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(54) Title: TILE SYSTEMS WITH ENHANCED THERMAL PROPERTIES AND METHODS OF MAKING AND USING SAME

(57) Abstract: The various embodiments of the present invention are directed to tile systems and to methods of making and using the tile systems. The tile systems provide improved thermal properties to floor and wall coverings in either heated or unheated applications. The tile systems generally include a tile and a discrete phase change material.



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TILE SYSTEMS WITH ENHANCED THERMAL PROPERTIES AND METHODS OF MAKING AND USING SAME

CROSS-REFERENCE TO RELATED APPLICATION

5 The present application claims the benefit of United States Provisional Patent Application Serial Number 61/177,224 filed 11 May 2009, and entitled "Tile Systems with Enhanced Thermal Properties and Methods of Making and Using Same," which is hereby incorporated by reference in its entirety as if fully set forth below.

TECHNICAL FIELD

10 The various embodiments of the present invention relate generally to tile systems. More particularly, the various embodiments of the invention relate to tile systems with improved thermal performance and to methods of making and using such tile systems.

BACKGROUND

15 Ceramic tiles are prized for their aesthetic and wear-resistant properties for applications such as floor and wall coverings. One disadvantage that ceramic tiles have relative to other decorative covering materials (e.g., solid wood, plastic laminates, and carpeting) is that surfaces covered with ceramic tiles tend to feel colder. During winter months, interior spaces are actively heated, and the significant temperature difference between outside and inside drives the heat loss through the floor and walls. There is a need to reduce the heat lost through the floor and walls
20 by increasing the thermal insulating ability of ceramic tile products.

 Often there is the desire to warm floors by installing radiant heating systems underneath the flooring; and, if the flooring is to be actively heated, then ceramic tile is often preferred due to its superior ability to conduct heat to its upper surface, where the heat can be used to heat the room and its occupants via radiative, convective, and conductive means. Thermal energy from a
25 floor heating system flows away from the heating elements in all directions. Heat transferred up through the flooring is used for heating, while heat flowing towards the sub-floor is lost. The overall system efficiency will be at least partly determined by the relative rates of heat transfer towards and away from the floor's top surface. As such, in addition to reducing heat lost to the sub-floor, there is a need to increase the ability of ceramic tile to conduct heat from heating

elements towards the room. Additionally, whether the floor is directly heated or not, the sub-floor and foundation act as a heat sink, and so the overall system efficiency can be increased if the flooring is constructed to prevent or reduce heat loss to the sub-floor. As was described above for floors, heating systems also can be installed either onto walls or as a part of the wall, and the desire to improve the flow of heat into the space adjacent to the wall outer surface while also reducing the loss of heat in the opposite direction is governed by the same considerations.

Accordingly, there is a need for tile systems having improved thermal properties. It is to the provision of such systems, and the associated methods of manufacture and use that the various embodiments of the present invention are directed.

10 BRIEF SUMMARY

Various embodiments of the present invention are directed to improved floor and wall tile systems with enhanced thermal properties. The tile systems provide enhanced thermal properties to floor and wall coverings. The improved tile systems, which can be implemented in either heated or unheated applications, generally include a tile and a phase change material (PCM). The PCMs can provide heat capacity via sensible and latent heat storage methods.

According to some embodiments, a tile system includes a tile and a PCM that is in thermal communication with the tile. The PCM does not comprise a portion of the tile, and is configured to increase the heat capacity of the tile system. The tile system can also include an optional heating element in thermal communication with the PCM and/or a thermally insulating layer disposed between the tile and a surface of a floor or wall on which the tile system is disposed.

In some cases, the PCM is a solid state PCM. In other cases, it is a liquid PCM encapsulated in a thermally conductive container (e.g., a metal container). Similarly, in some situations, the tile is a ceramic tile.

The PCM can be positioned in a variety of locations. For example, the PCM can be disposed in a cavity within a backside surface of the tile. It can also be disposed directly on a backside surface of the tile.

In some embodiments, the tile comprises a portion of a floating floor or wall tile unit. Such a tile unit can include a substrate, such that the tile is disposed on, or within a cavity within, the substrate. In these situations, in addition to the above-described locations, the PCM can be disposed: between a backside surface of the tile and a top surface of the substrate; at least partially within a cavity within a top surface of the substrate; entirely within the substrate (e.g., when the PCM comprises a portion of the substrate); on, or within a cavity within, a backside surface of the substrate; or a combination of one or more of the foregoing locations.

According to some embodiments of the present invention, a tile system can include a tile unit that includes a substrate and a tile that is disposed on, or within a cavity within, the substrate; and a PCM in thermal communication with the tile. The PCM does not comprise a portion of the tile, and it is configured to increase the heat capacity of the tile system. The PCM can be disposed in a cavity within a backside surface of the tile, directly on the backside surface of the tile, between the backside surface of the tile and a top surface of the substrate, at least partially within a cavity within the top surface of the substrate, entirely within the substrate, on a backside surface of the substrate, within a cavity within the backside surface of the substrate, or a combination comprising at least one of the foregoing.

The tile system can also include a heating element in thermal communication with the phase change material and/or a thermally insulating layer disposed between the tile unit and a surface of a floor or wall on which the tile unit is disposed. In certain situations, the thermally insulating material can be located below the heating element, while the tile is located above the heating element and the PCM can be between the tile and thermally insulating material.

In some implementations, the substrate can have a thermally conductive element that is in thermal communication with the PCM and the tile. In this manner, the thermally conductive element can facilitate heat transfer between the PCM and the tile.

Other embodiments are directed to methods of making the tile systems. The improved tile systems can be readily manufactured, having both a modest manufacturing cost and a relatively non-complicated geometry and construction.

Still other embodiments are directed to methods of using the tile systems. The tile systems can be installed using techniques that are either standard in the traditional tile industry or, for groutless tile products, an easier alternative that allows a do-it-yourself installation. The tile systems provide for relatively simple installation of tile surfaces having both the enhanced thermal properties, which are not normally found in tile systems.

Other aspects and features of embodiments of the present invention will become apparent to those of ordinary skill in the art, upon reviewing the following detailed description in conjunction with the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 includes schematic illustrations of (a) the backside of a conventional high-temperature ceramic tile, and (b) a cross-sectional side-view of the same tile with a phase change material (PCM) disposed in certain cavities on the posterior of the tile according to some embodiments of the present invention.

Fig. 2 is a schematic illustration of a groutless ceramic floor tile according to some embodiments of the present invention.

Fig. 3a is a schematic plan-view illustration of the underside of a groutless ceramic floor tile wherein PCMs are disposed within the cavities within the underside of the substrate according to some embodiments of the present invention.

Fig. 3b is a schematic illustration of a cross-sectional side-view of a groutless ceramic floor tile wherein PCMs are disposed within the cavities within the topside surface of the substrate according to some embodiments of the present invention.

Fig. 4 includes schematic illustrations of the underside of a groutless ceramic floor tile wherein PCMs are disposed (a) directly on the underside surface of the substrate and (b) within a cavity within the underside of the substrate according to some embodiments of the present invention.

Fig. 5 is a schematic illustration of a groutless ceramic tile floor system with two groutless tiles mated together, wherein the PCMs are disposed between the ceramic tile decorative component and the substrate according to some embodiments of the present invention.

5 Fig. 6 is a schematic illustration of a groutless ceramic tile floor system with two groutless tiles mated together, wherein the PCMs are positioned in defined cavities in the substrate itself according to some embodiments of the present invention.

Fig. 7 is a schematic illustration of a groutless ceramic tile floor system with two groutless tiles mated together, wherein the PCMs are incorporated into the polymeric frame itself
10 as an additive according to some embodiments of the present invention.

Fig. 8 is a schematic illustration of a groutless ceramic tile floor system with two groutless tiles mated together, wherein the PCMs are positioned onto the backside of the polymeric frame according to some embodiments of the present invention.

Fig. 9 is a schematic illustration of (a) a side cross-section, (b) a bottom view, and (c) a
15 top view of a groutless wall tile unit according to some embodiments of the present invention.

Fig. 10 is a schematic illustration of (a) rear view and (b) a top view of an installed groutless wall tile system according to some embodiments of the present invention.

DETAILED DESCRIPTION

Referring now to the figures, wherein like reference numerals represent like parts
20 throughout the several views, exemplary embodiments of the present invention will be described in detail. Throughout this description, various components may be identified having specific values or parameters, however, these items are provided as exemplary embodiments. Indeed, the exemplary embodiments do not limit the various aspects and concepts of the present invention as many comparable parameters, sizes, ranges, and/or values may be implemented. The terms
25 “first,” “second,” and the like, “primary,” “secondary,” and the like, do not denote any order, quantity, or importance, but rather are used to distinguish one element from another. Further, the

terms “a,” “an,” and “the” do not denote a limitation of quantity, but rather denote the presence of “at least one” of the referenced item.

Disclosed herein are improved tile systems and methods of making and using the tile systems. For either heated or unheated, floor or wall applications, the improved tile systems described herein provide increased efficiency of heating and/or cooling a building by enhancing the ability of tiles to store and release thermal energy, thereby minimizing the dynamic temperature differences that normally develop and are the driving force behind unwanted heating or heat loss. Further, the methods used to obtain these advantages are consistent with established manufacturing and installation processes considered normal for tiles and other flooring or wall decor. The various embodiments of the present invention allow for products having thermally enhanced properties without the deleterious effects on other, normally desired properties, namely wear resistance, appearance, and ease of installation.

Heat transfers from a hotter region or object to a cooler region or object, and the transfer of heat over time (i.e., the “rate”) is determined by the temperature difference between the “hot” and “cold” objects (i.e., the “temperature gradient”) and the radiative, convective, and conductive thermal properties of the objects of interest. For buildings, significant amounts of heat are lost via radiation; particularly through windows and roofs. Buildings in colder climates are normally well-insulated to reduce the conductive, convective, and radiative transfer of building heat from the interior walls to the exterior surfaces. Heat can also be lost from a building through the floor, where it passes through the sub-floor and into the foundation; or heat can be lost through the wall, where the heat is lost to radiative or convective transfer from the external wall. The costs associated with heating and cooling a building can be reduced if the transfer of heat can be reduced and/or the temperature gradient between conditioned spaces and their immediate surroundings (e.g. floor, walls, and ceiling) can be reduced.

To achieve this goal, the tile systems disclosed herein generally include a (i.e., at least one) tile and a phase change material (PCM) that does not comprise a portion of the tile itself. The tile can be any type of tile, including a ceramic tile, marble tile, granite tile, quartz tile, natural stone tile, porcelain tile, glass tile, a variety of metal or polymer tiles, wood plank, laminate floor tile (i.e., floating floor unit), and the like. In addition, the tiles can be

conventional (i.e., non-floating) floor or wall tiles, or they can be incorporated into a floating floor or wall tile system, as will be described in more detail below.

For convenience, and not by way of limitation, reference will now be made to ceramic tiles. It should be recognized by those skilled in the art to which this disclosure pertains that other types of tile, such as those listed above, can be used in place of ceramic tiles in the embodiments described below.

Table 1 provides the thermal properties of traditional ceramic tiles compared with other flooring and wall material types. Relative to most other building and construction materials (e.g., wall board, insulation, wood paneling, carpeting, laminated flooring, polymers, and the like), ceramic tiles generally exhibit a higher rate of heat conduction (i.e., “thermal conductivity”). In addition, ceramic tiles normally possess a higher value of thermal effusivity, a property that combines several material properties (heat capacity, density and thermal conductivity) into a single parameter. The thermal effusivity is a measure of how quickly a cooler object will absorb heat when placed into contact with a hotter object. The effusivity values in Table 1 illustrate why an unheated ceramic tile floor can “feel” colder than a floor made using wood, plastic laminates or carpet, because the tile can pull heat away from the body more quickly.

TABLE 1

Material	Thermal Conductivity [Watts / m K]	Thermal Effusivity [Watts / $\sqrt{s \text{ m}^2 \text{ K}}$]	Heat Capacity [Joules / Kg K]
Porcelain floor tile	1.484	1675	792
Mosaic floor tile	1.196	1453	750
Porous wall tile	0.969	1255	740
Simulated wood laminate	0.266	595	1380 *
Engineered wood laminate	0.210	542	1000 *
Polyurethane elastomer	0.255	623	1371

All measurements are for 25°C.

* - denotes the value at 25°C is extrapolated from data at slightly higher temperatures.

Table 2 provides the range of thermal property values normally seen for various types of standard ceramic tile products. The limits of these property values can be expanded somewhat

with concerted effort. Achieving very large value increases or decreases, however, is unlikely, particularly for the heat capacity. Thus, methods of increasing the thermal property values, for example, the heat capacity, of ceramic tile products are necessary.

TABLE 2

Ceramic Tile Product	Thermal Conductivity [Watts / m K]	Thermal Effusivity [Watts / $\sqrt{s \text{ m}^2 \text{ K}}$]	Heat Capacity [Joules / g K]	Density (g/cc)
High Fire Porcelain 1	1.523	1703	0.802	2.376
High Fire Porcelain 2	1.484	1675	0.792	2.387
Mosaic Tile	1.196	1453	0.750	2.354
High Fire Porcelain 3	1.241	1476	0.740	2.373
Low Fire Porcelain 1	1.073	1369	0.740	2.363
Wall Tile	0.969	1255	0.740	2.195

5

Materials typically store heat through an increase in temperature, and the thermal energy stored this way is termed “sensible heat.” The amount of sensible heat that can be stored by an object is set by its heat capacity, which is related to the material(s) of construction as well as the structure (e.g., porous versus highly dense). There is another heat storage mechanism where the storage or release of “latent heat” takes place at nearly constant temperature when a substance changes its physical state. An example of latent heat absorption is when a solid melts to form a liquid, whereas an example of latent heat evolution occurs when a liquid solidifies to form a solid.

10

PCMs store sensible heat as their temperature increases. When a specific temperature is reached, however, the PCM undergoes a phase transformation and can store a relatively large amount of latent heat. In transformations involving latent heat, the temperature does not increase or decrease markedly until the phase transformation is completed. Most PCMs of interest experience a solid-liquid phase transformation (i.e., melting). Paraffin waxes and salt hydrates are traditional PCMs; and, since they melt, the containment method or design, particularly for the corrosive salts, is a fundamental issue in employing PCMs.

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Some PCMs experience a second, solid-solid phase transformation at a temperature below their melting point. Although the latent heat absorbed or evolved is normally lower than for the solid-liquid transformation, solid state PCMs (SS-PCMs) are attractive for some applications because they do not require a containment method or design. To make better use of PCMs that melt into liquids, methods have been developed to encapsulate solid-liquid PCMs inside a shell of some other material that is phase and shape stable over the temperature range of use.

The tile systems of the present invention can make use of both liquid PCMs and SS-PCMs. The liquid PCMs, when used, are accompanied by a container or shell so as to prevent leakage or loss of the liquid PCM to the external environment. Such a container or shell should be made of a thermally conducting material so as to allow heat to more easily transfer between the PCM and the tile.

The PCMs can be incorporated in a variety of locations on, or adjacent to, the tiles. As stated above, in some cases, the tiles can be conventional or non-floating tiles, which are installed directly on a floor or wall using cementitious or resinous fixatives. In other cases, the tiles are incorporated into a floating tile system in which the tile itself is indirectly installed on a floor or wall via some intermediate substrate or base structure or structures. The individual tile units in a groutless tile system are composite structures having the means necessary to effect safe and easy installation of the tiles onto the floors or walls without using additional fixatives or grouting materials. Examples of floating tile systems include so-called "groutless tile" floor or wall systems. Groutless tile flooring systems, while briefly described below, are described in more detail in commonly-assigned United States Patent Application Publication No. 2008/0184646 and International Patent Application Publication No. WO 2008/097860, which are incorporated by reference herein in their entireties as if fully set forth below. Similarly, while described in brief below, groutless tile wall systems are described in more detail in commonly-assigned International Patent Application No. PCT/US2009/068113, which is incorporated by reference herein in its entirety as if fully set forth below.

In an example of a non-floating floor or wall system, the ceramic tile, which is manufactured with a cavity-containing back pattern, has a solid PCM or an encapsulated liquid

PCM disposed on its backside such that the PCM and the ceramic tile are chemically and/or mechanically bonded. Such a composite tile can be installed using industry standard methods (e.g., using an adhesive grouting material). One such composite tile shown in Fig. 1.

Fig. 1a includes a schematic illustration of the backside of a conventional high-
5 temperature ceramic tile, generally designated by reference numeral 100. The backside of the tile 100 includes hexagonal-shaped hollow spaces/regions or cavities 102. Such patterns are normally designed into ceramic tiles because these patterns save on material and facilitate several unit operations during manufacture. The pattern shown is one of many such patterns a ceramic tile may have on its backside that can accommodate the PCMs. In the pattern shown in
10 Fig. 1a, for a conventional 12-inch x 12-inch ceramic tile, about 30 to about 40 milliliters (mL) of a PCM can be placed into the about 0.7 millimeter (mm) deep cavities via a number of methods, and the volume capacity of the back pattern could be increased substantially.

Fig. 1b provides a schematic illustration of a side view of such a PCM-containing ceramic tile 100. In this illustration, the PCMs 104 are incorporated into a portion of the
15 plurality of cavities 102. It should be noted that the number of cavities 102 into which the PCMs 104 are disposed can vary based on the application and the level of heat storage desired. Thus, if greater heat storage is desired, a larger number of PCMs 104 can be placed in the cavities 102 of the ceramic floor or wall tile 100. The particular location where the PCMs are placed can be also be tailored for the particular application.

20 In another non-floating floor or wall system example, the ceramic tile can have a flat or substantially-flat backside, such that one or more PCMs are disposed directly on the backside surface of the tile. A solid PCM or an encapsulated liquid PCM can be chemically and/or mechanically bonded to the backside surface of the tile. Just as with the tiles with the cavity-containing backsides, such a composite tile can be installed using industry standard methods.

25 In contrast to non-floating tiles, when a groutless tile floor or wall system is used, the PCM can be incorporated in a number of locations. As will be described and illustrated, the PCM can be incorporated either: 1) in the back-pattern of the ceramic tile (this is already described above for non-floating tile systems); 2) in a continuous layer between the bottom

surface of the ceramic tile and a top layer of the groutless tile's base or substrate layer; 3) in cavities formed inside the groutless tile's base or substrate layer; 4) as a filler/component of the groutless tile's base or substrate layer; 5) in the back-pattern of the groutless tile's base or substrate layer; and/or 6) as one or more of the previous five situations in combination.

5 For convenience, and not by way of limitation, reference will now be made to groutless tile floor systems where each tile is encased by a polymeric frame or substrate to provide a so-called "groutless tile" unit. Again, such groutless tile units and systems are described in more detail in commonly-assigned United States Patent Application Publication No. 2008/0184646 and International Patent Application Publication No. WO 2008/097860. In addition to having a
10 ceramic tile encased by a polymeric frame, the tile units of these floor systems generally include mechanical joints for connecting adjacent groutless tiles.

Fig. 2 illustrates an exemplary groutless floor tile, which can be used in the tile systems disclosed herein. The groutless tile is generally designated by numeral 200. The groutless tile 200 includes a durable, decorative component 202 (e.g., ceramic tile, marble tile, granite tile,
15 quartz tile, natural stone tile, porcelain tile, hardwood planks, engineered wood planks, glass tile, a variety of metal or polymer tiles, and the like) that is disposed on a substrate 204. The decorative component 202 will be described as a ceramic tile in this illustration of a tile unit for convenience.

The decorative component 202 can be affixed to the substrate 204 using a wide variety of
20 methods. The substrate 204 can be constructed of a suitable material that is chemical resistant, stain resistant, at least partially non-porous, and formable to within sufficient precision. In exemplary embodiments, the substrate 204 is formed from a polymeric material. While the groutless tile unit 200 is depicted as square-shaped in Fig. 2, it will be clear that alternatively shaped groutless tiles (e.g., circles, rectangles, diamonds, hexagons, octagons, triangles, and the
25 like) are also contemplated.

The substrate 204 shown in Fig. 2, is designed to have larger dimensions than the decorative component 202 such that the decorative component 202 can be disposed within a groove defined within the substrate 204. The top surface of the decorative component 202 and

the top surface of the substrate 204 can form a continuous surface, if desired. The substrate 204 includes a flange portion 206 disposed along the side edges or walls of the substrate 204. The flange portion 206 provides the location of a mechanical joint, which is designed such that it is operable for coupling together one or more adjacent groutless tiles 200. When two or more adjacent groutless tiles 200 are coupled using the mechanical joint of the flange portion 206, it is the top surfaces of the substrates 204 of the coupled tile units 200, which are adjacent to the top surfaces of the decorative components 202, that can provide the appearance of a grouted finish.

Fig. 3 schematically illustrates the backside and side cross-section of one type of design for a groutless floor tile as shown in Fig. 2. In the backside view of Fig. 3a, the groutless tile 300 includes the substrate 304 and the decorative component 302 (of which the back side is shown in the cut-away circle). The substrate 304 includes the flange portions 306, which are disposed along the side edges or walls of the substrate 304 and are used to form the mechanical joints to couple adjacent groutless tiles. The substrate 304 also includes a plurality of cavities 308. These cavities 308, which can be formed when the substrate 304 is molded or by removing portions of the substrate 304 after the substrate has been manufactured, can be designed to accommodate the PCMs 310.

In the side cross-section of the groutless floor tile 300 shown in Fig. 3b, the ceramic tile decorative component 302 is disposed within a groove or channel within the substrate 302, as described above, with the exception that the substrate 304 has additional cavities on the topside surface that can provide locations for the PCMs 310. It should be noted that, instead of (or in addition to) placing them in cavities within the substrate 304, one or more PCMs 310 can be placed directly on the topside surface of the substrate such that a sandwich is formed between the ceramic tile decorative component 302 and the substrate 304.

To manufacture such a design, a cohesive layer or discrete portions of PCMs 310 could be adhered to the ceramic tile component 302 or simply placed against the ceramic tile component 302. Next, the combined ceramic tile component 302 with the PCM 310 can be molded around using the polymeric material that forms the substrate 304. Alternatively, after molding the substrate 304, the PCMs 310 can be melted and inserted into the cavities molded into the polymeric substrate 304.

Fig. 4 schematically illustrates the backside of another type of design for a groutless floor tile as shown in Fig. 2. In the backside view of Fig. 4a, only the substrate 404 is shown. The substrate 404 includes the flange portions 406, which are disposed along the side edges or walls of the substrate 404 and are used to form the mechanical joints to couple adjacent groutless tiles. The substrate 404 further includes a plurality of protruding legs 412, which can be used to at least partially support the groutless tile on the flooring surface on which it is installed. In this design, the PCM 410 can be disposed directly on the backside surface of the substrate 404.

Alternatively, in the backside view of Fig. 4b, wherein only the substrate 404 is shown again, the PCM 410 can be disposed within a cavity 408 within the backside of the substrate 404, similar to the design of Fig. 3a. The cavity 408 in this design (like the cavities 308 of the design shown in Fig. 3a) can be configured to penetrate through the entire thickness of the substrate 404 such that the PCM 410 makes direct contact to the back of the ceramic tile decorative component (not shown).

Thus, the cavities shown in Figs. 3 and 4 can be designed to accommodate PCMs such that the PCMs are directly in contact with the backside of the ceramic tile and/or with the thermally insulating polymer substrate between the ceramic tile and the sub-floor. Regardless of whether the PCMs are incorporated in the cavities on the bottom or top of the substrate, the mechanical integrity or strength of the composite tile structure is not degraded. Thus, an adequate underlying structural support is provided to the ceramic tile component on top.

Figs. 5 through 8 provide additional views of various embodiments making use of a groutless floor tile system, with PCMs shown in various locations. These illustrations all show two groutless tiles mated together. For example, in Fig. 5, the PCMs 510 are placed between the ceramic tile component 502 and the substrate 504, making contact to both the ceramic tile component 502 and the substrate 504. In Fig. 6, the PCMs 610 are placed in defined cavities within the substrate 604, but do not contact the ceramic tile component 602. In Fig. 7, the PCMs 710 are incorporated into the substrate 704 itself as an additive. Again, the PCMs 710 of Fig. 7 do not contact the ceramic tile component 702. Finally, In Fig. 8, the PCMs 810, which do not contact the ceramic tile component 802, are placed onto the backside of the substrate 804.

For convenience, and not by way of limitation, reference will now be made to groutless tile wall systems that comprise a tile unit, a mounting unit, a wall-fastening device that is configured to fasten the mounting unit to a wall, and a tile unit-fastening device that is configured to fasten the tile unit to the mounting unit. In general, the mounting unit occupies a small fraction (e.g., less than 30 percent) of an area of the wall. When the tile unit is fastened to the mounting unit, and the mounting unit is fastened to the wall, at least a portion of the tile unit does not contact the wall directly. This portion corresponds to at least the portion that is fastened to the mounting unit, but can include up to the entire surface of the tile unit. Again, such groutless tile units and systems are described in more detail in commonly-assigned International Patent Application No. PCT/US2009/068113.

The tile units used in these groutless wall tile systems can be designed similar to the groutless floor tile units. That is, these tile units can include a decorative tile component disposed within a groove or channel of a polymeric frame or substrate. These tile units, however, do not necessarily require any mechanical joints for connecting adjacent groutless tile units because they are held in place by the tile unit-fastening devices.

One example of such a tile unit is shown in Fig. 9. Fig. 9 includes side-, top-, and bottom-views of a groutless wall tile unit 900. In this illustration, the groutless wall tile unit includes four decorative ceramic tiles 902 disposed in a channel within a substrate 904. The substrate can include a recessed mounting point 918 for mating with the tile unit-fastening device (not shown). If the edges of the ceramic tiles 902 are not mated together, then a sealant 912 can be placed in the spaces between the ceramic tiles 902 in a given tile unit 900. Optionally, the ceramic tiles 902 can be fixed into place using an adhesive or fixative 914.

Another example of a groutless wall tile system is shown in Fig. 10. Fig. 10 includes front and rear views of an installed groutless wall tile system, wherein the groutless wall tile units 1000 are mounted to a wall (not shown) by means of a mounting unit 1020 that adopts a rail-like structure. The rail-like mounting units are fixed to the wall by means of mounting unit-fastening devices (not shown) that can be screws, nails, bolts, or the like. The groutless wall tile units 1000 include a decorative ceramic tile component 1002 that is disposed on a substrate or platform 1004. The substrate 1004 includes tile unit-fastening devices 1018 in the form of clips

or hooks that can attach to the rail-like mounting unit 1020. As indicated in the rear view of the installed tile system of Fig. 10a, there is a gap or design space between the surface of the ceramic tiles 1002 of the tile units 1000 and the wall surface (which would be in direct contact with the backside surface of the rail-like mounting units 1020).

5 Just as was the case for the groutless tile floor units, the PCMs can be placed in a variety of locations on or within the groutless tile wall units. Specifically, the PCMs can be placed between the top surface of the substrate and the bottom surface of the decorative ceramic tile component, within cavities on the topside and/or backside of the substrate, within the substrate as a filler material, and/or in any cavities on the backside of the decorative ceramic tile component
10 itself. In addition to these locations, when the tile system allows for it, the PCMs can be placed in the gap or design space between the tile units and the wall itself. In this manner, a larger continuous layer of a PCM can be used because there is less concern for space than there would be in trying to place a PCM in the substrate of a groutless tile unit.

The wall or floor tile systems that make use of so-called groutless tiles, which do not
15 require cementitious or resinous grouting material for installation, confer additional advantages relating to the greater ease of installation as well as the ability to non-destructively/temporarily remove (e.g., for inspection and repair) and reinstall the tile systems. In addition, it is possible for the material used to form the substrates for the ceramic tiles to be formed from one or more distinctive materials or components that can provide specific intrinsic thermal properties. For
20 example, when the substrate is formed from a polymeric (e.g., polyurethane, polystyrene, polyvinylchloride, or the like) foam, the substrate can confer a thermally insulative property to the tile behind the backside surface of the tile. This can serve to decrease the flow of heat to or from the space towards which the tile's decorative top surface is facing. In another example, the substrate can be designed to facilitate the conduction of heat between the tile and the PCM. For
25 example, components comprising a thermally conductive material (e.g., metal, graphite, or the like) can be disposed between the ceramic tile and the PCM, thereby permitting heat to be transferred more readily between the ceramic tile and the PCM. Yet another example involves designing the substrate to have a thermally conductive material disposed between the ceramic tile and PCM, while a thermally insulative material is disposed around those surfaces of the PCM

that are not in conductive thermal contact with the ceramic tile. Such a design can slow or prevent the transfer of heat between the PCM and the wall or floor onto which the tile systems are installed, while simultaneously facilitating the conduction of heat between the ceramic tile and the PCM.

5 In some cases, the improved tile systems described herein can include a heating element, which is placed in thermal communication with the PCM. For non-floating wall or floor tiles, this heating element can be disposed between the tile and the floor or wall. For floating wall or floor tile systems, the heating element can be included as part of the substrate or can be separate from the tile unit. This optional heating element can serve to activate the PCM by contributing
10 heat to the PCM, which can then transfer such heat more efficiently to the ceramic tile. The heating element can be controlled using known techniques used in conventional radiant heating systems. Such techniques would be understood by those skilled in the art to which the various embodiments of the present invention pertain.

 The tile systems described herein can also implement an optional thermally insulating
15 layer to further reduce heat loss. For example, with non-floating floor or wall tiles, this can be a thin fabric or foam underlayment that is placed between the ceramic tiles (which contain PCMs on their backside surfaces and/or within any cavities on their backside surfaces). With floating floors, the optional thermally insulating layer can be placed between the substrate and the wall or floor surface, between the PCM and the substrate surface in cases where the PCM is placed
20 between the ceramic tile and the topside surface of the substrate, in the cavities within the backside surface of the substrate such that the PCM is between the thermally insulating layer and the bottom of the cavity within the substrate, and/or the like.

 In certain embodiments, regardless of whether a ceramic tile or groutless tile is used, the ceramic tile itself may possess a chemical formula and structure such that its intrinsic thermal
25 properties are enhanced relative to standard ceramic tiles.

 During operation, the tile systems described herein will be able to store latent heat or absorb thermal energy from their environment (i.e., the “space” in which the tile system is installed) without as large a concomitant increase in their temperature as would be seen in the

absence of a PCM. As the driving force for thermal conduction, convection, or radiation between surfaces is the difference in temperature, the ability to obtain thermal storage with a reduced temperature increase leads to a reduction in unwanted heat transfers (i.e., heat “losses”). It is these unwanted heat transfers that lead to more energy consumed in the process of heating or
5 cooling a living space. Thus, the use of PCM as a passive means for improved heat storage and energy efficiency is effected using the tile systems described herein.

Similarly, for tile systems that also include the optional heating elements, the PCM can further increase the thermal heat capacity of the floor or wall, thereby allowing more heat from the heating elements to be transferred to, and stored in, the floor or wall. Further, this additional
10 heat is transferred and stored in the floor or wall at a lower heating element temperature than would be required without the use of a PCM. As a result, there is greater overall efficiency in the heating system. The reason for this phenomenon is that the transfer of heat in the direction opposite the tile surface (i.e., into the floor or wall) is considered lost heat, and the amount of lost heat generally increases as the heating element temperature increases. Thus, if a lower heating
15 element temperature is used to achieve the same or better result (i.e., the same amount of, or more, heat transferred to the tile, and ultimately into the room in which the tile system is installed), then the overall efficiency of the system is increased.

The tile systems disclosed herein can be used in a variety of manners. For example, the tile systems can be used simply to transfer heat to and from the tile surface, which will result in a
20 transfer of heat to and from the room or environment in which the tile system is installed. In addition, the tile systems can be used to decrease the consumption of energy, for example in heating, ventilation and air conditioning costs. This can be accomplished by matching the heat flow dynamics(e.g., including the actual storage and release of heat, the rate of heat transfer, and the like) of the PCM-containing tile system such that the release of heat can be off-set to a
25 desired time of day. For example, the tile system can be configured, with the appropriate choice of PCM, tile material, and other optional components as described above, such that heat is collected by the PCM during the day, and released in the evenings when the sun is down, the load on the air conditioning system is lowered and its efficiency is increased, and the electric rates are lower. Similarly, the tile system can be configured such that heat is transferred to the

tile surface (and, ultimately, to the room or environment in which the tile system is installed) by the PCM during the day, and collected in the evenings, as may be desired for the particular application.

The various embodiments of the present invention are further illustrated by the following non-limiting example.

EXAMPLE 1: Calculated Benefits of PCM Incorporation

This example illustrates the effect that adding PCMs to ceramic tile products can have. In this analysis, the latent heat storage capability for a number of PCM candidates, which undergo their transition over the temperature range around room temperature (i.e., about 20° C to about 40°C), was compared with the sensible heat storage capacity of a typical porcelain ceramic tile, having a dimension of 12 inches by 12 inches and weighing about 1.5 kilograms, and a composite tile comprising the same typical porcelain ceramic tile encapsulated with about 350 grams of polyurethane over that same temperature range.

Assumptions made include volume available to accommodate PCMs in both tile types and the temperature range of interest. The volume of the back-pattern of the back side of a typical ceramic tile was set at 30 cubic centimeters. The heat storage capacity of such a tile was set at 24,060 Joules at the temperature range of interest. Similarly, the volume of available space in the groutless tile polymeric frame was set at 100 cubic centimeters; and the heat storage capacity of such a groutless tile was set at 33,657 Joules at the temperature range of interest.

The known properties of the PCM candidates are provided in Table 3¹. These properties include transition temperature, heat of fusion, and density.

Based on the properties of the PCM candidates and the assumed volume and heat storage of the tile component, the data in Table 4 was calculated. As shown by the data of Table 3, the use of PCMs results in a latent heat storage capability that is a substantial fraction of the original

¹ Douglas C. Hittle ["Phase Change Materials in Floor Tiles for Thermal Energy Storage", October 2002; Award No. DE-FC26-00NT40999]

heat storage capacity for both tiles, particularly for the composite, or groutless, tile, where one could expect to incorporate more PCM into the structure. The data in Table 4 does not account for the increase in sensible heat storage due to the capacity of the PCM, but this storage component would further increase the overall heat storage capacity and effectiveness for tiles
5 containing the PCMs.

TABLE 3

Material	Transition Temperature (°C)	Heat of Fusion (Joules per gram)	Density (gram per cubic centimeter)
Solid state PCM			
Pentaerythritol (PE)	188	269	1.390
Pentaglycerine (PG)	89	139	1.220
Neopentyl Glycol (NPG)	48	119	1.060
60% NPG + 40% PG	26	76	1.124
Normal Paraffin / Waxes			
Tetradecane C14	5.5	228	0.825
Hexadecane C16	16.7	237	0.835
Octadecane C18 (Technical grade)	28	244	0.814
Eicosane C20	36.7	244	0.856
Commercially Available PCMs from Outlast Technologies			
Kenwax 18	31.2	165	0.765
Kenwax 19	36.8	151	0.811
Technical Grade Octadecane	28	244	0.814

5

TABLE 4

Material	Additional Heat Storage (Joules per square foot)			
	Ceramic Tile	% Gain	Groutless Tile	% Gain
60% NPG + 40% PG	2563	11 %	8542	25%
Octadecane C18 (Technical grade)	5958	25%	19862	59%
Eicosane C20	6266	26%	20886	62%
Kenwax 18	3787	16%	12623	38%
Kenwax 19	3674	15%	12246	36%
Technical Grade Octadecane	5958	25%	19862	59%

The embodiments of the present invention are not limited to the particular components, process steps, and materials disclosed herein as such components, process steps, and materials may vary somewhat. Moreover, the terminology employed herein is used for the purpose of describing exemplary embodiments only and the terminology is not intended to be limiting since
5 the scope of the various embodiments of the present invention will be limited only by the appended claims and equivalents thereof.

Therefore, while embodiments of this disclosure have been described in detail with particular reference to exemplary embodiments, those skilled in the art will understand that variations and modifications can be effected within the scope of the disclosure as defined in the
10 appended claims. Accordingly, the scope of the various embodiments of the present invention should not be limited to the above discussed embodiments, and should only be defined by the following claims and all equivalents.

CLAIMS

What is claimed is:

1. A tile system, comprising:

a tile; and

5 a phase change material in thermal communication with the tile, wherein the phase change material does not comprise a portion of the tile, and wherein the phase change material is configured to increase the heat capacity of the tile system.

2. The tile system of Claim 1, further comprising a heating element in thermal communication with the phase change material.

10 3. The tile system of Claim 1, further comprising a thermally insulating layer disposed between the tile and a surface of a floor or wall on which the tile system is disposed.

4. The tile system of Claim 1, wherein the tile is a ceramic tile.

5. The tile system of Claim 1, wherein the phase change material is a solid state phase change material.

15 6. The tile system of Claim 1, wherein the phase change material is a liquid phase change material encapsulated in a thermally conductive container.

7. The tile system of Claim 1, wherein the phase change material is disposed in a cavity within a backside surface of the tile.

20 8. The tile system of Claim 1, wherein the phase change material is disposed directly on a backside surface of the tile.

9. The tile system of Claim 1, wherein the tile comprises a portion of a floating floor or wall tile unit.

10. The tile system of Claim 9, wherein the floating floor or wall tile unit further comprises a substrate, wherein the tile is disposed on, or within a cavity within, the substrate.

11. The tile system of Claim 10, wherein the phase change material is interposed between a backside surface of the tile and a top surface of the substrate.

5 12. The tile system of Claim 10, wherein the phase change material is disposed at least partially within a cavity within a top surface of the substrate.

13. The tile system of Claim 10, wherein the phase change material comprises a portion of the substrate and is entirely encapsulated by the substrate.

10 14. The tile system of Claim 10, wherein the phase change material is disposed on, or within a cavity within, a backside surface of the substrate.

15. A tile system, comprising:

a tile unit, comprising a substrate and a tile that is disposed on, or within a cavity within, the substrate; and

a phase change material in thermal communication with the tile;

15 wherein the phase change material does not comprise a portion of the tile;

wherein the phase change material is configured to increase the heat capacity of the tile system; and

20 wherein the phase change material is disposed in a cavity within a backside surface of the tile, directly on the backside surface of the tile, between the backside surface of the tile and a top surface of the substrate, at least partially within a cavity within the top surface of the substrate, entirely within the substrate, on a backside surface of the substrate, within a cavity within the backside surface of the substrate, or a combination comprising at least one of the foregoing.

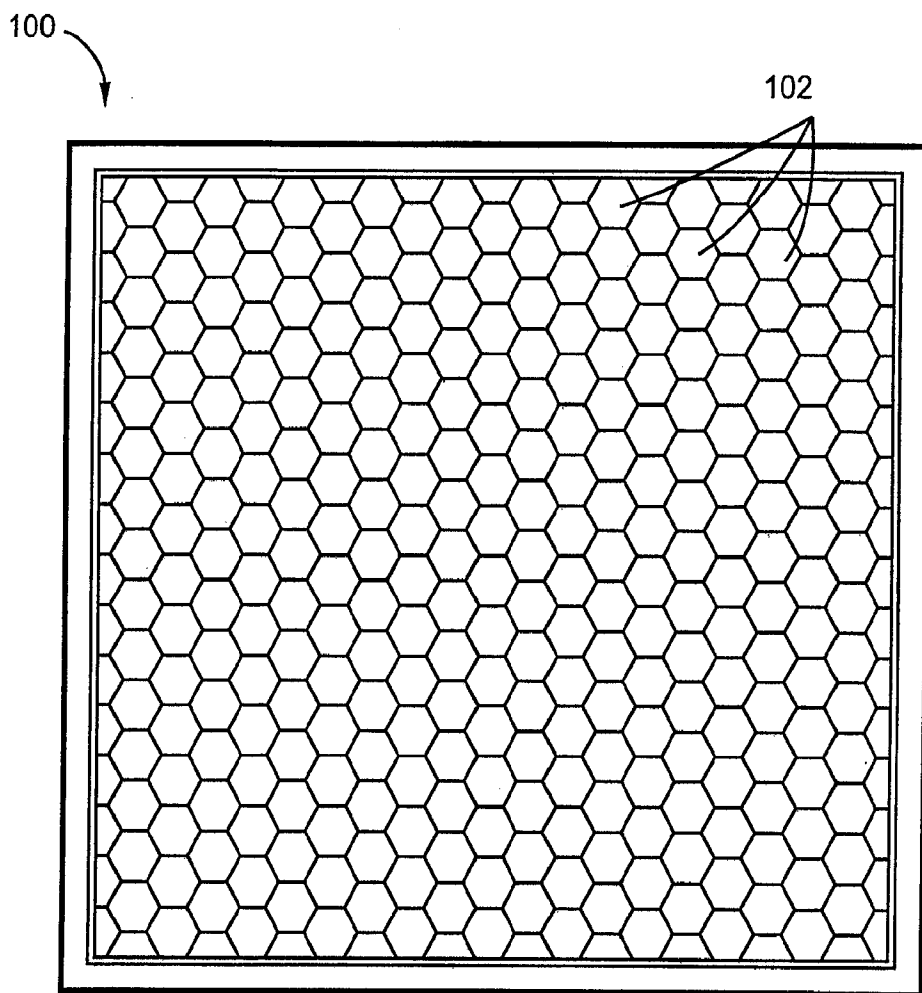
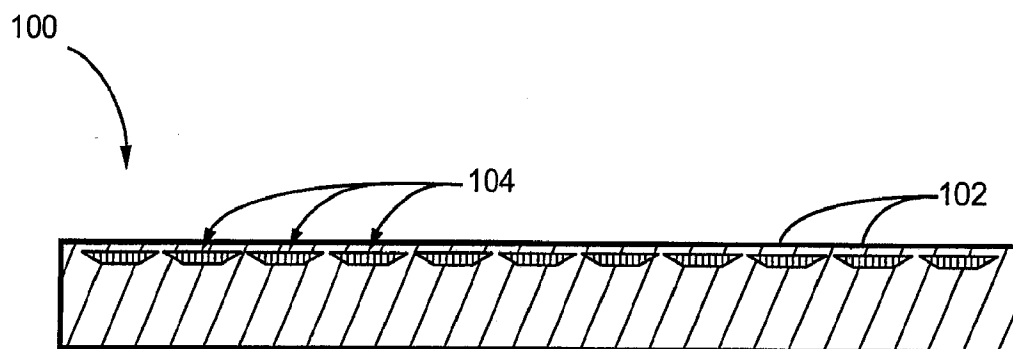
16. The tile system of Claim 15, further comprising a heating element in thermal communication with the phase change material.

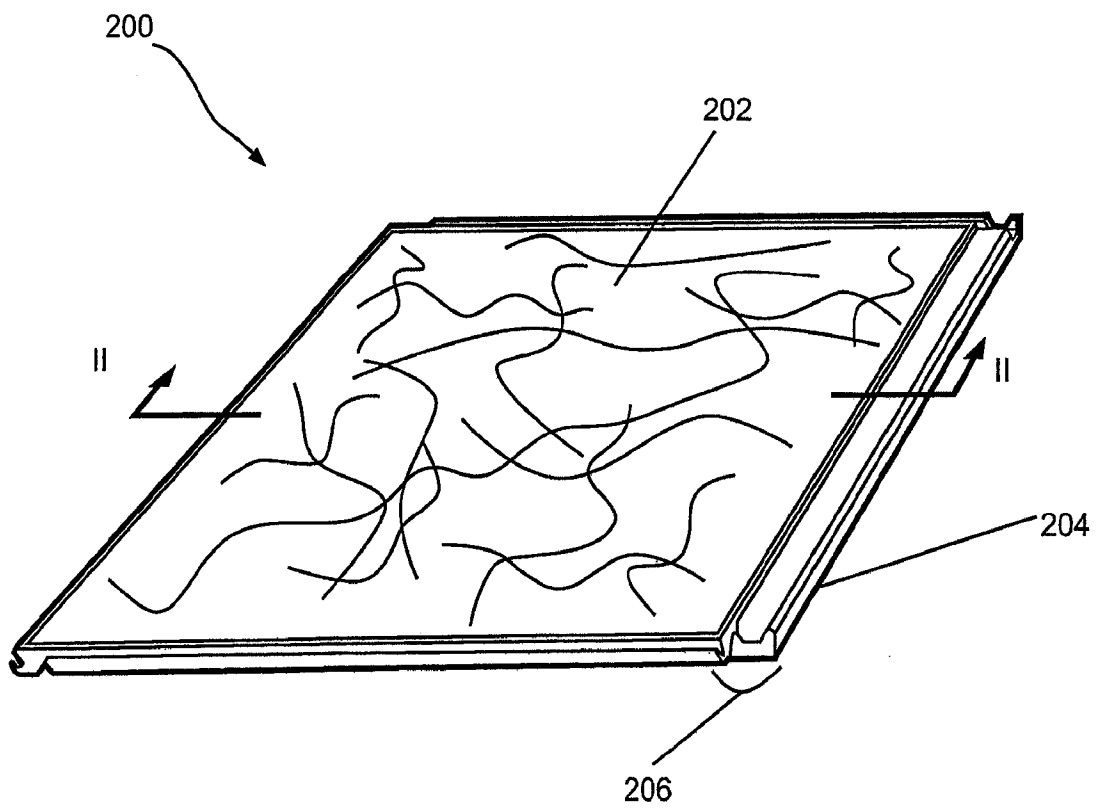
17. The tile system of Claim 15, further comprising a thermally insulating layer disposed between the tile unit and a surface of a floor or wall on which the tile unit is disposed.

18. The tile system of Claim 15, wherein the phase change material is a solid state phase change material.

5 19. The tile system of Claim 15, wherein the phase change material is a liquid phase change material encapsulated in a thermally conductive container.

10 20. The tile system of Claim 15, wherein the substrate comprises a thermally conductive element in thermal communication with the phase change material and the tile, wherein the thermally conductive element facilitates heat transfer between the phase change material and the tile.

**Fig. 1a****Fig. 1b**

**Fig. 2**

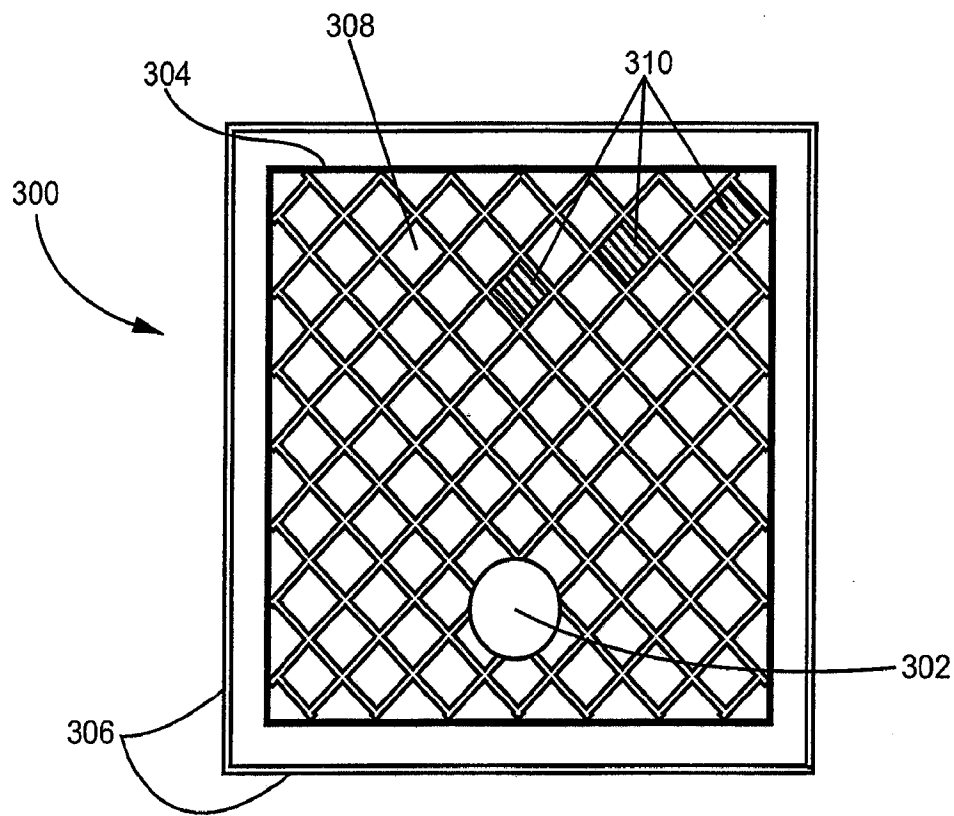


Fig. 3a

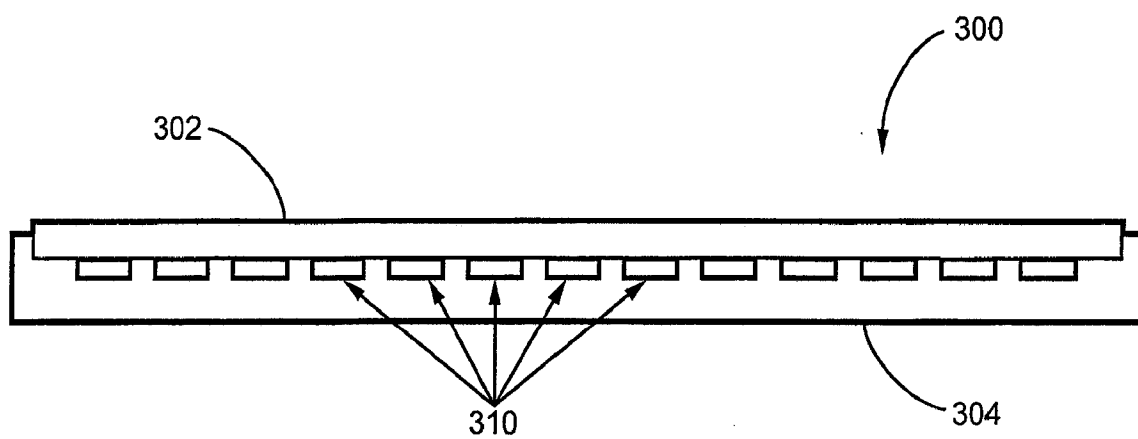


Fig. 3b

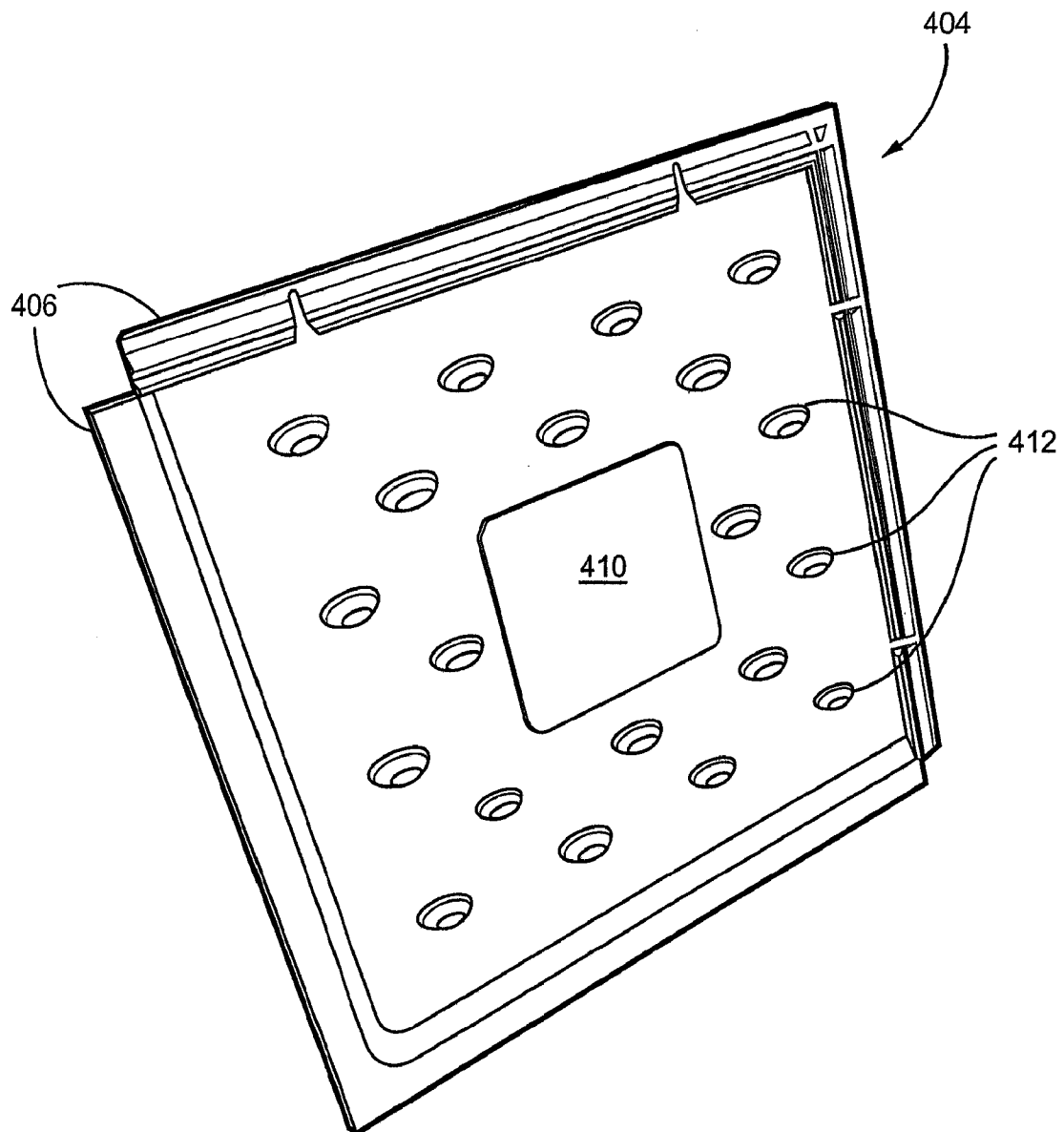
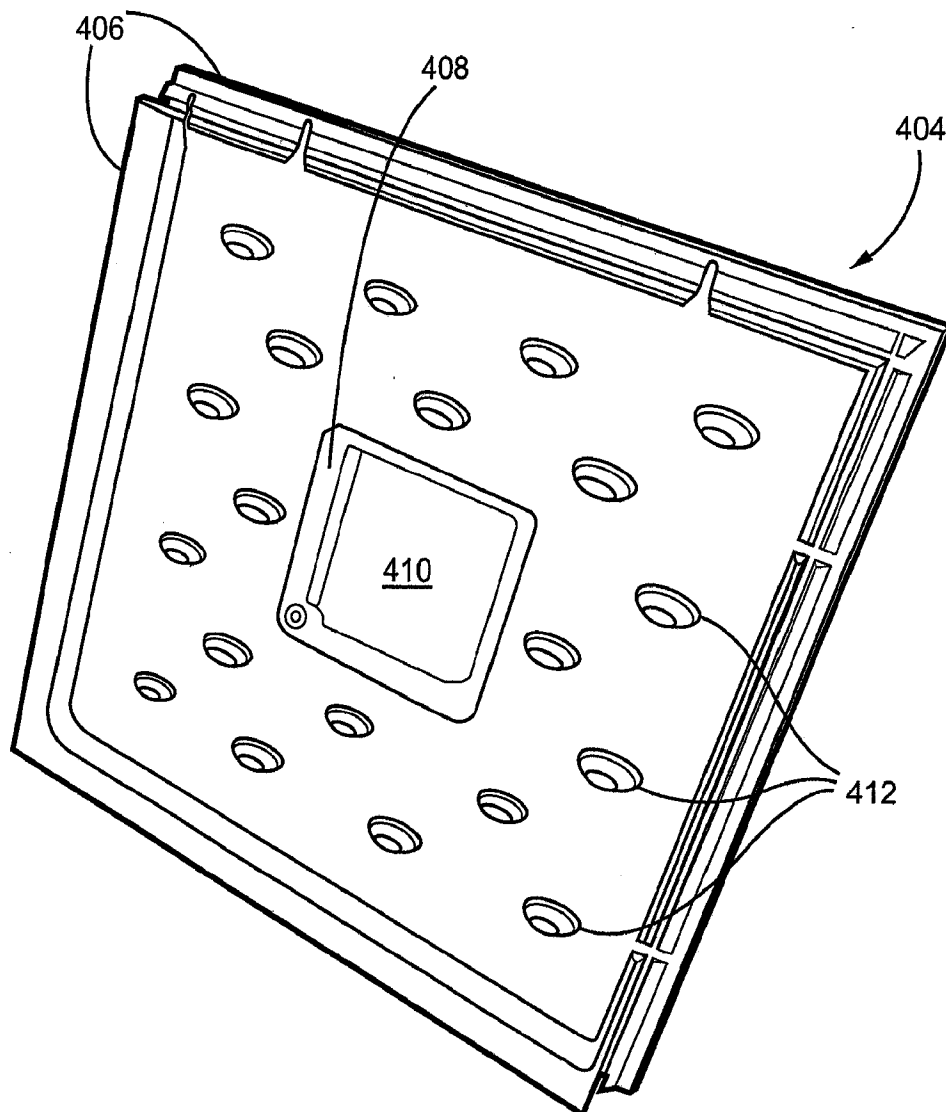


Fig. 4a

**Fig. 4b**

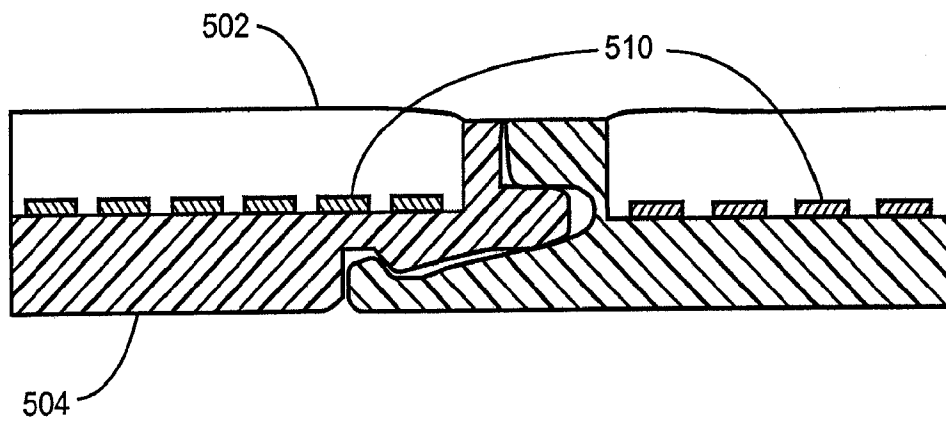


Fig. 5

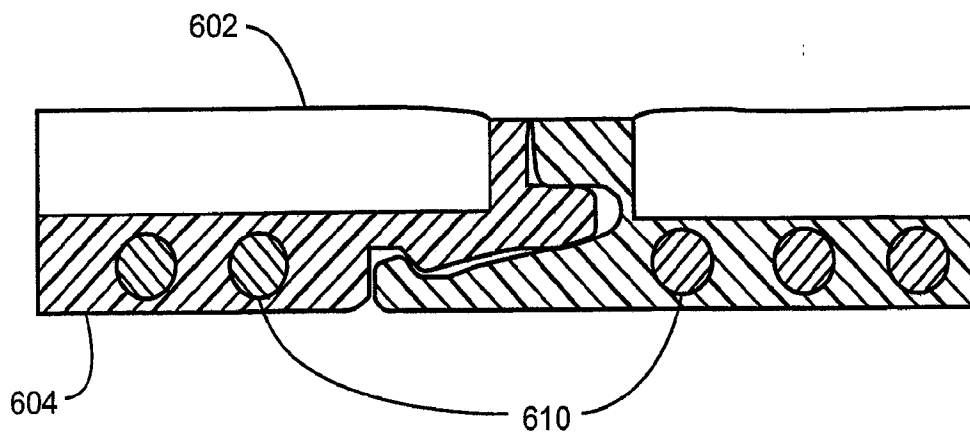


Fig. 6

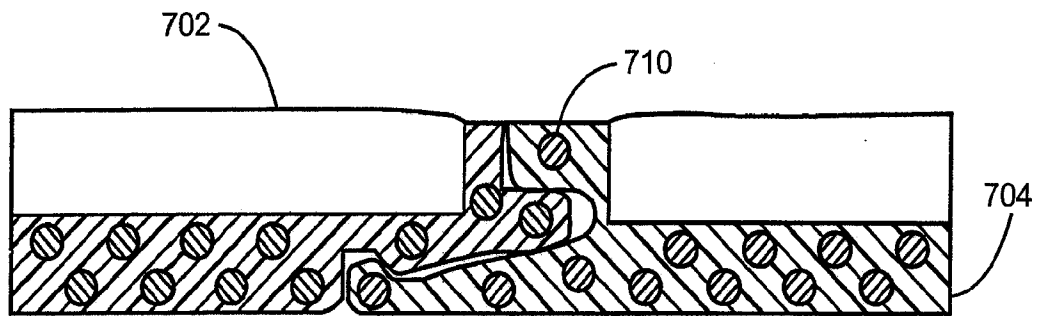


Fig. 7

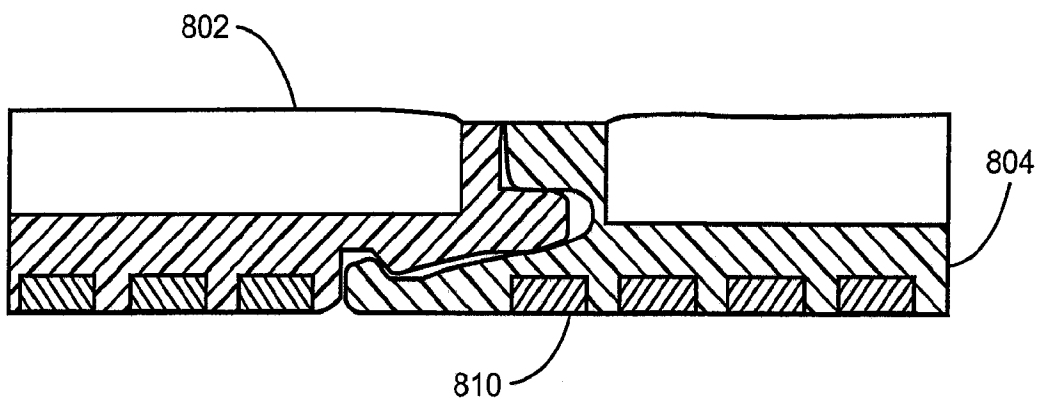


Fig. 8

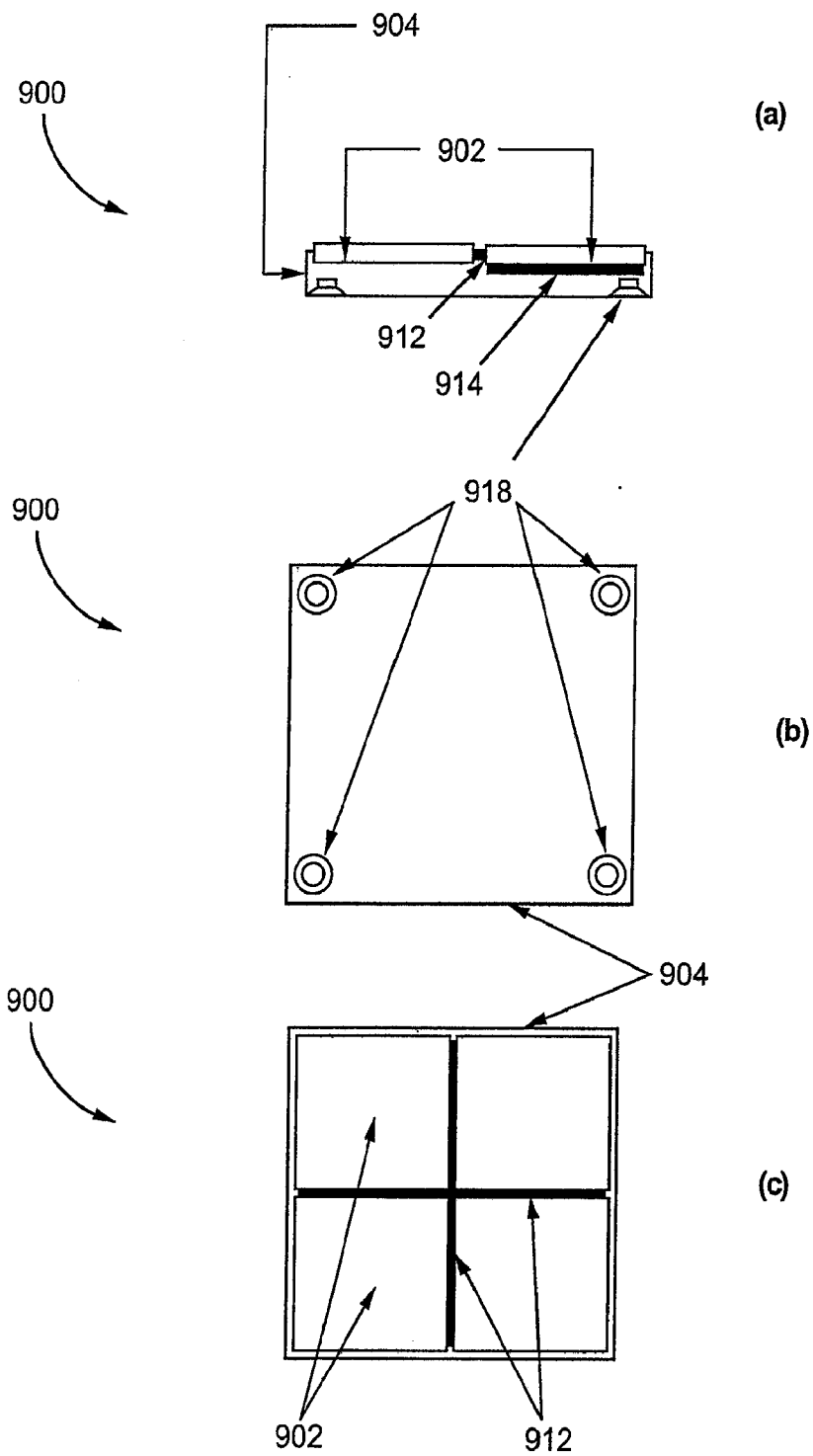
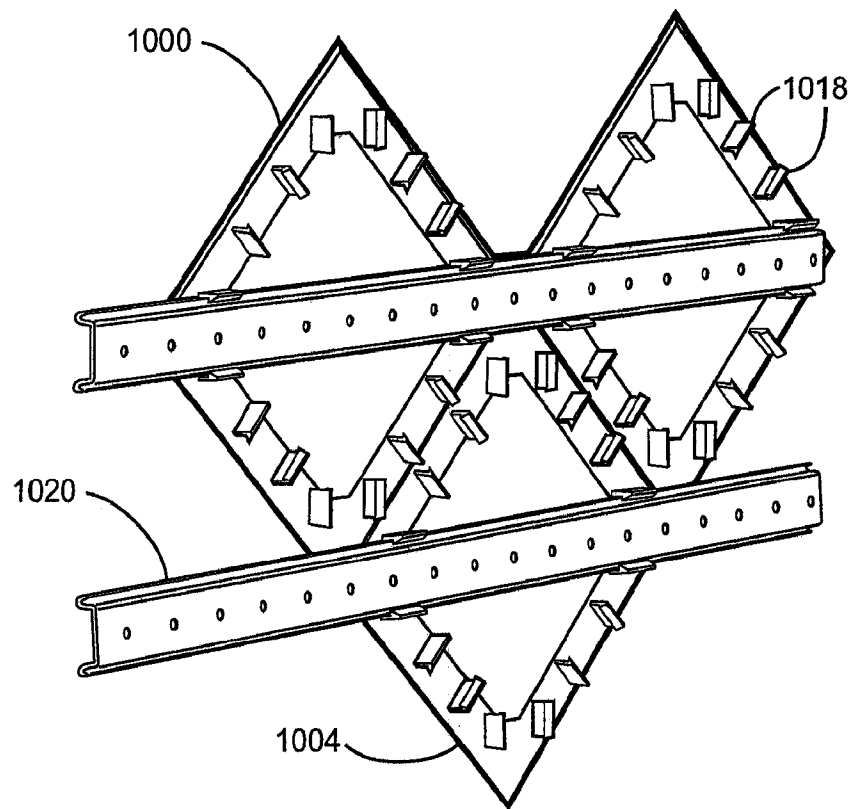
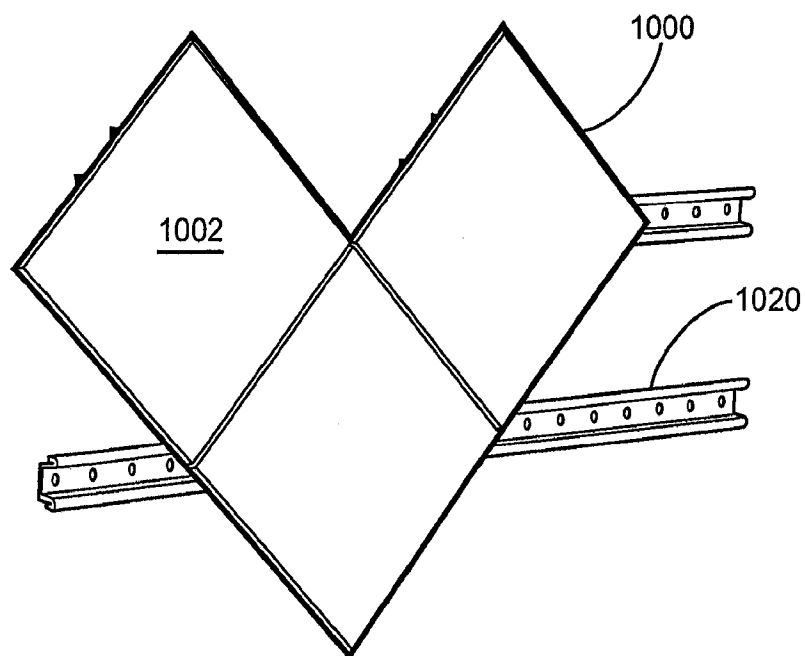


Fig. 9

**Fig. 10a****Fig. 10b**