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MULTI-MATERIAL SHEATHING SYSTEM

Abstract

A sheathing system that envelops a building structure includes a multi-layer panel having at least one structural layer formed of a non-wood material, such as polycarbonate. The panel also includes at least one layer of a high R-value insulation material.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION [0001] This application claims priority to and any benefit of U.S. Provisional Application No. 63/554,262, filed Feb. 16, 2024, the content of which is incorporated herein by reference in its entirety.

BACKGROUND

[0002] In contemporary building construction, wall sheathing systems are employed to provide structural support, insulation, and protection against external environmental factors. Conventional wall sheathing materials, such as plywood and oriented strand board (OSB), have been widely used and are typically seen as capable of providing structural support or rigidity to a structure; however, these materials generally lack sufficient thermal insulation properties. Among other shortcomings, the inadequate insulating property of conventional sheathing translates into greater energy expenditures to maintain the temperature and humidity levels of conditioned spaces.

[0003] To address the insulation challenge, traditional practice involves the application of separate insulation layers in conjunction with conventional wall sheathing materials. While this approach can enhance energy efficiency, it adds complexity to the construction process and increases material and labor costs. In addition to its limited ability to insulate, conventional wall sheathing materials are also susceptible to moisture infiltration and degradation over time, which can compromise both the structural integrity and thermal performance of the building envelope. To address the moisture problem, conventional building practices call for wrapping sheathing with a water-resistant wrap. Applying wrap is a labor-intensive task, which can increase labor and material costs. Moreover, wraps are generally susceptible to being displaced during construction and can trap moisture between the wrap and sheathing.

[0004] In an attempt to address the aforementioned problems, conventional sheathing materials have evolved into more complex assemblies, wherein multiple materials are joined together to form an integral multi-material sheathing (MMS) material. The MMS material is usually formed as a panel of a predetermined size, such as 4-foot by 8-foot.

[0005] For example, as shown in FIGS. **1**A-**1**B, a conventional MMS material **100** (e.g., panel) comprises two distinct layers and is formed by coupling a layer of OSB **102** having a thickness of 7/16 inch and a layer of extruded polystyrene (XPS) foam insulation **104** having a thickness of ¾ inch. The panel **100** has a thickness P.sub.t of 1.19 inches and a weight of 56 pounds. The panel **100** has a racking strength of 477 pounds per linear foot (plf), a max deflection of 3.4945 inches, and a nail retention of 60 pounds. Consequently, the panel **100** is considered a structural panel. A structural sheathing panel provides integrity and rigidity to the building structure, fortifying it against internal and external forces. For example, the structural sheathing panel provides shear resistance to the building. The structural sheathing panel also provides a suitable surface for application of other materials (e.g., siding).

[0006] The panel **100** has a nailing torque force of at least 270.9 pounds. The arrow **110** in FIG. **1**B shows the panel **100** oriented in an installation direction (i.e., facing a frame of a building structure, such as wall studs or roof trusses). By virtue of combining the layers **102** and **104**, the panel **100** is effective as both a sheathing and an insulating material, with the panel **100** providing adequate structural support when installed to the frame.

[0007] As another example, as shown in FIGS. **2**A-**2**B, a conventional MMS material **200** (e.g., panel) comprises two distinct layers and is formed by coupling a layer of OSB **202** having a thickness of ¼ inch and a layer of extruded polystyrene (XPS) foam insulation **204** having a thickness of ¾ inch. Thus, the layer of OSB **202** is substantially thinner than the layer of OSB **102** described above. The panel **200** has a thickness P.sub.t of 1 inch and a weight of 30 pounds. The panel **200** has a racking strength of 347 pounds per linear foot (plf), a max deflection of 3.1739 inches, and a nail retention of 20 pounds. Consequently, the panel **200** is considered a non-structural panel. The panel **200** has a nailing torque force of 206.3 pounds. The arrow **210** in FIG. **2**B shows the panel **200** oriented in an installation direction (i.e., facing a frame of a building structure, such as wall studs or roof trusses). By virtue of combining the layers **202** and **204**, the panel **200** is effective as both a sheathing and an insulating material; however, the reduced thickness of the layer **202** means the panel **200** itself does not provide adequate structural support when installed to the frame.

[0008] As yet another example, as shown in FIGS. **3**A-**3**B, a conventional MMS material **300** (e.g., panel) comprises three distinct layers and is formed by coupling a layer of OSB **302** having a thickness of 7/16 inch between a layer of polyisocyanurate (polyiso) foam insulation **304** having a thickness of 1 inch and a relatively thin layer barrier layer **306**. The barrier layer **306** comprises a bulk water resistant and water vapor permeable material (e.g., a resin-impregnated paper) having a thickness much less than 1/16 inch. The panel **300** has a thickness P.sub.t of 1.5 inches and a weight of 60 pounds. The panel **300** has a racking strength of 388 pounds per linear foot (plf), a max deflection of 3.7245 inches, and a nail retention of 60 pounds. Consequently, the panel **300** is considered a structural panel. The panel **300** has a nailing torque force of 240.5 pounds. The arrow **310** in FIG. **3**B shows the panel **300** oriented in an installation direction (i.e., facing a frame of a building structure, such as a wall or roof). By virtue of combining the layers **302**, **304**, and **306**, the panel **300** functions as a sheathing material, an insulating material, and a water-resistant material, with the panel **300** providing structural support when installed to the frame. Use of the panel **300** may obviate the need for installing a separate house wrap.

[0009] Notwithstanding these conventional assemblies, there is still an unmet need for an improved integral sheathing panel that better balances physical properties (e.g., thickness, weight), short term performance (e.g., racking strength, max deflection, nail retention), and long term performance (e.g., nailing torque force) of the panel.

SUMMARY

[0010] The present disclosure is directed to a high strength but lightweight multi-material sheathing (MMS) system that, when utilized to envelope at least a portion of a building structure, provides enhanced thermal insulation and weather resistant properties. The disclosed wall sheathing system combines lightweight structural layer(s) and a high R-value insulation layer to provide a unique solution. Embodiments of the present disclosure relate to a sheathing system that utilizes one or more thin layers of strong yet lightweight material, combined with a high R-value insulation layer. In some embodiments, a layer of OSB is also utilized. The collective layers of the sheathing system may offer benefits including, but not limited to, decreased thickness, reduced weight, improved thermal insulation, improved structural strength, improved nailability, improved fire and smoke performance, and enhanced energy efficiency. All aspects of the disclosed sheathing system (alone or in combination) can contribute to the overall improved performance and sustainability of a building structure.

[0011] In accordance with aspects herein disclosed, a sheathing system is provided that includes one or more structural layers and an insulation layer. The structural layer comprises a polycarbonate material and has a first surface and an opposing second surface. In an exemplary aspect, the structural layer is substantially bulk water resistant and substantially water vapor permeable. The insulation layer comprises an extruded polystyrene and has a third surface and an opposite fourth surface. The third surface of the insulation layer is secured to the second surface of the structural layer. In some further aspects, the sheathing system also comprises an additional structural layer comprising the polycarbonate material and having a fifth surface and an opposing sixth surface. Alternatively, in some further aspects, the sheathing system also comprises an additional structural layer comprising OSB and having a fifth surface and an opposing sixth surface. The fifth surface of the additional structural layer can be at least partially secured to the fourth surface of the insulation layer.

[0012] In accordance with the disclosed aspects, the sheathing system weighs less than conventional systems. For example, the inventive sheathing panels have a total weight between 10 to 45 pounds, a thickness of no greater than 1.5 inches (preferably no greater than 1 inch), and an R-value of at least 3.5 (preferably at least 4.5). Thus, the disclosed sheathing system is superior to conventional structural panel systems, which are generally heavier, thicker, and have a lower R-value.
[0013] This summary is provided to introduce and not limit the scope of the general inventive concepts, provided hereafter in further detail. The general inventive concepts encompass an improved lightweight, high-strength multi-material sheathing panel, as well as methods and systems of using the panels as a sheathing material on at least part of a building structure.
[0014] In one exemplary embodiment, a 2-layer panel, which can be used as a sheathing material for a building, comprises: a first structural layer; and an insulation layer, wherein the first structural layer comprises a polymeric material, wherein a thickness of the first structural layer is in the range of 1/32 inch to ⅛ inch, and wherein a thickness of the insulation layer is in the range of ½ inch to 4 inches.
[0015] In some embodiments, the thickness of the first structural layer is about 1/16 inch.
[0016] In some embodiments, the polymeric material of the first structural layer comprises at least one of polycarbonate (PC), polyester, polypropylene (PP), polymethyl methacrylate (PMMA), polyvinyl chloride (PVC), polyethylene (PE), high density polyethylene (HDPE), polyethylene terephthalate (PET), polyethylene terephthalate glycol (PETG), polyamide 6 (PA6), polyamide 66 (PA66), polystyrene (PS), acrylonitrile butadiene styrene (ABS), and copolymers and/or blends thereof.
[0017] In some embodiments, the first structural layer comprises polycarbonate.
[0018] In some embodiments, the first structural layer consists of polycarbonate.
[0019] In some embodiments, the first structural layer further comprises one or more filler materials.
[0020] In some embodiments, the insulation layer comprises at least one of extruded polystyrene, expanded polystyrene, foamed polyurethane, polyisocyanurate, fiberglass, mineral wool, polyethylene terephthalate, polyester, phenolic foam, aerogel blanket, aerogel board, and polyurethane.
[0021] In some embodiments, the insulation layer comprises extruded polystyrene.
[0022] In some embodiments, the insulation layer consists of extruded polystyrene.
[0023] In some embodiments, the insulation layer comprises mineral wool.
[0024] In some embodiments, the insulation layer consists of mineral wool.
[0025] In some embodiments, the panel has a nail withdrawal force between 20 pounds and 400 pounds.
[0026] In some embodiments, the sheathing material has a racking performance greater than 250 plf.
[0027] In some embodiments, the sheathing material has a racking performance greater than 440 plf.
[0028] In some embodiments, a thickness of the panel is less than or equal to 1.5 inches and an R-value of the panel is at least 4.5.
[0029] In some embodiments, a thickness of the panel is less than or equal to 1 inch and an R-value of the panel is at least 3.5.
[0030] In some embodiments, a thickness of the panel is less than or equal to 1 inch and an R-value of the panel is at least 4.5.
[0031] In some embodiments, a weight of the panel is in the range of 10 pounds to 45 pounds.
[0032] In some embodiments, a weight of the panel is in the range of 10 pounds to 45 pounds, a thickness of the panel is less than or equal to 1.5 inches, and an R-value of the panel is at least 4.5.
[0033] In some embodiments, the panel further comprises a second structural layer to form a 3-

layer panel.
[0034] In some embodiments, the second structural layer is identical to the first structural layer.
[0035] In some embodiments, the second structural layer comprises a polymeric material, and a thickness of the second structural layer is in the range of 1/32 inch to ⅛ inch.
[0036] In some embodiments, the thickness of the second structural layer is about 1/16 inch.
[0037] In some embodiments, the polymeric material of the second structural layer comprises at least one of polycarbonate (PC), polyester, polypropylene (PP), polymethyl methacrylate (PMMA), polyvinyl chloride (PVC), polyethylene (PE), high density polyethylene (HDPE), polyethylene terephthalate (PET), polyethylene terephthalate glycol (PETG), polyamide 6 (PA6), polyamide 66 (PA66), polystyrene (PS), acrylonitrile butadiene styrene (ABS), and copolymers and/or blends thereof.
[0038] In some embodiments, the second structural layer comprises polycarbonate.
[0039] In some embodiments, the second structural layer consists of polycarbonate.
[0040] In some embodiments, the second structural layer further comprises one or more filler materials.
[0041] In some embodiments, the panel has an ultimate shear strength according to ASTM E72 of at least 250 plf.
[0042] In some embodiments, the panel has an ultimate shear strength according to ASTM E72 of at least 500 plf.
[0043] In some embodiments, the panel has an ultimate shear deflection according to ASTM E72 of less than 4 inches.
[0044] In some embodiments, the panel has a nail retention according to ASTM D1761 in the range of 30 pounds to 200 pounds.
[0045] In some embodiments, a thickness of the panel is less than or equal to 1.5 inches and an R-value of the panel is at least 4.5.
[0046] In some embodiments, a thickness of the panel is less than or equal to 1 inch and an R-value of the panel is at least 3.5.
[0047] In some embodiments, a thickness of the panel is less than or equal to 1 inch and an R-value of the panel is at least 4.5.
[0048] In some embodiments, a thickness of the panel is less than or equal to 1.5 inches, an R-value of the panel is at least 4.5, and a racking strength of the panel according to ASTM E72 is at least 600 plf.
[0049] In some embodiments, a thickness of the panel is less than or equal to 1 inch, an R-value of the panel is at least 3.5, and a racking strength of the panel according to ASTM E72 is at least 700 plf.
[0050] In some embodiments, a thickness of the panel is in the range of 0.5 inches to 2 inches; and a racking strength of the panel according to ASTM E72 is in the range of 500 plf to 900 plf.
[0051] In some embodiments, a weight of the panel is in the range of 10 pounds to 45 pounds.
[0052] In some embodiments, a weight of the panel is in the range of 10 pounds to 45 pounds, a thickness of the panel is less than or equal to 1.5 inches, and an R-value of the panel is at least 4.5.
[0053] In some embodiments, the second structural layer comprises a wood composite material, and a thickness of the second structural layer is in the range of ¼ inch to 1⅛ inches.
[0054] In some embodiments, the wood composite material comprises at least one of oriented strand board, fiberboard, and plywood.
[0055] In some embodiments, the second structural layer comprises oriented strand board.
[0056] In some embodiments, the second structural layer consists of oriented strand board.
[0057] In some embodiments, the panel has an ultimate shear strength according to ASTM E72 of at least 250 plf.
[0058] In some embodiments, the panel has an ultimate shear strength according to ASTM E72 of at least 500 plf.

[0059] In some embodiments, the panel has an ultimate shear deflection according to ASTM E72 of less than 4 inches.
[0060] In some embodiments, the panel has a nail retention according to ASTM D1761 in the range of 30 pounds to 90 pounds.
[0061] In some embodiments, a thickness of the panel is less than or equal to 1.5 inches and an R-value of the panel is at least 4.5.
[0062] In some embodiments, a thickness of the panel is less than or equal to 1.1 inches and an R-value of the panel is at least 3.5.
[0063] In some embodiments, a thickness of the panel is less than or equal to 1.1 inches and an R-value of the panel is at least 4.5.
[0064] In some embodiments, a weight of the panel is in the range of 10 pounds to 45 pounds.
[0065] In some embodiments, a weight of the panel is in the range of 10 pounds to 45 pounds, a thickness of the panel is less than or equal to 1.5 inches, and an R-value of the panel is at least 4.5.
[0066] In one exemplary embodiment, a 3-layer panel, which can be used as a sheathing material for a building, comprises: a first structural layer; a second structural layer; and an insulation layer, wherein the insulation layer is disposed between the first structural layer and the second structural layer, wherein at least one of the first structural layer and the second structural layer comprises a polymeric material, wherein the panel has an ultimate shear strength according to ASTM E72 of at least 500 plf, wherein the panel has an ultimate shear deflection according to ASTM E72 of less than 4 inches, and wherein the panel has a nail retention according to ASTM D1761 in the range of 30 pounds to 200 pounds.
[0067] In one exemplary embodiment, a 3-layer panel, which can be used as a sheathing material for a building, comprises: a first structural layer; a second structural layer; and an insulation layer, wherein the insulation layer is disposed between the first structural layer and the second structural layer, wherein one of the first structural layer and the second structural layer comprises a polymeric material, wherein one of the first structural layer and the second structural layer comprises a wood composite material, wherein the panel has an ultimate shear strength according to ASTM E72 of at least 500 plf, wherein the panel has an ultimate shear deflection according to ASTM E72 of less than 4 inches, and wherein the panel has a nail retention according to ASTM D1761 in the range of 30 pounds to 200 pounds.
[0068] Other aspects and features of the general inventive concepts will become more readily apparent to those of ordinary skill in the art upon review of the following description of various exemplary embodiments in conjunction with the accompanying figures.

Description

DESCRIPTION OF THE DRAWINGS
[0069] The present invention is described in detail herein with reference to the attached drawings, wherein:
[0070] FIGS. **1**A-**1**B show a conventional 2-layer sheathing panel. FIG. **1**A is a perspective view of the sheathing panel. FIG. **1**B is a side elevation (cross-sectional) view of the sheathing panel.
[0071] FIGS. **2**A-**2**B show another conventional 2-layer sheathing panel. FIG. **2**A is a perspective view of the sheathing panel. FIG. **2**B is a side elevation (cross-sectional) view of the sheathing panel.
[0072] FIGS. **3**A-**3**B show a conventional 3-layer sheathing panel. FIG. **3**A is a perspective view of the sheathing panel. FIG. **3**B is a side elevation (cross-sectional) view of the sheathing panel.
[0073] FIGS. **4**A-**4**E show a 2-layer sheathing panel, according to an exemplary embodiment. FIG. **4**A is a perspective view of the sheathing panel. FIG. **4**B is a side elevation (cross-sectional) view of the sheathing panel. FIG. **4**C is a separated perspective view of the sheathing panel. FIG. **4**D is a

side elevation view of the panel of FIG. **4**B brought in proximity to a building structure. FIG. **4**E is a side elevation view of the panel of FIG. **4**B installed on the building structure.

[0074] FIGS. **5**A-**5**G show a 3-layer sheathing panel, according to an exemplary embodiment. FIG. **5**A is a perspective view of the sheathing panel. FIG. **5**B is a side elevation (cross-sectional) view of the sheathing panel. FIG. **5**C is a separated perspective view of the sheathing panel. FIG. **5**D is a side elevation view of the panel of FIG. **5**B (with two structural layers of different material) brought in proximity to a building structure. FIG. **5**E is a side elevation view of the panel of FIG. **5**D installed on the building structure. FIG. **5**F is a side elevation view of the panel of FIG. **5**B (with two structural layers of the same material) brought in proximity to a building structure. FIG. **5**G is a side elevation view of the panel of FIG. **5**F installed on the building structure.

[0075] FIG. **6** is a plan view of a portion of a 2-layer sheathing panel, according to an exemplary embodiment

[0076] FIG. **7** is a plan view of a portion of a 3-layer sheathing panel, according to an exemplary embodiment

[0077] FIG. **8** is a plan view of a portion of a 3-layer sheathing panel, according to an exemplary embodiment

[0078] FIG. **9** is a plan view of a portion of a 3-layer sheathing panel, according to an exemplary embodiment

[0079] FIGS. **10**A-**10**B illustrate a coupling technique for a 3-layer sheathing panel, according to an exemplary embodiment.

[0080] FIGS. **11**A-**11**B show a 3-layer sheathing panel having a central support layer, according to an exemplary embodiment.

[0081] FIG. **12** is a graph that plots racking strength values and maximum deflection values for several sheathing panels.

[0082] FIGS. **13**A-**13**B show two exemplary 3-layer sheathing panels, each panel having a polycarbonate layer at different locations therein.

[0083] FIG. **14** is a graph that plots racking strength values for several sheathing panels.

DETAILED DESCRIPTION

[0084] Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which the embodiments belong. Although any methods and materials similar or equivalent to those described herein can be used in the practice or testing of the various embodiments, some preferred methods and materials are described herein. In the drawings, the thickness of the lines, layers, and regions can be exaggerated for clarity. It is to be noted that like numbers found throughout the figures denote like elements.

[0085] As used in the specification and the appended claims, the singular forms "a," "an," and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise.

[0086] Unless otherwise indicated, all numbers expressing quantities of ingredients, chemical and molecular properties, reaction conditions, and so forth used in the specification and claims are to be understood as being modified in all instances by the term "about." Accordingly, unless indicated to the contrary, the numerical parameters set forth in the specification and attached claims are approximations that can vary depending upon the desired properties sought to be obtained by the present exemplary embodiments. At the very least, each numerical parameter should be construed in light of the number of significant digits and ordinary rounding approaches.

[0087] Unless otherwise indicated, any element, property, feature, or combination of elements, properties, and features, can be used in any embodiment disclosed herein, regardless of whether the element, property, feature, or combination of elements, properties, and features was explicitly disclosed in the embodiment. It will be readily understood that features described in relation to any particular aspect described herein can be applicable to other aspects described herein provided the features are compatible with that aspect.

[0088] Every numerical range given throughout this specification and claims will include every narrower numerical range that falls within such broader numerical range, as if such narrower numerical ranges were all expressly written herein.

[0089] The term “R-value” is the unit used to measure the effectiveness of thermal insulation and is the reciprocal of thermal conductivity, which for foam board materials having substantially parallel faces, is defined as the rate of flow of thermal energy (BTU/hr. or Watt) per unit area (square foot (ft.sup.2) or square meter (m.sup.2)) per degree of temperature difference (Fahrenheit or Kelvin) across the thickness of the slab material (inches or meters). The thermal performance of a polymeric insulation product is based on the R-value of the insulation product, which is a measure of the product's resistance to heat flow. The R-value is defined by Equation (1):

[00001] $R = T / k$ [0090] where “T” is the thickness of the insulation product expressed in inches, “k” is the thermal conductivity of the insulation product expressed in BTU.Math.in/hr.Math.ft.sup.2.Math.° F., and “R” is the R-value of the insulation expressed in hr.Math.ft.sup.2.Math.° F./BTU.

[0091] As used herein, an insulation product's thickness (T) can be determined in accordance with ASTM C167-18 and both k-value and area weight (in lb/ft.sup.2) can be determined in accordance with ASTM C518-21 or ASTM C177-19.

[0092] The following describes select aspects relating to a sheathing system for use in constructing a building structure (e.g., a residential home, a commercial building, an industrial building). The disclosed sheathing system can comprise panels capable of being attached to a frame of a building structure, thereby forming a sheath that envelops at least a portion of the building structure. The sheath formed by the disclosed sheathing system can correspond to a wall portion (e.g., vertical surface) or a roofing portion of the building structure, by way of example.

[0093] The multi-material sheathing system disclosed herein provides for various improvements over conventional sheathing systems. The unique collection of individual layers (also referenced herein as “components”) utilized in the production of the disclosed sheathing system provide for a stronger, thinner, and lighter sheathing panel having a higher R-value per inch of total thickness, which offers several advantages over conventional sheathing systems.

[0094] The materials used in the novel sheathing system herein provide a thinner structural layer that maintains or exceeds the structural performance of conventional systems. As one of ordinary skill in the art can appreciate, thinner materials generally take up less space within the building envelope, allowing for more efficient utilization of interior space. This can be especially crucial in applications where maximizing usable area is essential, such as in residential homes or commercial buildings. Thinner materials are also generally lighter in weight, which can simplify handling, transportation, and installation. Additionally, the utilization of alternative materials for sheathing systems, as will be described, greatly reduces weight. Reduced weight can also have positive implications for the structural load on the building's foundation and framing. Thin materials provide architects and builders with greater flexibility in designing and implementing various architectural elements, such as curves, angles, and intricate details. This can also lead to faster construction times due to easier handling and installation. The thin materials can subsequently result in reduced labor costs and faster project completion.

[0095] The materials utilized and described herein provide an insulated sheathing system with a high R-value. The higher the R-value, the more effective insulative characteristics are attributed to the sheathing system. More specifically, a sheathing system with a high R-value generally indicates that the sheathing system is effective at reducing heat flow through walls, roofs, and floors. This translates to lower energy consumption for heating and cooling, lower utility bills and a smaller carbon footprint. High R-value sheathing systems also help maintain more consistent indoor temperatures by reducing drafts, cold spots, and heat loss, further providing occupants with a more comfortable living or working environment year-round. As is generally known in the building industry, minimum insulation R-values on external sheathing of a building structure may be required by code. In this regard, conventional sheathing systems may require a builder add insulation after a sheathing panel is affixed to the building structure in order to obtain the adequate R-value, further complicating the construction process and leading to additional resource expenditures.

[0096] Turning to FIGS. **4**A-**4**E, a sheathing system for externally enveloping at least a portion of a building structure, according to an exemplary embodiment, is disclosed. The sheathing system includes a panel **400** that comprises two distinct layers and is formed by coupling a structural layer **402** and an insulation layer **404** (i.e., a “2-layer system”). The arrow **410** in FIG. **4**B shows the panel **400** oriented in an installation direction (i.e., facing a frame of a building structure, such as a wall or roof).

[0097] As shown in FIG. **4**C, the structural layer **402** comprises a first surface **414** and a second surface **415** opposite the first surface **414**. The structural layer **402** can have a thickness measured as a distance from the first surface **414** to the second surface **415** opposite the first surface **414**. The insulation layer **404** comprises a third surface **416** and a fourth surface **417** opposite the third surface **416**. A thickness of the insulation layer **404** can be measured as a distance from the third surface **416** to the fourth surface **417**.

[0098] The panel **400** is formed by coupling the second surface **415** of the structural layer **402** to the third surface **416** of the insulation layer **404**, wherein the panel **400** has an overall thickness of a distance measured from the first surface **414** to the fourth surface **417**. More specifically, the structural layer **402** can be coupled to the insulation layer **404** by bonding, adhering, applying, or mechanically fastening one layer to the other. By way of example, the panel **400** can be formed by applying a glue layer to the second surface **415** of the structural layer **402** or the third surface **416** of the insulation layer **404** and adhering one surface to the other. In some embodiments, the glue layer can have a weight range from about 4.885 gm/cm2 (1 lbs./MSF) to about 244.5 gm/cm2 (50 lbs./MSF). The glue layer can comprise any variety of adhesive, such as a pressure sensitive adhesive (PSA), a resin (e.g., phenol-formaldehyde, polyvinyl acetate), hot-melt, isocyanate-based adhesive, tar, or other adhesives, by way of non-limiting examples. As another example, the panel **400** can be formed without use of any glue. In this case, the second surface **415** of the structural layer **402** and the third surface **416** of the insulation layer **404** are joined together with no layer of glue therebetween.

[0099] Continuing with FIGS. **4**D-**4**E, one arrangement for coupling the panel **400** of the sheathing system to a building frame structure **440** is illustrated. In particular, the 2-layer system is intended to be installed on the building frame structure **440** that already includes a sheathing material **442** (e.g., OSB) installed thereon. Alternatively, the 2-layer system could be installed on the building frame structure **440** at the same time that the sheathing material **442** is installed on the building frame structure **440**. In other words, the panel **400** could be aligned with a sheet of OSB so that the layers **402**, **404**, and **442** are installed simultaneously.

[0100] The configuration shown in FIGS. **4**D-**4**E contemplates that the panel **400** has the insulation layer **404** adjacent the building frame structure **440** (i.e., adjacent the OSB material **442**). In some embodiments, the panel **400** has the structural layer **402** adjacent the building frame structure **440**, which merely involves flipping the panel over prior to installing it to the frame structure **440**. The panel **400** can be installed on or otherwise secured to the building frame structure **440** by use of a suitable number of fasteners **444**. The fastener **444** can comprise any variety of fastener, such as a nail, screw, bolt, adhesive, anchor, rail molding, cleat, magnet, pegboard, suction, hook and loop, or any other suitable fastener generally known in the art. Typically, the fasteners **444** extend through the structural layer **402**, the insulation layer **404**, the OSB layer **442**, and into the frame structure **440** (e.g., wall studs), as shown in FIG. **4**E. Of course, this would not be the case for non-penetrating fasteners, such as adhesive. In some embodiments, one type of fastener (or fastening means) joins the layers **402**, **404** together to form the unitary panel **400**, while another type of fastener (or fastening means) joins the panel to the sheathing material **442** and/or the building frame structure **440**.

[0101] The fastener **444** can be used to secure the panel **400** to the sheathing material **442** attached to the building frame structure **440**. It is preferable that the panel **400** provides resistance such that the fastener **444** is prevented from being withdrawn from the panel **400**. Indeed, the nail retention of the sheathing material **442** (e.g., OSB) installed on the building frame structure **440** is enhanced by installation of the panel **400** thereon.

[0102] The sheathing system comprises a unique layered panel system with specific materials chosen for each layer. The materials chosen for each layer leads to the sheathing system meeting or exceeding current industry standard sheathing systems with respect to nail withdrawal force. The 2-layer system is comprised of a non-lignocellulosic structural layer **402** and an insulation layer **404** comprising extruded polystyrene (XPS). For example, in an exemplary embodiment, the structural layer **402** of the panel **400** is comprised of polycarbonate material. The structural layer **402** has a thickness in the range of 1/32 inch (about 0.0313 inches) to 1/16 inch (about 0.0625 inches). The 2-layer system shown in FIG. **4**A has a thickness in the range of 17/32 inch (about 0.5313 inches) to 2 1/16 inches (about 2.0625 inches) and a nail withdrawal force in the range of 30-90 lbs. measured in accordance with ASTM D1761 (see also ASTM D1037) standards. In comparison, an industry standard wall sheathing comprised of oriented strand board (OSB) at a thickness of 7/16 inch (about 0.4375 inches) has a nail withdrawal force of less than 60 lbs. or 137 lbs. per inch.

[0103] Typically, many of the panels **400** are installed around an exterior framing of a structure to form the building's sheathing or a substantial portion thereof. Any joint formed between adjacent panels can be effectively “closed” by use of sealant, tape, or the like.

[0104] Continuing with FIGS. **4**A-**4**B, different thicknesses of the panel **400** are described and can vary based on its intended use. In implementations where better insulating properties are desirable, the overall thickness of the panel **400** can be greater. For example, the panel **400** can have an R-value of 10 when the overall thickness of the panel **400** is 2 inches. In implementations where lower insulative properties are acceptable, the panel **400** can have an overall thickness of 1 inch or less while still preserving an R-value of at least 3.5. In implementations where higher insulative properties are required, the panel **400** can have an overall thickness of 4 inches or more to obtain an R-value much higher than 3.5. One skilled in the art will appreciate that many other thicknesses can be used (e.g., the panel **400** can have an R-value of 7 when the overall thickness is 1.5 inches), though the overall thickness of the panel **400** is preferably in the range of 0.5 inch to 2 inches. It is contemplated that values beyond that range for the overall thickness can be used depending on the particular needs of a project. As with conventional sheathing solutions, the R-value of the panel **400** increases with its overall thickness. Accordingly, the panel **400** can be designed to have an R-value ranging at least from 3.5 to 10. In various embodiments, the total R-value of the sheathing system can vary depending on the proportion of the insulation layer **404** to the structural layer **402** in the panel **400**.

[0105] As noted above, the proportion of the thickness of structural layer **402** to the thickness of insulation layer **404** can vary based on the particular needs of a project. For example, when greater structural strength is desired in areas prone to high winds or seismic forces, one may want to increase the relative structural thickness. Alternatively, when greater insulation is desired and strength can be sacrificed, such as in less temperate climates, one may want to increase the relative thickness of the insulation layer. In a preferred arrangement, the ratio of insulation layer **404** thickness to structural layer **402** thickness is about 3:1. As an example, a sheathing system employing panels **400** with a 3:1 ratio and an overall thickness of 1 inch would have a ¼ inch thick structural layer **402** and a ¾ inch thick insulation layer **404**. In other exemplary embodiments, the ratio of insulation layer **404** thickness to structural layer **402** thickness can be 6:1, 5:1, 4:1, 2:1, 1.5:1, or 1:1, by way of non-limiting examples. Additional ratios not disclosed herein are considered within the purview of the present disclosure.

[0106] The structural layer **402** can have a variety of thicknesses based on structural needs of the building. By way of example, the structural layer **402** can have a thickness of ⅛ inch. Additionally, the structural layer can have a thickness in the range of 1/64 inch to 1 inch. To accommodate the differing insulation needs described above, the insulation layer **404** can have a thickness in the range of ¼ inch to 1½ inches. As such, the combined thickness of the structural layer **402** and the insulation layer **404** can be in the range of ½ inch to 2 inches. In an exemplary configuration, the thickness of the structural layer **402** and the insulation layer **404** is equal to or less than 1 inch, having an R-value of 3.5 or greater. In another exemplary configuration, the thickness of the structural layer **402** and the insulation layer **404** is equal to or less than 1 inch, having an R-value of 5 or greater. Furthermore, alternative embodiments have an R-value-to-thickness ratio of at least 5, such as resulting from a 2-inch system with an R-value of 10.

[0107] As described herein, the purpose of the insulation layer **404** is to provide enhanced thermal resistance. The insulation layer **404** of the panel **400** can comprise materials selected to have a high R-Value. In one exemplary embodiment, the insulation layer **404** comprises extruded polystyrene (XPS). It is contemplated that insulation layer **404** can comprise any insulating material, including but not limited to fiberglass, wood, foam, polymers, wood composite materials, expanded polystyrene (EPS), foamed polyurethane, polyisocyanurate board, fiber-reinforced polymer, thermoplastic, polymer-based materials, mineral wool, closed cell thermoplastic, thermoplastic polystyrene, polyethylene terephthalate, polyester resin, phenolic foam, aerogel blanket, aerogel board, cellulosic insulation, rock wool insulation, or any combination thereof. Polymer-based insulation materials, which can also or alternatively be utilized in insulation layer **404**, can include polyurethane, phenolic foam, TPO, thermoplastic polyolefin (TPO), and ethylene propylene diene monomer (EPDM), among other things.

[0108] On the other hand, the structural layer **402** provides rigidity and structural support to the envelope of the building structure. Accordingly, the structural layer **402** can be comprised of any one or more materials that resist kinetic forces, such as polycarbonate or certain composites. Additional materials that can provide the rigidity and structural support that the structural layer **402** requires can be one or more of materials such as polypropylene, high density polyethylene (HDPE), or a wood composite. However, as described herein, wood composites alone may be undesirable due to properties such as weight, moisture absorption, etc. Consequently, a structural layer formed of a water-resistant material such as polycarbonate can obviate the need for a separate moisture barrier, wrap, or the like.

[0109] Structural layer **402** can comprise a polymer, polycarbonate (PC), stainless steel, glass, polyester, polypropylene (PP), polyethylene (PE), acrylic, acrylonitrile styrene acrylate (ASA), cyclic olefin copolymer (COC), polycyclohexylenedimethylene terephtalate (PCT), polyether ketone, polyaryletherketones, polyetherimide, polyethersulfone, polymethyl methacrylate (PMMA), polyvinyl chloride (PVC), polyphthalmide, polyphenylene oxide (PPO), polyphenylene sulfide (PPS), recycled high-density polyethylene (HDPE), any recycled plastic or polymer, polysulfone, or syndiotactic polystyrene. The polymer can comprise one or more of polyvinyl styrene, plexiglass, high-density polypropylene (HDPP), hard plastic, soft plastic, polyethylene terephthalate (PET), polyethylene terephthalate glycol (PETG), polyamide 6 (PA6), polyadmide 66 (PA66), polystyrene (PS), acrylonitrile butadiene styrene (ABS), polyurethane, thermoplastic, thermosets, elastomer, hemp, shellac, amber, wool, silk, natural rubber, cellulose, silicone, polybutylene terephthalate (PBT), styrene-butadiene rubber, or other polymers or copolymers, such as PC/ABS, PC/PBT, PC/PET, PVC-acrylic, and fiber/filler reinforced polymer or copolymers thereof. In a further example, recycled materials, including recycled polycarbonate, can be used for the structural layer **402**. Additionally, other recycled materials can also be considered for the structural layer **402**, such as recycled plastics or composite materials made from reclaimed wood fibers and plastic.

[0110] In other aspects, the structural layer **402** can comprise a polymer composite formed from a

polymer and at least one filler material. The addition of a filler material can add desired physical properties to the structural layer **402**, such as texture, color, strength, reduced weight, or other physical properties. The polymer composite can comprise a filler material that is added to the polymer in a ratio of between 1 percent and 90 percent by weight filler material to polymer. In further aspects, the filler material can comprise any amount of a powder, talc, calcium carbonate, calcium carbonate pellets, cellulose, sand, silica, magnesium oxide, aluminum oxide, clay, inorganic powder, a colorant, ground tire rubber, rubber, calcium sulfate, calcium silicate, barium sulfate, mica, kaolin, silicone dioxide, diatomaceous earth, minerals, fibrous glass, carbon fibers, glass, polymer beads, magnesium hydroxide, fly ash, polymer foam beads, masonry filler, wollastonite, short glass fibers, long glass fibers, glass beads, coal, dolomite, carbon black, silica, magnetite, hematite, halloysite, zinc oxide, titanium dioxide, Al(OH).sub.3, Mg(OH).sub.2, concrete filler, gravel, stone, sand, steel, aluminum, or any other material that can be added to the polymer of the structural layer **402**. In alternative embodiments, organic filler, rice hulls, nut flour, wood flour, vegetable fibers, cotton fiber, starch, synthetic organic filler, rubber particles, chalk, quartz, granite, alumino-silicates, vermiculite, nepheline-senite, barium ferrite, barium titanate, molybdenum disulphide, potassium titanate, metal oxides, metal hydrates, metal powder, zinc, beryllium oxide, blowing agent, PBT, ceramics, or other materials that can be added to the polymer, can be used as the filler material. In another embodiment, glass fibers, carbon fibers, mineral fillers (e.g., calcium carbonate, talc, or mica), aramid fibers, glass beads, nanoclays, metal particles, natural fibers (e.g., hemp, jute, or flax), graphene, rubber particles, ceramic fillers (e.g., alumina or silica), recycled materials (e.g., plastic or rubber materials), wood fibers/flour, conductive fillers (e.g., carbon black or metal powders), flame retardant fillers (e.g., phosphorus-based compounds or halogenated additives) can be contemplated for use as the filler material.
[0111] In some embodiments, the filler material can have a size of up to 1 mm. The polymer composite can have filler material comprised of substances with sizes ranging from 1 micron to 1,000 microns, 1 micron to 1 centimeter, or 10 mesh to 100 mesh, by way of non-limiting examples. In an embodiment, the filler material can be added to the polymer in a ratio of 1 percent by weight up to 90 percent by weight of the polymer. In another embodiment, a ratio of between 30 percent by weight and 60 percent by weight of the polymer can be used for the filler material.
[0112] The panel **400** of the sheathing system can be milled or shaped into any desirable shape or size. Generally formed as a planar sheet in any one or more standard sizes (e.g., 1.319 m×2.438 m (4 ft×8 ft), 1.319 m×3.048 m (4 ft×10 ft), or 1.319 m×3.658 m (4 ft×12 ft)), the panel **400** can be shaped or cut according to specific dimensions and/or design requirements (e.g., different geometric shapes). Using cutting or shaping tools available on a worksite (e.g., a circular saw) or precision tooling (e.g., a Computer Numerical Control (CNC) machine), each layer of the sheathing system **400** can be cut or milled accordingly.
[0113] The structural layer **402** can be resistant to bulk water but permeable to water vapor. The structural layer **402** can be characterized by water vapor permeance in the range of about 0.1 U.S. perms to about 1.0 U.S. perms, and have a water vapor transmission rate from about 0.07 to about 7 g/m.sup.2/24 hr. (at 73° F.50% RH via ASTM E96 procedure A). Additional embodiments of the structural layer **402** have a water vapor permeance from about 0.1 to about 12 U.S. perms (at 73° F.-50% RH via ASTM E96 procedure B), and a liquid water transmission rate from about 1 to about 28 grams/100 in.sup.2/24 hr., via Cobb ring per ASTM D5795.
[0114] Turning now to FIGS. **5**A-**5**G, a sheathing system for externally enveloping at least a portion of a building structure, according to another exemplary embodiment, is disclosed. The sheathing system is a panel **500** that comprises at least three distinct layers. At a high level, the panel **500** comprises the panel **400** of FIGS. **4**A-**4**E with the addition of a second structural layer **506**. Thus, the panel **500** comprises a first structural layer **502**, an insulation layer **504**, and a second structural layer **506** (i.e., a “3-layer sheathing system”). Accordingly, the panel **500** and each of the first structural layer **502** and the insulation layer **504** can have any one or more

characteristics of the panel **400**, the structural layer **402**, and the insulation layer **404**, respectively, as described in relation to FIGS. **4**A-**4**E. Additionally, the second structural layer **506** can have any one or more characteristics of the structural layer **402**, as described in relation to FIGS. **4**A-**4**E (see FIGS. 5F-5G). Alternatively, the second structural layer **506** can have any one or more characteristics of the sheathing material layer **442**, as described in relation to FIGS. **4**A-**4**E (see FIGS. 5D-5E). The arrow **510** in FIG. 5B shows the panel **500** oriented in an installation direction (i.e., facing a frame of a building structure, such as a wall or roof).

[0115] The inclusion of both a first structural layer **502** and a second structural layer **506** can be advantageous as it provides weather resistance to both sides of the insulation layer **504**. Additionally, the first structural layer **502** and the second structural layer **506** can provide improved racking resistance over a single structural layer. Other design and structural requirements for a particular intended use can make it advantageous to have a second structural layer rather than a single structural layer.

[0116] As shown in FIG. 5C, the first structural layer **502** comprises a second surface **515** and a first surface **514** opposite the second surface **515**. A thickness of the first structural layer **502** can be measured as a distance from the first surface **514** to the second surface **515**. The insulation layer **504** comprises a fourth surface **517** and a third surface **516** opposite the fourth surface **517**. A thickness of the insulation layer **504** can be measured as a distance from the third surface **516** to the fourth surface **517**. The second structural layer **506** comprises a sixth surface **519** and a fifth surface **518** opposite the sixth surface **519**. A thickness of the second structural layer **506** can be measured as a distance from the fifth surface **518** to the sixth surface **519**.

[0117] The panel **500** is formed by coupling the second surface **515** of the first structural layer **502** to the third surface **516** of the insulation layer **504**. Additionally, the fourth surface **517** of the insulation layer **504** is coupled to the fifth surface **518** of the second structural layer **506**. More specifically, the first structural layer **502** can be coupled to the insulation layer **504** by bonding, adhering, applying, or mechanically fastening one layer to the other. Additionally, the second structural layer **506** can be coupled to the insulation layer **504** by bonding, adhering, applying, or mechanically fastening one of the layers to the other. By way of example, the panel **500** can be formed by applying a glue layer or adhesive to the second surface **515** of the first structural layer **502** or the third surface **516** of the insulation layer **504** and adhering one surface to the other. By way of further example, the panel **500** can be formed by applying a glue layer or adhesive to the fourth surface **517** of the insulation layer **504** or the fifth surface **518** of the second structural layer **506** and adhering one surface to the other.

[0118] Continuing with FIGS. 5D-5G, one arrangement for coupling the panel **500** of the sheathing system to a building frame structure **540** is illustrated. In particular, the 3-layer system is intended to be installed directly on the building frame structure **540** (e.g., studs).

[0119] The configuration shown in FIGS. **5**D-5G contemplates that the panel **500** has the second structural layer **506** adjacent the building frame structure **540** (i.e., to be placed in direct contact with the frame **540**). In some embodiments, the panel **500** has the first structural layer **502** adjacent the building frame structure **540**, which merely involves flipping the panel over prior to installing it to the frame structure **540**. The panel **500** can be installed on or otherwise secured to the building frame structure **540** by use of a suitable number of fasteners **544**. The fastener **544** can comprise any variety of fastener, such as a nail, screw, bolt, adhesive, anchor, rail molding, cleat, magnet, pegboard, suction, hook and loop, or any other suitable fastener generally known in the art. In general, the fasteners **544** extend through the first structural layer **502**, the insulation layer **504**, the second structural layer **506**, and into the frame structure **540** (e.g., wall studs), as shown in FIGS. **5**E and **5**G. As described herein, it is preferable that the panel **500** provides resistance to withdrawal of the fastener **544** from the panel **500**.

[0120] In one embodiment, the distance from an exterior-facing or outer surface of the first structural layer **502** to an inner-facing or inner surface of the second structural layer **506** that is adjacent the frame structure **540** (i.e., the thickness P.sub.t of panel **500**) is 1 inch or less, with the panel **500** having an R-value of 5 or greater. In another embodiment, the thickness P.sub.t of the panel **500** is 1.5 inches or less, with the panel **500** having an R-value of 7.5 or greater. In yet another embodiment, the thickness P.sub.t of the panel **500** is no greater than 2 inches.

[0121] As discussed in regard to other aspects described herein, the ratio of thickness of the first structural layer **502** and the second structural layer **506** relative to the thickness of insulation layer **504** can vary based on an intended use of the disclosed sheathing system. For example, when greater structural strength is desired, such as in areas prone to high winds or seismic forces, the combined thickness of the first structural layer **502** and the second structural layer **506** can increase as a proportion of the overall thickness of the panel **500**, or the thickness as measured from the first surface **514** to the sixth surface **519**. In a further example, when greater insulation is desired and strength can be sacrificed, such as in less temperate climates, the insulation layer **504** can be a greater proportion of the overall thickness. In a preferred arrangement, the ratio of insulation layer **504** thickness relative to the combined thickness of the first structural layer **502** and the second structural layer **506** can be about 3:1. In an embodiment, the panel **500** can have a ratio of insulation layer **504** thickness relative to a combined thickness of the first structural layer **502** and the second structural layer **506** of about 3:1 and an overall thickness of 1 inch. This embodiment would have a combined thickness of the first structural layer **502** and the second structural layer **506** of ¼ inch and a thickness of the insulation layer **504** of ¾ inch. In some other embodiments, the ratio of insulation layer **504** thickness relative to a combined thickness of the first structural layer **502** and the second structural layer **506** can be 6:1, 5:1, 4:1, 2:1, 1.5:1, or 1:1, by way of non-limiting examples. Additional ratios can be contemplated.

[0122] The purpose of the first structural layer **502** and the second structural layer **506** is to provide rigidity and structural support to the envelope of a building structure. Additionally, the material used for the first structural layer **502** and the second structural layer **506** can provide for other physical properties based on the intended use. For example, according to one or more design constraints, the panel **500** can be spaced to have a particular external texture, weight, or other physical property. For example, in one embodiment, the sheathing system employing the panel **500** can require superior racking resistance due to high seismic activity. Additionally, the panel **500** can require a particular texture, nail withdrawal force, or other physical properties to aid in the building envelope. Accordingly, the first structural layer **502** and the second structural layer **506** can be comprised of any one or more materials that resist racking forces, are lightweight, have one or more textures, resist nail withdrawal, or provide other desired physical properties. In one embodiment, both the first structural layer **502** and the second structural layer **506** can comprise the same material, as illustrated in FIGS. **5**F-**5**G. In an alternative embodiment, if different physical properties are desired for the first structural layer **502** and the second structural layer **506**, they can each be formed from different materials, as illustrated in FIGS. **5**D-**5**E.

[0123] In the exemplary embodiment shown in FIGS. **5**D-**5**E, the first structural layer **502** is formed of polycarbonate and the second structural layer **506** is a layer of OSB or similar wood composite material. In the exemplary embodiment shown in FIGS. **5**F-**5**G, the first structural layer **502** and the second structural layer **506** are both formed of polycarbonate.

[0124] As described above, the first structural layer **502** and the second structural layer **506** can have differing physical requirements and thus can have differing thicknesses. In one example, the first structural layer **502** can be exposed to external impact forces and can require a thicker material to resist such an impact. Alternatively, the second structural layer **506** may not require such impact resistance and can thus be thinner than the first structural layer **502**. As such, the first structural layer **502** can have a thickness in the range of 1/64 inch to 1 inch. The second structural layer **506** can have a thickness in the range of 1/64 inch to 1 inch. The insulation layer **504** can have a thickness in the range of ¼ inch to 1½ inches. The combined thickness of the first structural layer **502**, the insulation layer **504**, and the second structural layer **506** can be in the range of about ½ inch to about 2½ inches. In an exemplary configuration, the thickness of the first structural layer **502**, the insulation layer **504**, and the second structural layer **506** is equal to or less than 1 inch, having an R-value of 5 or greater. Furthermore, alternative embodiments have an R-value-to-thickness ratio of at least 5, such as resulting from a 2-inch system with an R-value of 10.

[0125] The exemplary embodiments of the 2-layer sheathing systems and the 3-layer sheathing systems described herein are generally summarized in Table 1.

TABLE-US-00001 TABLE 1 First Layer FL Second Layer SL Third Layer TL # (FL) Thickness (SL) Thickness (TL) Thickness 1 Polycarbonate 1/32 in.- XPS Foam ½ in.- None None ⅛ in. 2 in. 2 Polycarbonate 1/32 in.- XPS Foam ½ in.- OSB ¼ in.- ⅛ in. 2 in. 1⅛ in. 3 Polycarbonate 1/32 in.- XPS Foam ½ in.- Polycarbonate 1/32 in.- ⅛ in. 2 in. ⅛ in.

[0126] The ASTM E72 ultimate shear strength (plf) values for these exemplary embodiments are summarized in Table 2.

TABLE-US-00002 TABLE 2 # Ultimate Shear Strength (pounds per linear foot) 1 N/A 2 >500 3 500-1,000

[0127] The ASTM E72 ultimate shear deflection (in) values for these exemplary embodiments are summarized in Table 3.

TABLE-US-00003 TABLE 3 # Ultimate Shear Deflection (inches) 1 N/A 2 <4 3 <4

[0128] The ASTM D1761 nail retention (lbf) values for these exemplary embodiments are summarized in Table 4.

TABLE-US-00004 TABLE 4 # Nail Retention (pound of force) 1 30-200 2 30-200 3 30-400

[0129] An alternative embodiment of the panel **400** (of the 2-layer system shown in FIGS. **4**A-**4**E) is illustrated in FIG. **6**. As shown in the top-down view of FIG. **6**, the modified panel **450** includes a plurality of drainage channels or grooves formed in the insulation layer **404** to prevent moisture buildup. The plurality of drainage grooves **456** can be recessed within (or extend from) the insulation layer **404**. The offset or recess distance formed by the drainage grooves **456** is depicted by a distance **460** that extends from a recess surface **466** to the outer surface **417** of the insulation layer **404**. The distance **460** being in the range of 0.01 inch to 0.1 inch. In this exemplary embodiment, a thickness P.sub.t of the panel **450**, as measured from the outer structural surface **414** to the outer insulation surface **417**, is in the range of about 1 inch to about 2 inches.

[0130] The drainage grooves **456** are designed on the surface of the panel **450** such that gravity allows for the drainage of water from the sheathing system. The drainage grooves **456** create pathways that guide water away from the panel **450** and away from the building envelope. The panel **450** can comprise a series of drainage grooves **456** arranged vertically such that as water or moisture encounters the drainage grooves **456**, gravity pulls the water down and away from the building envelope. In one embodiment, drainage grooves **456** can take the form of a square groove as depicted in FIG. **6**. In other embodiments, drainage grooves **456** are V-shaped grooves, rectangular grooves, or curved grooves. Additional shapes can be contemplated for use as the drainage grooves **456**.

[0131] Similarly, an alternative embodiment of the panel **500** (of the 3-layer system shown in FIGS. **5**A-**5**G) is illustrated in FIG. **7**. As shown in the top-down view of FIG. **7**, the modified panel **550** includes a plurality of drainage channels or grooves formed in the second structural layer **506** to prevent moisture buildup. The plurality of drainage grooves **558** can be recessed within (or extend from) the second structural layer **506**. The offset or recess distance formed by the drainage grooves **558** is depicted by a distance **560** that extends from a recess surface **566** to the outer surface **519** of the second structural layer **506**. The distance **560** being in the range of 0.01 inch to 0.1 inch. In some embodiments, a thickness P.sub.t of the panel **550**, as measured from the first outer structural surface **514** to the second outer structural surface **519**, is in the range of about 1 inch to about 2 inches. In one exemplary embodiment, the thickness P.sub.t of the panel **550** is 1 inch or less. In some embodiments, the number of drainage grooves **558** per foot of the panel **550** can be in the range of 1 drainage groove per foot to 12 drainage grooves per foot.

[0132] The drainage grooves **558** are designed on the surface of the panel **550** such that gravity allows for the drainage of water from the sheathing system. The drainage grooves **558** create pathways that guide water away from the panel **550** and away from the building envelope. The panel **550** can comprise a series of drainage grooves **558** arranged vertically such that as water or moisture encounters the drainage grooves **558**, gravity pulls the water down and away from the building envelope. In one embodiment, drainage grooves **558** can take the form of a square groove as depicted in FIG. **7**. In other embodiments, drainage grooves **558** are V-shaped grooves, rectangular grooves, or curved grooves. Additional shapes can be contemplated for use as the drainage grooves **558**.
[0133] Another alternative embodiment of the panel **500** (of the 3-layer system shown in FIGS. **5**A-**5**G) is illustrated in FIG. **8**. As shown in the top-down view of FIG. **8**, the modified panel **570** comprises the first structural layer **502**, the insulation layer **504**, and the second structural layer **506**, wherein a plurality of drainage channels or grooves are formed in the insulation layer **504** to prevent moisture buildup. The drainage grooves **578** allow moisture to flow between the second structural layer **506** and the insulation layer **504**.
[0134] The drainage grooves **578** extend through the panel **570** such that gravity allows for the drainage of water from the sheathing system. The drainage grooves **578** create pathways that guide water through and away from the panel **570** and away from the building envelope. In one embodiment, drainage grooves **578** can take the form of a square groove as depicted in FIG. **8**. In other embodiments, drainage grooves **578** are V-shaped grooves, rectangular grooves, or curved grooves. Additional shapes can be contemplated for use as the drainage grooves **578**.
[0135] Another alternative embodiment of the panel **500** (of the 3-layer system shown in FIGS. **5**A-**5**G) is illustrated in FIG. **9**. As shown in the top-down view of FIG. **9**, the modified panel **590** comprises the first structural layer **502**, the insulation layer **504**, and the second structural layer **506**, wherein a plurality of drainage channels or grooves are formed in the outer surface of the second structural layer **506** to prevent moisture buildup.
[0136] The drainage grooves **598** provide a varied cross section with non-perpendicular surfaces. The pattern of the drainage grooves **598** are designed to improve flow of moisture next to the panel **590** for eventual extraction from the sheathing system altogether. As part of the sheathing system, the drainage grooves **598** allow gravity to cause the drainage of water from the sheathing system. The drainage grooves **598** create pathways that guide water away from the panel **590** and away from the building envelope.
[0137] As shown in FIGS. **6-9**, the drainage grooves **456**, **558**, **578**, **598** can be vertical in orientation such that water flows directly down. Alternatively, the drainage grooves **456**, **558**, **578**, **598** may be oriented in a horizontal arrangement or parallel to the ground when the sheathing system (e.g., panels **450**, **550**, **570**, **590**) is installed. In other embodiments, the drainage grooves **456**, **558**, **578**, **598** can be oriented in a diagonal arrangement, a radial arrangement, or a serpentine arrangement.
[0138] Alternative embodiments for coupling a first structural layer **1002**, an insulation layer **1006**, and a second structural layer **1004** are depicted in FIGS. **10**A-**10**B. With specific reference to FIG. **10**A, a perspective view of a sheathing system panel **1000** is shown, which comprises the first structural layer **1002**, the second structural layer **1004**, the insulation layer **1006**, and one or more rods **1008**. The illustration of FIG. **10**A has a cutout portion of the first structural layer **1002** exposing the rods **1008** for purposes of illustration only. In one embodiment, the rods **1008** extend from the first structural layer **1002** through the insulation layer **1006** to the second structural layer **1004**. In some aspects, the rods **1008** can take the form of a cylinder, a plane, a prism, a bar, or other shape that can connect the first structural layer **1002** and the second structural layer **1004** together.
[0139] Turning now to FIG. **10**B, FIG. **10**B depicts a cross section of the panel **1000** that incorporates the rods **1008** to connect the first structural layer **1002** and the second structural layer

1004. The rods **1008** in the panel **1000** can be made of high-strength and heat-resistant polymers. Various polymer materials can be utilized for the rods, depending on the specific requirements of the sheathing system panel **1000**. For instance, engineering thermoplastics, such as nylon (e.g., nylon 6 or nylon 6/6), polypropylene, polycarbonate, or polyethylene terephthalate (PET) can be suitable options for the rods **1008**.

[0140] In an additional embodiment, to fuse the panel **1000** together, a melting process can be used to secure the rods **1008** to the first structural layer **1002** and the second structural layer **1004**. Additionally, the rods **1008** can comprise thermoplastic materials, wherein rods **1008** can be softened and fused during the assembly process. The melting process or a fusing process can involve the application of heat to the rods **1008**, causing them to soften and melt slightly. The rods **1008** can penetrate the first structural layer **1002**, the second structural layer **1004**, and the insulation layer **1006**, filling any gaps or voids between them. As the molten rods **1008** cool and solidify, they create a strong bond and form a fused connection, permanently securing the first structural layer **1002** and the second structural layer **1004** together at ends **1012** and **1014**.

[0141] In some embodiments, a melting process can be achieved through various methods. One approach is to use heated metal plates or heated molds that are pressed against the first structural layer **1002** and the second structural layer **1004**. The heat from the plates or molds transfers to the rods **1008** at ends **1012** and **1014**, causing them to melt and fuse with the first structural layer **1002** and the second structural layer **1004**. Alternatively, localized heat sources, such as hot air or infrared heating, can be directed at specific areas where the rods **1008** are inserted, enabling selective melting and fusion.

[0142] In other embodiments, the sheathing system panel **1000** can comprise rods **1008** made of metal, which provide a robust and durable solution for connecting the first structural layer **1002**, the second structural layer **1004**, and the insulation layer **1006**. Metal rods offer high strength, rigidity, and resistance to various environmental conditions. Metals utilized for this purpose include stainless steel, aluminum, or steel alloys.

[0143] In some other embodiments, the rods **1008** can have various diameters and lengths to accommodate different panel sizes and design requirements. The ends **1012** and **1014** of the rods **1008** can be threaded, allowing them to be easily inserted and securely fastened to the structural layers. Alternatively, the rods **1008** can be designed with enlarged heads or flanges that mechanically lock into the outer surfaces of the layers, providing a secure connection without the need for additional fasteners.

[0144] In an additional embodiment, the rods **1008** can have a flanged or enlarged portion on the ends **1014** such that the rods **1008** hold the insulation layer **1006** to the second structural layer **1004**. The rods **1008** can then be connected to the first structural layer **1002** and the second structural layer **1004** by means of melting, fusing, or other means.

[0145] Another alternative construction for a sheathing system panel **1100** is shown in FIGS. **11**A-**11**B. The panel **1100** comprises a first structural layer **1102**, a second structural layer **1104**, and a support layer **1106**. The first structural layer **1102** and the second structural layer **1104** may have any of the characteristics of the structural layers described herein for other sheathing system panel embodiments. Accordingly, for the sake of brevity, a detailed description of the first structural layer **1102** and the second structural layer **1104** will not be repeated with respect to the sheathing system panel **1100** illustrated in FIGS. **11**A-**11**B.

[0146] Between the first structural layer **1102** and the second structural layer **1104** is support layer **1106**. The support layer **1106** comprises a series of walls or structures that separate the first structural layer **1102** and the second structural layer **1104**. As shown in FIG. **11**A, the support layer **1106** can have a series of walls that extend perpendicular from the first structural layer **1102** to the second structural layer **1104**. The support layer **1106** creates elongated hexagonal spaces or void portions that extend from the first structural layer **1102** to the second structural layer **1104**, such as insulation void portion **1108**. As an example, the support layer **1106** comprises walls that extend from the first structural layer **1102** to the second structural layer **1104** creating insulation void portion **1108**. The insulation void portion **1108**, as shown in FIG. **11**A can be oriented such as to extend from the first structural layer **1102** and the second structural layer **1104**. In another embodiment, as shown in FIG. **11**B, the support layer **1106** can have a series of structures that extend from the first structural layer **1102** to the second structural layer **1104**. The support layer **1106** creates elongated hexagonal spaces or void portions that are parallel with the first structural layer **1102** and the second structural layer **1104**, such as insulation void portion **1108**. The insulation void portion **1108**, as shown in FIG. **11**B can be oriented parallel to the first structural layer **1102** and the second structural layer **1104**.

[0147] The support layer **1106** can be comprised of any material that may be used or formed into a wall or support structure. For example, the support layer **1106** can be comprised of polycarbonate, polyurethane, metal, wood, or any other structurally supportive material, as required by the intended use of the support layer **1106**.

[0148] The insulation void portion **1108** refers to the space or cavity created by the support layer **1106** of the panel **1100**. The insulation void portion **1108** can be filled with insulation material to ensure that the insulation material is properly contained within the panel. In some embodiments, the insulation material can comprise various insulating substances such as foam, fiberglass, or polymer-based insulation. The insulation void portion **1108** can be filled using spray foam, polyisocyanurate, EPS, recycled XPS, XPS, or other insulation materials. These materials can be sprayed, poured, or stuffed into the insulation void portion **1108**. As can be seen in FIG. **11**A, with the insulation void portion **1108** perpendicular to the first structural layer **1102** and the second structural layer **1104**, the insulation void portion **1108** can be filled when one or more of the structural layers is not secured to the sheathing system **1100**. However, as can be seen in FIG. **11**B, having the insulation void portion **1108** parallel to the first structural layer **1102** and the second structural layer **1104**, the insulation void portion **1108** can be filled when the sheathing system panel **1100** is completely assembled.

[0149] In some embodiments, the support layer **1106** in the panel **1100** can be designed with a honeycomb pattern, creating a series of interconnected, hexagonal-shaped cells or chambers that form a regular and uniform structure throughout the support layer. A plurality of hexagonal cells or chambers created by the support layer **1106** produces a network of interconnected walls that distribute applied loads and stresses evenly across the panel **1100**, improving its structural integrity. As shown in FIG. **11**A, the hexagonal cells or insulation void portion **1108** can be oriented such that the openings of the insulation void portion **1108** are adjacent to or facing the first structural layer **1102** and the second structural layer **1104**. Additionally, as shown in FIG. **11**B, the hexagonal cells or insulation void portion **1108** can be oriented such that the openings of the insulation void portion **1108** are parallel to the first structural layer **1102** and the second structural layer **1104**.

[0150] In addition to the honeycomb pattern, in is contemplated that various other patterns can be employed in the support layer **1106** of the sheathing system panel **1100**. These patterns offer different structural characteristics and can be selected based on specific design requirements and desired performance attributes. Other patterns can include, for instance: a square grid pattern with a series of interconnected square cells that form a grid-like structure; a triangular truss pattern that consists of interconnected triangular cells that create a truss-like framework; a diamond pattern that features interconnected diamond-shaped cells that form a repeating pattern; or a hexagonal grid pattern that, similar to the honeycomb pattern, consists of interconnected hexagonal cells. However, unlike the honeycomb pattern, the hexagonal grid does not form a continuous network of cells but rather a grid-like arrangement. In another embodiment, the support layer **1106** may include a random pattern that is a non-repetitive arrangement of cells or voids. The support layer can be designed with varying sizes and shapes of voids, providing flexibility in material distribution and load-bearing capabilities.

[0151] The use of polycarbonate as at least one structural layer in an insulated sheathing system panel gives the panel an ability to resist nail withdrawal at a reduced thickness and/or weight, without sacrificing thermal or structural performance.

[0152] For example, as shown in the graph **1200** of FIG. **12**, two inventive panels (I1, I2) were compared to three conventional control panels (C1, C2, C3). I1 is a 3-layer sheathing panel comprising a first structural layer of ¼ inch thick OSB, an insulation layer of ¾ inch thick XPS, and a second structural layer of 1/16 inch thick polycarbonate. I2 is a 3-layer sheathing panel comprising a first structural layer of ¼ inch thick OSB, an insulation layer of ¾ inch thick XPS, and a second structural layer of 1/32 inch thick polycarbonate. C1 is a 2-layer sheathing panel comprising a structural layer of 7/16 inch thick OSB and an insulation layer of ¾ inch thick XPS (see FIGS. **1**A-**1**B). C2 is a 2-layer sheathing panel comprising a non-structural layer of ¼ inch thick OSB and an insulation layer of ¾ inch thick XPS (see FIGS. **2**A-**2**B). C3 is a 3-layer sheathing panel comprising a structural layer of 7/16 inch thick OSB, an insulation layer of 1 inch thick polyiso, and a non-structural, paper-thin (i.e., much less than 1/16 inch thick) layer of material that is bulk water resistant and water vapor permeable (see FIGS. **3**A-**3**B). I1, I2, C1, and C3 are considered structural panels, while C2 is not considered a structural panel (i.e., since ¼ inch OSB is not rated as a structural sheathing material by the American Plywood Association (APA) because it does not provide enough racking shear resistance per the IRC 2021 recommendation).

[0153] The weight and thickness of each of the evaluated panels is presented in Table 5.

TABLE-US-00005 TABLE 5

#	Weight (lbs)	Thickness (in)
I1	42	1.06
I2	38	1.03
C1	56	1.2
C2	30	1
C3	60	1.5

As can be seen in Table 5, amongst the structural panels (I1, I2, C1, and C3), the inventive panels I1 and I2 have the lowest weights and thicknesses.

[0154] Furthermore, as shown in the graph **1200**, the inventive panels I1 and I2 have better resistance to deflection than the conventional panels C1, C2, and C3. Additionally, the inventive panel I1 has better racking strength than the conventional panels C1, C2, and C3, while the inventive panel I2 has better racking strength than the conventional panels C2 and C3.

[0155] In addition to the racking strength and the maximum deflection, the nail retention (i.e., the amount of force necessary to overcome the panel resistance to nail removal and the amount of force necessary to hold siding securely if fasteners are not nailed on the studs) was measured for each of the panels. The measurements of the panels are summarized in Table 6.

TABLE-US-00006 TABLE 6

#	Racking (plf)	Max Deflection (in)	Nail Retention (lb)
I1	547	1.8752	120
I2	432	1.4397	60
C1	477	3.4945	60
C2	347	3.1739	20
C3	388	3.7245	60

Racking strength, maximum deflection, and nail retention provide a metric for assessing short-term performance of a sheathing system panel. Here, the inventive panel I1 exhibited significantly improved nail retention performance compared to the conventional panels C1, C2, and C3. The inventive panel I2 demonstrated comparable nail retention performance to the conventional structural panels C1 and C3, notwithstanding that it was the thinnest and lightest of the structural panels (i.e., I1, I2, C1, and C3).

[0156] To assess long term performance of the sheathing system panels, nailing torque force (lb) was measured. The nailing torque force is the force applied vertically on the plane of the panel that is perpendicular to the nail. The force is measured by applying a compressive force that is perpendicular to the nail. The force is measured when the displacement of the panel reaches ½ inch. This proprietary test is based on ASTM D1037, section 13. The measurements of the panels are summarized in Table 7.

TABLE-US-00007 TABLE 7

#	Nailing Torque Force (lb)
I1	334.3
I2	270.9
C1	277.5
C2	206.3
C3	240.5

Again, the inventive panel I1 exhibited significantly improved nailing torque force performance compared to the conventional panels C1, C2, and C3. The inventive panel I2 demonstrated comparable nailing torque force performance to the conventional structural panels C1 and C3, notwithstanding that it was the thinnest and lightest of the structural panels (i.e., I1, I2, C1, and

C3).
[0157] As another indicator of long term performance, the panels (i.e., I1, I2, C1, C2, and C3) were assessed for long term sagging properties. This test involved taking 4 ft×4 ft samples of the panels and affixing them to a mock wooden frame (i.e., SPF No. 2 type stud) using 16d 2.5 inch nails. Three samples were measured for each panel. A linear actuator was used to apply a force to each sample necessary to achieve 0.5 inch displacement of the sample. A larger displacement was avoided, as it would begin to overlap with the sample's nail retention property. The applied force is intended to simulate the sagging force needed to deform the panel. The measurements of the panels are summarized in Table 8.
TABLE-US-00008 TABLE 8 # Nailing Torque Force (lb) I1 ~334 I2 ~271 C1 ~278 C2 ~206 C3 ~241
Again, the inventive panel I1 exhibited improved sagging resistance performance compared to the conventional panels C1 and C2. The inventive panel I2 demonstrated sagging resistance performance comparable to the C1 panel and better than the C2 panel, notwithstanding that it was the thinnest and lightest of the panels (i.e., I1, I2, C1, and C2).
[0158] In addition to establishing that inclusion of a polycarbonate layer in a multi-layer sheathing panel can result in a lighter and/or thinner sheathing system that has improved or at least comparable performance to conventional sheathing systems, the impact of the location of the polycarbonate layer in the panel was also explored.
[0159] In particular, in the context of an extended plate and beam (EP&B) wall system, two different embodiments of an inventive 3-layer sheathing panel were evaluated against a conventional (control) 2-layer sheathing panel sheathing panel. The assessed panels are summarized in Table 9.
TABLE-US-00009 TABLE 9 Middle Outer Racking Deflection # Inner Layer Layer Layer (plf) (in) EP&B-1 1/16″ 2″ foam 7/16″ 600-800 1.8-3 polycarbonate OSB (662) (2.5) EP&B-2 2″ foam 1/16″ 7/16″ 500-700 1.8-3 polycarbonate OSB (585) (2.7) EP&B- 2″ foam N/A 7/16″ 300-500 1.3-2 Control OSB (310) (1.6)
From Table 9, it can be seen that all three panels include the same 2-inch foam insulation layer and the same 7/16-inch OSB structural layer. However, the EP&B-Control panel does not include any polycarbonate layer. The EP&B-Control panel is similar to the panel **100** shown in FIGS. **1**A-**1**B. Both the EP&B-1 and EP&B-2 panels include a 1/16-inch polycarbonate structural layer, although the polycarbonate layer is the innermost layer in the EP&B-1 panel and the polycarbonate layer is the middle layer in the EP&B-2 panel.
[0160] In particular, as shown in FIG. **13**A, the EP&B-1 panel **1300** includes an outer layer **1302** of OSB, a middle layer **1304** of foam insulation, and an inner layer **1306** of polycarbonate. As shown in FIG. **13**B, the EP&B-2 panel **1320** includes an outer layer **1302** of OSB, a middle layer **1304** of polycarbonate, and an inner layer **1306** of foam insulation. In FIGS. **13**A-**13**B, both panels **1300**, **1320** are shown installed on the frame **1310** of an EP&B wall system.
[0161] Table 9 also includes the expected ranges of values for the racking strength and the maximum deflection of the panels. The actual measured values of the panels are plotted in the graph **1400** of FIG. **14**. As shown in the graph **1400**, for a minimum recommended racking strength of 500 plf, the 2-layer panel (EP&B-Control) lacking any polycarbonate layer failed to reach the recommended racking strength, while both the inventive panels (EP&B-1 and EP&B-2) containing a layer of polycarbonate exceeded the recommended racking strength. In other words, it was surprisingly found that inclusion of a relatively thin (e.g., about 1/16 inch) layer of polycarbonate could substantially improve the racking performance of an otherwise identical 2-layer panel.
[0162] The inventive concepts have been described above both generically and with regard to various exemplary embodiments. Although the general inventive concepts have been set forth in what is believed to be exemplary illustrative embodiments, a wide variety of alternatives known to those of skill in the art can be selected within the disclosure.

[0163] While specific elements and steps are discussed in connection to one another, it is understood that any element and/or steps provided herein is contemplated as being combinable with any other elements and/or steps regardless of explicit provision of the same while still being within the scope provided herein. Since many possible embodiments can be made of the disclosure without departing from the scope thereof, it is to be understood that all matter herein set forth or shown in the accompanying drawings is to be interpreted as illustrative and not in a limiting sense.

Claims

1. A panel for use as a sheathing material for a building, the panel consisting of: a first structural layer; a second structural layer; an insulation layer; and an adhesive, wherein the first structural layer comprises a first polymeric material, wherein a thickness of the first structural layer is in the range of 1/32 inch to ⅛ inch, wherein a thickness of the insulation layer is in the range of ½ inch to 2 inches 4 inches, wherein the insulation layer is positioned between the first structural layer and the second structural layer, and wherein the insulation layer is bonded to the first structural layer and the second structural layer by the adhesive.
2. The panel of claim 1, wherein the first polymeric material comprises at least one of polycarbonate, polyester, polypropylene, polymethyl methacrylate, polyvinyl chloride, polyethylene, high density polyethylene, and acrylonitrile butadiene styrene (ABS), and combinations thereof.
3. The panel of claim 1, wherein the first structural layer comprises polycarbonate.
4. The panel of claim 1, wherein the first structural layer further comprises one or more filler materials.
5. The panel of claim 1, wherein the insulation layer comprises at least one of extruded polystyrene, expanded polystyrene, foamed polyurethane, polyisocyanurate, fiberglass, mineral wool, polyethylene terephthalate, polyester, phenolic foam, aerogel blanket, aerogel board, and polyurethane.
6. The panel of claim 1, wherein the insulation layer comprises extruded polystyrene.
7-10. (canceled)
11. The panel of claim 1, wherein the second structural layer comprises a second polymeric material, and wherein a thickness of the second structural layer is in the range of 1/32 inch to ⅛ inch.
12. The panel of claim 11, wherein the second polymeric material comprises at least one of polycarbonate, polyester, polypropylene, polymethyl methacrylate, polyvinyl chloride, polyethylene, high density polyethylene, and acrylonitrile butadiene styrene (ABS), and combinations thereof.
13. The panel of claim 11, wherein the second structural layer comprises polycarbonate.
14. The panel of claim 11, wherein the panel has an ultimate shear strength according to ASTM E72 of at least 250 plf.
15. The panel of claim 11, wherein the panel has an ultimate shear deflection according to ASTM E72 of less than 4 inches.
16. The panel of claim 11, wherein the panel has a nail retention according to ASTM D1761 in the range of 30 pounds to 200 pounds.
17. The panel of claim 1, wherein a thickness of the panel is less than or equal to 1.5 inches and an R-value of the panel is at least 4.5.
18. The panel of claim 1, wherein a weight of the panel is in the range of 10 pounds to 45 pounds.
19. The panel of claim 1, wherein the second structural layer comprises a wood composite material, and wherein a thickness of the second structural layer is in the range of ¼ inch to 1⅛ inches.
20. The panel of claim 19, wherein the wood composite material comprises at least one of oriented strand board, fiberboard, and plywood.

21-22. (canceled)
23. The panel of claim 1, wherein a thickness of the insulation layer is in the range of ½ inch to 2 inches.