(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
16 July 2020 (16.07.2020)

WIPO | PCT

(10) International Publication Number
WO 2020/146767 A1

(51) International Patent Classification:
A47C 7/74 (2006.01) *F25B 21/04* (2006.01) *B60N 2/56* (2006.01) *F28D 20/02* (2006.01) *C09K 5/06* (2006.01)

(21) International Application Number: PCT/US2020/013141

(22) International Filing Date: 10 January 2020 (10.01.2020)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/791,299 11 January 2019 (11.01.2019) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report (Art. 21(3))*
— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

WO 2020/146767 A1

(54) Title: COMPOSITE COATINGS CONTAINING PHASE CHANGE MATERIALS

(57) Abstract: Methods and formulations for use of phase change materials (PCMs) as coatings or integrated with building materials are disclosed. A formulation comprises an amount of phase change material, for example a mass fraction of about 0.01 to about 0.50. The PCM materials may be applied as a surface treatment such as paint, for example in order to provide improved thermal regulation to a building or a portion thereof.

TITLE: COMPOSITE COATINGS CONTAINING PHASE CHANGE MATERIALS

FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

This invention was made with government support under contract No. 1130028 awarded by the National Science Foundation. The government has certain rights in the invention.

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a non-provisional of, and claims priority to, U.S. Provisional Application No. 62/791,299 filed January 11, 2019 and entitled "COMPOSITE COATINGS CONTAINING PHASE CHANGE MATERIALS." The foregoing application is hereby incorporated by reference in its entirety.

TECHNICAL FIELD

The present disclosure relates to phase change materials (PCMs), and in particular to PCMs incorporated into base coating materials for use in building construction practices.

BACKGROUND

The prospect of PCMs incorporated into base coating materials as a legitimate alternative to traditional base coating materials shows promise of many advantages including energy savings, reducing heating, ventilation and air conditioning (HVAC) loads, increasing thermal mass, reducing internal temperature fluctuations, and enabling a more desirable thermal environment. Accordingly, improved base coating materials, systems, and methods are desirable.

SUMMARY

Formulations, systems, and methods for PCM-composite coatings are disclosed herein. In an exemplary embodiment, a formulation for phase change material (PCM)-composite coating comprising an amount of phase change material having a mass fraction range of about 0.01 to about 0.50 comprises organic material, inorganic material, microencapsulated PCM, and bulk PCM.

In another exemplary embodiment, a system for determining a thermal performance of a formulation for PCM-composite coating comprises a temperature-controlled environmental chamber; an interior wall envelope element; a data acquisition unit; and a plurality of wall layers.

In another exemplary embodiment a method for treating a building surface with PCM comprises selecting the building surface to be treated; determining, for the building surface: (i) an amount of PCM to utilize per unit area, and (ii) a ratio of PCM to at least one other component of a treatment material; mixing the PCM with the at least one other component to form the treatment material; and applying the treatment material to the building surface to modify at least one thermal characteristic of the building surface.

The contents of this summary section are intended as a simplified introduction to the disclosure and are not intended to be used to limit the scope of any claim.

BRIEF DESCRIPTION OF THE DRAWINGS

With reference to the following description and accompanying drawings:

FIG. 1 illustrates an exemplary interior and exterior layered wall section incorporating PCMs in accordance with various exemplary embodiments;

FIG. 2 illustrates a PCM-composite coating with dispersed PCM throughout the base material in accordance with various exemplary embodiments;

FIG. 3 illustrates a schematic of a layered wall system within an interior chamber simulating the desired external environment for a specific location and time, in accordance with an exemplary embodiment;

FIGS. 4A, 4B, and 4C illustrate exemplary microencapsulated PCM powder and individual microcapsules in accordance with various embodiments;

FIG. 5 illustrates thermal performance of exemplary PCM products in accordance with various exemplary embodiments;

FIG. 6 illustrates thermal efficiency characteristics of exemplary PCM products in accordance with various exemplary embodiments;

FIG. 7A illustrates viscosity of exemplary PCM-paint mixtures in accordance with various exemplary embodiments;

FIG. 7B illustrates viscosity of exemplary PCM-plaster mixtures in accordance with various exemplary embodiments;

FIG. 7C illustrates viscosity of exemplary PCM-stucco mixtures in accordance with various exemplary embodiments;

FIG. 8 illustrates specific heat and enthalpy performance of exemplary materials in accordance with various embodiments;

FIGS. 9A, 9B, and 9C illustrate exemplary material ratios for exemplary PCM products in accordance with various exemplary embodiments;

FIGS. 10A, 10B, and 10C illustrate thermal performance of exemplary PCM products in accordance with various embodiments;

FIG. 11 illustrates thermal performance of an exemplary PCM product in accordance with various embodiments; and

FIG. 12 illustrates a method for use of a PCM product in accordance with various embodiments.

DETAILED DESCRIPTION

The following description is of various exemplary embodiments only, and is not intended to limit the scope, applicability or configuration of the present disclosure in any way. Rather, the following description is intended to provide a convenient illustration for implementing various embodiments including the best mode. As will become apparent, various changes may be made in the function and arrangement of the elements described in these embodiments without departing from principles of the present disclosure.

For the sake of brevity, traditional insulating materials for manipulating the thermal environment of a building, as well as traditional approaches for mixture proportioning of traditional coating materials, and/or the like may not be described in detail herein. It should be noted that many alternative or additional insulating materials and/or structural or coating materials may be present in a PCM-composite system, related methods, and/or products arising therefrom.

Principles of the present disclosure contemplate new PCM-composite coatings which can self-regulate and self-adapt, which allows these coatings to help manipulate and maintain a desired thermal environment for new construction and retrofit projects with existing insulation. By providing methods to mix, utilize, and apply PCM-composite coatings, exemplary embodiments disclose cost-saving, renewable energy solutions. Disclosed herein are formulations for PCM-composite coatings, including specified mass proportion ranges of each base coating material constituent and the range for the specified PCM-to-base coating material ratio. Also disclosed are various methods for preparation and use of such materials and coatings. These PCM-composite coatings are easily applicable for users and ensure that users get the aesthetic and wall covering features expected from a coating material, but also have an advanced temperature-regulating feature that is superior to traditional insulating materials.

Traditional insulating materials for manipulating the thermal environment of a building include, but are not limited to, fiberglass insulation, foam board, mineral wood, and cork. The high thermal resistance (R-value) or low thermal conductivity of these materials enables them to lower the rate at which heat may pass through them. These materials are often limited to new construction or only placed within the attics of existing buildings. Traditional coating materials, including but not limited to paint, stucco, and plaster, are typically applied to buildings only for aesthetics or wall covers. In contrast, the present disclosure contemplates PCM-composite coatings' abilities to manipulate and maintain a desired thermal environment. Besides possessing the desired features of traditional coating materials, exemplary PCM-composite coatings include a thermal energy storing component. Incorporating PCM microcapsules into the base layer (e.g., stucco, plaster, and paint) and coating building envelopes with the PCM-composite coating can increase the thermal mass of the building envelopes. Increasing the thermal mass of building envelopes can delay heat transfer rates. Further, while traditional insulating materials control the rate of heat that passes between them, the present disclosure contemplates storing heat at a desired temperature for human thermal comfort.

Exemplary base coating materials suitable for use in a formula with PCM may include stucco, plaster, and paint. However, PCM components may be included in any suitable materials and/or composite structures, as desired, in order to achieve a desired thermal effect or effects.

An exemplary PCM-composite coating includes stucco. As used herein, stucco is comprised of portland cement, fly ash, clay, lime, aggregate (lightweight silica sand), and fibers (steel, polymer, glass, and/or natural). However, it will be appreciated that any suitable variety of stucco may be utilized, as desired. As used herein, PCM is comprised of a phase change material (organic or inorganic). Further, the PCM is contained within a capsule made of a polymer material or natural material (pumice, expanded shale, expanded clay, perlite, and/or silica). An exemplary embodiment specifies the mass fraction range of stucco and water, and PCM-to-stucco ratio based on mass for the final PCM-stucco composite coating.

An exemplary embodiment includes mass fraction ranges of stucco between 0.60-0.90, water between 0.10-0.40, and PCM-to-stucco and water ratio between 0.01-0.40. Water is mixed into the stucco until a uniform consistency is achieved, and PCM is then added and mixed until a uniform consistency is achieved throughout. However, it will be appreciated that any suitable ratios may be utilized, as desired.

An additional exemplary embodiment includes incorporating PCMs into stucco at a PCM-to-stucco and water ratio of 0.14. The composite PCM-stucco coating mixture contains a stucco mass fraction of 0.70, a water mass fraction of 0.18, and a PCM mass fraction of 0.12. These mass fraction ranges achieve a similar consistency as traditional stucco. However, it will be appreciated that any suitable ratios may be utilized, as desired.

An exemplary PCM-composite coating includes plaster. As used herein, plaster is comprised of calcium sulfate, calcium carbonate, mica, and clay. However, it will be appreciated that any suitable variety of plaster may be utilized, as desired. As used herein, PCM is comprised of a phase change material (organic or inorganic). Further, the PCM is contained within a capsule made of a polymer material or natural material (pumice, expanded shale, expanded clay, perlite, and/or silica). The embodiment includes mass fraction ranges of plaster between 0.35-0.60; water between 0.40-0.65; and PCM-to-plaster and water ratio between 0.01-0.50. Water is mixed into the plaster until a uniform consistency is achieved, and PCM is then added and mixed until a uniform consistency is achieved throughout.

An additional exemplary embodiment includes incorporating PCMs into plaster at a PCM-to-plaster and water ratio of 0.41. The composite PCM-plaster coating mixture contains a plaster mass fraction of 0.32, a water mass fraction of 0.39, and a PCM mass fraction of 0.29. These mass fraction ranges achieve a similar consistency as traditional plaster. However, it will be appreciated that any suitable ratios may be utilized, as desired.

An exemplary PCM-composite coating includes paint (*e.g.*, latex-based, water-based, etc.). However, it will be appreciated that any suitable variety of paint may be utilized, as desired. As used herein, latex-based paint is comprised of binder (polymer solids), filler, pigment, and water. Further, microencapsulated PCM is comprised of a phase change material (organic or inorganic) contained within a capsule made of a polymer material. The embodiment includes mass fraction ranges of total polymer solids between 0.25-0.60; water between 0.40-0.75; and PCM-to-paint ratio between 0.01-0.40. Water is mixed into the paint until a uniform consistency is achieved, and PCM is then added and additional water is added and mixed until a uniform consistency is achieved throughout.

An additional exemplary embodiment includes incorporating PCMs into latex-based paint at an initial polymer solids fraction of 0.41 and a water fraction of 0.59. Additional water is added at a mass fraction of 0.28 and mixed into the base coating material until a uniform consistency is achieved. PCM is then added at a PCM-to-paint ratio of 0.33. This ratio incorporates PCM at a mass fraction of 0.25 into the base coating material and additional water is added at a mass fraction of 0.28 and is mixed until a uniform consistency is achieved. The total polymer solids mass fraction for the PCM-paint composite coating mix is 0.44 and the total water mass fraction is 0.56. These mass fraction ranges achieve a similar consistency as traditional latex-based paint. However, it will be appreciated that any suitable ratios may be utilized, as desired.

In a next step after preparation of the PCM-composite coatings, conventional paint and finish tools may be employed to apply the coatings to a substrate. These tools include, but are not limited to, brushes, rollers, putty/joint knives, knives, scrapers, shaver blades, electric airless sprayers, hand-held sprayers, pressure washers, and texture sprayers.

With reference now to FIGS. 1 through 12, in various exemplary embodiments, principles of the present disclosure contemplate integration of PCMs into various building components, surface treatments, and/or the like. For example, an exemplary formulation for PCM coating may comprise an amount of PCM having a mass fraction range of about 0.01 to about 0.50, the formulation comprising organic material, inorganic material, microencapsulated phase change materials, and/or bulk phase change materials, together with approaches for operation and results thereof. In one exemplary embodiment, the formulation may comprise an amount of stucco having a mass fraction range of about 0.60 to about 0.90. In another exemplary embodiment, the formulation may comprise an amount of plaster having a mass fraction range of about 0.35 to about 0.60. In another exemplary embodiment, the formulation may comprise an amount of paint having a mass fraction range of about 0.25 to about 0.60. The paint may be acrylic latex-based paint. The formulation may further comprise an amount of water having a mass fraction range of about 0.10 to about 0.75.

In one exemplary embodiment, as shown in FIG. 1, the formulation may comprise PCM-composite coating incorporated into organic material, such as a base plaster coating and a finish plaster coating. The first layer of a wall may include inorganic material, such as fiberglass insulation surrounding metal beams. Gypsum board is then affixed on the outside of the wall, and is coated with the base plaster incorporated with PCM-composite coating.

The finish plaster incorporated with PCM-composite is then coated on the outside as a final layer.

In another exemplary embodiment, also seen in FIG. 1, the formulation may comprise a PCM-composite coating incorporated into organic material, such as a base stucco coat and a finish stucco coat. The first layer of a wall may include inorganic material, such as fiberglass insulation surrounding metal beams. Foam board, oriented strand board (OSB), and/or the like is then affixed on the outside of the wall and is layered with building paper and steel lath. The building paper and steel lath are coated with a base stucco coat incorporated with PCM-composite coating. The finish stucco coat incorporated with PCM-composite may then be coated on the outside as a final layer. Additionally, other thermal coatings, such as reflective paints, absorbent paints, and/or the like may be applied to the finished stucco.

With reference now to FIG. 2, in various exemplary embodiments a base material may be combined with PCMs. For example, a PCM-composite coating with dispersed PCMs throughout the base material may be utilized to coat an interior and/or exterior surface of a building. Bulk PCMs may comprise organic and/or inorganic material. The PCMs may comprise individual microcapsules. The PCMs may comprise a microencapsulated powder. The PCMs may comprise a cake. The PCMs may comprise a slurry. The PCM microcapsules may be spherical in shape without agglomerations. Agglomerated PCM microcapsules may negatively impact the microstructure and properties of PCM-composite. The individual PCM microcapsules may allow for a uniform dispersion within the PCM-composite coating.

With reference now to FIG. 3, a schematic of a system 300 for determining a thermal performance of a formulation for phase change material-composite coating is depicted. The system 300 may comprise a temperature-controlled environmental chamber 310, an interior wall envelope element 320, a DAQ unit 330, and a plurality of wall layers 340.

The temperature-controlled environmental chamber 310 may be configured to simulate a desired external environment. For example, the temperature-controlled environmental chamber 310 may simulate a temperature of a hot summer day. The DAQ unit 330 may be configured to measure temperature at various locations throughout the system 300. For example, the DAQ unit 330 may include thermocouples to measure the layers of the plurality of wall layers 340. The plurality of wall layers 340 may be configured to be simultaneously subjected to the same environmental conditions. For example, multiple types of PCM-composite coating may be subjected to the same environmental conditions at the same time. The efficiency of multiple types of PCM-composite coating may thus be measured at once.

With reference now to FIGS. 4A through 4C, in one exemplary embodiment, PCM microcapsules may be configured to have a phase transition temperature of about 24 degrees Celsius. The PCM microcapsules may be configured to have a median particle size of about 20 µm. In another exemplary embodiment, the PCM microcapsules may be configured to have a phase transition temperature of about 35 degrees Celsius. The PCM microcapsules may be configured to have a median particle size of about 50 µm. However, PCM microcapsules having any suitable phase transition temperature maybe utilized, for example a phase transition temperature of above about 24 degrees Celsius and below about 40 degrees Celsius. Additionally, PCM microcapsules having any suitable median particle size may be utilized, for example a median particle size of between about 10 µm and about 100 µm.

Exemplary formulations for PCM-composite coating may be configured to be applied to a plurality of wall layers. The thermal performance of the formulation for PCM-composite coating may be configured to be measured at a range of temperatures. The PCM-composite coatings may undergo a solid-to-liquid and/or liquid-to-solid phase transition. A preferred target thermal energy storage capacity may be desired. To that end, certain amounts of PCM microcapsules may be added to the base coating to achieve a thermal energy storage target. The preferred thermal energy storage target may be measured, for example in kilojoules per square meter. In one exemplary embodiment, a user may prefer a PCM-paint coating with a thermal energy storage target of about 284 kilojoules per square meter. Depending on the type of PCM microcapsule used, in order to achieve the desired thermal energy storage target, the PCM-paint coating may contain about 1281 grams of PCM microcapsules with a phase transition temperature of about 24 degrees Celsius, or about 850 grams of PCM microcapsules with a phase transition temperature of about 35 degrees Celsius, or another suitable amount of PCM microcapsules having a suitable phase transition temperature.

In another exemplary embodiment, a user may prefer a PCM-paint coating with a thermal energy storage target of about 568 kilojoules per square meter. Depending on the type of PCM microcapsule used, , in order to achieve the desired thermal energy storage target, the PCM-paint coating may contain about 2551 grams PCM microcapsules with a phase transition temperature of about 24 degrees Celsius, or about 1701 grams of PCM microcapsules with a phase transition temperature of about 35 degrees Celsius, or another suitable amount of PCM microcapsules having a suitable phase transition temperature.

Turning now to FIG. 5, it can be seen that exemplary PCM-treated surfaces and/or PCM-impregnated materials provide a meaningful amount of thermal regulation and/or insulation. PCM-treated surfaces and PCM-impregnated materials may provide thermal regulation by reducing and delaying the peak temperature compared to a traditional insulative material, such as fiberglass insulation. For example, FIG. 5 shows how a layer of PCM microcapsules with a phase transition temperature of about 35 degrees Celsius and a thermal energy storage target of about 284 kilojoules can significantly reduce the peak temperature by more than 40 percent and delay the peak temperature to a later time. Further, by doubling this layer of PCM microcapsules with a phase transition temperature of about 35 degrees Celsius and a thermal energy storage target of about 568 kilojoules, the effects may be even more pronounced. This may demonstrate the ability of PCM-impregnated coatings to flatten the cyclic thermal loads that a building may be subjected to.

Similarly, FIG. 6 shows that exemplary treated surfaces and materials offer desirable thermal efficiency factors (TEF). As disclosed, the TEF is a normalized metric for comparison of PCM-treated surfaces and PCM-impregnated materials with conventional insulative materials. A higher value of TEF implies a higher ability of the material to maintain a constant temperature in a building. Based on the R-value and unit thickness of different materials, the TEF of PCM-coatings is higher than traditional commercially available insulating materials, as coatings are inherently less thick than traditional commercially available insulating materials.

Yet further, FIGS. 7A, 7B, and 7C illustrate that, in accordance with various exemplary embodiments and methods, appropriate amounts of PCMs may be included in paint, plaster, and/or stucco while maintaining desirable viscosity levels such that the PCM-modified materials may be applied and/or worked in connection with conventional equipment and/or application processes. The physical workability of the PCM-modified paint, plaster, and/or stucco coatings may be similar to their non-PCM coating counterparts so that no additional training or specialized equipment is required, ensuring easier adoption of this novel coating technology.

Additionally, FIG. 8 illustrates desirable thermal performance characteristics of exemplary PCM-modified materials disclosed herein. Specifically, FIG. 8 shows the incremental increase in thermal capacity of PCM-paint coatings as the amount of PCM that is incorporated increases. These coatings may be compared with pure PCM to observe any differences in thermal characteristics.

Moreover, FIGS. 9A, 9B, and 9C further illustrate desirable thermal performance characteristics of exemplary PCM-modified materials disclosed herein. Specifically, each demonstrate the water and base coating material fractions which determine a suitable amount of PCM to be incorporated. A purpose of the material fractions is to maintain similar physical characteristics with traditional commercially available insulating materials.

Further, FIGS. 10A, 10B, and 10C also illustrate desirable thermal performance characteristics of exemplary PCM-modified materials disclosed herein. Specifically, each show plots representing the results of testing performed within the environmental chamber, as disclosed in FIG. 3. The plots represent the superior thermal performance of PCM coatings against their respective controls which do not contain PCM. Like FIG. 5, the PCM coatings show a significant reduction and delay in the peak temperature. Via application of principles of the present disclosure, traditional commercially available coatings are now able to provide insulative thermal properties while still maintaining their physical properties.

Yet further, FIG. 11 illustrates desirable thermal performance characteristics of exemplary PCM-modified materials disclosed herein. Specifically, FIG. 11 demonstrates the results of small field scale testing of the PCM-paint coating using a phase transition temperature of 35 degrees Celsius. The peak reduction and delay in temperature is again observed under actual ambient temperature conditions for multiple heating and cooling cycles.

Turning now to FIG. 12, in various exemplary embodiments a method 1200 for treating a surface with PCM may be utilized. The method may include selecting a surface for treatment (step 1210), determining a particular PCM type, amount, ratios, and so forth for the treatment material in light of desired thermal performance of the treated surface (step 1220), mixing the PCM with the base material (step 1230), and applying the PCM-modified material to the target surface (step 1240). A PCM may be selected based on the environmental climate conditions the building to be treated is subjected to. The PCM type, amount, ratios, etc., may then be chosen to achieve the maximum thermal efficiency for that building in that particular geographic location. Any of the foregoing treatment steps may be repeated, as desired, for example applying a second coat of PCM-modified material to the target surface. Additionally, the entire method may be repeated for a particular target surface with different materials, ratios, and so forth, such that a surface may receive (for example) a first treatment with a first type of PCM, and thereafter a second treatment with a second type of PCM. In this manner, the overall thermal characteristics of the treated surface may be significantly modified and/or customized, as desired.

While the principles of this disclosure have been shown in various embodiments, many modifications of structure, arrangements, proportions, the elements, materials and components, used in practice, which are particularly adapted for a specific environment and operating requirements may be used without departing from the principles and scope of this disclosure. These and other changes or modifications are intended to be included within the scope of the present disclosure.

The present disclosure has been described with reference to various embodiments. However, one of ordinary skill in the art appreciates that various modifications and changes can be made without departing from the scope of the present disclosure. Accordingly, the specification is to be regarded in an illustrative rather than a restrictive sense, and all such modifications are intended to be included within the scope of the present disclosure. Likewise, benefits, other advantages, and solutions to problems have been described above with regard to various embodiments. However, benefits, advantages, solutions to problems, and any element(s) that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as a critical, required, or essential feature or element.

As used in the description and the appended claims, the singular forms “a,” “an” and “the” are used interchangeably and intended to include the plural forms as well and fall within each meaning, unless the context clearly indicates otherwise. Also, as used herein, “and/or” refers to and encompasses any and all possible combinations of one or more of the listed items, as well as the lack of combinations when interpreted in the alternative (“or”). As used herein, the terms "comprises," "comprising," or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a process, method, article, or apparatus that comprises a list of elements does not include only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus. When language similar to "at least one of A, B, or C" or "at least one of A, B, and C" is used in the specification or claims, the phrase is intended to mean any of the following: (1) at least one of A; (2) at least one of B; (3) at least one of C; (4) at least one of A and at least one of B; (5) at least one of B and at least one of C; (6) at least one of A and at least one of C; or (7) at least one of A, at least one of B, and at least one of C.

CLAIMS

What is claimed is:

1. A formulation for phase change material (PCM)-composite coating comprising an amount of phase change material having a mass fraction range of about 0.01 to about 0.50, the formulation comprising:

organic material;

inorganic material;

microencapsulated PCM; and

bulk PCM.

2. The formulation of claim 1, further comprising an amount of stucco having a mass fraction range of about 0.60 to about 0.90.

3. The formulation of claim 1, further comprising an amount of plaster having a mass fraction range of about 0.35 to about 0.60.

4. The formulation of claim 1, further comprising an amount of paint having a mass fraction range of about 0.25 to about 0.60.

5. The formulation of claim 1, further comprising an amount of water having a mass fraction range of about 0.10 to about 0.75.

6. The formulation of claim 1, wherein the microencapsulated PCMs comprise a microencapsulated powder.

7. The formulation of claim 1, wherein the microencapsulated PCMs comprise a cake.

8. The formulation of claim 1, wherein the microencapsulated PCMs comprise a slurry.

9. The formulation of claim 6, wherein the microencapsulated powder is configured to have a phase transition temperature of about 24 degrees Celsius.

10. The formulation of claim 6, wherein the microencapsulated powder is configured to have a phase transition temperature of about 35 degrees Celsius.

11. The formulation of claim 9, wherein the microencapsulated powder median particle size is configured to be about 20 μm.

12. The formulation of claim 10, wherein the microencapsulated powder median particle size is configured to be about 50 μm.

13. The formulation of claim 4, wherein the paint is acrylic latex-based paint.

14. A system for determining a thermal performance of a formulation for PCM-composite coating, the system comprising:

a temperature-controlled environmental chamber;

an interior wall envelope element;

a data acquisition unit; and

a plurality of wall layers.

15. A method for treating a building surface with PCM, the method comprising:

selecting the building surface to be treated;

determining, for the building surface: (i) an amount of PCM to utilize per unit area, and (ii) a ratio of PCM to at least one other component of a treatment material;

mixing the PCM with the at least one other component to form the treatment material; and

applying the treatment material to the building surface to modify at least one thermal characteristic of the building surface.

16. The method of claim 15, wherein the thermal characteristic is thermal energy storage.

17. The method of claim 15, wherein the thermal characteristic is thermal insulation.

18. The method of claim 15, wherein the at least one other component comprises stucco.

19. The method of claim 15, wherein the building surface comprises a material impregnated with PCM.

20. The method of claim 15, wherein the treatment material comprises a first PCM and a second PCM, and wherein the first PCM and the second PCM differ by at least one of molecular composition, median particle size, or phase transition temperature.

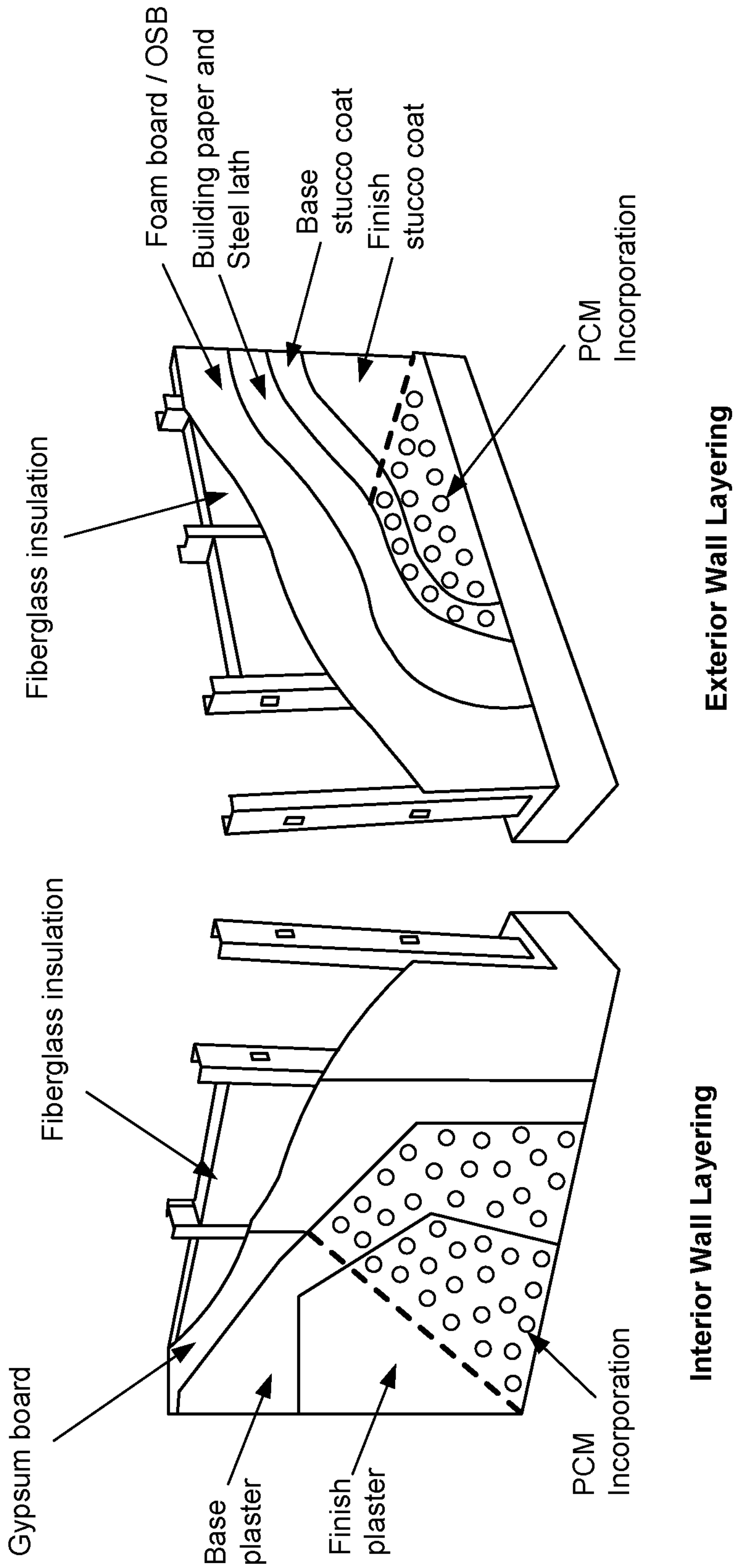
Foam board / OSB
Building paper and Steel lath
Base stucco coat
Finish stucco coat
Fiberglass insulation
PCM Incorporation
Exterior Wall Layering
Fiberglass insulation
Gypsum board
Base plaster
Finish plaster
PCM Incorporation
Interior Wall Layering

FIG. 1

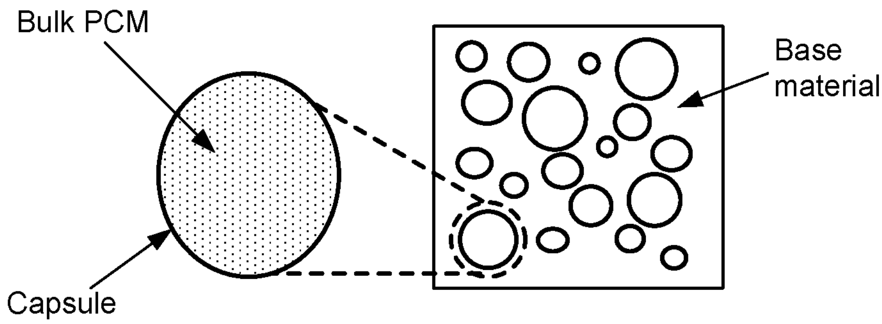
Bulk PCM
Base material
Capsule

FIG. 2

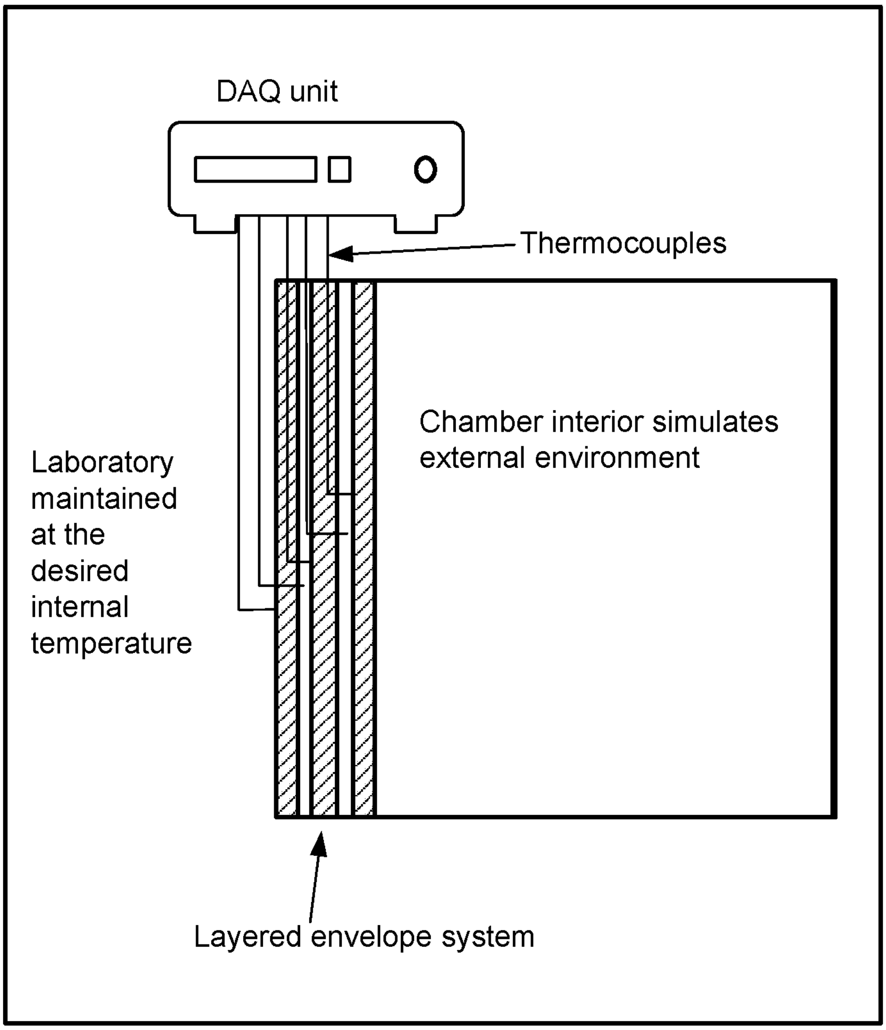
DAQ unit
Thermocouples
Chamber interior simulates external environment
Laboratory maintained at the desired internal temperature
Layered envelope system

FIG. 3

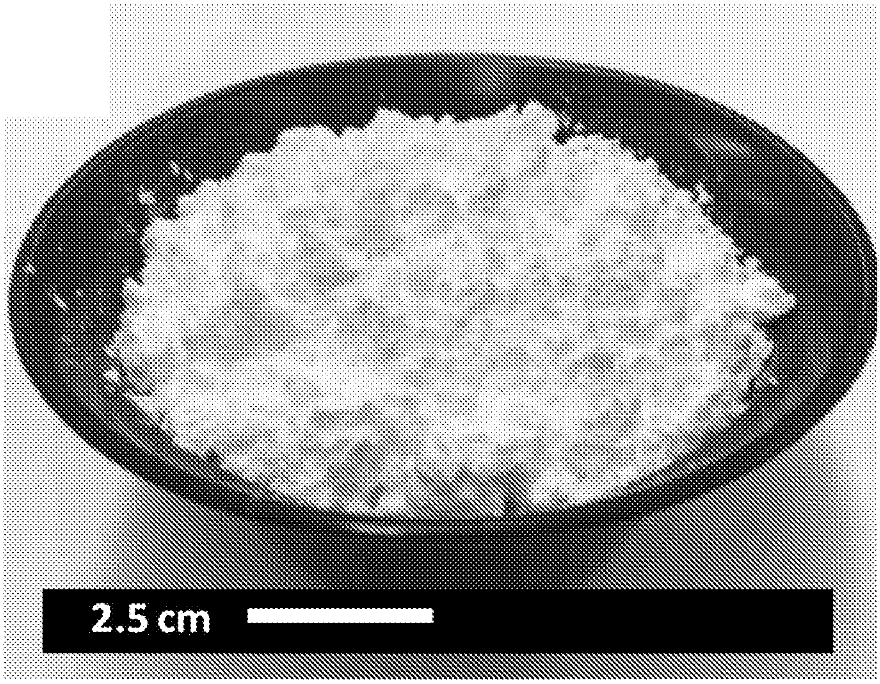

FIG. 4A

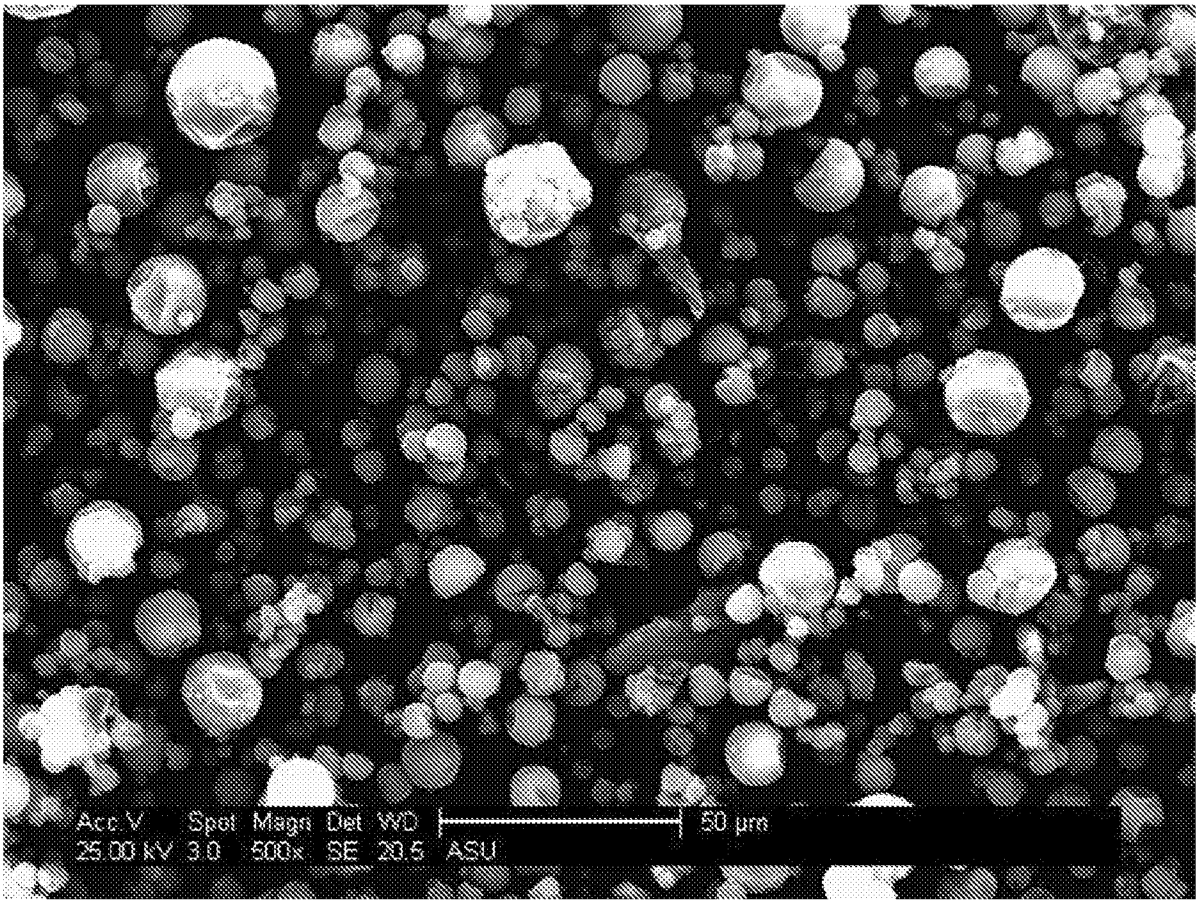

FIG. 4B

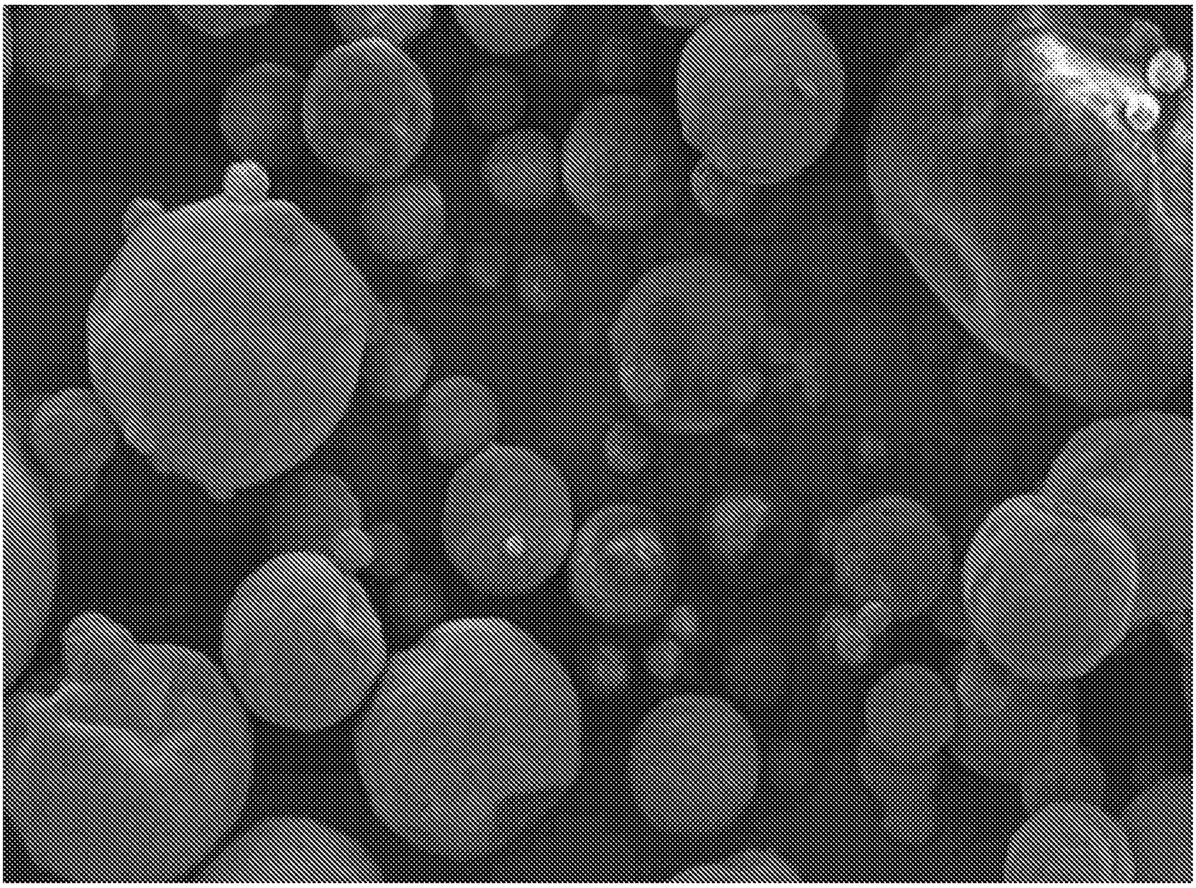

FIG. 4C

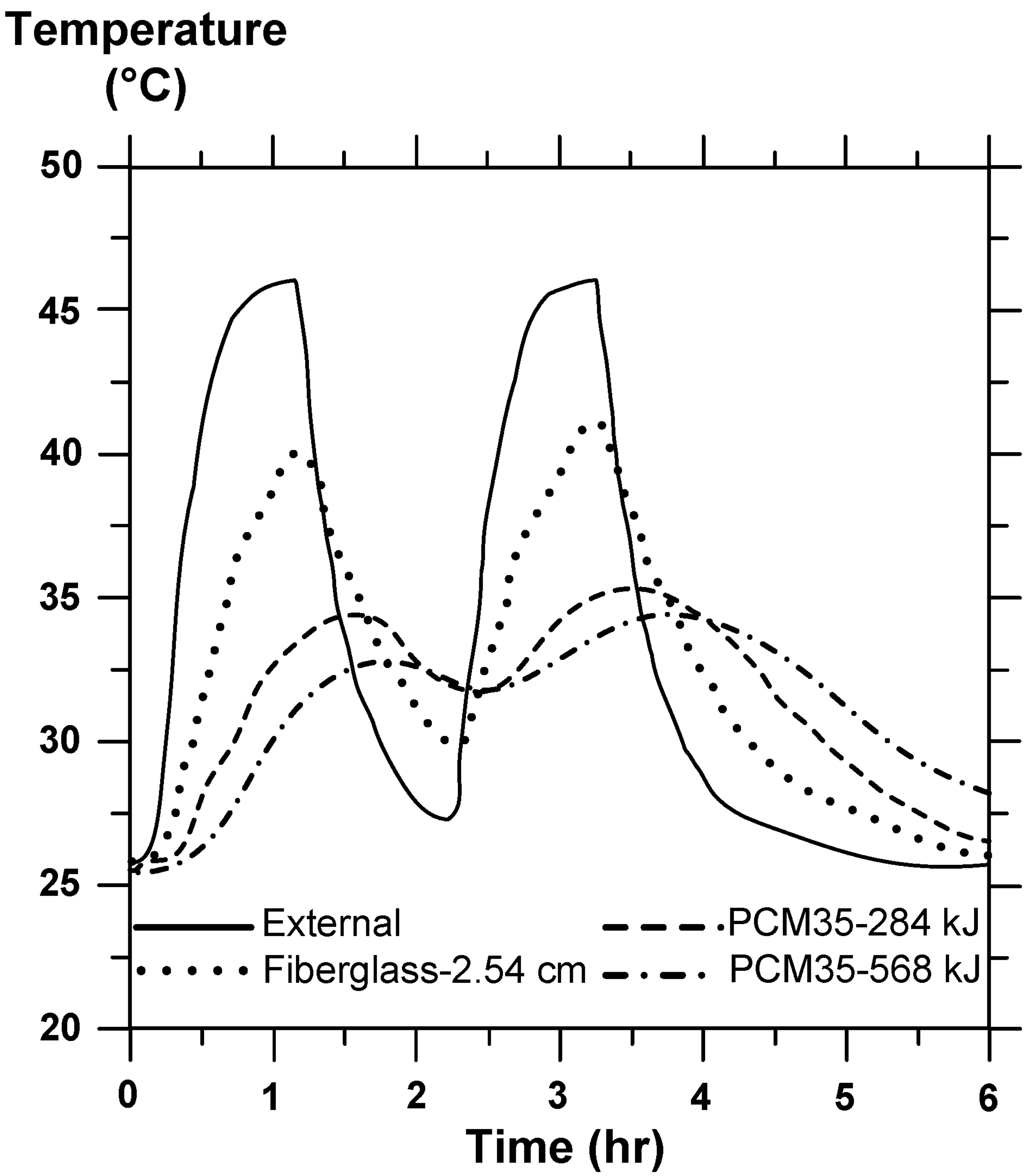
Temperature (°C)
50
45
40
35
30
25
20
0
1
2
3
4
5
6
Time (hr)
External
Fiberglass-2.54 cm
PCM35-284 kJ
PCM35-568 kJ

FIG. 5

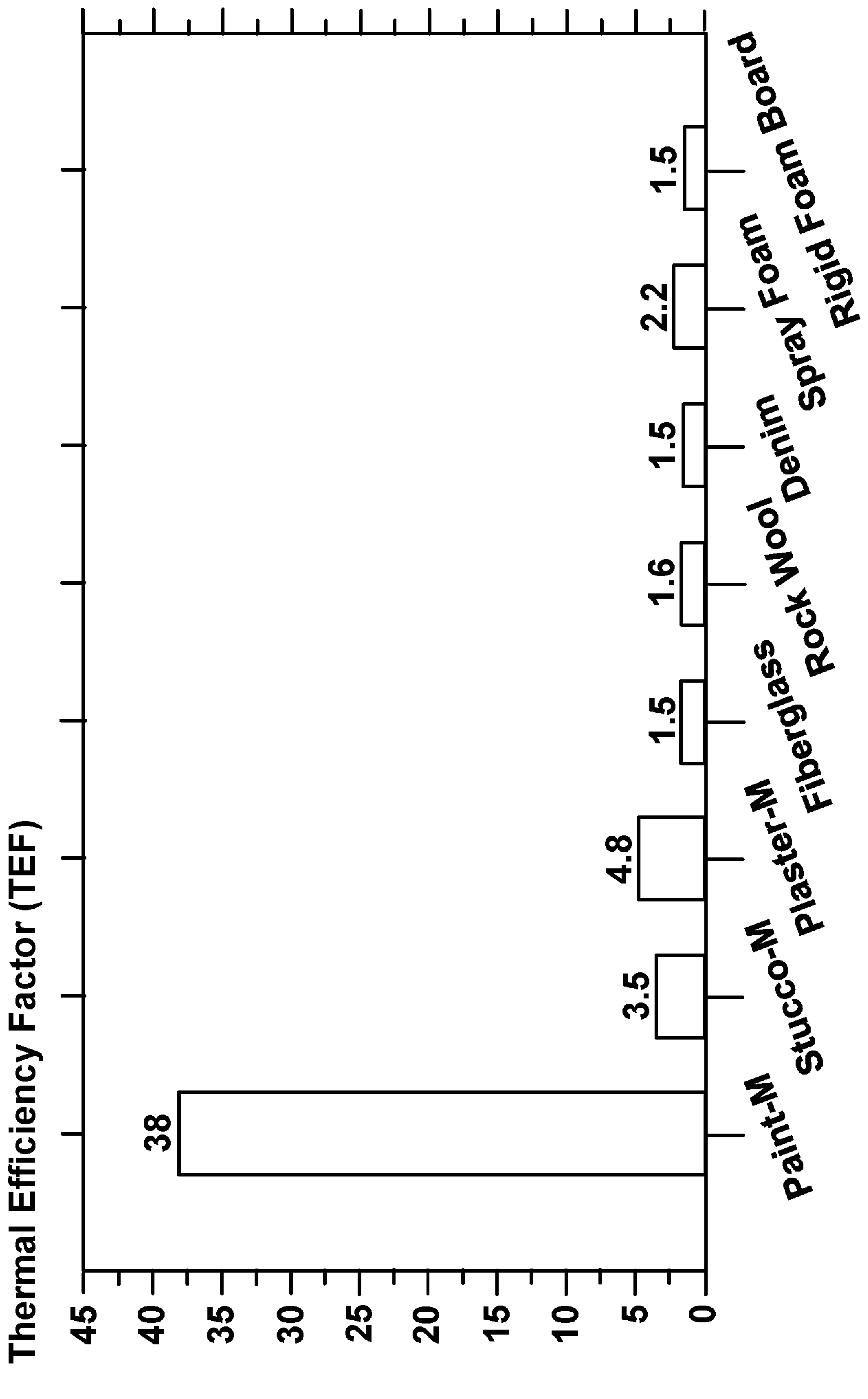
Thermal Efficiency Factor (TEF)
45
40
35
30
25
20
15
10
5
0
38
3.5
4.8
1.5
1.6
1.5
2.2
1.5
Paint-M
Stucco-M
Plaster-M
Fiberglass
Rock Wool
Denim
Spray Foam
Rigid Foam Board

FIG. 6

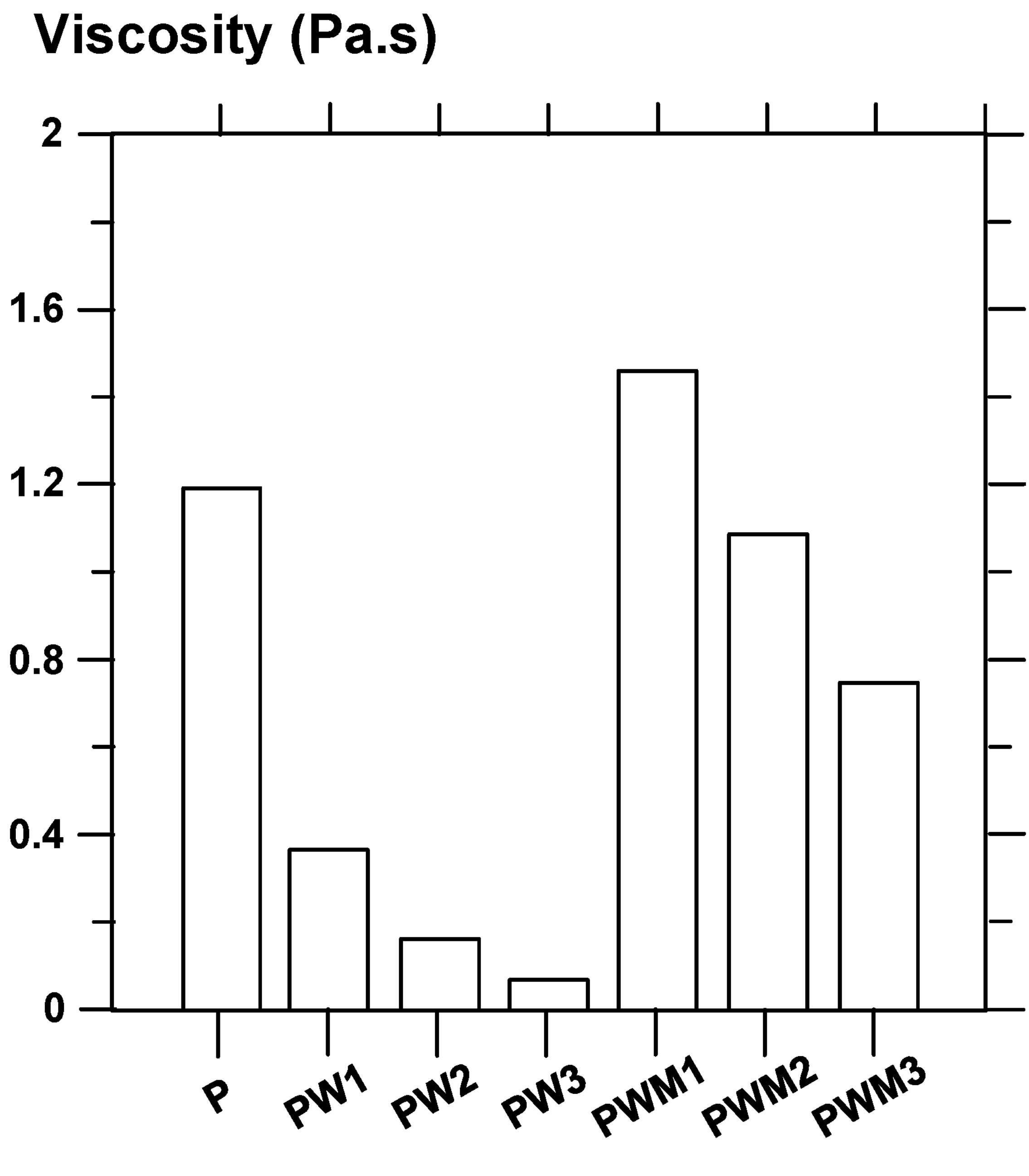

FIG. 7A

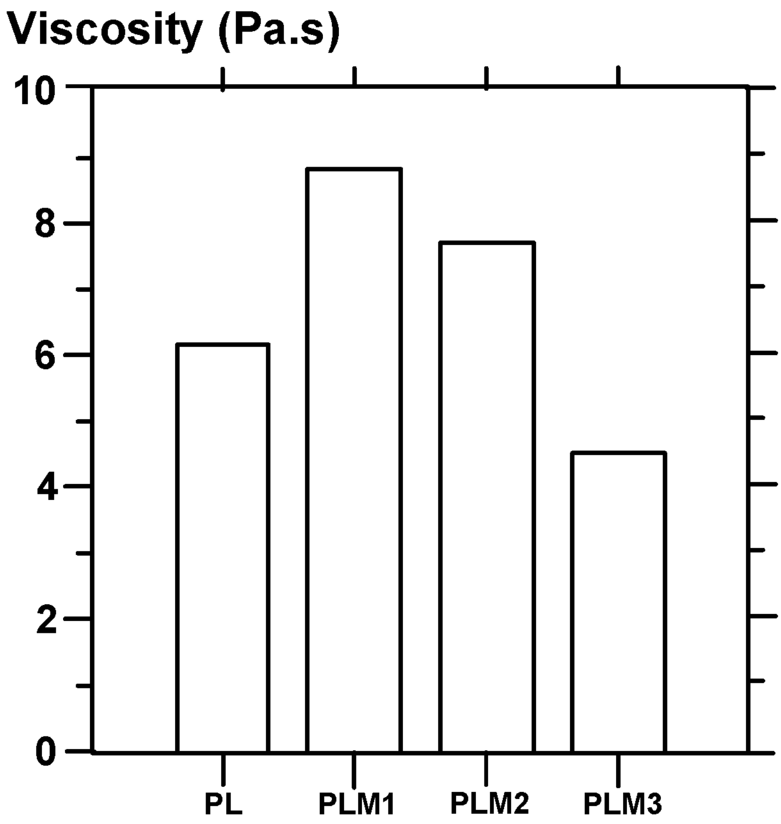
Viscosity (Pa.s)
10
8
6
4
2
0
PL
PLM1
PLM2
PLM3

FIG. 7B

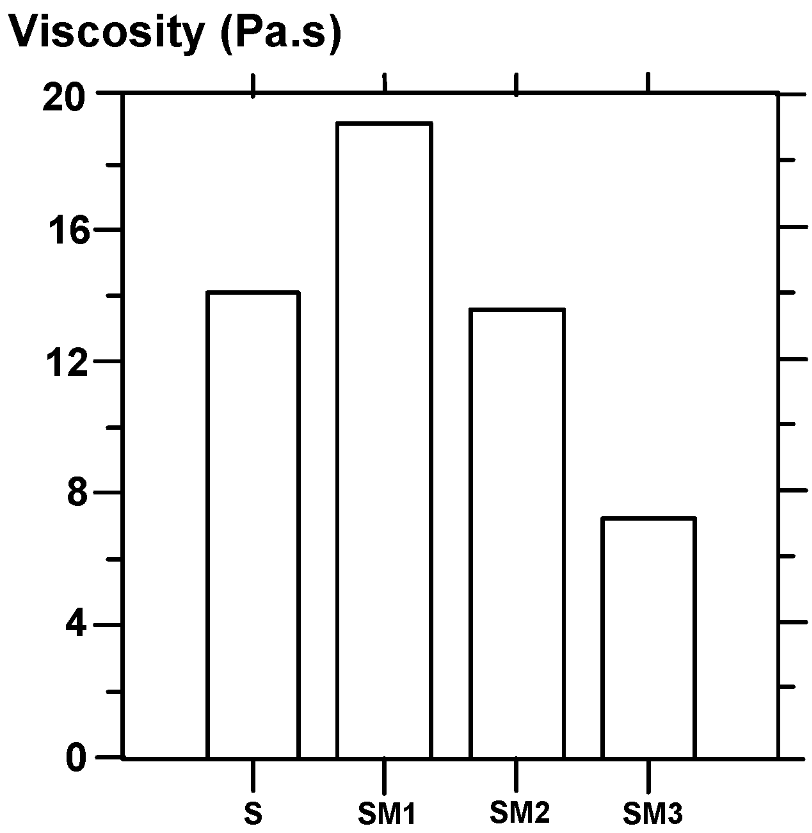
Viscosity (Pa.s)
20
16
12
8
4
0
S
SM1
SM2
SM3

FIG. 7C

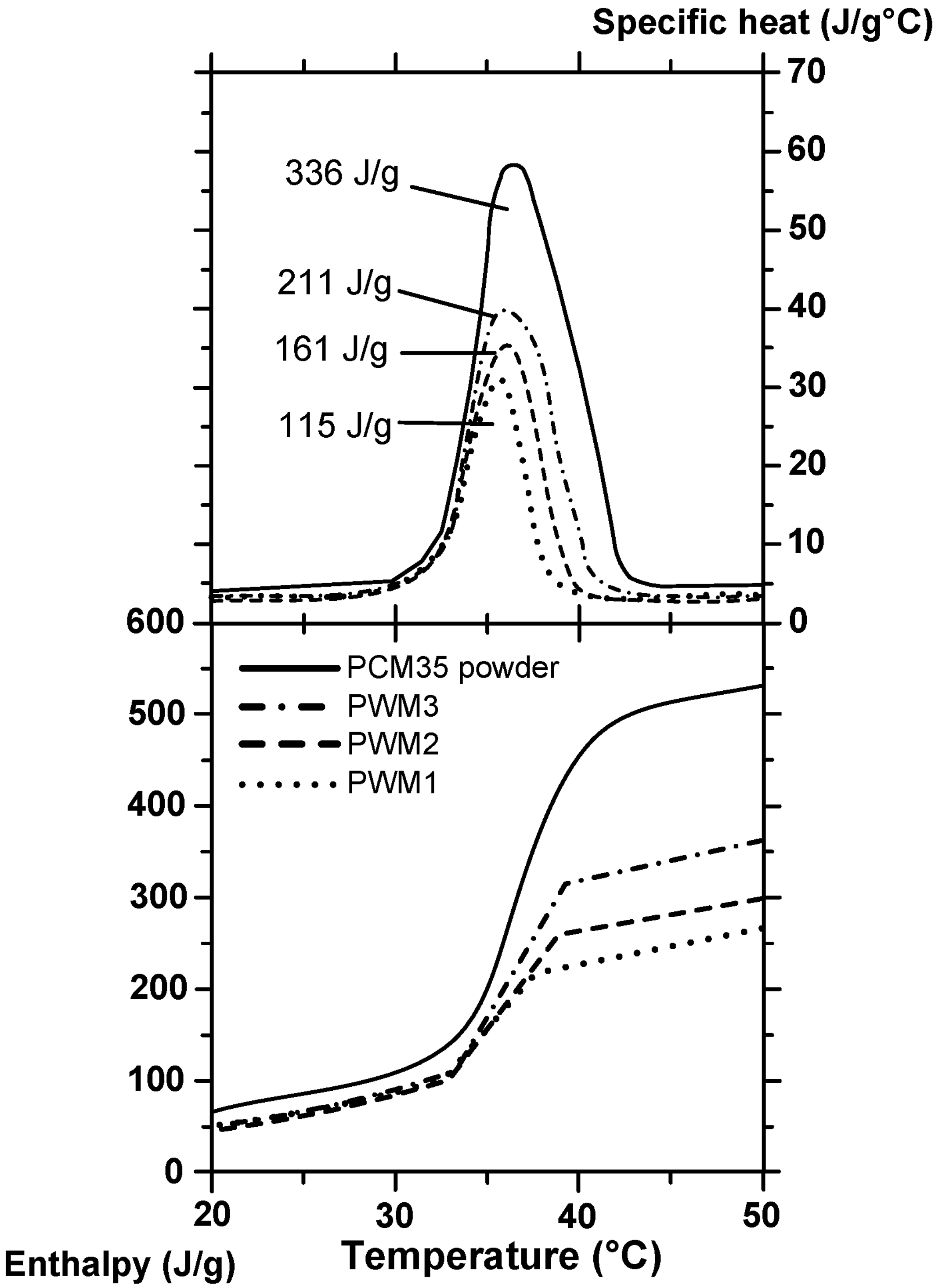
Specific heat (J/g°C)
70
60
50
40
30
20
10
0
336 J/g
211 J/g
161 J/g
115 J/g
600
500
400
300
200
100
0
PCM35 powder
PWM3
PWM2
PWM1
20
30
40
50
Enthalpy (J/g)
Temperature (°C)

FIG. 8

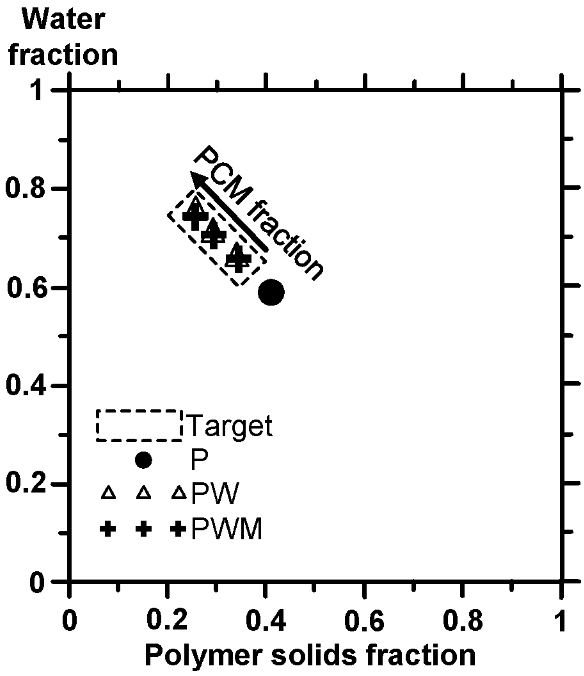

FIG. 9A

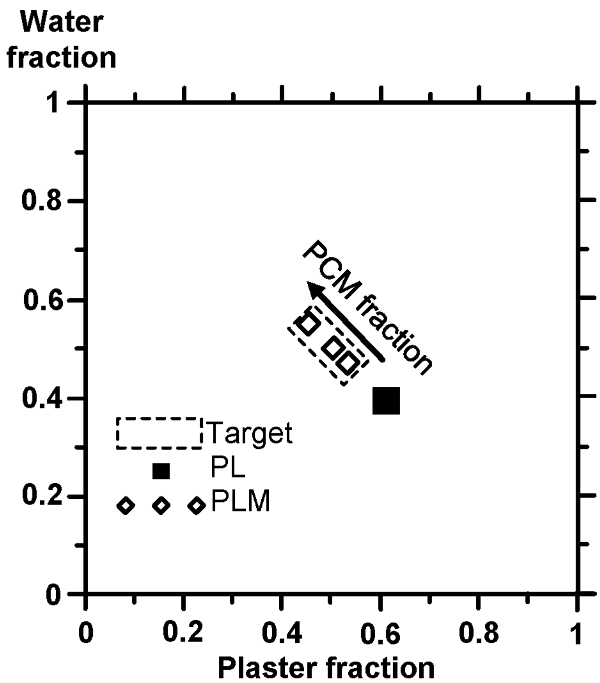

FIG. 9B

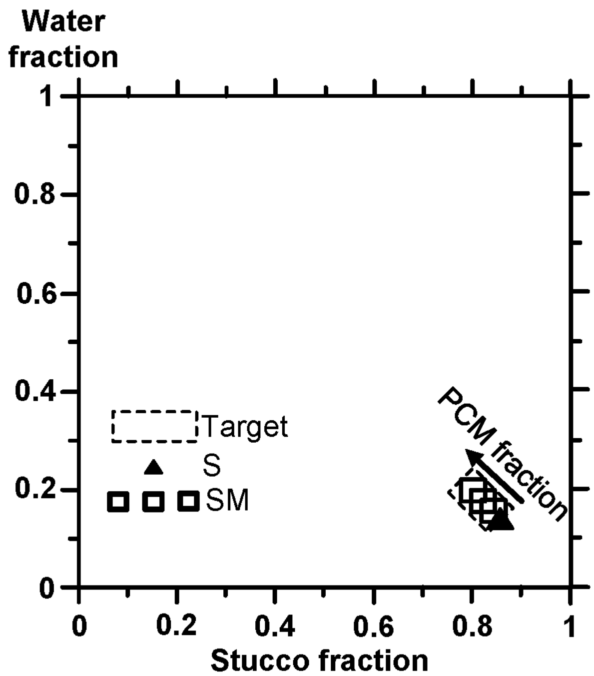

FIG. 9C

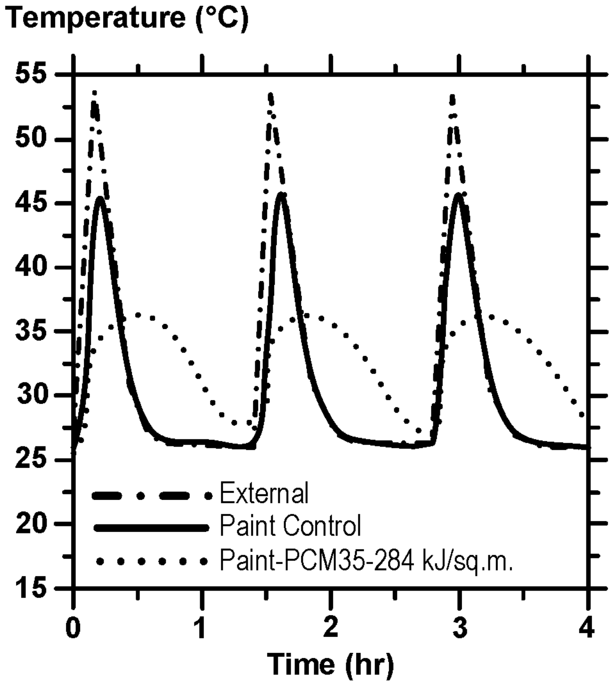

FIG. 10A

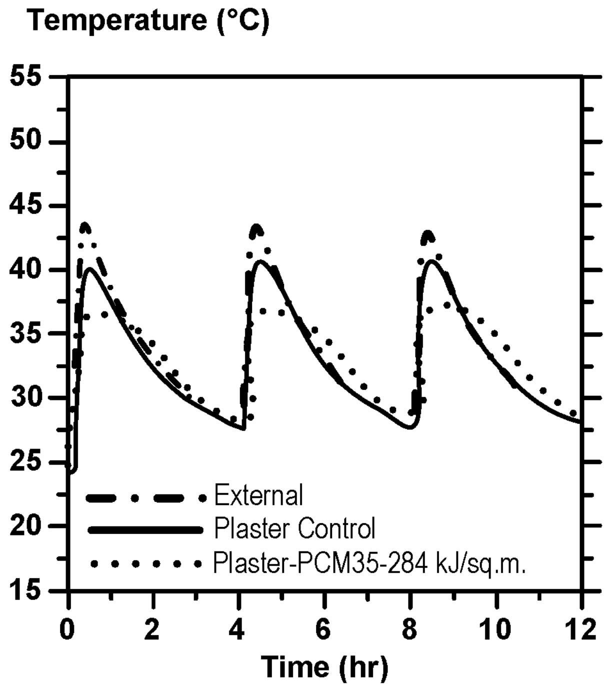

FIG. 10B

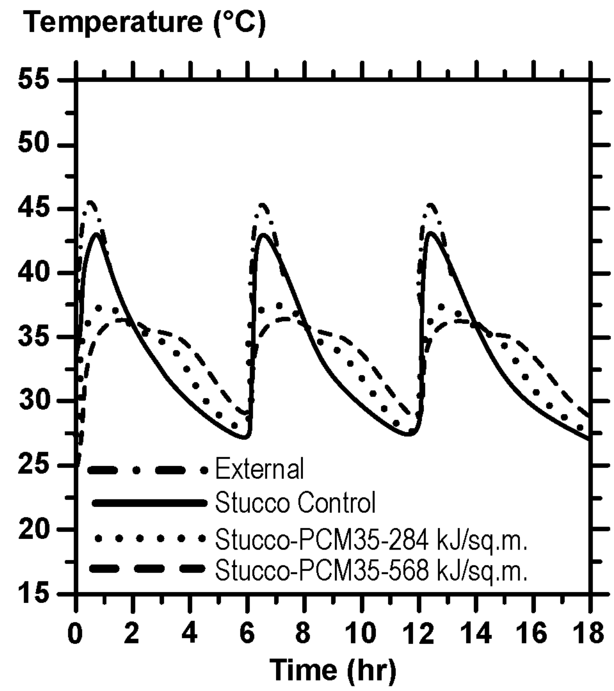

FIG. 10C

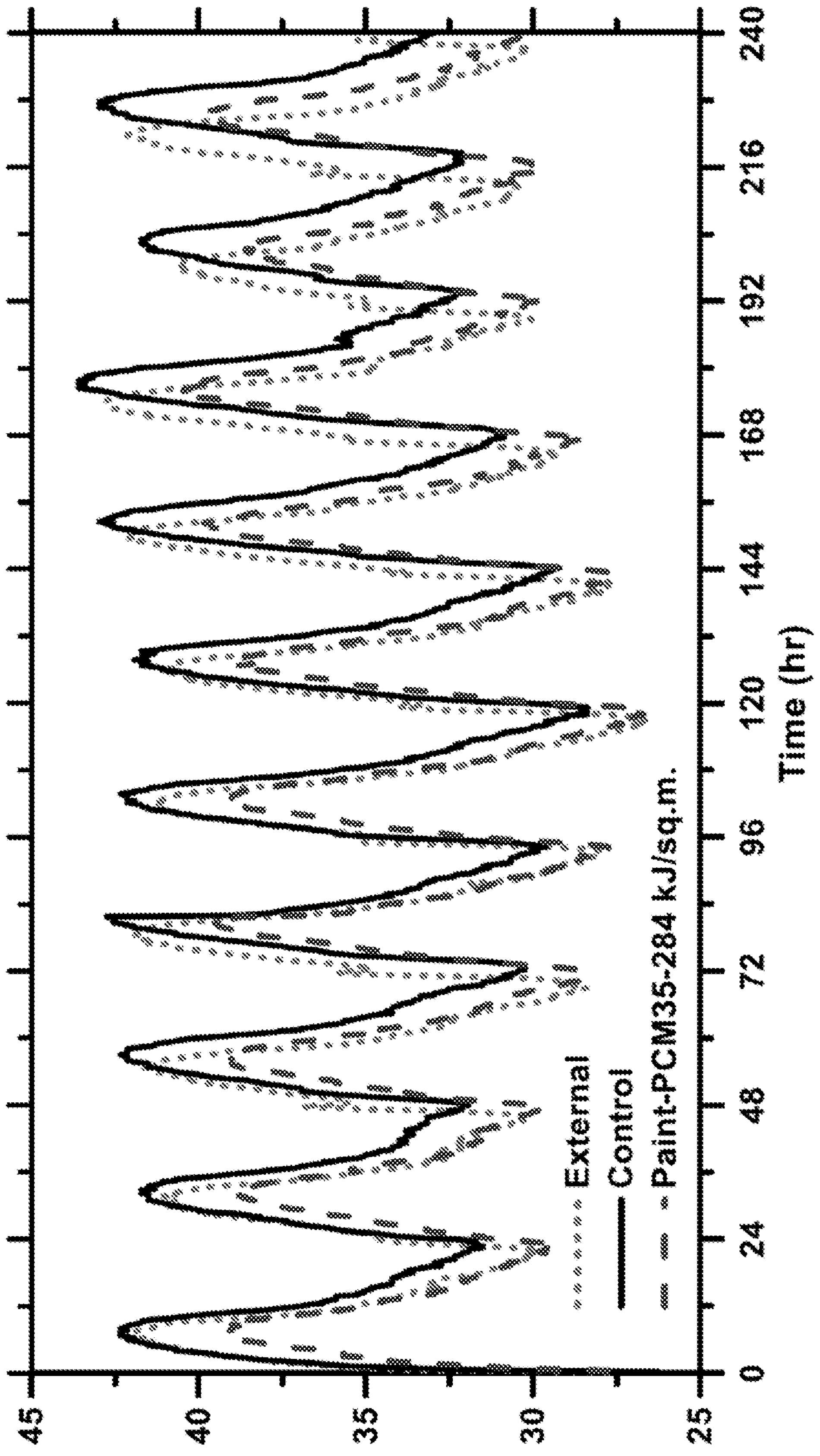
External
Control
Paint-PCM35-284 kJ/sq.m.
Time (hr)
0
24
48
72
96
120
144
168
192
216
240
25
30
35
40
45

FIG. 11

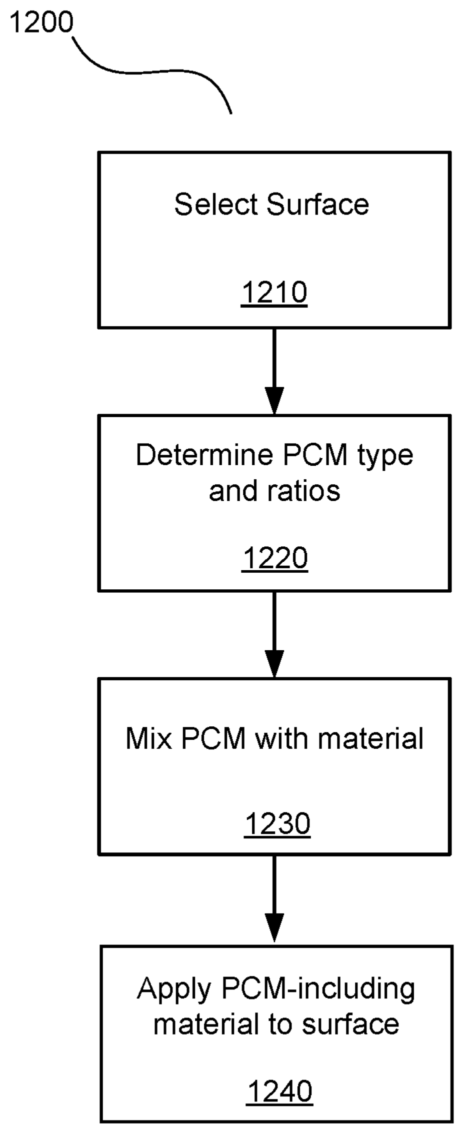
1200
Select Surface
1210
Determine PCM type and ratios
1220
Mix PCM with material
1230
Apply PCM-including material to surface
1240

FIG. 12

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 20/13141

A. CLASSIFICATION OF SUBJECT MATTER

IPC - A47C 7/74; B60N 2/56; C09K 5/06; F25B 21/04; F28D 20/02 (2020.01)

CPC - A41D 13/005; A47C 7/744; B60N 2/5635; B60N 2/5678; C09K 5/063; C04B 2103/0071; F28D 20/023; Y02E 60/145

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
See Search History document

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X -- Y	US 4,747,240 A (VOISINET et al), 31 May 1988 (31.05.1988), claim 1; col 1 ln 4-7, col 1 ln 33-47, col 1 ln 60-68, col 2 ln 1-9, col 2 ln 16-18, col 2 ln 46-51, col 3 ln 57-62.	1-3 ----- 6, 9-12
X	US 2017/0167133 A1 (EASTMAN CHEMICAL COMPANY), 15 June 2017 (15.06.2017), Table 2; para [0032]-[0036], [0078]-[0079], [0088], [0092], [0097]-[0100].	1, 4, 5, 13
X	US 2013/0034732 A1 (PARKER et al), 07 February 2013 (07.02.2013), table 2; para [0009], [0041], [0058], [0131], [0138], [0154], [0159], [0171], [0196], [0244], [0252].	1, 7, 8
Y	US 7,166,355 B2 (JAHNS et al), 23 January 2007 (23.01.2007), col 2 ln 16-36, col 3 ln 29-39, col 7 ln 46, col 10 ln 17-40, col 11 ln 2-5.	6, 9-12
A	'Stucco', WIKIPEDIA, 02 January 2019 (02.01.2019), [retrieved 18 March 2020 (18.03.2020) via <https://en.wikipedia.org/w/index.php?title=Stucco&oldid=876485062>].	2

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"D" document cited by the applicant in the international application

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 March 2020	20 MAY 2020

Name and mailing address of the ISA/US	Authorized officer
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Lee Young Telephone No. PCT Helpdesk: 571-272-4300

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 20/13141

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be searched, the appropriate additional search fees must be paid.

Group I: Claims 1-13, directed to a formulation for phase change material (PCM)-composite coating.

Group II: Claim 14, directed to a system for determining a thermal performance of a formulation for PCM-composite coating.

Group III: Claims 15-20, directed to a method for treating a building surface with PCM.

The inventions listed as Groups I-III do not relate to a single inventive concept under PCT Rule 13.1 because under PCT Rule 13.2 they lack the same or corresponding technical features for the following reasons:

***** Continued in the Supplemental Sheet below *****

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-13

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

Continuation of: Box III - Observations where unity of invention is lacking:

Special Technical Features

Group I includes the special technical feature of a formulation comprising an amount of phase change material having a mass fraction range of about 0.01 to about 0.50, the formulation comprising: organic material; inorganic material; microencapsulated PCM; and bulk PCM; not required by Groups II-III.

Group II includes the special technical features of a system for determining a thermal performance of a formulation, the system comprising: a temperature-controlled environmental chamber; an interior wall envelope element; a data acquisition unit; and a plurality of wall layers; not required by Groups I or III.

Group III includes the special technical feature of a method for treating a building surface, the method comprising: selecting the building surface to be treated; determining, for the building surface: (i) an amount of PCM to utilize per unit area, and (ii) a ratio of PCM to at least one other component of a treatment material; mixing the PCM with the at least one other component to form the treatment material; and applying the treatment material to the building surface to modify at least one thermal characteristic of the building surface; not required by Groups I-II.

Shared Technical Features

Groups I-III share the common technical features of a coating composition comprising at least one phase change material (PCM) and at least one other component. However, these shared technical features do not represent a contribution over prior art as being anticipated by US 2017/0167133 A1 to Eastman Chemical Company (hereinafter 'Eastman'), which teaches a coating composition (para [0032], 'A modified surface coating or paint comprising ...') comprising at least one phase change material (PCM) and at least one other component (para [0012], 'Briefly, the present invention is a PCM emulsion ... the carrier includes at least one functional moiety capable of forming a stable emulsion with the PCM in the fluid medium'; para [0032]-[0036], 'comprising: ... a base coating; and ... a phase change material (PCM)').

Therefore, Groups I-III lack unity under PCT Rule 13 because no two of them share a same or corresponding technical feature.