



2023

March

coou African Journal of Environmental Research Vol 4, No. 1, 2023. pp 201-222

PHASE CHANGE MATERIALS IN CONCRETE AS AN INNOVATIVE OPTION FOR ENERGY EFFICIENT BUILDINGS IN LAGOS NIGERIA

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Abstract

Global concern for ever-increasing energy consumption and rapid population growth continues to put pressure on existing basic amenities such as housing and infrastructure. More so, the world population is projected to increase by 2.5 billion by 2050, with most of the increase in Asia and Africa. Lagos Nigeria, the commercial hub of West Africa, has been greatly affected by these scenarios of housing shortages and inadequate energy supply, with less than 10hrs daily supply of electricity to homes for sustainable living and comfort. The resultant carbon emission effects of fossil-based energy supply are of serious concern. According to research, continued resistance to adoption of innovative construction materials with their energy efficiency contributions has been found greatly responsible for this devastating condition. Hence, the need for this study with the aim of carrying out a general overview of the different types of Phase Change Materials applicable in buildings for energy efficiency and material conservation for sustainable housing in Lagos, Nigeria. This review is aimed at providing critical information necessary for researchers, designers, engineers and policy cum decisions makers in the construction sector to make safe, durable, and cost-effective decisions on thermally efficient buildings using MPCM. The overview covers the properties, advantages, and drawbacks as examined and evaluated in correlation with existing findings of residential buildings energy consumption study carried out in Lagos. Literature shows that most commercially available microcapsules are polymers with a few drawbacks such as low mechanical stiffness, flammability, and low thermal conductivity. Thus, concrete cost effectiveness and thermally efficient buildings, using MPCMs for Energy efficiency attainment in housing production is a viable option. The paper concludes that exploring the thermal efficiency efficacy of MPCM application to replace the existing 89.9% of building envelopes content in Lagos residential building construction materials will result in efficient energy consumption for a more sustainable housing environment.

Keywords: Building Materials, Energy efficiency, Phase Change, Thermal Properties, Sustainable Architecture

INTRODUCTION

The world population is projected to increase by 2.5 billion by 2050 with most of this increase expected to be in Asia and Africa (Swilling et al, 2018). This future population growth would put pressure on existing basic amenities such as housing and infrastructure; therefore, it is anticipated that there would be an increase in demand for building materials Habert et al (2020). Buildings account for, at least, 40% of the total global energy consumption, over one-third of global energy growth and one-third of worldwide carbon emission (Liu, Wang, Qian & 2017; Cui et al, 2018). This significant energy demand is attributed to greater use of space cooling, lighting, and electrical appliances (BP et al, 2018). According to BP Statistical Review of World energy 2019 report, non-renewable energy, especially fossil fuels, dominate the world energy market with a share of 81% and led to carbon emissions growth of 2.0% - the fastest growth for seven years. China, the US and India together accounted for more than two thirds of the global increase in energy demand in 2018; with US consumption expanding at its fastest rate for 30 years (BP, 2018; Vickers, 2017).

With the increasing depletion of this non-renewable energy sources, researchers in recent times are ardently looking for innovative ways to optimally store and recycle energy to maximize efficient and effective energy usage. Thus, improving the energy efficiency of buildings would not only overtime diminish the dependence on non-renewable energy, but would also reduce total carbon emissions into the environment. Many innovative ideas have been suggested for an energy efficient building using renewable energy ranging from policy making to increase the thermal inertia of buildings (European Commission (CEED), 2012; De Gracia & Cabeza, 2015). Phase change materials (PCMs) incorporated into building materials has been widely discussed as a promising renewable energy source to increase the thermal inertia of buildings (Zalba et al, 2003; Zhou et al 2012; Khudhair & Farid, 2004; Marani & Nehdi, 2019).

PCMs are organic, inorganic, eutectic, substances that can be thermally activated up to melting temperature such that they store absorbed heat in their matrices in latent form and release this heat during cooling. This melting and cooling cycle could control the diurnal ambient temperature. PCMs can improve the efficiency of buildings through thermal energy storage (TES) and thermal regulation (Khadiran et al, 2015). Ordinarily, buildings should be sustainably designed to provide thermal comfort for occupants, with at least supplementary energy for heating and cooling. Also, the building envelope and insulation properties could have appreciable role in the delay and decay of fluctuating ambient temperature (Zhang et al, 2006). However, in buildings, it is difficult to achieve passive ideal energy conservation due to their complex thermodynamic nature (Soares et al, 2013). Hence, PCMs in buildings would further add to the TES of the building envelope and partition elements.

However, since PCM will exist as solid and liquid during each thermal cycle, it therefore must be contained to prevent leakage into the surrounding construction material. Microencapsulation has shown great potential as an effective way of containing and incorporating PCMs into building

materials. This technique involves encapsulating phase change materials in protective spherical micron size shells -microcapsules- that are compatible with both the PCM and the matrix of the building material it is being incorporated. Microencapsulated phase change materials MPCM have been applied directly into building material, for example: as partial replacement for sand in concrete (Aguayo et al, 2016; Jayalath et al, 2016; Haurie et al, 2016) or percentage by weight in gypsum board (Kusama et al, 2017; Lachheb et al, 2017). An ideal microcapsule or shell would have certain properties such as: high mechanical and thermal strength, high thermal conductivity, thermal durability, unreactive with the PCM, prevent leakage of PCM (Rathore et al, 2020), and compatibility with matrix of applied building material

LITERATURE REVIEW

General overview of phase change materials

The cardinal property of phase change materials is its ability to store heat energy in latent form (Hunger et al, 2009). The latent heat is the large quantity of energy absorbed or released by a material during phase change from liquid to solid or vice versa without change in temperature. The magnitude of this energy, for example, can be shown by comparing the latent heat of a phase change material, such as $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$ (193kJ/kg), with the sensible heat capacity of concrete (1kJ/kgK) (Khudhair & Farid, 2004; Farid et al, 2004).

For application in buildings, phase change materials should have some desired specific thermo physical, chemical, kinetic, environmental, and economic properties as largely recommended by various researches.

Table 1: Specific desired properties for phase change materials applicable in buildings

Properties	Characteristics
Thermo physical	phase change temperature within human comfort range, high density, small volume change during phase change, favourable phase equilibrium without phase segregation, long-thermal stability, high thermal conductivity, high specific heat, high latent heat of transition and good heat transfer
Chemical	long-term chemical stability upon numerous cycling, non-toxic, non-corrosive, non-flammable, compatibility with construction materials, total reversible phase cycles, and non-explosive.
Kinetic	high crystallization rate, no super cooling, and high nucleation rate
Environmental	non-polluting, low embodied energy, recycling potential and low environmental impact
Economic	inexpensive, abundant, and readily available

Source: (Cabeza et al, 2011; Agyenim et al, 2010; Kenisarin et al, 2007; Sharma et al, 2009)

Types of phase change materials

PCMs are classified into three groups based on their chemical composition: (i) organic compounds (paraffin and non-paraffin), (ii) inorganic compounds and (iii) eutectic. These are as shown in Figure 2, together with some of their general advantages.

Organic PCMs

The paraffin, (especially commercial ones) suitable for buildings are inexpensive and available in large temperature range from approximately 20⁰C to about 70⁰C. They are non-reactive; they have low vapor pressure in melt state, and have appreciable thermal density of 120kJ/kg to about 210KJ/kg (Baetens, Jelle & Gustavsen, 2010). Unfortunately, these groups of organic PCMs suffer some setback such as large volume change (Hasnain, 1998), low thermal conductivity - about 0.2W/mK. Encapsulation can be used to overcome large volume change while matrix structures or metallic fillers can enhance thermal conductivity (Farid et al, 2004). Non-commercial ones are expensive, and flammable (fire-retardant could be applied) (Sittisart & Farid, 2011) and exhibit low phase change enthalpy as shown in Table 2 and Figure 1.

Table 2: Organic PCMs

PCM	Microcapsules	Microcapsule size (µm)	T _f (⁰ C)	Latent heat (kJ/kg)	References
Micronal DS	Polymethylmethacrylate (PMMA)	5	26	110	[36, 37]
Micronal 5040X	PMMA	200-800	23	100	[38]
Micronal 5038X	PMMA	200-800	26	110	[38, 39]
Micronal DS 5001 X	Polymer shell	100-300	23	110	[40]
Paraffin	Polymer shell	17-20	37	n.a	[41]
Paraffin	PMMA	50-300	23	100	[42]
Paraffin	Copolymer	5	24	70	[43]
Paraffin	Melamine-formaldehyde	15-20	24	160	[44]
Paraffin MPCM	Polyurethane and polyuria	1-20	41.4	192	[45]

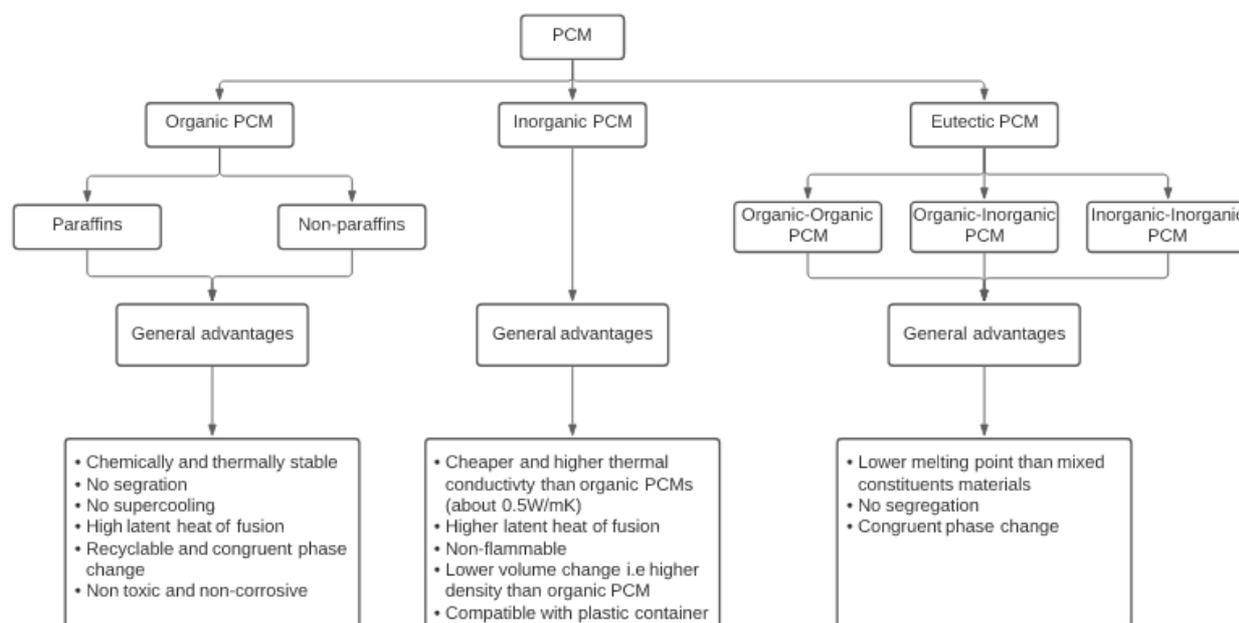


Figure 1. Types of phase change materials and their general advantages

On the other hand, the non-paraffin is fatty acids, esters, glycols, and alcohols. They are about 2-3 times more expensive than paraffin, but generally have superior freezing and melting properties (Hasnain, 1998). From the non-paraffin, fatty acids have gained a lot of recognition because of its: relatively low melting point range, high latent heat of fusion, no super cooling during crystallization, durable after numerous thermal cycling, relatively inexpensive and small volume change during phase transition (Baeten, Jell & Gustavsen, 2010; Fauzi, 2014; Song et al, 2014; Song, 2014). Although, fatty acids could be slightly corrosive (Sharma, Tyagi, Chen & Buddhi, 2009). Commonly known fatty acids are capris, lauric, caprylic, meristic, stearic and palm tic; their freezing temperature is between 17 and 64⁰C and melting temperature between 16 and 65⁰C with latent heat of fusion around 155kJ/kg up to 180KJ/kg (Baetens R, Jelle BP & Gustavsen, 2010).

Inorganic PCMs

These are available as salts, hydrated salts and metallic. Most common inorganic PCMs are hydrated salts. They show superior potential applications especially due to their cost advantage, comfortable phase transition temperature and high energy storage density (Nazir et al, 2019; Reddy, Mudgal & Mallick, 2018). For ease of manufacturing and disposal environment impact, salt hydrates are better than paraffin (De Gracia et al, 2010). However, they may suffer some few drawbacks such as being corrosive to most metals; undergo super cooling, phase segregation during transition, phase decomposition upon numerous thermal cycling and exhibit varying chemical stability (Baetens, Jelle & Gustavsen, 2010; Memon, 2014). Addition of nucleating and thickening agents are often used to suppress the effect of super cooling and phase segregation (Evangelakis et

al, 2021; Safari, Saidur, Sulaiman, Xu & Dong, 2017), unfortunately these two agents would cause phase separation issue at a later time after many cycles (Wu, Liu, Yang, Wu & Li, 2021). Microencapsulation could reduce super cooling, phase segregation and prevent high volume change because it enhances high surface-area-to-volume ratio (Khudhair & Farid, 2004; Biswas, Lu, Soroushian & Shrestha, 2014). More so, thermal conductivity agents such as expanded graphite and copper when added to salt hydrate have been shown to improve thermal conductivity (Cheng et al, 2019).

Eutectic PCMs

Eutectic PCM is a mixture of binary or ternary solids in proportions that gives a phase change material with single sharp melting point lower than any of the mixed constituents. According to constituent materials, this group may be subdivided into 3 groups (i) organic-organic, (ii) inorganic-inorganic and (iii) organic-inorganic. In general, they do not segregate and have congruent phase change (Sharma, Tyagi, Chen & Buddhi, 2009)]. The numerous advantages that eutectic PCMs offer over its mixed constituents could help researchers come up with high performance phase change materials with specific desired properties. Eutectic of hydrated salts have shown potential possibilities that could solve some of the existing problems in single hydrated salt. It can be used to tune transition point, reduce super cooling, lower the phase transition point (Wu et al, 2021), and in some cases no observable phase separation (Šavija & Schlangen, 2016).

Microcapsules

Microcapsules are the protective micron size container to prevent leakage of the PCM to the surrounding matrix. Their sizes vary between 1 and 300m (Frølich L, Wadsö L & Sandberg, 2016). They can be applied directly into building material, for example: as partial replacement for sand in concrete (Aguayo et al, 2016; Jayalath et al, 2016; Haurie et al, 2016) or percentage by weight in gypsum wallboard (Kusama & Ishidoya, 2017; Lachheb et al, 2017). The microcapsules, also called shells, provide optimal use of PCMs within building materials such as gypsum wallboard, mortar, concrete, plaster; and within building components such as floors, roofs, walls, ceilings. An ideal shell would have certain properties such as: high mechanical and thermal strength, high thermal conductivity, thermal durability, unreactive with the PCM, prevent leakage of PCM (Rathore, Shukla & Gupta, 2017), and compatibility with matrix of applied building material.

The material which the shells are made from greatly affects their properties. Table 1 is a compendium of some of the commercially available PCM microcapsules that have been used in building materials. Also, it can be seen from Table 2, that most of the commercially available PCM microcapsules are polymers. However, because of some drawbacks of polymer shells such as low mechanical stiffness (Hunger et al, 2009; Giro-Paloma et al, 2016), flammability and low thermal conductivity (Li et al, 2013; Zhao et al, 2016), other material types that could perform better are needed. The desire to reduce the drawbacks has led to many researchers proposing innovative non-polymer materials for microcapsules (Liu, Wang & Qian, 2017). Liu, Wang and Qian (2017),

proposed a novel shell for PCM using ecospheres. It showed that chemosphere is a cheap and easy to synthesize shell compared to existing polymers, and enjoys many advantages over polymer shells. Such advantages include higher mechanical strength because of their 20MPa crushing strength, higher thermal and chemical stability, and higher thermal conductivity because they contain mainly of polycrystalline dense mullite. However, sealing of the surface of these non-polymeric shells with materials that would be chemically inert and prevent leakage of PCM is still a challenge. Therefore, more research work is still needed on microcapsules, most especially non-polymeric shells, as it appears, they could have great potential compared to traditional PCM application in building and MPCM using polymers as shells.

MPCM Incorporation Building Material

Construction materials are expected to meet some minimum standards as stated in various design codes. Any alterations to the constituents making up the material could affect its known properties, behaviour, and its performance in service. Incorporating MPCM into building materials could affect or induce effects on some of the intrinsic properties of the material. Hence, critical review and characterization of concrete and mortar, ultra-high-performance-concrete (UHPC) and wallboard with PCM microcapsules as TES are discussed below.

Mortar and concrete

Fresh Properties

MPCM effects on properties of fresh mortar and concrete has been widely studied by researchers over the past decades. Concrete being one of the most widely used construction material and well known for its strength, especially in load bearing structures, it is cardinal to critically review the effects of PCM microcapsules on its early-stage properties compensate for the workability loss as explained in Figure 2.

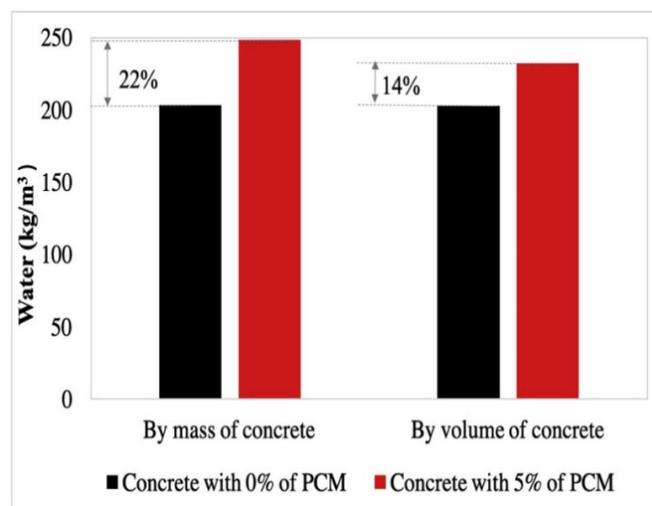


Figure 2: Increase water demand by mix before and after 5% PCM addition

Source: Hunger et al (2009)

Hydration

The application of MPCM into concrete will reduce the temperature rise experienced during cement hydration process, due to the endothermic reaction of the PCM during melting. This phenomenon could help curtail the maximum thermal stress attributed to hydration heat in massive concrete structures and result in less thermal cracking in cementitious composite (Eddahhak et al, 2014). In addition, PCM has the early curing age advantage in cementitious material (Hunger et al, 2009). Often, to measure the hydration rate and heat of hydration, isothermal calorimetric and semi-adiabatic calorimetric are used (Soare et al, 2013). Eddahhak et al, (2014) and Lecompte et al (2015), used semi-adiabatic calorimetric to measure the heat of cement hydration integrated with phase change material microcapsules. These studies found out that in mortars with broken PCM microcapsules, hydration reactions could be delayed, compared to those with unbroken microcapsules. They attributed the delay to leakage of the PCM into the mortar matrix. In another study, Hunger et al. (2009) and Falzone et al (2015) used Micronal DS 5008X as microencapsulated PCM in self-compacting concrete. Semi-adiabatic calorimetric test was carried out to determine the effects of the PCM microcapsules on heat of hydration. The result revealed that incorporating PCM in concrete could reduce the hydration temperature and delay the hydration peak temperature. More so, increasing the amount of PCM microcapsules in concrete could increase the peak of the rate of heat of hydration coupled with a time delay (Figueiredo et al, 2016). It could, therefore, be concluded that MPCM in concrete or mortar could be used to control curing in cementitious' composite, control and reduce thermal stress and consequently mitigate cracks developed in mass concrete structure due to hydration reaction.

Mechanical property results show great potential application for microencapsulated PCM in concrete and mortar matrix in the future. Therefore, more research in this area is required to determine the optimum microcapsules to be incorporated in cement or mortar without significant adverse effect on its strength. Furthermore, PCM microcapsules reduced-density-effect on cementitious material makes it a potential for light weight structures with strength loss within an acceptable structural range (Wang et. Al, 2016; Memon et al, 2015). Compressive strengths of mortars with and without Cano PCM is shown in Figure 3.

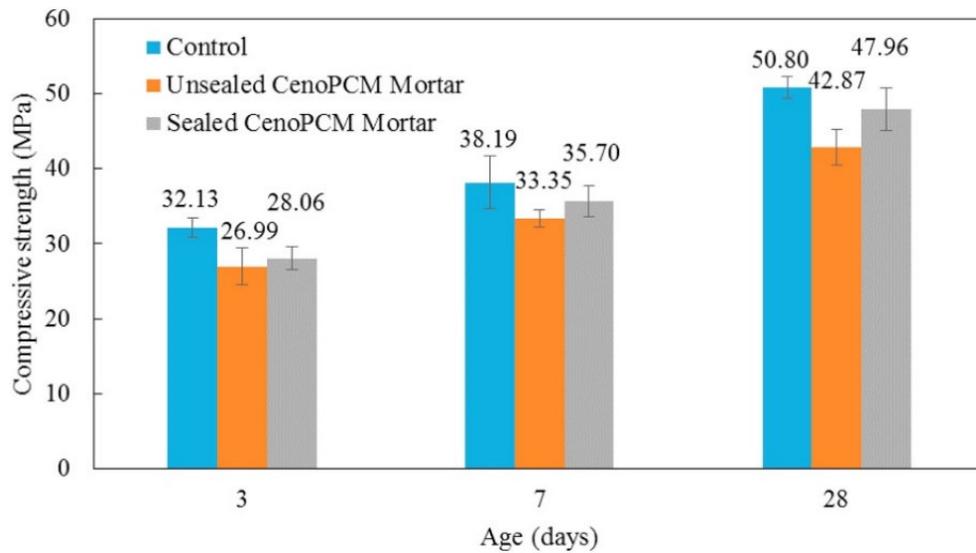


Figure 3: Compressive strengths of mortars with and without Cano PCM

Source: Liu et al (2017)

Thermal properties

To increase the thermal energy storage of concrete or mortar, PCMs are incorporated into these building materials due to their intrinsic ability to store and release heat in latent form. Ordinarily, concrete and mortar have known thermal properties, e.g., thermal conductivity; therefore, it is important to know the effect of adding PCMs to cementitious material. Hence, literature results of properties such as thermal conductivity, specific heat capacity and thermal diffusivity of cementitious composite enhanced with PCM microcapsules are discussed for energy efficiency.

Thermal conductivity

Generally, incorporating PCM microcapsule in concrete and mortar reduces their thermal conductivity. Besides, the thermal conductivity in cementitious composite decreases as the amount of added phase change microcapsules increases. This could be due to the relatively low thermal conductivity of PCM compared to the concrete or mortar matrix (Jayalath et al, 2016; Haurie et al, 2016). Also, it was observed that even small dosage of PCM microcapsules -up to 5%- reduced the thermal conductivity of concrete by about 37% (Jayalath et al, 2016). However, low dosage may not have significant effect on the thermal conductivity of concrete. In addition, the reduced thermal conductivity of cementitious composite could also be linked to the increase in air voids and reduction in density of the composite matrix due to addition of microcapsules (Jayalath et al, 2016; Haurie et al, 2016). Mostly in literature, hot disk and guarded hot disk methods among other available methods have been greatly used to measure the thermal conductivity of material.

Conclusively, addition of MPCM reduces the thermal conductivity of concrete or mortar. However, thermal conductivity of concrete or mortar may be improved by choosing a PCM with high thermal conductivity or enhanced with metallic fillers to improve conductivity or microcapsules with high

thermal conductivity may be used. The reduced thermal conductivity may be advantageous as this could be used to improve concrete thermal insulation capacity (Lucas, Ferreira & De Aguiar, 2013).

Specific heat capacity and thermal diffusivity:

Incorporating PCMs into building materials would substantially increase their specific heat capacity considering PCM's ability to store and release great amount of heat in latent form over a small volume change. The largeness of this heat capacity can be demonstrated in concrete (heat capacity of 1kJ/kgK) integrated with PCM, such as Na₂ SO₄.H₂O (254kJ/kg). The most accurate way to measure the specific heat capacity of concrete has been argued over the years by researchers even though differential scanning calorimeters (DSC) has been widely used for measuring the specific heat capacity of cementitious composites (Jayalath et al, 2016). However, a major limitation attributed to DSC technique is that only small sample size can be analyzed and must be homogeneous (Marani & Nehdi, 2019), although the equivalent heat capacity from the DSC curves is clearly controlled by the heating rate and mass of sample (Eddhahak et al, 2014). Other methods for computing specific heat capacity have been ardently discussed in literature (Meshgin & Xi, 2014; Bahrar et al, 2018; Eddhahak-Ouni et al, 2014).

Gypsum wall board incorporated with MPCM

In the United States, gypsum wall board, also known as plaster board or dry wall is the most common indoor building material. About 30 billion square feet of this material is used for domestic construction uses per year and it has some advantages such as fire resistance, availability, low cost, ease of installation, sound attenuation and nontoxicity (Cui et al, 2015). Therefore, the effect of incorporating MPCM into gypsum board needs to be properly reviewed.

Thermal conductivity and heat capacity

It has been largely recorded in the literature, both numerically and experimentally, that the incorporation of MPCMs into drywalls reduced its thermal conductivity and greatly increased its heat capacity compared to ordinary wall boards (Xu et al, 2016; Cao et al, 2017; Haurie et al, 2016; Hauer et al, 2005; Mehling & Cabeza, 2008 ; Pomianowski et al, 2014). This reduction in thermal conductivity leads to greater energy efficiency and sustainability

The heat capacity of plaster boards with MPCM increases with the replacement level until an optimum amount is reached where further replacements leads to reduction in heat capacity (Hauer et al, 2005; Cabeza et Al, 2015). The optimum amount of MPCM to be added into the wallboard matrix has been observed to be unique for each research study. This may be due to differences in experimentation condition, properties of PCMs used in the study, material properties of the microcapsules, and properties of the wall board and method of preparation of the enhanced wallboard.

As discussed under cementitious material, addition of MPCM into wall board also need to be ardently checked for fire retardancy. It has been shown that the addition of organic PCM, paraffin, increased the flammability of the wall board compared to a plain wallboard (Cabeza et al, 2015). Microencapsulation can contain the PCM and prevent it from getting into the porous structure of the dry wall. However, in a fire event, the temperature could be around 800°C (Walton, Thomas & Ohmiya, 2016). And in such scenario, there is great likelihood that the microcapsule fails and lead to leakage of the PCM into the porous structure of the plaster board to further increase the fire load (Asimakopoulou, Kolaitis & Founti, 2015). And research, to improve fire resistance of MPCM, PCM was mixed with fire retardant and some success was recorded.

Most of the studies on flammability of plaster board enhanced with MPCM used paraffins as PCM. This could be because of its commercially availability, and its reliable phase change property. However, paraffin suffers a major setback and that is flammability. Non paraffin or organic PCM could be explored further since both have better fire retardancy. More so, more studies could be carried out on how the microcapsule can be coated with fire retardants without necessarily affecting the thermal conductivity of the MPCM itself.

Energy saving potential of PCM

The building industry is a very conservative industry. As such is resistant to innovations to promote new energy efficient building. Ryghaug and Sørensen (2009) reported research on how energy efficiency fails in the building industry. It argued that deficiency in public policy to promote energy efficient building, limited governmental efforts, and the conservativeness of the building industry are the three main impedances.

Heating, ventilating, and air conditioning (HVAC) systems have been one of the active ways buildings are being thermally maintained. These systems consume 20-40 % of the total energy consumption in buildings in the USA (Pilehvar et al, 2019). Conditioning vacant indoor space using HVAC systems cause energy waste (Erickson et al, 2021). More also research has shown that more than half of the overall energy consumption in offices are used during unoccupied hours (Rodríguez et al., 2020). PCM incorporated into building could be one of the ways to reduce the operational carbon of buildings through its ability for peak load shifting, reduction of indoor temperatures and flattening the fluctuation indoor temperature (Wang et.al, 2015; Ramakrishnan et al, 2015; Fang et al, 2010). In Figure 4, the incorporation of PCM into building walls ensures thermal comfort for human by reducing the indoor temperature fluctuation, peak load reduction and shifting.

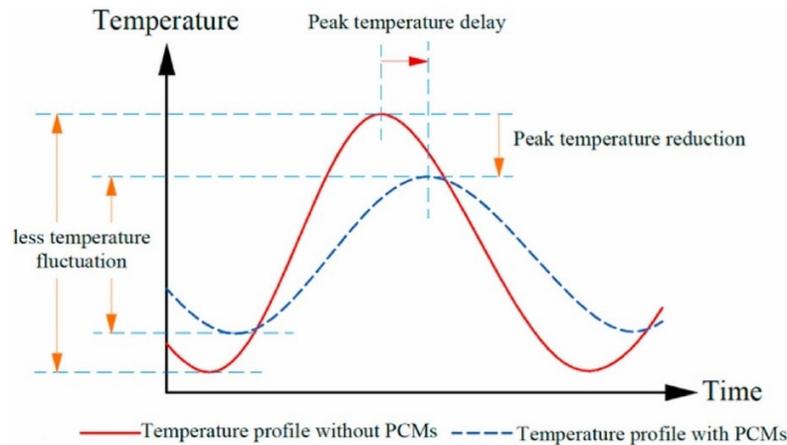


Figure 4: Energy saving potential of building walls with PCM

Source: Haurie et.al (2014)

Nevertheless, despite the huge energy saving potential of PCMs it has not been widely used in the built environment. It is possible this could be due to the absence of actual data showing the performance of building incorporated with PCMs over time. A huge number of numerical experiments, mostly in wallboards, have been carried out and published to bolster the energy savings potential of PCMs; however, this does not represent a substitute for actual data considering a lot of assumptions that goes into modelling.

METHODOLOGY

The study adopted extensive review of literatures and case studies of randomly selected residential buildings in urban neighbourhoods in sixteen Local Government Areas of Lagos state Nigeria. The survey was carried out through photographs of case study buildings (see Plates 1-4) and physical measurement of building envelope elements. This was to identify the buildings construction materials usages and possible energy efficiency.

FINDINGS

Residential Building Construction Materials in Lagos

This refers to the contribution of the construction materials characteristics of households to energy consumption as described by Walls, Roof, Ceilings, Windows, Colour, form, Occupancy rate and roof types. It can be deduced from the view of respondents that household's wall material is represented by 89.9% hollow sand Crete block wall, 8.3% solid brick wall and 1.6% concrete wall. The roof is dominated by corrugated asbestos 47.2%, Iron sheet 26.0%, Aluminium 23.5%, as reinforced concrete represents 1.2% of the roofing materials used in the construction of sampled

houses population. Out of the ceiling materials used in the sampled units, 65% were made up of asbestos, 10.8% P.O.P, 10.1% wood, while 4.8% were U.P.VC, (see Table 3).

Table 3: Building Construction Characteristics

	DESCRIPTION	FREQUENCY	PERCENTAGES (%)
WALL	Solid brick wall	36	8.3
	Hollow sandcrete block wall	390	89.9
	Concrete wall	7	1.6
	Others	1	0.2
	Total	434	100
ROOFS			
	Corrugated Asbestos	205	47.2
	Corrugated Aluminium	102	23.5
	Corrugated Iron sheet	113	26.0
	Reinforced concrete slab	5	1.2
	Others	9	2.1
	Total	434	100
CEILINGS			
	Asbestos	282	65.0
	Wood	44	10.1
	P.O.P	47	10.8
	U.P.V.C	21	4.8
	Others	40	9.3
	Total	434	100.0



Plate 1: Block of Flats at Lagos Island



Plate 2: Terraced Building at University of Lagos



Plate 3: Face-to-Face at Ikeja, Lagos



Plate 4: Multi Family Face-To-Face at Mushin, Lagos

Plates [1-4]: Typical Sampled Residential Buildings

A critical evaluation of Table 3 shows a high percentage of concrete construction material usages, which suggest a need for innovative materials or an improvement on the walling for energy improvement through thermal conductivity property contribution on energy consumption. The roof material components also cementerious and it's accounted for 47.2.% usage in construction, the high humidity value of Lagos will not aid an energy efficiency attainment.

From the foregoing, one can deduce through literature that exploring the thermal efficiency efficacy of MPCM application to replace the existing 89.9% of building envelopes content in Lagos residential buildings construction material will result in efficient energy consumption and a sustainable housing environment. More so, findings revealed that the greater proportion of residential buildings are mostly built with hollow sandcrete block, with asbestos ceiling, having an external circumference in the range of (50 – 100) meter, an external envelope area of (250 – 500) m² with a total floor area range of (250 – 500) m² not more than 25m length in the range of (1000 – 3000) m³ building volume. Most of the households were fixed with single glazed widows, of areas between (1 – 2.5) m² and a total external opening door and window area of (10 – 20) m², with an occupancy rate of five person families. This was assessed through pictorial assessment in Plates 1-4.

DISCUSSIONS

It has been noted that buildings accounting for at least 40% of the global energy consumption and 1/3 of global energy growth of worldwide carbon emission. The issues surrounding energy consumption in Lagos (Nigeria's commercial centre) of about 60% of clean energy supply from

the national grid source suggest a holistic approach solution. Outcome of previous research on existing buildings dominated by thermally insensitive designs and construction, in a high humid climate, clearly suggest a forensic investigation. To this end the most commonly used material for external enclosure (WALL) is a prime building component. However, the issue of construction sector resistance to change (a worldwide phenomenon) remains a challenge for an innovative energy efficient alternative material for housing construction envelope in Nigeria.

Building envelope is used to describe the physical components of the buildings' characteristics, with respect to external walls, windows, door openings and roof to designers, owners and occupants in most time. This, to a great extent determines much of the energy consumed in the building, as their direct interaction with the external environment affects the building's indoor environment. Design ability to the right envelopes' material choices for construction process in attainment of optimal energy use plays a significant role in conservation and efficiency. The building envelopes therefore, involve considerations, for material selections, process considerations, and elemental choice towards use and efficiency attainments. They include the following: external wall, window openings and roof. For the purpose of this paper, external enclosure (WALL) is the prime building component under consideration for alternative material innovation such as PCM. This is on the basis of its thermal conductivity properties consideration and energy efficiency consideration. Lagos city has a mean temperature of 30 degree Celsius and a warm humid climate with a dust laden atmosphere. The humidity is over 80% in the morning, a drop below 65% in the afternoon, and is the major cause of discomfort to inhabitants of Lagos. This requires high amounts of energy to ease the heat produced. A minimum temperature usually occurs between evening and morning, while maximum temperature occurs in the afternoon, and a high energy demand may be required to ease the warm condition. With residential buildings in Lagos having been adjudged to be thermally insensitive, any introduction of thermally sensitive materials or improvement will be welcome, more so if they are energy efficient as energy shortages sometimes encourage a fossil-based alternative that does not encourage a sustainable living environment.

CONCLUSION

Increasing energy efficiency of buildings through Innovative (PCMs) incorporated into building materials is inevitable in order to bridge energy supply gap for sustainable housing in Lagos. Exploring the thermal efficiency of MCPM application to replace the existing 89.9% of building envelopes content will impact positively on efficient energy consumption paving way for energy efficient building construction, through innovative materials. This increases thermal inertia of buildings (walling) thereby giving way to sustainable design to provide thermal comfort for occupants, with supplementary cooling energy in the study area. With building envelopes accounting for more than 47% of energy consumption in Lagos housing PCM application properties in delay of fluctuating temperature through complex thermodynamic nature. Replacing 89.9% composition of building envelope and improving the roof concrete (12%) in the Lagos residential buildings, will result in rapid response to energy efficiency through adoption and application of innovative construction of PCM. The paper concludes that exploring the thermal

efficiency efficacy of MPCM application to replace the existing 89.9% of building envelopes content in Lagos residential buildings construction material will result in efficient energy consumption and a sustainable housing environment.

RECOMMENDATION

It is therefore recommended that energy efficiency, and sustainable housing environment attainment in Lagos should be driven through the innovative incorporation of PCM in construction materials. This will be for the replacement of 89.9% composition of building envelopes and improvement of roof concrete in Lagos residential buildings. This will be made achievable by legislations and policy inclusions in the building code and the proposed green energy efficiency code in Lagos.

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