this embodiment is placed on the roof or wall, the roof/wall insulates one side.

[**0059**] **FIGS. 7 and 8** illustrate how the heat transfer device of **FIG. 6** can be designed to receive solar radiation in the winter while reflecting away this radiation during the summer.

[**0060**] Insulated Outside Evaporator Embodiment

[**0061**] By way of example, **FIG. 9** illustrates the preferred outside evaporator of a heat pump of this invention. Interconnected vertical panels contain the phase change material with the working fluid passages on one side of these panels. Air spaces between the panels allow upward air flow. The four sides are comprised of insulate panels. Air enters the bottom and is forced through the system by a fan located at the top. When the fan is not operational, convective air flow largely ceases and the insulating side panels largely eliminate heat transfer with the outside air.

[**0062**] In the preferred outside unit illustrated by **FIG. 9**, the functionality of the housing is particularly important. In a heat pump using a PCM chemical to improve the efficiency for heating a building, the heat pump includes a condenser that functionally releases thermal energy into a building, a compressor that compresses a working fluid, an evaporator that takes in thermal energy, a fan that directs air through the evaporator, and a housing that contains and connects said evaporator and fan. The housing has an outer surface with a respective surface area. Preferably, at least 50% of the said housing surface area provides insulation resistant to heat flow and also seals that surface against air flow. Preferably, a fan directs air through the said housing methods known in design are incorporated in the design to minimize air flow with the fan is not on. Use of a shutter that blocks air from flowing through the housing when the fan is not running is an example of one design option. This insulated housing serves the important purpose of preserving the stored heat in the PCM chemical until such time it is needed to provide heat to the building served by the heat pump. **FIG. 9** illustrates an embodiment with insulation on the sides and a fan on top. Air is preferable pulled in the top and forced out the bottom. A screen and other methods known in the science are used to prevent plugging of the air path ways through the evaporator.

[**0063**] Whether the PCM panel of **FIG. 4, 6**, or **9**, the preferred thickness of these panels are between 0.25 and 5 inches and more preferably between 0.5 and 3 inches. Most preferably, the thickness is about 2 inches, which provides an optimum between storage capacity and good access for heat transfer.

[**0064**] Within the scope of this invention, the use of phase change materials in the exterior component (outside house) of the heat pump is not limited to phase change materials based on fatty acid derivatives. Essentially any phase change material can be used in the preferred embodiment of **FIG. 1**. The preferred embodiment of **FIG. 1**. is in the structure of **FIG. 4**; however, the incorporation of phase change materials into the embodiment of **FIG. 1** can be in a variety of larger geometries including but not limited to flat surfaces, curved surfaces, or cylindrical surfaces.

[**0065**] An alternative phase change material for use in the exterior component of a heat pump (the evaporator in the case of the heating cycle of the heat pump) is water. The advantage of water is that it can readily be melted during the warm winter days for use during the night. Since the economic viability of using the heat pump with a conventional evaporator alternative to electrical or natural gas heating is typically favored until temperatures go below about 30° F. Water is a good, example phase change material for this application since it is a good heat storage media at 32° F.—a low temperature point where the heat pump is favored over natural gas. Salts or antifreeze can be added to the water to create freezing at temperatures lower than 32° F., as desired.

[**0066**] Proper use of convection heating created by the fan-induced air flow over the evaporator is important. The value of water is realized when the highest temperature of the day is above 32° F. while the lowest temperature of the day is below 32° F. When temperatures are below 32° F., the outside convection fan is not used in favor of conducting heat from water(the phase change material in the evaporator) that can freeze therein releasing its latent heat. During that part of the day when the outside temperature is above 32° F. (more preferably above 33° F.), the outside fan is turned on until such time that the temperature of water is above 32° F. as an indication that the water has melted.

[**0067**] Smart Fan Embodiment

[**0068**] When used for residential heating, the preferred means for controlling fan operation in the evaporator of the heat pump is to operate the fan when the exterior air temperature is warmer than the evaporator coil by an incremental temperature difference. This incremental temperature difference is preferably between 1° F. and 5° F. During those days when the heat pump is not used for heating, control of the fan to store energy in the phase change material is not required. This mode of operating the fan of an outside evaporator unit based on the outside temperature being warmer than the evaporator coils is hereafter referred to as a "Smart Fan" method of operation.

[0069] The advantage of operating a heat pump in this manner is that the heat pump can operate a nighttime with efficiencies similar to those realized during the warmer daytime hours. An additional advantage of operating a heat pump in this manner is that the phase change material moderates the temperature extremes that otherwise occur in the heat pump. For example, a heat pump will readily generate evaporator temperatures 5° F. to 20° F. lower than ambient temperatures to cause the flow of heat from the surroundings into the working fluid of the heat pump. By example, if the outside temperature is 20° F., this translates to a working fluid temperature of about 10° F. The good thermal conductivity of the phase change material reduces the temperature driving force and stores energy creating a working fluid temperature of about 29° F. for the same outside conditions. The higher working fluid temperature provides the following advantages: a) higher heat pump efficiency, b) high outlet air temperatures in the house, and c) reduced or eliminated icing of the exterior evaporator. All of these advantages are most significant. By reducing or eliminating icing, the heat pump will allow operation at even lower temperatures than would otherwise be possible. Reducing or eliminating icing is realized at all subfreezing outside temperatures since icing is caused by the temperature difference between the evaporator coils and the outside air temperature—this temperature difference is reduced by the heat capacity of the phase change material provided the heat pump is only operated intermittently (as is usually the case).

[0070] Phase change materials used with heat pump evaporators are preferably water or mixtures containing water. In general and for either heating or cooling applications, the phase change material preferably has substantial latent heat capabilities between 20° F. and 100° F. The optimal phase change material will depend upon location.

[0071] In the most preferred residential heating embodiments, convection heating of the exterior coils is supplemented with solar heating. As previously described, solar heating can be on a flat evaporator embodiment. Alternatively, air can be heated by the solar heating embodiment (such as SOLARWALL) and directed over the exterior component of the heat pump. Allowing solar heating elements to function independent of the heat pump has the operational advantage of allowing the solar heating element to directly heat the house when the outside temperatures are warm enough, and then, using the solar heating element to enhance heat pump performance when outside temperatures are too cool to directly use the solar heating element to directly warm the house.

[0072] Preferably, the solar heating embodiment is on the roof with air flow under the upper, hot surface. Preferably, the solar heating embodiment provides both heated air and roofing therein avoiding shingling costs. Preferably, in the summer water is sprayed on the roof, preferably in an automated manner with methods known in the science, so that the large heat transfer surface provides a cooling heat transfer during summer nights. Drainage should be periodically complete to avoid microscopic growth. Preferably, the air cooled under the heat transfer surface is drawn from a source that is not itself laden with moisture. The cooled air could be directed for ventilation or contacted with water for further cooling and used to cool the exterior air conditioning coils.

[0073] The embodiments of **FIGS. 5, 7,** and **8** are designed to selectively receive solar radiation during winter months. When in position, the large face of the rectangular configuration is preferably oriented such that the top edge of the plane is level. The end of the plane is at an angle from vertical such that the sunlight hits the plane at a perpendicular angle at a time during that half of the year when heating is required. For areas like Arkansas where the heating season is short, it is preferred to have the sunlight hit the plane at a vertical angle during the longest day of the year. Further north, it is too ambitious to pursue heat pump use during the shortest day of the year, and so, the angle is such that sun light hits the plane at a vertical angle at 1 to 2 months prior (and accordingly after) the shortest day of the year.

[0074] The advantage of this configuration is that solar energy is used to improve the efficiency of the heat pump. This advantage is realized in the wintertime; however, in the summer the incidental angle of the sun is such that it does not induce much radiation onto the surface and reduce the cooling efficiency of the heat pump.

[0075] It should be understood that the embodiments of the present invention may essentially be of any geometry that generally fits in the space of the rectangular plane described herein.

[0076] To further reduce incidental radiation during the summer, shields are preferably attached to the rectangular embodiment such that sunlight largely does not hit the shield (see **FIG. 7**) during the season when the heat pump provides heating. During the heating season, the face of the rectangle is largely perpendicular to the incidental radiation. As the year progresses to summer, the greater the incidental sunlight angle is from vertical. The shield is designed such that during the air conditioning season the sunlight hits the shield (rather than the face of the rectangle) and is preferably reflected away from the plane. During the hottest three months of the year, essentially no light hits the tubing or interconnected metal for heat transfer—essentially all sunlight being reflected away from the tubing (see **FIG. 8**). The preferred shield consists of one or more surfaces that are generally perpendicular to the plane of finned coils. More specifically, the shield is a series corrugated surfaces such as that illustrated by the insert of **FIG. 8**.

[0077] The preferred location for the flat rectangular embodiment of this invention is on a roof with exposure to the winter sun. Operating as a solar energy receiver, fan convection is not necessary with the solar energy received is greater than or equal to the energy taken from the evaporator to heat the building. Operation without a fan is preferred. In such an application, no exterior fan is used to force air over the coil and the heat pump operation is regulated to provide a lower, steady heat flow rather than typical operation where the heat pump runs at full capacity for several minutes and then shuts off for several minutes. During the summer, nighttime operation, radiant heat losses will at times be sufficient to alleviate the need for fan use. Preferably, in the summer a spray of water on the face of the condenser will reduce the need for fan use. Reducing fan use saves on electricity and reduces noise.

[0078] Referring to **FIG. 6**, optionally, to assist airflow through the coil, a fan under the coil pulls air down and into the coil. Ducting surrounds the bottom surface of the flat coil embodiment and directs air flow to the fan—forcing essentially all air that flow through the coils to also go through the fanning area.

[0079] Preferably, the fan is reversible. When providing heat to the house, the fan pulls air down through the coils. When providing cooling, the fan pushes air up through the coils. Glass or other transparent material is optionally placed above the coil to trap in heat during the winter—in this embodiment air preferably flows in under the glass and above the soil plane at the lowest part of the glass surface. The preferred color of the coil fins is black. The preferred color of the shields is any reflective metallic color.

[0080] Optionally, water is sprayed in the air during cooling months (summer) such that the water mixes with air prior to contacting the coil. This provides evaporative cooling and lowers the coil temperature more than would otherwise be achievable.

[0081] Alternative to positioning on a roof, the rectangular embodiment is at ground level with a Southern exposure (for use in the Northern hemisphere). Alternatively, the rectangular embodiment is set with the face at a near-vertical orientation next to a building's siding or in place of the building's siding.

[0082] The preferred use of the coil of this embodiment is with a heat pump. The heat pump preferably can operate at different condenser/evaporator pressures so as to increase the COP values when the ambient temperatures are similar to inside set point temperatures. With solar heating of the coil during the heating season, the coil will at times reach temperatures several degrees warmer than inside temperatures (Likewise, with evaporative cooling the coil temperature will often be cooler than set point temperatures during the cooling season.). In these instances, heating (cooling) can be achieved by merely circulating the heat pump fluid. The preferred mode of operation under these circumstances is to circulate the cooling fluid with the least energy-intensive means available to the system when such circulation alone provides sufficient heating (cooling).

[0083] The preferred method to circulate the heat pump fluid when circulation alone is sufficient is to open or bypass all throttling devices in the cycle by methods known in the science including but not limited to opening a throttling valve or by-passing a throttling valve through a parallel tube that is activated by opening a solenoid valve. Circulation can be induced by compressing the heat pump fluid at the minimum pressure ratio that will allow circulation. Alternatively, the compressor can be by-passed by methods known in the science with pump being used to move liquid at a location parallel to the throttle.

[0084] The rectangular condenser/evaporator embodiment may function with or without significant heat storage capacity. When designed without significant heat storage capacity, heat transfer fins are preferably attached to the tubing as is conventional in air conditioner coils. In such embodiments, the fins surface is preferably perpendicular to the face of the rectangular embodiment in an arrangement known in the science such that gravity would assist the flow of condensed liquids to the bottom of the embodiment.

[0085] **FIG. 10** illustrates how a heat pump system can be integrated into a sheet of plywood for prefabrication. The prefabrication reduces installation costs. Integration the outside unit on the wall further reduces installation costs and specifically eliminates the cost of the concrete slab where the outside unit is typically mounted.

[0086] Alternative Embodiments and Chemicals

[0087] While in the preferred embodiment, 10% to 90% of the outside of the surface contacts a gas comprised primarily of air, and 10% to 90% of the outside of this surface contacts a phase change material; an alternative embodiment has the tube containing the working fluid (typically a refrigerant) substantially enclosed in the phase change material container.

[0088] By way of example, the working fluid could be in a 0.25 inch tube that is located in a 4 inch pipe containing the phase change material. The 0.25 inch tube is substantially in the 4 inch pipe; however, it is outside the pipe at locations adjacent to where it enters/exits the pipe and is manifolded by methods commonly used in evaporator/condenser design.

[0089] In this alternative embodiment and specifically in the heat pump mode, the 0.25 inch tube and phase change material (PCM) alone reach temperatures lower that the temperature at the PCM container to air interface. This is important since the low temperatures at the air interface can induce condensation and freezing that requires an energy-intensive thawing cycle. By operating the fan to warm the PCM essentially continuously during the warm part of the day, the container-air interface will not reach temperatures as low as those reached in the PCM and the cycle will be more efficient and require lower maintenance.

[0090] The preferred PCM for the outside, evaporator coil of the heat pump is a water-salt mixture that freezes between about −8° C. and 0° C. More preferred, the salt-water mixture freezes between about −6° C. and −2° C. Several salts and water-salt compositions that are capable of operating at these conditions are summarized in Lang's Handbook of Chemistry.

[0091] For summer operation as an air conditioner, it is preferred to have the PCM in the outside condenser to be a material having a melting point between 80° F. and 100° F. It is preferred to spray water over the cooler during the nighttime hours to cool and freeze the PCM for use as a cool temperature reservoir during the daytime. Devices could be made with both types of PCM materials(type for use with cooling and type for use with heating) present or where the PCM can be changed twice a year.

[0092] Thin Container/Pouch Design

[0093] It is highly desirable to reduce the resistance to air flow and travel path of air in the outside evaporator unit during heating and the outside condenser unit during cooling.

[0094] **FIG. 11** illustrates an alternative design of a PCM-containing device wherein the PCM is located in thin containers **1**, for example, a container that is 2 inches thick, 2 feet wide, and 3 feet long. Tubing **2** containing the working fluid is located adjacent to the container **2**. By way of example, the tubing is 0.25 inch copper tubing that is glued to the container. A heat transfer enhancer **3** is placed above the tubing **2**. By way of example, this heat transfer enhancer is a series of thin aluminum fins that direct flow over the tubing **2**. By alternative example, the heat transfer enhancer is an aluminum mesh resembling steel wool in appearance. A spacing plate **4** is located above the heat transfer enhancer. This plate **4**, by example, divides an air travel path of 8 inches into an air travel path of 4 inches through a heat transfer enhancer followed by a travel path of 4 inches through a low-resistance space. This plate **4** allows two such paths parallel paths to be located between containers **1**. The advantage created by this plate is that it creates travel paths similar to those encountered with conventional air conditioner heat exchangers while allowing for larger containers. Above the plate, a second heat transfer enhancer **3** is located in contact with a different PCM container such that it is located on a different location of the container. Tubing **2** is located between the heat transfer enhancer **3** and container **1**.

[0095] This configuration allows the stacking of functional assemblies as indicated by **FIG. 11**. Air flows in from three sides through the open portion at the middle of the spacing plate **4** and out the fourth side. Preferably the fourth side is upward-facing (placed as the top) with a fan mounted (similar to **FIG. 9**) to pull air through the evaporator/condenser.

[0096] In the embodiment of **FIG. 11**, the containers, tubing, heat transfer enhancers, and plates can be stacked as illustrated by **FIG. 11**. This stacking can increase the weight on the bottom units. This weight can increase stresses during freezing and thawing and lead to leaks. To reduce the stresses, the containers can be supported from their perimeters; however, for this to be effective at least one of the stacked elements (containers, tubing, heat transfer enhancers, or plates) must have a structural strength. The Hanging Laminated Pouch Embodiment overcomes the problems with weight accumulating on the bottom of a series of containers.

[0097] Water Heating Embodiment

[0098] A water heating embodiment of the present invention incorporates a working fluid conduit next to the energy storage of a PCM heats water rather than air. In this embodiment, the PCM stores enough thermal energy to heat water as it flows through the system. The PCM preferably melts over a temperature range from 70° F. to 140° F. A working fluid melts the PCM, which stores energy. The stored energy delivers heat to the water at a rate greater than the capacity of the heat pump system for short periods of time such as during a shower. The advantage of this system is that the efficiency of the heat pump is used to heat hot water. In addition to the heat provided by the heat pump, electrical heating devices are used to increase the water temperature to values greater than 140° F. The cool water source flows through the PCM-based hot water heater in a flow path such that it contacts (through the container wall) the PCM with the lowest melting point first. Unlike air systems, this water heater system is preferably designed such that water has longer flow paths next to the PCM allowing for greater heat transfer. **FIG. 12** shows this embodiment where the PCM modules are not stacked, but rather end-on-end to provide greater flow paths and heat exchange to the water. The advantage of this unit is that the stored heat can be delivered at a rate fast enough to heat the water while the heat pump or electrical resistance alone would not be able to supply the heat fast enough. Also, the heat pump as enhanced with the PCM operates at greater efficiency than is possible without the PCM. Also, when this is a controllable dump of heat from a heat pump, the heat can actually be pumped from the house into the hot water therein providing both cooling and hot water with little or no additional heating beyond that used/required for air conditioning.

[0099] Hot Water Heater Embodiments

[0100] The preferred means for heating the PCM in a hot water heater (or hot water preheater) is with the hot compressor effluent of a vapor-compression air conditioner or heat pump. In the vapor-compression cycle, the compressor exit is the hottest temperature reached by the working fluid in the cycle. This highest temperature is best utilized to heat water exiting a flow-through hot water heater. **FIG. 12** shows a hot water heater using containerized PCM, a counter/cross flow of the refrigerant through the system, and a packing element that enhances heat transfer. **FIG. 13** shows a more-conventional arrangement in a tube-and-shell configuration. The end cap section of the shell **61** of the embodiment of **FIG. 13** directs water flow to and through the pipes **62**. On the shell side of the pipes, a refrigerant tube **63** coils around the bundle of tubes. The shell side of the tubes is divided into multiple sections along the longitudinal direction by shell-side dividers **64**. PCM chemicals are static in the shell side cavity **65** with lower-melting PCM chemicals on the water entrance side and higher-melting PCM chemicals on the water exit side. The water in the tubes joins at the exit-side cap **66** to exit at a hot temperature suitable for use as hot water or suitable for heating to higher temperatures. Lower-temperature PCM chemicals typically have latent heat storage between about 20 and 40° C. Higher-temperature PCM chemicals typically have latent heat storage between about 60 and 110° C.

[0101] Methods known in the art to avoid pinch-point-related heat transfer limitations may be used to maximize the utilization of available heat and minimize the creation of entropy. The entering refrigerant tubing **63** preferable comes directly from the compressor and proceeds in a countercurrent coiling configuration to exit the hot water heater at the water entrance side. The advantage of this heat pump configuration is that it stores the hottest temperature of the vapor-compression cycle for use to heat water and allows the water consumption and heat pump operation to be largely independent. However, it would be advantageous to operate the heat pump and charge the hot water heater on an as-needed basis. Using the heat pump or air conditioner to provide hot water can reduce the electrical consumption by about 50% to 80% as compared to electrical hot water heating. The highest energy savings are reached during the summer when the heat pump under this configuration takes heat from the house air and puts that heat into the water—thus providing both air conditioning and hot-water heating.

[**0102**] Hanging Laminated Pouch Embodiments

[**0103**] An alternative configuration to the PCM container **1** of **FIG. 11** is illustrated in **FIG. 14**. The PCM container of **FIG. 14** consists of at least two sheets **41** that are laminated to create sealed pouches **42** containing PCM chemical. The sheets could be any of a range of materials used to contain liquids including but not limited to such materials as flexible plastics, rubbers, or aluminum. Plastics such as polyethylene or PET would work well as would aluminum foil coated with a puncture-resistant plastic. Laminating to create and seal the pouches **42** can be performed by a number of methods known in the science, including but not limited to the use of an adhesive or heating of thermoplastic sheets to create a bond. These laminates are preferably prepared to create multiple pouches in one sheet such as that illustrated by **FIG. 14**.

[**0104**] If the envelope-like pouches created by flexible sheets were laid on-upon-the-other, the bottom pouches would be under considerable pressure and related stresses. In addition, air would not readily flow between pouches. To overcome these problems, the embodiment of **FIG. 15** places the laminated pouch array in a vessel **43**. The load-supporting bar **45** is placed on the top end of the laminated pouch array and this load-supporting bar is supported **44** by the vessel **43** such that air is directed and flows about evenly between the multiple laminated pouch arrays in the vessel **43**. This configuration allows each laminated pouch array to be supported without its weight adding to the stresses on other laminated pouch arrays and creates longitudinal air flow pattern that takes air across the entire laminated pouch array and is referred to as the "Hanging Laminated Pouch Configuration". The pouches **42** of PCM are supported by a tensile load on the sheets rather than compressive loads of stacked sheets—the needed tensile strength is much less expensive to design into devices. In the hanging position, the vertical dimensions of the pouches preferably do not exceed three feet, more preferably do not exceed one and a half feet, and most preferably are between two and fifteen inches. The longer vertical dimensions of the pouches **42** are to be avoided because the increase the pressure of the fluids at the bottom of the pouches and cause bulging. The pouches **42** are preferably arranged to create an even air flow distribution over all pouches. The configuration of **FIG. 15** is an alternative to more-costly tube-and-shell configurations and sphere or cylinder encapsulations that are used to store PCM chemicals and provide contact with air for thermal energy storage.

[**0105**] Although the Hanging Laminated Pouch Configuration of **FIG. 15** illustrates air entering at the top and exiting at the bottom of the vessel **43**, the embodiments of the Hanging Laminated Pouch Configuration are not limited to an particular direction of air flow or location of air entrances and exits to the vessel **43**.

[**0106**] In the configuration of **FIG. 15**, cold air is introduced into the vessel **43** to charge (freeze) the PCM chemical and warmer air is passed through the vessel to use the stored coolness (charge). Alternatively, refrigerant tubing can be passed through the vessel and placed in direct contact with the PCM pouches. Preferably, a 3-way heat exchange is established such as that illustrated by **FIGS. 1 and 2**. **FIG. 16** illustrates an embodiment where refrigerant tubes **46** are placed next to the laminated pouch array. A packing sheet **47** is then placed next to the refrigerant tubes **46**. The packing material **47** serves substantially the same purpose and is substantially the same as the heat transfer enhancer **3** of **FIG. 11**. The packing sheet **47** can be any of a variety of materials that allows air to freely flow through the packing material while providing resistance to compression (compression that would choke air flow between the PCM containers). In addition, the preferred packing material enhances heat transfer by creating turbulence in the air flow and by conducting heat from air to the tubing **46** or laminate **41**. A mesh of aluminum wool is a suitable packing sheet **47** while other materials that are less likely to puncture the laminate **41** are preferred. **FIGS. 16 and 17** show the expanded front and side views illustrating the preferred arrangement of laminate **41**, tubing **46**, and packing **47**.

[**0107**] **FIG. 18** illustrates how multiple laminated pouch arrays, tubing **46**, and packing **47** are hung in a vessel **48** to provide contact between the tubing **46** and laminate **41** where the packing **47** keeps the tubing and laminates in close contact while allowing air flow. In this configuration, the refrigerant tubing **46** is networked by methods known in the design of evaporators and condensers for heat pumps—this includes at least one refrigerant tube entrance into the vessel **48** and at least one refrigerant tube exit from the vessel. The embodiment of **FIGS. 18 and 19** may be used as either the evaporator or condenser of a heat pump and may be used for either heat exchange with inside air or outside air in these capacities.

[**0108**] When used with inside air, longer air contact paths/times are preferred as compared to uses with outside air. This is because the goal of heat exchange with inside air is to change the air temperature—typically by more than 10° F. and preferably more than 15° F. When used with inside air, air is preferably directed along the entire longitudinal length of the laminated pouch arrays.

[**0109**] When used with outside air, the purpose is not to change the outside air temperature, but rather to change the refrigerant temperature; therefore, higher air throughputs are pursued with shorter laminate **41** contact times/paths. **FIGS. 18 and 19*a*** show the preferred configuration for creating shorter contact times with the air. In this configuration, a plate **49** prevents the air from entering at the top of the laminated pouch array and directs the air to the sides of the array. Air enters the sides and exits down the middle of laminated pouch array and out the bottom. Since air will tend to follow the path of least resistance, packing **50** is placed at locations along the laminated pouch array that are not naturally filled by the packing sheet **7**. This packing **50** may be any of a number of materials capable of filling empty spaces and thereby significantly increasing the resistance to air flow to locations where air flow is not desired such as an PCM-void location on the laminated pouch array. In addition, plates/dividers **51** are placed at the bottom of the vessel in a manner that allows flow out the middle of the laminated pouch arrays but not along the perimeter at the bottom of the laminated pouch arrays. The preferred means of sealing between the hanging laminated pouch arrays and the lower divider **51** is with packing that fills in void spaces.

[**0110**] The vessel of **FIG. 16** containing the PCM chemical without refrigerant tubing is useful to provide air conditioning at locations where evaporative coolers provide marginal performance. In these locations, the cooler nighttime air can be evaporatively cooled and used to freeze the PCM chemical during the night by directing the evaporatively-cooled air through the PCM vessel during the night. During the day, building air can be circulated through the PCM vessel to chill the air. The embodiment of **FIG. 16** is also effective for peak load shifting.

[**0111**] Pouch Defined Air Flow Embodiment

[**0112**] The preferred hanging laminated pouch configuration is illustrated in **FIG. 19***b*. The sealed pouches **42** containing PCM serve two purposes: 1) they contain the PCM chemical, and 2) their arrangement assists in directly air flow in the desired pattern. Typically, the desired air flow pattern is one of equal distribution of air flow over all of the PCM materials. In the embodiment of **FIG. 19***b*, an absence of pouches **42** at the top and sides of the container provides for air access throughout the length of the hanging pouch. As air progresses down the sides of the hanging pouch, a lower cross sectional area is encountered and air the path of least resistance is for an even flow of air over the pouches **42** toward the inside of the hanging laminated pouch configuration. A progressively larger section in the downward direction along the middle section of the configuration further facilitates the cumulative path of least resistance to air being one of equal distribution over the pouches **42**. Multiple configurations are possible, all based on locating pouches **42** on the sheet **41** in a manner that provides even air flow across the pouches.

[**0113**] This hanging laminated pouch configuration is a means for encapsulating a PCM chemical in a configuration for exchanging heat between air and the PCM chemical, wherein the PCM chemical is encapsulated by two sheets wherein the two sheets are laminated to seal the PCM chemical between the two sheets. In practice, the laminated sheets contain multiple pouches of PCM chemical and multiple laminated sheets are fastened in a container to hang vertically from a support at the top of the top of the laminated sheets. The vessel has an entrance and exit for air flow.

[**0114**] Desiccant Embodiments

[**0115**] To further enhance the cooling ability, desiccants can be used to remove moisture from the air. In this moisture removal process, the air and desiccant heat in response to the heat of adsorption of the water. Cooling of the warm air with PCM is preferred since this PCM can store the coolness of night. Depending upon the specifics of the application, this dehumidification and cooling will be sufficient to provide the needed building air conditioning. To provide further cooling, the cool air can be evaporatively cooled as illustrated by **FIG. 20***a*. If evaporative cooling alone is insufficient, the final cooling can be provided by a conventional air conditioner as illustrated by **FIG. 20***b*.

[**0116**] In this configuration, the desiccant must be periodically dried. The preferred means for drying the desiccant is with the heat of the condenser coils of the air conditioner where the coils are in the same vessel as the desiccant and outside air is circulated through the desiccant container during the drying. Alternatively, solar heat can be directed to the desiccant container during drying. The preferred means to cool the desiccant after drying is to circulate air between the PCM vessel and the desiccant vessel until the desiccant is chilled to about 4° F.-10° F. of the PCM vessel temperature. In this operation, the PCM vessel may be cooled/charged twice—preferably during the night. One time to provide cooling for the desiccant and the second time to cool air after it flows from the desiccant and prior to release to the house. Air circulation to provide these cooling and drying options are known in the art.

[**0117**] Preferred Smart Fan Embodiments

[**0118**] The utility of the smart fan operation described herein is not limited to use with phase change materials nor is it limited to use with outside evaporators. For the smart fan mode of operation to provide benefit, the outside unit (either outside evaporator for heat pump heating or outside condenser for heat pump cooling) must have a heat capacity sufficiently large to provide the needed thermal energy to moderate temperatures changes in the outside unit.

[**0119**] The benefit of smart fan operation is that the smart fan in combination with a high heat capacity in the outside unit reduces the extremes in temperature (moderates temperature changes) of the outside unit. For air conditioning, the outside unit (condenser) does not get as hot, and therefore, the coefficient of performance of the air conditioner (heat pump) is increased. For heating, the outside unit (evaporator) does not get as cold, and therefore, the heat pump efficiency is increased. It should be noted that in the limit of the heat pump operating continuously for times of about one half hour or more at a time (undersized unit), the benefits of the smart fan diminish. However, there are always times of the year where even an undersized heat pump unit does not operate continuously for more than one half hour at a time.

[**0120**] The necessary components of a smart fan are 1) a sufficiently high heat capacity built into the coil system of the outside unit, and 2) a control strategy operating the fan based on measured or anticipated temperatures (coil temperature and outside temperature).

[**0121**] A sufficient heat capacity can be built into the coil system of the outside unit by a number of methods known in the art. Use of thicker working fluid tubing increases the heat capacity. Use of phase change materials per the other embodiments of this invention increases the heat capacity. Placement of the coil tube inside a larger tube filled with a fluid increases the heat capacity. Contacting the fins that surround the coil directly with an object having the necessary heat capacity will increase the heat capacity. Placement of the coil tube inside a plastic sheath filled with a fluid increases the heat capacity.

[**0122**] A control strategy for operating the fan (hence the name "Smart Fan") can be based on measured temperatures, an algorithm based on anticipated temperatures, or any combination of these. Control strategies based on measured temperatures would operate the fan: 1) preferably at any time the average temperature of the outside evaporator coil is more than about 3° F. cooler than the outside temperature, 2) preferably at any time the average temperature of the outside condenser coil is more than about 3° F. warmer than the outside temperature, 3) more preferably at any time the average temperature of the outside evaporator coil is more than about 1° F. cooler than the outside temperature, and 4) preferably at any time the average temperature of the outside condenser coil is more than about 1° F. warmer than the outside temperature. Here, the 1° F. and 3° F. are referred to as targeted approach temperatures. Statistically, the times necessary to reach these temperature constraints can be correlated with the temperature constraints. The times would be the times allowed after the heat pump's compressor is turned off. Thus methods known in the science can be used to developed control strategies based on these estimated times rather than measured temperatures. The times will be specific to the heat pump (or air conditioner) models.

[0123] In a fundamental sense, control strategies based on measured temperatures are substantially independent of the said heat capacities while control strategies based on times are dependent both on the said heat capacities and the targeted approach temperatures. The temperature-based control strategy is preferred for embodiments of this invention based on phase change materials designed to store sufficient heat to allow operation without outside fan operation during night time heating.

[0124] For alternative embodiments that use a Smart Fan and energy storage to moderate temperature changes between heat pump operating cycles (cycles refer to times when the compressor is operating and are typically 3 to 30 minutes), the heat capacity requirements of the outside unit are obviously less than nighttime storage units. The "Smart Fan Moderating System" is based on recharging the heat capacity between the typical 3 to 30 minute compressor operation times. The "24-hour Cycle PCM Embodiments" are based on recharging the heat capacity (preferably a containerized PCM chemical) on 24-hour cycles.

[0125] The amount of PCM chemical and corresponding heat storage capacity for a 24-hour Cycle PCM Embodiment is about what is required to provide heat for a typical winter night. This quantity is thus substantially dependent upon where the heat pump is being used geographically. More preferably, the optimal thermal characteristics and amount of PCM chemical in a 24-hour Cycle PCM Embodiment is based on averaged calculations dependent upon geographic location, cost of PCM chemical, and cost of electricity—these economic optimizations can be performed by methods known in the science.

[0126] The optimal amount of heat capacity in a Smart Fan Moderating System is preferably sufficient to provide 2 to 30 minutes of heat pump operation resulting in an outside average coil temperature change of less than 10° F. (absolute) without the outside fan operating. In a heating mode this translates to the average temperature of the coil being no more than 10° F. cooler than the average temperature of the coil prior to starting the heat pump. In a cooling mode this translates to the average temperature of the coil being no more than 10° F. warmer than the average temperature of the coil prior to starting the heat pump. More preferably, the optimal amount of heat capacity in a Smart Fan Moderating System is sufficient to provide 5 to 20 minutes of heat pump operation resulting in an outside average coil temperature change of less than 10° F. (absolute) without the outside fan operating.

[0127] In the Smart Fan Moderating System, the fan may be switched off when the approach temperature is reached. Alternatively, the fan may be turned off when a time, previously correlated with approach temperature, is reached after the compressor has switched off. In the approach temperature mode, the fan is preferably turned on based when the approach temperature is exceeded shortly after the compressor is switched on. In the time mode of operation, the fan is preferably automatically switched on when the compressor is switched on.

[0128] This Smart Fan Moderating system is a method of operating the fan of the outside unit of a heat pump. To work well, the working fluid conduit of the outside unit must be in contact with mass of material where the primary purpose of the mass of material is to absorb and release heat thereby moderating temperature fluctuations. To a first approximation, the heat capacity of the said mass of material should be at least five times greater than the copper tubing in the outside component of a typical house heat pump. A typical house heat pump contains about 200 feet of copper tubing with a mass near 17 kg. Five times the heat capacity of this copper tubing is approximately 30 kJ/° C.; therefore, the said mass of material should have a heat capacity of at least 30 kJ/° C., and preferably of a mass identified by temperature rise criteria without fan operation as previously described.

[0129] Most Preferred Embodiment

[0130] The most preferred embodiment of this invention utilizes the hanging bag configuration of **FIG. 18** in the evaporator housing illustrated in **FIG. 9** with heat flow controlled by the Smart Fan method. The general concepts and design of the evaporator and condenser units described herein may be incorporated into the outside or inside evaporator/condenser of a heat pump (or air conditioner system). When used inside the house for exchange with internal air, the preferred melting temperatures for the PCM for air conditioning are between 50° F. and 75° F. When used inside the house for exchange with internal air, the preferred melting temperatures for the PCM for air heat pump heating are between 75° F. and 105° F.

[0131] My previous patent, Ser. No. 09/945,682, which is hereby incorporated by reference to the same extent as if fully set forth herein, discloses a method for producing a composition of fatty acid derivatives for use as phase change material (PCM) chemicals and a method of using PCM chemicals. The value of the production method lies in the ability of a simple process to provide high conversions of feed stocks to useful PCM chemicals. The thermal storage ability of these chemicals can be used to both eliminate the need for air conditioning and to shift air conditioning load to non-peak-demand times.

[0132] Method of Manufacturing PCM Chemicals from Triglyceride Feed stocks

[0133] **FIG. 21** illustrates a preferred method for manufacturing a triglyceride-based PCM chemical. The process consists of mixing a triglyceride that largely solidifies above the temperature of PCM chemical use with a triglyceride that largely solidifies below the temperature of PCM chemical use. After mixing, the mixture is heated to a temperature suitable for transesterification reaction. Subsequent to transesterification, the mixture is cooled and that solid fraction with a suitable melting point temperature is separated as product with the remaining triglyceride returned to the feed for mixing and further reaction. For purposes of terminology in this invention, a triglyceride is a fatty acid glyceride. Solvents improve separation. The solvent is preferably largely recycled internally with makeup solvent added as needed.

[0134] Solvents are preferably more volatile than the PCM product. The solvent does not react with the other reactants as compared to a co-reactant that can both react and serve many of the same purposes as a solvent. Common solvents include but are not limited to acetone, volatile ethers, and volatile hydrocarbons. The solvent is preferably removed from the final product by flashing the more-volatile solvent from the product.

[0135] To provide high yields of product, the reaction occurring in the reactor of **FIG. 21** as well as the reactor of **FIG. 22** must be a reversible reaction whereby a reversible reaction is defined as having an equilibrium constant between 0.02 and 50 for reactions where the liquid concentrations in the equilibrium constant cancel to produce a dimensionless equilibrium constant. For reactions where concentrations do not cancel in the equilibrium constant, the reaction is determined to be reversible if, when reactants are reacted in stoichiometric amounts relative to the desired product, the ratio of initial reactant concentration to reaction after the mixture has reacted to equilibrium is between 0.02 and 50. The embodiments of this invention are not limited to specific feed streams to the process. Rather, the embodiments of this invention include a process for the production of phase change material (PCM) chemicals wherein a reactant is reacted in a reaction mixture to yield a PCM chemical, the improvement which comprises the steps of carrying out said reaction in a reactor generating a reactor output stream, cooling said reactor output stream generating a stream containing solid reactor product suspended in liquid reactor product, separating the solid product from the liquid product generating a concentrated solid product and a mostly liquid product, recirculating either the concentrated solid product or the mostly liquid product as a feed to the reactor, and reacting of the recirculated chemical in a reversible reaction.

[0136] While the solid-liquid separation processes of **FIGS. 21 and 22** are preferred to vapor-liquid separation processes, the embodiments of this invention can be practiced with vapor-liquid separation processes in place of the solid-liquid separation processes of **FIGS. 21 and 22**.

[0137] In the configuration of **FIG. 21** the recycled liquid freezes at a lower-than-desired temperature (on a solvent-free basis) and has a relatively high concentration of unsaturated fatty acids derivatives. An oil/fat having a lower unsaturated fatty acid content is added prior to interesterification reaction in an amount of 0.01 to 1.0 times the mass of the recycled fatty acid derivatives and preferably between 0.05 and 0.2. The low concentration of saturated fatty acids substantially limits the amount of high-freezing-point derivatives that are formed with very high yields of the preferred-freezing-point derivatives being formed and frozen out of solution.

[0138] Alternative to a solvent that is largely soluble with the PCM product, an anti-solvent that is substantially not soluble with the feed stock may be used. In addition to reducing viscosity, the solvent serves the purpose of displacing liquid fat/oil derivatives from solid fat/oil derivatives during solid-liquid separation processes.

[0139] Optionally, a solid-liquid separation may be performed prior to the solid-liquid process that produces product (see **FIG. 22**); this optional solid-liquid separation process is useful for reaction products in which a fraction of the products melts above the targeted PCM application temperature. Counter-current heat exchange is preferred but optional and applicable by methods known in the science.

[0140] Feed stocks other than triglycerides provide an alternative embodiment and additional degrees of freedom to control melting point temperatures of the transesterification products. When feed stocks in addition to triglycerides are used, the process consists of mixing a triglyceride derivative that largely solidifies above the application temperature with a triglyceride derivative that largely solidified below room temperature. After mixing, the mixture is heated to a temperature suitable for reversible reaction. Subsequent to reaction, the mixture is cooled and that solid fraction with a suitable melting point temperature is separated as product with the remaining product returned to the feed for mixing and further reaction. Solvent technology would facilitate separation.

[0141] During the reaction processes of **FIGS. 21 and 22**, irreversible reactions may parallel the reversible reactions. Provided these irreversible reactions are slow relative to the reversible reactions, the irreversible reactions can enhance product quality and/or product yields. Here, slow is defined as having a reactive triglyceride half-life less than 20% of the dominant reversible reactions.

[0142] The reactions of **FIGS. 21 and 22** are not limited to particular catalysts or temperatures. Heterogeneous catalysts are preferred. When homogeneous catalysts are used, a separation process needs to be performed to remove the homogeneous catalyst from the product. Typically the reaction temperatures will be between 25 and 325° C. The pressure of the reaction may be a function of temperature and can be optimized by methods known in design to maintain a liquid phase. Catalysts and reactions known in the science may be used including but not limited to catalysts promoting transesterification, alcoholysis, inter-esterification, hydrogenation, cis-trans isomerization, and other chemistry of ester bonds including nitrogen, phosphorous, sulfur, and group 1a metal derivatives. Preferred feed stocks include animal fat, soybean oil, palm oil, animal greases, and used cooking oils since these are the most abundant and least costly of fat and oil feed stocks. For example, a preferred feed stock is 60% to 90% (by mass) beef tallow and 10% to 40% soybean oil reacted in a transesterification reaction over 10-20 mesh calcium carbonate catalyst in a packed-bed reactor operated at a temperature between 200 and 280° C. For the process of **FIG. 22**, the feed stock stream labeled "other" is any chemical that reversibly reacts with the fatty acids of the triglyceride feeds. Examples include methanol, ethanol and diethylene glycol but are not limited to alcohols.

[0143] The fractionation processes may be solid-liquid separation processes or vapor-liquid separation processes. Preferably, solid-liquid separation is used. For any given product, the choice of solvent can impact the temperature at which separation is performed. Typically, the solid-liquid separation processes are conducted at temperatures between 10° C. and 35° C.

[0144] The natural fats and oils may be fed to the processes of **FIG. 21** or **22** after the reaction or prior to the reaction. If the naturally occurring fat/oil has a higher fraction of product having the desired latent heat properties as compared to the natural fat/oil after reaction, the natural fat/oil is preferably fed to the process after the reaction.

[0145] The process of **FIG. 21** can be used to produce a variety of fats and acids with an emphasis on ester bond chemistry. The preferred PCM chemicals of this process are comprised mostly of triglycerides since these triglycerides provide the largest variety of chemical species with the largest number of chemical species falling within the targeted PCM chemical temperature range.

[0146] For use in building climate control, compositions of these chemicals are preferably >50% triglycerides with >10% but <50% of the fatty acid content of said triglycerides being saturated fatty acids. More preferably, >70% triglycerides with >20% but <40% of the fatty acid content of said triglycerides being saturated fatty acids.

[0147] For triglycerides or esters terminating in alkyl groups, emulsions can be formed with water. The formation of stable emulsions with water can be used in PCM device applications were fire-retardant materials are desired.

[0148] Preferred Method of Using Charged PCM Chemicals

[0149] PCM chemicals are considered charged when they are frozen, if the intended use is to cool the contents of a house, and when they are unfrozen, when the intended use is to heat a house. The preferred method of using the PCM chemicals is to charge the chemical and consume the charge in 24-hour cycles. The preferred form of the PCM chemical is in an isolated form where heat transfers through the isolating surface to air. This surface prevents odors, oxidation, and biological growth in the PCM chemical.

[0150] For air-cooling operations the preferred method comprises having air contact the encapsulated PCM chemicals prior to contacting the evaporator coils of an air conditioning system by locating the evaporator coils downstream from the PCM device. The evaporator coils of the air conditioning system are only operated when additional cooling is needed beyond that supplied by the PCM chemicals. The preferred method to determine if additional cooling is need by the coils is to use a two-temperature control system—one temperature higher than the other. When inside air temperature rises above the lower temperature set point, inside air flow is directed next to the encapsulated PCM chemicals with the evaporator coils not operational. When the inside air temperature rises above the higher set point temperature, the evaporator coils are activated to provide additional cooling.

[0151] For heating operations the preferred method comprises having air contact the encapsulated PCM chemicals prior to contacting the auxiliary heating means. Auxiliary heating means include but are not limited to heat pumps and furnaces. The auxiliary heating means is only operated when additional heating is needed. The preferred method to determine if additional heating is need by the coils is to use a two-temperature control system—one temperature higher than the other. When inside air temperature falls below the higher temperature set point, inside air flow is directed next to the encapsulated PCM chemicals with the auxiliary heating means not operational. When the inside air temperature falls below the lower set point temperature, the auxiliary heating means is activated to provide additional heating.

[0152] One skilled in the art could readily set up the control system described in the previous two paragraphs, therefore that operation is not described in detail.

[0153] Preferred Method of Charging PCM Chemicals

[0154] PCM chemicals are charged during the night when the PCM chemicals are used to provide cooling. The chemicals are charged during the day when providing heating.

[0155] For typical building cooling applications, two sources are available to directly or indirectly charge PCM chemicals: (1) use of outside air or (2) use of a chiller (normally a vapor-compression air conditioner). When the outside air has a wet-bulb temperature that is less than approximately 5° F. lower than the desired indoor air temperature, the use of outside air is preferred to use of a chiller. Preferably, the outside air is contacted with water to cool the air to its wet-bulb temperature. Unlike direct use of evaporative cooling in a building, when cooling PCM devices, maximum cooling of ambient air is preferably achieved by cooling the outside air to 100% relative humidity (i.e. the wet-bulb temperature of the ambient air). When outside air cannot be sufficiently cooled, evaporatively cooled air is further cooled with a chiller prior to use in cooling the PCM devices. When the wet-bulb temperature of the outside air is warmer than about 5° F. less than the set point temperature in the building, the chiller is preferably used without supplemental cooling from evaporatively cooled outside air.

[0156] For this method of recharging the encapsulated PCM chemical used to cool a building, water that accumulated in the system is drained from the system, contacting of the said air with water is terminated by terminating the water supply for at least 8 consecutive hours for each 24 hours of system utilization, and all surfaces contacted by the said air are present without water on the said surfaces for at least 6 consecutive hours for each 24 hours of system utilization.

[0157] Preferred Method and Embodiment for Using PCM Chemicals

[0158] The preferred method and embodiment for using PCMs in moderating climates in a building consists of an apparatus with the following features:

[0159] 1. A device containing PCM chemical with at least one surface over which air can travel with a heat flux through the surface to or from the PCM chemical;

[0160] 2. A means of connecting the said device with air external to the building;

[0161] 3. A fan or other means for conveying air from outside the building, across the said surface to charge the PCM chemicals, and then back to outside the building;

[0162] 4. A control means that uses external air temperature or time of day to start and stop flow of air across the PCM; and

[0163] 5. A surface and air-flow means through which heat is transferred from air inside the building to the PCM chemical to provide cooling for the building, or alternatively, through which heat is transferred from the PCM chemical to the air inside the building to provide heating.

[0164] The surface that separates the PCM chemical from air preferably totally encapsulates the PCM chemical, said surface preferably being a plastic or metal. The encapsulated PCM devices are preferably contained in a tank through which air flows therein contacting the outside surfaces of the

PCM devices. In the preferred embodiment the means of connecting the said tank with air external to the building is an air duct.

[0165] In the preferred embodiment operated in an air conditioning mode, the first step (charging step) of the method of operation includes directing air from outside the building through a first duct to the PCM device then over the PCM heat exchange surface(s) and then through a second duct and back outside the building. The location of the said fan or other means for conveying air is preferably next to or in one of the ducts. This first step is preferably performed at night when the external temperature is below the temperature at which the PCM chemical undergoes a phase transition. The temperature for the latent heat transformation is preferably between 50° F. and 100° F. For summer cooling, said temperatures are more preferably between 65° F. and 75° F. and most preferably between 68° F. and 73° F. A second step of the method of operation includes directing air from inside the building through a duct to the PCM device then over the PCM heat exchange surface(s) and then through a different duct and back inside the building. Optionally, an auxiliary cooling means is located downstream of the PCM device. This second step is preferably performed when the temperature of air in the building is above the temperature at which the PCM undergoes a process through which it absorbs a significant latent heat.

[0166] The use of evaporative cooling during the night and not during the day has the distinct advantage of allowing the equipment to undergo a drying cycle during the day. This drying cycle will substantially prevent fungal and other growth on the equipment. When possible, the equipment undergoing drying is preferably placed in direct sunlight to facilitate drying and to allow radiation to also inhibit fungal growth. Methods of water introduction are known and practiced in the science and art of water coolers (also called evaporative coolers or swamp coolers).

[0167] For air conditioning, preferably at least part of the air-flow patterns includes the first step during the cooler nighttime hours and the second step during the warmer daytime hours. Wet-bulb temperatures are lower at nighttime and provide a better driving force for cooling the house. The system that uses the coolest web-bulb temperatures within a 24 hour period to chill the PCM chemicals is referred to as the "PCM-LW24" system.

[0168] Optionally, during the cooler nighttime hours, evaporatively cooled external air can be used to freeze the PCM chemical during the night followed by using the PCM to chill external air that is not evaporatively cooled and is subsequently put inside the building. To prevent accumulation of air in the building, a means is needed to vent warmer air from inside the building as it is displaced by cooled air being conveyed into the building.

[0169] For heating during the winter, the preferred embodiment has a third step of the method of operation directing air from outside the building through a first duct to the PCM device then over the PCM heat exchange surface(s) and then through a second duct and back outside the building. This first step preferably performed during the day when the external temperature is above the temperature at which the PCM undergoes a process through which it releases a significant latent heat. The temperature for the latent heat transformation is preferably between 60° F. and 100° F., more preferably between 75° F. and 85° F. and most preferably between 77° F. and 83° F. A fourth step of the method of operation includes directing air from inside the building through a duct to the PCM device then over the PCM heat exchange surface(s) and then through a different duct and back inside the building. This fourth step is preferably performed when the temperature of air in the building is below the temperature at which the PCM undergoes a phase transition.

[0170] When used in combination with a heat pump (for heating the building), the PCM provides a higher temperature heat sink than is possible during the nighttime. In this embodiment, heat is removed from the PCM chemical during the nighttime and pumped into the house. Alternatively, heat can be taken from outside air during the day with a heat pump and stored in a higher-temperature PCM.

[0171] Maintenance costs associated with organism growth on the contact elements of evaporative coolers can be substantial. To reduce or eliminate these costs, the preferred method of using evaporative coolers with PCM devices is to keep the evaporative coolers dry and warm during substantial parts of the day. Warm is preferably >80 F therein inhibiting bacterial growth—such modes of operation can diminish performance of evaporative coolers used in conventional applications but do not diminish performances of the embodiments of this invention. To further inhibit growth of organisms, the evaporative cooler is preferable directly exposed to sunlight and respective ultraviolet radiation with designs configured to maximize the effectiveness of this exposure to minimize organism growth.

[0172] The preferred means for evaporatively cooling the air is to spray a fine mist of water into the air followed by flow through a demisting pad. After the demisting pad, the water that does not evaporate accumulates and leaves by a water drain. The system is designed to allow no water to accumulate and for the system to be entirely dried each 24 hour cycle with the exception of water located at least six inches down the drain pipe.

[0173] Combinations with Air Cycle

[0174] As an alternative to the conventional vapor-compression chiller to enhance cooling, an open air-cycle refrigerator is well-suited to supplement cooling for PCM devices. When wet-bulb temperatures are too high and/or moisture should be removed from interior air to meet comfort standards, the PCM-LW24 system needs to be enhanced with an auxiliary air conditioning system. One embodiment of this invention uses an air cycle to enhance the capabilities of the PCM-LW24 system. The air cycle is used to either; chill nighttime air to lower temperatures and assist cooling of the PCM or, alternatively, the air cycle is used to lower the temperature of the air by expansion after the air contacts PCM device during daytime cooling of interior air.

[0175] The preferred air cycle (also referred to as reverse Brayton cycle) includes an embodiment that can route/duct air differently, depending upon the purpose of the interaction between the air cycle and the PCM-LW24 system. To assist nighttime air in cooling the PCM, the following procedure is preferred: (1) outside air is routed to an expander that expands air to a lower pressure with associated cooling, (2) the expanded air is routed to and contacts the PCM devices, (3) after cooling the PCM devices, the warmed air is routed to a compressor that compresses the air to ambient pressure, and (4) the ambient pressure air is released to the outside. The expansion work is used to power the compressor. This method has utility for cooling the PCM chemicals when the outside nighttime air is too warm to perform this otherwise.

[0176] Preferred pressure ratios for expansion are 0.98 to 0.7 and most preferably between 0.98 and 0.85. Preferably, the pressure ratio of the reverse Brayton cycle is variable with preferred pressure ratios identified to optimize overall coefficients of performance. The preferred PCM devices are encapsulated PCM placed in a vessel that can handle the low pressures. The size of the encapsulated PCM devices can be identified by methods known in the art.

[0177] The reverse Brayton cycle operated in this method where the air is at less than atmospheric pressure when contacting the PCM device has a non-obvious advantage in that all the cooling provided by expansion results in additional cooling. In the conventional reverse Brayton cycle, some of the cooling is lost as the driving force temperature difference needed for heat transfer. This advantage substantially increases the efficiency of this cycle.

[0178] Preferably the same compressors and expanders are also capable of moving air for circulation, for chilling the PCM, and for chilling air beyond the capabilities of the PCM.

[0179] To assist the cooling capabilities of the PCM during the daytime, the following procedure is preferred: (1) inside air is routed to the compressor that compresses air to a higher pressure with associated warming, (2) the compressed air is routed to and contacts the PCM devices, (3) after the air is cooled by the PCM devices, the cooled air is routed to the expander that expands the air to ambient pressure with associated further chilling, and (4) the ambient pressure air is released to the outside. Preferably the expansion work is used, in part, to power the compressor. This method has utility for cooling the inside air when additional cooling is needed than can be required by the PCM devices. Methods known in the art will allow condensed water to be removed from the PCM devices.

[0180] The preferred configuration for the reverse Brayton cycle heating and cooling consists of 1) a PCM surface heat exchange area, 2) a large expander, 3) a large compressor connect to the large expander, and 4) a driving compressor powered by auxiliary means. The heat exchange area is at a higher pressure when providing heating and at a lower pressure when providing cooling. The only power applied to the system for heating or cooling purposes is to the driving compressor. The simple design of the large expander/compressor leads to low cost and high efficiency. The driving compressor/expander could be in parallel or series with the large compressors/expanders and is preferably connected in parallel.

[0181] During operation of the reverse Brayton cycle as a cooler, outside air first enters the expander expanding to a lower pressure. During expansion, shaft work from the expander physically drives the compressor. The expanded air is cooled proportionally to the shaft work transferred from the expander to the compressor. The cooled air next contacts the PCM devices therein cooling the PCM devices. In the preferred embodiment, most of the air is then compressed by the large compressor to atmospheric pressure and released. The air not compressed by the large compressor is compressed by the driving compressor and released. To both increase flow through the cycle and provide greater cooling, the volume of air sent through the driving compressor is increased by increasing the speed of the driving compressor.

[0182] During operation of the cycle as a heater, outside air first enters the compressor compressing to a higher pressure. Shaft work compression is provided by physical connection to the larger expander. The compressed air is heated proportionally to the shaft work transferred from the expander to the compressor. The heated air next contacts the PCM devices therein heating the PCM devices. In the preferred embodiment, the air is then expanded by the large expander to atmospheric pressure and released. The air not compressed by the large compressor is compressed by the driving compressor and diverted into the containing of PCM devices. To both increase flow through the cycle and provide greater heating, the volume of air sent through the driving compressor is increased by increasing the speed of the driving compressor.

[0183] Independent of the PCM chemical application, an evaporative cooler can be used in combination with a vapor-compression air conditioning system to provide the needed cooling. Unless humidity levels are extremely high, evaporative coolers can be used in place of vapor-compression cycles for much of the air conditioning needs. Preferred methods of operation use an evaporative cooler at all times when the cooler provides sufficient cooling. For most locations that require vapor compression cycle air conditioners this translates to using the vapor compression cycle with the evaporative cooler in insufficient to meet cooling standards.

[0184] Combinations with Adsorption (or Absorption) Cycle

[0185] One embodiment of this invention uses an adsorption or absorption system to enhance the capabilities of the PCM-LW24 system. In this embodiment, air is contacted with a material capable of removing moisture from the air (adsorbent or absorbent). As a result of removing moisture from the air, the temperature of the air is increased. The warmer air is then contacted with the PCM devices to cool the air. The air can either be directly circulated back into the house, or water can be sprayed into the air producing evaporative cooling to further chill the air prior to circulation back into the house.

[0186] When used to remove moisture for air to be released into the house, this process can be used at night or day. Methods known in the science can be used to remove the moisture from the adsorbent or absorbent. In some instances, the warm daytime air is sufficient to remove the moisture from the adsorbent/absorbent. In other instance, heat must be supplied to air that is used to regenerate the adsorbent/absorbent. Preferably, if hot air is produced to regenerate the adsorbent/absorbent, the hot air is used to heat water in a hot water heater. Regeneration of adsorbent/absorbent can be timed to coincide with needs to generate hot water in the hot water heater.

[0187] The most preferred embodiment of this invention is the PCM-LW24 system enhanced with adsorption (or absorption) to remove water from air and where the heat produced during the regeneration of adsorbent/absorbent is used to heat water in a hot water heater.

[0188] Further Details on Method of Manufacturing PCM Chemicals from Triglyceride Feed Stocks

[0189] A preferred method for producing phase change materials from fats and oil is to hydrogenate the fat or oil therein converting the bound fatty acids to a composition consisting mostly of palmitic and stearic acids when using common tallow, lard, or vegetable oil feed stocks. For some applications, the saturated triglyceride is useful. For other applications, the alkyl esters of the saturated fatty acids is useful. To produce the alkyl esters of the saturated fatty acids, the order of reaction is not important, either hydrogenation may be performed first or alcoholysis may be performed first. When using catalysts like palladium, hydrogenation and alcoholysis may be performed simultaneously in the same reactor.

[0190] While this invention has been described fully and completely with special emphasis upon preferred embodiments, it should be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described herein.

I claim:

1. A heat pump apparatus utilizing a phase change material chemical for heating a building, comprising:

a condenser that functionally releases thermal energy into a building;

a compressor that compresses a working fluid;

an evaporator that takes in thermal energy, and

a fan that directs air through the evaporator;

said evaporator having at least one conduit for flow of the working fluid through the evaporator, at least one sealed cavity containing a phase change material chemical, and at least one air path through which surrounding air can flow and transfer heat to said evaporator.

2. The heat pump apparatus according to claim 1, wherein

said at least one conduit has an outer perimeter with a cumulative area, at least 10% of which is in direct contact with said phase change material chemical.

3. The heat pump apparatus according to claim 1, wherein

the mass of phase change material chemical contained in said sealed cavity of said evaporator is at least 10 times greater than the mass of working fluid flowing through said evaporator.

4. The heat pump apparatus according to claim 1, wherein

said at least one conduit has a mean internal hydraulic radius of from about 0.02 inches to about 1 inch that is defined by the conduit wall; and

heat flows from outside the conduit wall to said working fluid inside said conduit, and the ratio of the cumulative thermal resistance between said working fluid and said phase change material chemical is from about 0.1 to about 10 times the cumulative thermal resistance between said working fluid and the air in said air path.

5. The heat pump apparatus according to claim 1, wherein

said at least one conduit has an outer perimeter with a cumulative area, at least 20% of which is in direct contact with said phase change material chemical; and at least 10% of which is in direct contact with the air in said air path.

6. The heat pump apparatus according to claim 1, further comprising:

a housing that contains and connects said evaporator and fan;

said housing having an outer surface with a surface area, at least 50% of which functions to provide insulation resistant to heat flow, and as a sealing surface resistant to air flow.

7. The heat pump apparatus according to claim 6, wherein

said fan directs air through said housing; and further comprising:

shutter means for blocking air from flowing through said housing when said fan is not running.

8. An apparatus utilizing a phase change material chemical for exchanging heat between a fluid and the phase change material chemical, comprising:

a phase change material chemical encapsulated between sheets of thermally conductive material.

9. The apparatus according to claim 8, wherein

said sheets are laminated to seal said phase change material chemical therebetween.

10. The apparatus according to claim 8, wherein

said phase change material chemical comprises multiple pouches of said phase change material chemical.

11. The apparatus according to claim 8, further comprising:

a container having an entrance and exit for fluid flow; and

said sheets having said phase change material chemical encapsulated therebetween are suspended in said container the path of fluid flowing between said entrance and said exit.

12. The apparatus according to claim 11, wherein

said sheets are suspended from an upper end thereof in said container and disposed vertically therein.

13. The apparatus according to claim 11, wherein

said fluid flowing through said container is air.

14. The apparatus according to claim 8, further comprising:

a sheet of porous material disposed between said sheets to facilitate even fluid flow and improved heat transfer between the fluid and said phase change material chemical.

15. The apparatus according to claim 8, further comprising:

at least one conduit disposed between said sheets for conducting a working fluid therethrough having an exterior surface in contact with said phase change material chemical in heat exchanging relation to function as an evaporator.

16. A method of exchanging heat with outside air in an outdoor heat pump unit having an evaporator/condenser and at least one conduit for conducting a flow of working fluid through the evaporator/condenser, and a fan that directs air through the evaporator/condenser, comprising the steps of:

providing a mass of material having a heat capacity greater than 30 kJ/° C. in contact with the working fluid conduit in thermal exchange relation, said mass of material absorbs heat and releases heat; and

operating said fan based on the temperature difference between the average temperature of said at least one conduit and the outside ambient temperature; whereby

said evaporator/condenser serves as an evaporator in a heating mode of operation, and as a condenser in a cooling mode of operation.

17. The method according to claim 16, wherein

in said cooling mode, said fan is switched on when the outside ambient temperature is at least 3° F. cooler than the average temperature of said at least one conduit.

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