International Journal for Housing Science and Its Applications
Publish March 30, 2025. Volume 46, Issue 1 Pages 72-83

https://doi.org/10.70517/ijhsa46108

Application of multifunctional building materials in urban high-rise buildings and its environmental adaptability analysis

Zijian Yu[1,*]

[1]Pusan National University, Busan, 612-022, South Korea

Corresponding authors: (e-mail: yzj_psu@163.com).

Abstract In this paper, rare earth elements Ce and La are selected to modify TiO_2 hollow microspheres to prepare Ce-La/TiO_2 hollow microspheres, followed by the fusion of decanoic acid-palmitic acid composite phase change materials with Ce-La/TiO_2 hollow microspheres using vacuum adsorption method to prepare decanoic acid-palmitic acid@Ce-La/TiO_2 multifunctional materials for construction. Four application cases of multifunctional building materials are presented, and the environmental adaptability of the materials is also described and defined in detail, and finally, the applications of multifunctional building materials and their adaptability are analyzed. Multifunctional building materials in a variety of regional environments, have maintained excellent moisturizing effect, the degree of corrosion of traditional building materials is more serious than the degree of corrosion of multifunctional building materials, the difference between the two is about 0.13. Laying decanoic acid-palmitic acid@Ce-La/TiO_2 material on the traditional building materials can effectively improve their corrosion prevention performance.

Index Terms multifunctional building materials, decanoic acid-palmitic acid, Ce-La/TiO2, urban high-rise buildings

I. Introduction

With the continuous development of China's social economy, the level of urban construction is constantly improving, and the status of super high-rise buildings in urban construction is getting higher and higher. In the process of super high-rise building design and construction, the concept of energy saving and environmental protection is also getting more and more attention [1]–[3]. Enterprises need to study the application of new materials for ultra-high-rise buildings in energy-saving design from the perspective of energy-saving design, clarify the problems that should be paid attention to, and improve the application quality of each material [4], [5].

In the construction process of ultra-high-rise buildings, the selection of new materials should be in accordance with the design and construction standards, and the safety and reliability of new materials should be ensured [6], [7]. Since concrete material is the main structural material in ultra-high-rise buildings, attention should be paid to the performance and quality of concrete material when selecting new materials [8]. Secondly, construction materials are for the service of engineering construction, to provide convenience for engineering construction, so when choosing new materials, we should pay attention to the principle of economy. Further in the high-rise building project, the selection of new materials should be consistent with the principle of energy saving [9], [10]. Finally, in the process of ultra-high-rise building construction, it is necessary to implement the concept of green environmental protection and reduce the damage and pollution caused by the building to the environment [11]. In the selection of new materials, it is necessary to try to use new materials that have a small impact on the environment and better performance to reduce the pollution of the environment [12]. It is also necessary to ensure that the production process of new materials can meet the green requirements and minimize the waste of resources [13].

Nowadays, the perception of building materials manufacturing has changed considerably. Whereas in the past there was always an attempt to find a wider field of application for a certain building material, in the future, on the contrary, the technical requirements for building components will determine the nature of the building material [14], [15]. In general, the heat resistance, sound insulation and mechanical properties of building materials, as well as their appearance, do not always meet the technical requirements at the same time. Therefore, scientists are turning to the study of multifunctional building materials it can be said that the prospects for the development of traditional building materials, such as concrete, are not bad, because it is possible to improve their properties by using a variety of new manufacturing processes or by mixing a variety of fibers into the building material [16], [17]. In these cases, engineering researchers should prioritize between the main properties of the material, such as heat resistance, which can be improved through the development of autoclaved or foam concrete, and mechanical properties, which will be improved through the use of high-quality and up to ultra-high-quality concretes for buildings [18], [19]. In order to make the building materials shine, building materials experts around the world are now actively developing composite multifunctional building materials [20].

The advantage of composite materials is that it can combine the properties of several single materials together. Recently, fewer and fewer building materials have been manufactured using a single raw material [21], [22]. Completely new products can be obtained by relying on changes in materials at the molecular level. Thus, synthetic materials that meet various specific requirements can be investigated using a combination of conventional raw materials [23].

Due to the population explosion and urbanization development, countless high-rise buildings rise up to meet the needs of the urban population to live, the popularity of high-rise buildings also brought many corresponding problems, many scholars for high-rise building energy saving and emission reduction, seismic and wind resistance, structural safety and engineering technology applications and other aspects of the research. Abbood et al. [24] on the definition of high-rise buildings, safety features and structural stability of the overview, and focus on the analysis of the existing high-rise building structural systems, such as seismic, wind resistance, etc., for the development of high-rise building construction system provides a certain reference. Giyasov et al. [25] comprehensively analyzed the development of urban high-rise building design and how high-rise buildings affect the urban living environment, based on actual case studies to assess the impact of high-rise building design on urban temperature and wind speed. Gamayunova et al. [26] based on high-rise building research literature and high-rise building technical document analysis, identified the characteristics of high-rise buildings and the concept of high-rise buildings in different regions, focusing on high-rise building specificity, construction technology and high-rise building operation and other key content. Gan et al. [27] conceptualized an overall framework based on building information modeling technology to promote the low-carbon sustainable design of high-rise buildings, and through the feedback of practice, it was proved that the proposed framework was effective in assessing the carbon emissions of high-rise buildings in their life cycle and provided a basis for decision-making on the design of high-rise buildings to reduce carbon emissions.

The application of multifunctional composite building materials is becoming more and more common, so many researchers have carried out in-depth and comprehensive studies from the functional characteristics of composite building materials, practical effects, as well as the manufacturing of composite building materials and the integration of design ideas, aiming at continuously exploring the potential of the application of multifunctional composite building materials, and continuously optimizing the design and manufacturing of multifunctional composite building materials. Based on the design and construction cases of high-rise buildings in the past ten years, Szolomicki and Golasz-Szolomicka [28] systematically reviewed the development of urban high-rise building engineering technology and construction materials, and made positive contributions to the optimization of high-rise building structures, materials and construction plans. Zhao et al. [29] analyzed the fabrication of a multifunctional reinforced grid building material in a thermoelectric element generator (TEG) configuration and showed on numerical evaluation experiments that this multifunctional building material can reduce the energy consumption of a building during its life cycle. Agustí-Juan et al. [30] explored the characteristics of digital building technologies and multifunctional building materials in the field of construction, and pointed out that multifunctional composite materials will consume more energy in their life cycle, and at the end of the life cycle, it will bring obstacles to the recycling of building materials, and the study deepened the knowledge and understanding of multifunctional composite building materials. Tang et al. [31] introduces the cutting-edge research on alkali activated materials (AAMs), pointing out that alkali activated materials (AAMs) have the potential to replace cementitious materials, which in addition to the basic load-bearing capacity, can also be fused with other materials to generate new composite building materials (multifunctional aam), which can effectively improve the reliability and longevity of the infrastructure, buildings, and at the same time, reduce their maintenance costs. D'Alessandro et al. [32] conducted a multi-physics field thermodynamic study in an attempt to investigate the fusion of metamorphic materials with structural concretes, which indicated that innovative concretes incorporating paraffin-based PCMs could be used in parapet structures around energy-efficient buildings and elucidated that PVMs have a lower mass density as well as the ability to interact positively thermally with cementitious materials. Chung [33] examined the electrical resistance, piezoresistive, hot spot, and electromagnetic parameters of multifunctional cementitious materials and proposed various structural optimizations to reduce the cost of composite building materials and improve durability, and finally discussed the application and role of cementitious composite building materials in the construction field.

In the preparation of multifunctional building materials, the more advanced vacuum adsorption method is adopted to prepare decanoic acid-palmitic acid@Ce-La/TiO_2 composites, which effectively avoids the interfering substances brought by the fusion process. In this paper, in order to improve the functionality of traditional building materials, we propose the decanoic acid-palmitic acid@Ce-La/TiO_2 multifunctional building materials, and divide the preparation process of this material into two stages. In the first step, rare earth elements Ce and La were selected to modify the TiO_2 hollow microspheres to make Ce-La/TiO_2 hollow microspheres. In the second step, decanoic acid-palmitic acid composite phase change material was composited with Ce-La/TiO_2 hollow microspheres using vacuum adsorption method to prepare decanoic acid-palmitic acid@Ce-La/TiO_2 composites. Finally, with the help of experimental verification method, the application cases of multifunctional building materials in high-rise buildings and their environmental adaptability are interpreted in depth, aiming to promote the sustainable development of urban buildings.

II. Definition and characterization of multifunctional building materials

II. A. Definition of multifunctional building materials

Nowadays, the way in which the manufacture of building materials is viewed has changed considerably. Whereas in the past it was always the case that people tried to find a wider field of application for a particular building material, in the future, on the contrary, the technical requirements for building components will determine the nature of the building material. As a rule, the heat resistance, diaphragm and mechanical properties as well as the appearance of building materials do not always meet the technical requirements at the same time. Therefore, scientists are turning to multifunctional building materials. Multifunctional building materials are building materials that fulfill the basic building functions with additional use functions. These materials not only have the basic properties of traditional building materials, such as structural support, protection, and decoration, but also incorporate new functions to enhance the performance and use experience of the building [34]–[36].

II. B. Characteristics of multifunctional building materials

Multifunctional building materials production and application has a history of many years, compared to traditional building materials, it has three aspects of the characteristics: First, has a good thermal insulation performance, which is multifunctional building materials in the research and development of the production process needs to pay attention to, due to the climatic characteristics of most regions are the four seasons, the difference between day and night temperatures, has a good thermal insulation performance of the multifunctional building materials to ensure that the main body of the building in the process of reducing internal energy loss, reduce the degree of dependence on heating and air conditioning in winter to achieve a better energy-saving effect". In the process of reducing the internal energy loss, reduce the degree of dependence on heating and air conditioning in winter, to achieve a better energy saving effect. Secondly, it has good structural stability, in recent years, some areas have more and more earthquakes and other geological disasters, and high-rise buildings are designed to be higher and higher, the volume is also growing, so that the user in the choice of building materials, pay more attention to the stability of the overall structure. Thirdly, it can meet the requirements of the concept of green environmental protection, in the process of decades of historical development, air quality and the natural environment continues to deteriorate, bringing great safety hazards to people's daily lives, with the country's emphasis on environmental issues continue to increase the degree of green environmental protection requirements in the construction project is also increasing. For the research and development and production of multifunctional building materials, only on the basis of the above three characteristics can we meet the basic requirements of the development of the high-rise building industry, so as to provide a basic guarantee for the development of the construction industry, and promote the overall development of the construction industry.

III. Preparation and application of multifunctional building materials and their environmental adaptation

III. A. Multifunctional building material preparation

In order to obtain multifunctional composites for buildings with synergistic light-heat-wet properties and improve the functionality of traditional building materials, decanoic acid-palmitic acid@Ce-La/TiO_2 composites were prepared. The preparation of decanoic acid-palmitic acid@Ce-La/TiO_2 composites was mainly divided into two stages, firstly, rare earth elements Ce and La were selected to modify TiO_2 hollow microspheres to prepare Ce-La/TiO_2 hollow microspheres, and then the vacuum adsorption method was used to composite the decanoic acid-palmitic acid composite phase change material with Ce-La/TiO_2 hollow microspheres to prepare decanoic acid-palmitic acid@Ce-La/TiO_2 composites. Ce-La/TiO_2 composites.

III. A. 1) Preparation of Ce-La/TiO_2 hollow microspheres

The test reagents used for the preparation of Ce-La/TiO_2 hollow microspheres are shown in Table 1 and the test apparatus is shown in Table 2. Preparation process: Preparation of nano-SiO_2 spheres: 50 ml of anhydrous ethanol, 20 ml of deionized water, 2.5 ml of ammonia were mixed and placed in a conical flask, and a homogeneous solution was obtained by magnetic stirring for 20 min at room temperature. A mixture consisting of a certain amount of tetraethyl silicate and 30 ml of anhydrous ethanol was added drop by drop to the above solution, and the drop was controlled to finish in 30 min. Then magnetic stirring was used for 4h to obtain nano-SiO_2 spheres, and after centrifugal washing of the nano-SiO_2 spheres using anhydrous ethanol for 3 times, they were dispersed in 20 ml of anhydrous ethanol to form a nano-SiO_2 spheres dispersion. Preparation of mixture A: 50 ml of anhydrous ethanol, a certain amount of different types of surfactants (polyvinylpyrrolidone or hydroxypropyl cellulose) and a certain ratio of doping elements Ce and La, i.e., $Ce(NO_3)_3 6H_2O$ and $La(NO_3)_3 6H_2O$, were sequentially added to the nanosized SiO_2 spheres dispersion. $6H_2O$, after ultrasonic dispersion for 30 min to make a homogeneous mixture A. Preparation of mixture B: a certain amount of tetrabutyl titanate was mixed with 30 ml of anhydrous ethanol, and the mixture B was formed by stirring homogeneously. Preparation of Ce-La/TiO_2 hollow microspheres: the mixture C was slowly heated up to 75 ℃, and the mixture C was mixed by refluxing at a constant temperature and magnetic stirring for 90 min, and washed five times with anhydrous ethanol centrifugal washing. centrifugal washing with anhydrous ethanol for 5 times and vacuum drying at 60 °C to obtain TiO_2-SiO_2 composite microsphere gel. The TiO_2-SiO_2 composite microsphere gel was calcined at a certain temperature with a holding time of 2h to obtain TiO_2-SiO_2 composite microspheres. The TiO_2-SiO_2 composite microspheres were dispersed in 30 ml of deionized water, and 50 ml of NaOH solution with a concentration of 0.3 mol/L was added, and then the reaction was carried out by medium-speed magnetic stirring, and the temperature was elevated to 85°C for 3 h. The reaction was washed by centrifugal washing with deionized water for 4 times in order to remove SiO_2 templates, and finally, it was placed in a vacuum drying oven at 60°C for drying, to obtain Ce-La/TiO_2 hollow microspheres.

Experimental reagent	Molecular formula	Specification	Manufacturer
Tetraethyl silicate (TEOS)	$C_8H_{20}O_4Si$	Analytically pure	Shanghai Maclin Biochemical Technology Co., LTD.
Tetrabutyl titanate (TBOT)	$C_{16}H_{36}O_4Ti$	Analytically pure	Shanghai Maclin Biochemical Technology Co., LTD.
Cerous nitrate hexahydrate	$Ce(NO_3)_36H_2O$	Analytically pure	Shanghai Maclin Biochemical Technology Co., LTD.
Lanthanum nitrate hexahydrate	$La(NO_3)_3\ 6H_2O$	Analytically pure	Shanghai Maclin Biochemical Technology Co., LTD.
Polythylzallolidone(PVP)	PVPK30	Analytically pure	Shanghai Maclin Biochemical Technology Co., LTD.
Hydroxypropyl cellulose(HPC)	$C_{36}H_{70}O_{19}$	Analytically pure	Shanghai Maclin Biochemical Technology Co., LTD.
Anhydrous ethanol	$CH_3CH\ _2OH$	Analytically pure	Shanghai Maclin Biochemical Technology Co., LTD.
Ammonia liquor	NH_3OH	Analytically pure	Shanghai Maclin Biochemical Technology Co., LTD.

Table 1: Test reagent

Experimental instrument	Model number	Manufacturer
Precision electronic balance	AUW120D	Shimadzu Corporation of Japan
Vacuum constant temperature drying oven	DZ-2BC II	Guangzhou Huruiming Instrument Co., LTD
Electric blast drying oven	101-2AB	Tianjin Test Instrument Co., LTD
Instrument thermostatic water bath	SL-11	Shanghai establish instrument Co., LTD
Digital display constant temperature magnetic stirrer	85-2	Jintan shore head Guorui experimental instrument factory
Separator funnel	PHS-25	Shanghai Yi Electrical Scientific Instrument Co., LTD
Cell washing centrifuge	TL-4.7W	Tianjin Test Instrument Co., LTD
Box type resistance furnace	SX-4-10	

Table 2: Experiment equipment

III. A. 2) Preparation of decanoic acid-palmitic acid@Ce-La/TiO_2 materials

Table 3 shows the performance indexes of raw materials. There are many kinds of phase change materials with phase change thermoregulation performance, but the phase change materials that can be applied to building materials are required to have a phase change temperature compatible with human comfort and at the same time, they are required to have a large latent heat, good energy storage, nontoxic, harmless and from a wide range of sources, and so on. Therefore, combining the results of previous research, this study selects decanoic acid and palmitic acid as the raw materials of phase change materials, and obtains the phase change temperature and enthalpy of phase change to meet the requirements of building composites through the composite preparation process.

The test parameters were set as shown in Table 4. The preparation method of decanoic acid-palmitic acid composite phase change material: decanoic acid and palmitic acid were mixed and weighed into a beaker according to the mass ratio of 85.5%/14.5%, dissolved and stirred for 2h at 60°C in a water bath to make it dispersed homogeneously to obtain the decanoic acid-palmitic acid composite phase change material. Decanoic acid-palmitic acid@Ce-La/TiO_2 composites were prepared by the following method: Ce-La/TiO_2 hollow microspheres, i.e., the surfactant was PVP, the Ce-La doping amount (the ratio of Ce-La to tetrabutyl titanate by volume) was 1.0 %, the Ce to La ratio by volume was 1.0, the tetraethyl silicate dosage (the ratio of tetraethyl silicate to tetrabutyl titanate by volume) was 0.5 and Calcined at 450 ℃, mixed with a certain amount of decanoic acid-palmitic acid composite phase change material (decanoic acid-palmitic acid and Ce-La/TiO_2 hollow microspheres of the mass ratio), placed in a vacuum constant temperature drying oven, controlling the different vacuum degrees, heating to 50 ℃ so that the decanoic acid-palmitic acid composite phase change material is fully adsorbed in Ce-La/TiO_2 hollow microspheres, fully reacted for 1 h and then open the valve. Repeat 3 times to obtain decanoic acid-palmitic acid@Ce-La/TiO_2 composite materials, the experimental instruments used in this test are mainly precision electronic balance and vacuum constant temperature drying oven.

Raw materials	Chemical formula	Manufacturer	Phase transition temperature /℃	Phase transition HAN /(J/g)
Capric acid	$CH_3(CH_2)_8CO(OH)$	Sinopharm Group Chemical reagent Co., LTD	31.52	164.8
Palmitic acid	$C_{16}H_{32}O_2$	Sinopharm Group Chemical reagent Co., LTD	61.99	219.4

Table 3: Performance indicators of raw materials

Sample number.	Vacuum degree /Pa	Dosage of capric acid and palmitic acid
1#	5.2×10^4	0.4
2#	5.2×10^4	0.45
3#	5.2×10^4	0.46
4#	5.2×10^4	0.47
5#	7.2×10^4	0.51
6#	5.7×10^4	0.52
7#	1.9×10^4	0.53

Table 4: Test parameter setting

III. B. Application cases of multifunctional building materials

III. B. 1) Insulation works

Decanoic acid-palmitic acid@Ce-La/TiO_2 composite material has been successfully used in EPS thin plaster exterior insulation project binder and protective layer plaster mortar. The mortar has been successfully applied in many neighborhoods, and the construction area of external thermal insulation reaches more than 200,000 square meters. For example, cell A, cell B, cell C, etc. At the same time, like a loss of swimming and diving hall and some other venues in the insulation renovation project also used decanoic acid - palmitic acid @ Ce-La/TiO_2 composite materials and processes.

III. B. 2) Protective works

At present, decanoic acid-palmitic acid@Ce-La/TiO_2 composites are widely used in many places by virtue of good quality and favorable price, and it has been used in city construction projects and municipal bridge concrete protection projects in other cities such as Baliutai overpass in a certain city and Wangdindi overpass in other cities.

III. B. 3) Damp-proofing of high-rise buildings

The application of decanoic acid-palmitic acid@Ce-La/TiO_2 composite material and construction technology has the advantages of simple construction and low cost, and the construction effect is also very good, which can be widely used in office buildings, office buildings and so on, for example, a group of conference rooms and living rooms, a cement factory and a neighborhood indoor are used in this kind of material and technology, and achieved better results,. Using decanoic acid-palmitic acid@Ce-La/TiO_2 composite material on the asbestos cement board smeared twice, after that, directly paste tiles, the whole project is completed, the construction period is reduced, the quality is improved, and the effect of moisture-proof is especially obvious.

III. B. 4) Underground waterproofing

There are also many successful examples of decanoic acid-palmitic acid@Ce-La/TiO_2 composites used for basement waterproofing. For example, a group plant basement using this material and technology, a technical teacher training college library basement waterproofing and other projects have also been successfully applied. In conclusion, decanoic acid - palmitic acid @ Ce-La/TiO_2 composite material water-based environmental protection, easy construction, reliable performance, is a new type of reliable performance in a variety of high-rise buildings can be widely used in new functional materials.

III. C. Environmental adaptation

In recent years, sustainable development of buildings has become an important research topic in the construction industry, and the development of multifunctional materials as the most direct way of sustainable development of buildings has also been attracting much attention. As the environmental adaptability of multifunctional building materials in urban high-rise buildings becomes more and more demanding, the application of multifunctional building materials is becoming more and more widespread. Multi-functional building materials itself has excellent performance makes it has as the potential advantages of the material itself, but the complexity of the external environment of the building, so that multi-functional building materials not only need to meet the requirements of sustainable development, but also need to meet the conditions of the use of the environment. Environmental adaptability refers to the ability of a system, organization or individual to maintain or enhance its performance and function through its own adjustment, improvement and optimization strategies when facing changes in the external environment. On the basis of theoretical analysis, the environmental adaptability of multifunctional building materials in urban high-rise buildings is explored in terms of irradiation resistance, corrosion resistance, high temperature resistance, etc., and the detailed investigation process will be carried out around it in the following.

IV. Multifunctional building material applications and their adaptation analysis

IV. A. Testing of material properties

IV. A. 1) Description of the test

The material was characterized using a series of thermal and spectroscopic techniques. Infrared spectroscopy was employed to analyze the molecular structure of the sample using an infrared spectrometer. Temperature and latent heat analysis was conducted to determine key thermal properties, including phase transition temperatures and latent heat values. A subcooling test was performed using a step-cooling curve to evaluate the degree of subcooling during the cooling process. To assess heat transfer properties, melting and cooling cycle experiments were carried out using a constant temperature heating bath and a low-temperature cooling bath. Finally, thermal stability was evaluated through thermogravimetric analysis (TGA), providing insight into the decomposition behavior and thermal endurance of the material.

IV. A. 2) Analysis of results

The infrared spectral test results of the multifunctional building materials are shown in Figure 1. Based on the data in the figure, it can be seen that the multifunctional building materials prepared in this paper mainly contain all the characteristic absorption peaks of two substances (decanoic acid-palmitic acid and Ce-La/TiO_2), and there is no new characteristic absorption peaks, which indicates that there is no chemical interaction between the raw materials and no new substances are produced, and in addition it can also be seen that the transmittance of decanoic acid-palmitic acid is greater than that of Ce-La/TiO_2, which indicates that the light-gathering performance of decanoic acid-palmitic acid is excellent. Palmitic acid has excellent light-gathering properties.

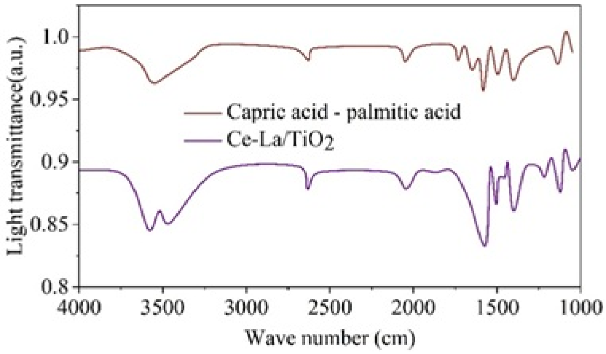


Figure 1: Infrared spectroscopic test results of multifunctional building materials

Temperature and latent heat measurements were performed on the decanoic acid-palmitic acid@Ce-La/TiO_2 samples in Table 4, and the results of temperature and latent heat measurements are shown in Table 5. According to the data in the table, it can be seen that with the increment of the mass fraction of decanoic acid-palmitic acid@Ce-La/TiO_2, the relative corresponding temperature and latent heat measurements are also enhanced, indicating that the moderate increase of its mass fraction can effectively enhance the thermal insulation performance of its multifunctional building materials.

N	Dosage of capric acid and palmitic acid	Temperature /℃	Latent heat (/J·g^{-1})
1#	0.4	33.871	165.087
2#	0.45	35.947	172.651
3#	0.46	36.015	184.416
4#	0.47	37.066	192.292
5#	0.51	38.627	200.888
6#	0.52	40.752	209.865
7#	0.53	45.581	215.669

Table 5: Measurement of temperature and latent heat

The subcooling tests were performed on Ce-La/TiO_2, decanoic acid-palmitic acid, and decanoic acid-palmitic acid@Ce-La/TiO_2, respectively, to demonstrate the performance enhancement of the two fusions, and the results of the subcooling degree test are shown in Figure 2. Decanoic acid-palmitic acid@Ce-La/TiO_2 has the lowest subcooling degree of about 0.87 °C, followed by decanoic acid-palmitic acid, and the highest one is Ce-La/TiO_2.This is because the entry of Ce-La/TiO_2 into the system can provide a preferential deposition site during the preparation of Ce-La/TiO_2 materials, induce non-uniform nucleation, and reduce the uniformity of the Ce-La/TiO_2 The crystallization driving force and phase transition resistance of nucleation led to a decrease in the supercooling degree of decanoic acid-palmitic acid material, but the precipitation occurred under the influence of gravity during the preparation of the material, which could not completely inhibit the phase separation of Ce-La/TiO_2, and thus the supercooling degree was decreased though, which inhibited the supercooling phenomenon from further aggravation.

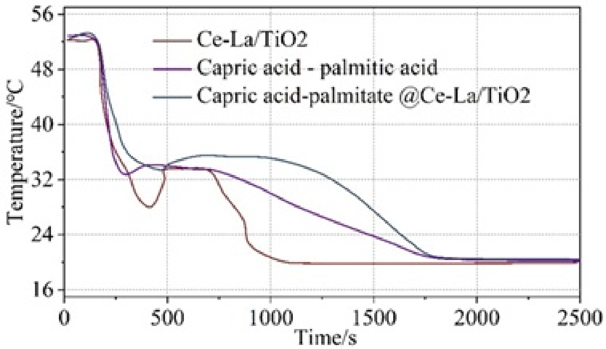


Figure 2: Subcooling test results

The heat transfer properties of Ce-La/TiO_2 and decanoic acid-palmitic acid@Ce-La/TiO_2 were tested using the experimental apparatus, and the results of the heat transfer properties are shown in Figure 3. During the heating and cooling process, the heating rate and cooling rate of decanoic acid-palmitic acid@Ce-La/TiO_2 material are significantly higher than that of Ce-La/TiO_2 material, and the phase transition platform is significantly shorter than that of Ce-La/TiO_2 material. The storage and exothermic times of the materials were calculated, and the storage and exothermic times of decanoic acid-palmitic acid@Ce-La/TiO_2 were 1989 s and 1271 s, respectively, and those of Ce-La/TiO_2 were 1617 s and 1012 s. The storage and exothermic times of decanoic acid-palmitic acid@Ce-La/TiO_2 were significantly higher than those of Ce-La/TiO_2. La/TiO_2, which indicates that the decanoic acid-palmitic acid@Ce-La/TiO_2 material possesses better heat transfer properties.

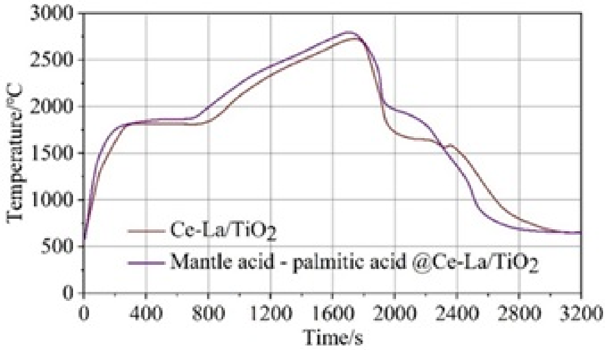


Figure 3: Heat transfer performance test results

The same method was taken to analyze the thermal stability of Ce-La/TiO_2, decanoic acid-palmitic acid, and decanoic acid-palmitic acid@Ce-La/TiO_2, and the results of the thermal stability analysis are demonstrated in Figure 4. When the temperature reaches 116 °C, the mass of the material starts to decrease dramatically, which is the mass change caused by the evaporation of the water of crystallization in the system. When the temperature reached 420°C, the mass loss of Ce-La/TiO_2, capric-palmitic acid, and capric-palmitic acid@Ce-La/TiO_2 was 90.09%, 85.7%, and 80.6%, respectively.

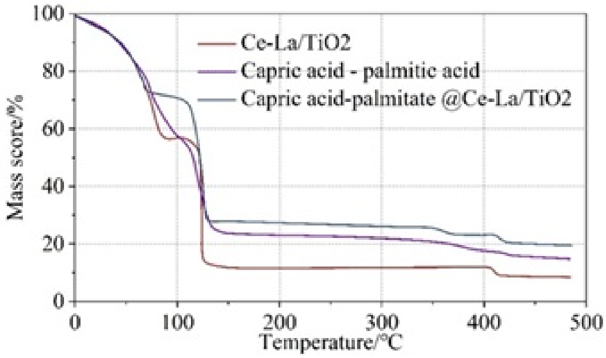


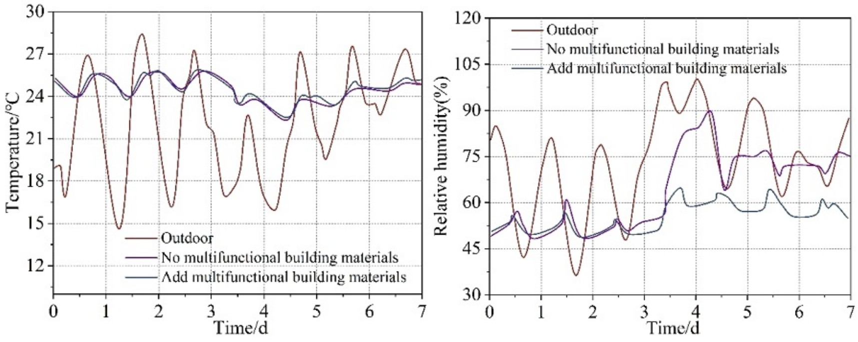
Figure 4: Thermal stability analysis results

IV. B. Analysis of the application effect of multifunctional building materials

This subsection analyzes the changes in indoor humidity after the application of decanoic acid-palmitic acid@Ce-La/TiO_2 in high-rise office buildings in different climatic regions using EnergyPlus numerical simulation software. EnergyPlus numerical simulation software is used to analyze the change of indoor humidity after the application of decanoic acid-palmitic acid@Ce-La/TiO_2 in high-rise office buildings in different climatic zones, with the aim of providing data support for the application of this material in actual high-rise buildings. The outdoor climate varies greatly in different climate zones, so typical cities in different climate zones are selected for simulation and analysis. The cold region choose Q city, cold region choose R city, hot summer and cold winter region choose S city, hot summer and warm winter region choose T city, mild region choose U city as the simulation of the city, simulation time period for the 15th of July to July 21st. Simulate the application effect in the case of laying thickness of 50mm, laying area of 70.32m2 (all four walls except doors and windows are laid with decanoic acid-palmitic acid@Ce-La/TiO_2 material), and the number of ventilation and air exchange is 0.5 times/h.

IV. B. 1) Effectiveness of application in cold regions

Figure 5 shows the dynamic change curves of indoor and outdoor temperature and humidity when there are no multifunctional building materials indoors in the severe cold region, where 5(a) to 5(b) are the temperature and relative humidity, respectively. As shown in the figure, the minimum outdoor temperature is 14.72°C and the maximum is 28.11°C, and the overall temperature is low. Before 3d, the temperature in the room with multifunctional building materials was not much different from that in the room without multifunctional building materials. after 3d, the temperature in the room without multifunctional building materials was lower than that in the room with multifunctional building materials by about 0.273℃ due to the lower outdoor temperature. Overall, the effect of multifunctional building materials on indoor temperature was not significant. During the simulation time period, the maximum outdoor relative humidity is 97.32% and the minimum is 35.94%, and there is a large difference in relative humidity between day and night. 2.8d ago, the difference in relative humidity between the room with and without multifunctional building materials was not significant, and it was all maintained between 52 and 63%. 2.8d later, with the large increase in the outdoor relative humidity, the relative humidity in the room with undeclared multifunctional building materials increased rapidly to 87.32%, and the relative humidity was about 0.273°C lower than that in the room with undeclared multifunctional building materials. The relative humidity rose rapidly to about 87.32% and then dropped to about 64.71% in a short time, which was very easy to cause the indoor staff's uncomfortable feeling. The relative humidity in the room with multifunctional building materials also rises, but the rise is small, only up to 65.88% or so, and there is no rapid decline in the situation, the overall indoor relative humidity is maintained in a more stable range. Compared with the room without multi-functional building materials, the maximum reduction of indoor relative humidity after laying multi-functional building materials is about 25.39%. It is easy to see that after laying multi-functional building materials, it can effectively slow down the fluctuation of indoor relative humidity caused by the sudden change of outdoor relative humidity, and play an obvious role in regulating indoor relative humidity.

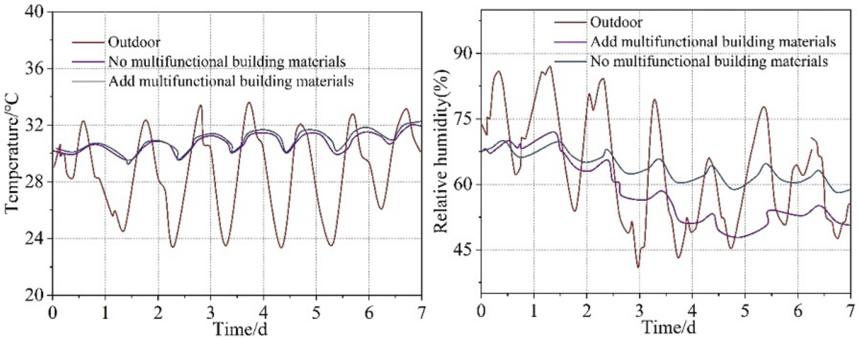


(a)Temperature (b)Relative humidity

Figure 5: Application effect of materials in cold areas

IV. B. 2) Effectiveness of application in cold regions

Figure 6 shows the dynamic change curve of indoor and outdoor temperature and humidity when there are no multi-functional building materials indoors in cold regions. In the simulated time period, the highest outdoor temperature is 33.13℃, the lowest temperature is 23.32℃, and the daily change rule of day and night is basically similar, so the indoor temperature does not change much, and the fluctuation range is about 28.79℃~30.82℃. Compared with the room without multifunctional building materials, the indoor temperature increases about 0.38℃ after laying multifunctional building materials. The maximum value of outdoor relative humidity is 87.47%, and the minimum value is 40.91%. As the simulation time advances, the indoor relative humidity in the room with multifunctional building materials is significantly lower than that in the room without multifunctional building materials, and the maximum reduction of indoor relative humidity is 11.54%. The relative humidity in the room with multifunctional building materials is basically maintained at 45.8%∼67.3%, which is in a more comfortable range.

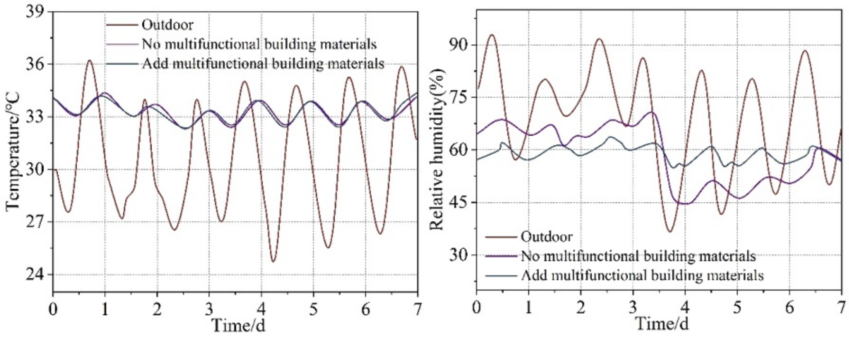


(a)Temperature (b)Relative humidity

Figure 6: Application effect in cold areas

IV. B. 3) Effectiveness of application in hot summer and cold winter areas

The application effect of hot summer and cold winter region based on multifunctional building materials is shown in Figure 7. Before 3.3d, the outdoor relative humidity has been in a high range, the maximum value of relative humidity reaches 94%, at this time, the relative humidity fluctuation range in the room without multifunctional building materials is 60.81∼69.92%, the relative humidity fluctuation range in the room with multifunctional building materials is 57.81∼62.03%, the indoor relative humidity after laying the multifunctional building materials is significantly reduced. In 3.3d, the outdoor relative humidity decreased rapidly from 85% to 35.86%, and the relative humidity in the room without multifunctional building materials also decreased significantly from 69.92% to 43.75%. The relative humidity in the room with multi-functional building materials did not appear to decline rapidly, and the indoor relative humidity was maintained between 54.98∼59.97%, which proved that multi-functional building materials can effectively regulate the indoor relative humidity, keep it in a stable range, and reduce the indoor relative humidity fluctuations caused by the large changes in outdoor relative humidity.

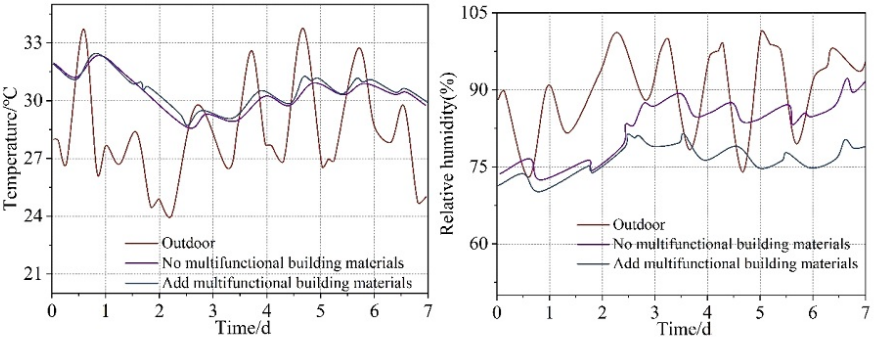


(a)Temperature (b)Relative humidity

Figure 7: Application effect in hot summer and cold winter areas

IV. B. 4) Effectiveness of application in hot summer and warm winter areas

Figure 8 demonstrates the effect of material application in hot summer and warm winter regions. The highest outdoor temperature is 33.72°C and the lowest is 23.81°C. There is a significant decrease in the outdoor temperature in about 1d, so the indoor temperature also shows a decreasing trend. The temperature trend of the room with multifunctional building materials and the room without multifunctional building materials is basically the same, and there is no obvious difference. The simulation time period outdoor relative humidity has been located in a high range, the maximum value of relative humidity is 97.91%, and the minimum value is 63.79%. From 1.5d, the outdoor relative humidity rises from 74.67% to 98.07%, at this time, the relative humidity in the room of the unpainted multifunctional building materials rises from 64.95% to about 84.03%, and the relative humidity in the room of the painted multifunctional building materials rises from 63.94% to 74.98%, and with the advancement of simulation time, the relative humidity in the room of the painted multifunctional building materials is higher than that in the room of the unpainted multifunctional building materials. As the simulation time progresses, the relative humidity in the room with multifunctional building materials is about 11.22% lower than that in the room without multifunctional building materials. After laying multifunctional building materials, the indoor relative humidity is significantly reduced, but due to the high outdoor relative humidity, the indoor relative humidity is still in the range of 63.88∼71.27%, so under this climatic condition, it should be combined with other humidification methods to achieve the purpose of reducing the indoor relative humidity to the range that is just comfortable.

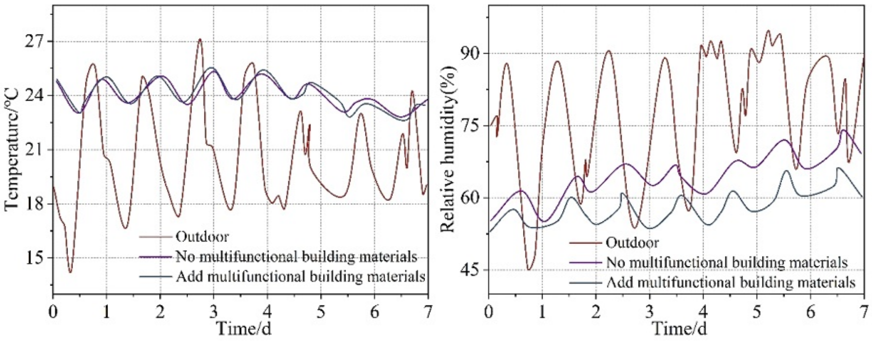


(a)Temperature (b)Relative humidity

Figure 8: Application effect in hot summer and warm winter areas

IV. B. 5) Effectiveness of application in moderate areas

Figure 9 shows the effect of multi-functional building materials in the application of mild areas. 4.2d before the daily outdoor temperature change is basically the same, the indoor temperature is also more stable, 4.2d after the outdoor temperature is reduced, the indoor temperature is also a small reduction in the temperature of the room with multi-functional building materials and the temperature of the room without multi-functional building materials is basically the same. The temperature in the room with multifunctional building materials is basically the same as the temperature in the room without multifunctional building materials. Outdoor relative humidity fluctuates widely in the simulated time period, with the maximum value of relative humidity being 93.91% and the minimum value being 43.73%, and the minimum relative humidity of each day is on the rise. The relative humidity in the room without multifunctional building materials gradually rises to about 67.84%, and the relative humidity in the room with multifunctional building materials also shows an overall slow rising trend, and the average reduction of indoor relative humidity after laying multifunctional building materials is about 8.23%. Under these climatic conditions, the multifunctional building materials with decanoic acid-palmitic acid@Ce-La/TiO_2 material can effectively reduce the indoor relative humidity and maintain the indoor relative humidity at about 52.99∼63.07%.



(a)Temperature (b)Relative humidity

Figure 9: Application effect in hot summer and cold winter areas

IV. C. Assessment of the environmental suitability of multifunctional building materials

As can be seen from the above, the environmental adaptability assessment includes irradiation resistance, corrosion resistance, high temperature resistance and other aspects, taking corrosion resistance as an example, the detailed development of multifunctional building materials in high-rise buildings in the environmental adaptability assessment, the experiments set up two kinds of samples, one for the traditional building materials, and the other for multifunctional building materials, two kinds of samples are placed in the outdoor at the same time, the experimental period of one month, every day, there is a professional statistics of the degree of corrosion. Corrosion degree, corrosion resistance test results as shown in Figure 10, the horizontal axis for the time, the vertical axis for the degree of corrosion, due to artificial statistics to avoid errors, the width of the outline of the two line segments indicates the error value of its data. It can be clearly seen that after a month of testing, it is found that the corrosion degree of traditional building materials is about 0.275, while the corrosion degree of multifunctional building materials is about 0.145, and there is an obvious gap between the two, with a difference value of about 0.13, which concludes that the corrosion resistance of the traditional building materials is significantly improved after adding decanoic acid-palmitic acid@Ce-La/TiO_2 materials on the basis of the traditional building materials, which is more helpful for the construction and development of urban high-rise buildings.

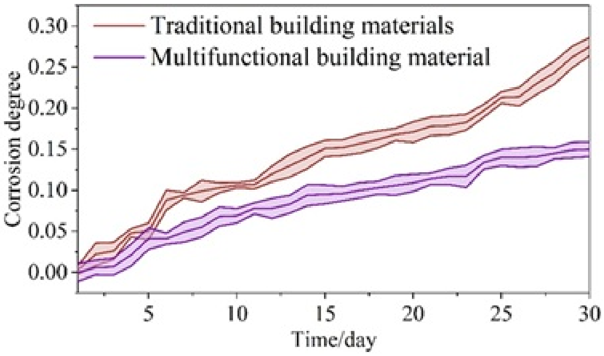


Figure 10: Corrosion resistance test results

V. Conclusion

The article prepares decanoic acid-palmitic acid@Ce-La/TiO_2 multifunctional building material through two processes, systematically outlines the specific application and environmental adaptability of this material in urban high-rise buildings, and verifies the reliability of this research through experimental analysis.

(1) Decanoic acid-palmitic acid@Ce-La/TiO_2, with heat storage and exothermic times of 1989s and 1271s, performs better in terms of heat transfer performance compared to Ce-La/TiO_2, as well as in terms of thermal stability, subcooling test, temperature and latent heat.

(2) Regardless of the region, after laying the multifunctional building materials, it can effectively reduce the indoor relative humidity caused by the sudden change of outdoor relative humidity, and well regulate the indoor relative humidity of the high-rise building, so that the building has a good living comfort.

(3) Through one-month experimental observation, it is found that the corrosion degree of traditional building materials is about 0.13 higher than that of multifunctional building materials, which indicates that the integration of decanoic acid-palmitic acid@Ce-La/TiO_2 materials on the original building materials can realize the purpose of enhancing the effect of environmental adaptability.

References

[1] Thongkamsuk P, Sudasna K, Tondee T. Waste generated in high-rise buildings construction: A current situation in Thailand. Energy Procedia. 2017 Oct 1;138:411-416.

[2] Fantilli AP, Mancinelli O, Chiaia B. The carbon footprint of normal and high-strength concrete used in low-rise and high-rise buildings. Case Studies in Construction Materials. 2019 Dec 1;11:e00296.

[3] Gan VJ, Chan CM, Tse KT, Lo IM, Cheng JC. A comparative analysis of embodied carbon in high-rise buildings regarding different design parameters. Journal of Cleaner Production. 2017 Sep 10;161:663-675.

[4] Thai HT, Ngo T, Uy B. A review on modular construction for high-rise buildings. InStructures 2020 Dec 1 (Vol. 28, pp. 1265-1290). Elsevier.

[5] Potekhin I, Mischenko V, Mottaeva A, Zheltenkov A. Evaluation of possibility to increasing sustainability of high-rise buildings through use university intellectual property. InE3S Web of Conferences 2018 (Vol. 33, p. 03020). EDP Sciences.

[6] Jafary Nasab T, Monavari SM, Jozi SA, Majedi H. Assessment of carbon footprint in the construction phase of high-rise constructions in Tehran. International Journal of Environmental Science and Technology. 2020 Jun;17:3153-3164.

[7] Hu L, Milke JA, Merci B. Special issue on fire safety of high-rise buildings. Fire Technology. 2017 Jan;53:1-3.

[8] Chau CK, Xu JM, Leung TM, Ng WY. Evaluation of the impacts of end-of-life management strategies for deconstruction of a high-rise concrete framed office building. Applied Energy. 2017 Jan 1;185:1595-1603.

[9] Ahmad T, Aibinu A, Thaheem MJ. The effects of high-rise residential construction on sustainability of housing systems. Procedia Engineering. 2017 Jan 1;180:1695-1704.

[10] Gu H, Liang S, Bergman R. Comparison of building construction and life-cycle cost for a high-rise mass timber building with its concrete alternative. Forest Products Journal. 2020 Nov 1;70(4):482-492.

[11] Wang J, Yu C, Pan W. Life cycle energy of high-rise office buildings in Hong Kong. Energy and Buildings. 2018 May 15;167:152-164.

[12] Chen Z, Gu H, Bergman RD, Liang S. Comparative life-cycle assessment of a high-rise mass timber building with an equivalent reinforced concrete alternative using the Athena impact estimator for buildings. Sustainability. 2020 Jun 9;12(11):4708.

[13] Nugroho NY, Triyadi S, Wonorahardjo S. Effect of high-rise buildings on the surrounding thermal environment. Building and Environment. 2022 Jan 1;207:108393.

[14] Bomberg M, Furtak M, Yarbrough D. Buildings with environmental quality management: Part 1: Designing multifunctional construction materials. Journal of Building Physics. 2017 Nov;41(3):193-208.

[15] Allen E, Iano J. Fundamentals of Building Construction: Materials and Methods. John Wiley & Sons; 2019 Oct 15.

[16] Heveran CM, Williams SL, Qiu J, Artier J, Hubler MH, Cook SM, Cameron JC, Srubar WV. Biomineralization and successive regeneration of engineered living building materials. Matter. 2020 Feb 5;2(2):481-94.

[17] Illston JM, Domone P. Construction Materials: Their Nature and Behaviour. CRC press; 2001 Aug 30.

[18] Elizondo-Martínez EJ, Andrés-Valeri VC, Jato-Espino D, Rodriguez-Hernandez J. Review of porous concrete as multifunctional and sustainable pavement. Journal of Building Engineering. 2020 Jan 1;27:100967.

[19] Anand CK, Amor B. Recent developments, future challenges and new research directions in LCA of buildings: A critical review. Renewable and Sustainable Energy Reviews. 2017 Jan 1;67:408-16.

[20] Lendlein A, Trask RS. Multifunctional materials: concepts, function-structure relationships, knowledge-based design, translational materials research. Multi-functional Materials. 2018 Aug 28;1(1):010201.

[21] Han B, Zhang L, Ou J. Smart and Multifunctional Concrete Toward Sustainable Infrastructures. Singapore:: Springer; 2017 Jun 12.

[22] Cao MQ, Liu TT, Zhu YH, Shu JC, Cao MS. Developing electromagnetic functional materials for green building. Journal of Building Engineering. 2022 Jan 1;45:103496.

[23] Liu TT, Cao MQ, Fang YS, Zhu YH, Cao MS. Green building materials lit up by electromagnetic absorption function: A review. Journal of Materials Science & Technology. 2022 Jun 10;112:329-44.

[24] Abbood IS, Jasim MA, Weli SS. High Rise Buildings: Design, Analysis, and Safety-An Overview. International Journal of Architectural Engineering technology. 2021 Mar;3:1-3.

[25] Giyasov B, Giyasova I. The impact of high-rise buildings on the living environment. InE3S Web of Conferences 2018 (Vol. 33, p. 01045). EDP Sciences.

[26] Gamayunova O, Spitsov D. Technical features of the construction of high-rise buildings. InE3S Web of Conferences 2020 (Vol. 164, p. 08008). EDP Sciences.

[27] Gan VJ, Deng M, Tse KT, Chan CM, Lo IM, Cheng JC. Holistic BIM framework for sustainable low carbon design of high-rise buildings. Journal of Cleaner Production. 2018 Sep 10;195:1091-104.

[28] Szolomicki J, Golasz-Szolomicka H. Technological advances and trends in modern high-rise buildings. Buildings. 2019 Aug 26;9(9):193.

[29] Zhao J, Karalis G, Liebscher M, Tzounis L, Köberle T, Fischer D, Simon F, Al Aiti M, Cuniberti G, Mechtcherine V. Mineral-impregnated carbon-fiber based reinforcing grids as thermal energy harvesters: a proof-of-concept study towards multifunctional building materials. Energy and Buildings. 2023 Nov 1;298:113564.

[30] Agustí-Juan I, Jipa A, Habert G. Environmental assessment of multi-functional building elements constructed with digital fabrication techniques. The International Journal of Life Cycle Assessment. 2019 Jun 1;24:1027-39.

[31] Tang Z, Li W, Hu Y, Zhou JL, Tam VW. Review on designs and properties of multifunctional alkali-activated materials (AAMs). Construction and Building Materials. 2019 Mar 10;200:474-89.

[32] D'Alessandro A, Pisello AL, Fabiani C, Ubertini F, Cabeza LF, Cotana F. Multifunctional smart concretes with novel phase change materials: Mechanical and thermo-energy investigation. Applied Energy. 2018 Feb 15;212:1448-61.

[33] Chung DD. Multifunctional Cement-Based Materials. CRC Press; 2018 Oct 8.

[34] Chen Y, Cai J, Boyd JG, Kennedy WJ, Naraghi M. Mechanics of emulsion electrospun porous carbon fibers as building blocks of multifunctional materials. ACS Applied Materials & Interfaces. 2018 Oct 12;10(44):38310-8.

[35] Parmigiani S, Falliano D, Moro S, Ferro GA, Restuccia L. 3D-printed multi-functional foamed concrete building components: Material properties, component design, and 3D printing application. Developments in the Built Environment. 2024 Dec 1;20:100483.

[36] Lv Q, Zhu X, Zhou T, Tian L, Liu Y, Wang Y, Zhang C. Multifunctional and recyclable aerogel/fiber building insulation composites with sandwich structure. Construction and Building Materials. 2024 Apr 12;423:135902.