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ENERGY EFFICIENCY IN RESIDENTIAL BUILDINGS USING NANO-WOOD COMPOSITE MATERIALS

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ABSTRACT

Wood is one of the conventional building materials in the world, due to its availability and sustainability in nature. The electric and thermal conductivity of wood have made it exceptional among the other conventional construction materials. Nevertheless, wood has deficiencies such as deterioration as a result of fungal and insect attack, vulnerability to fire and dimensional variability to water absorption. Nanotechnology has been in use in other scientific and technological fields for long period of time, but it is still fresh to some extent in architecture. When nanotechnology is applied to the conventional wood, a nono-wood composite will be produce with enhanced properties such as mechanical strength, fire resistance, durability, water immersion. This paper is aimed at examining how wood as a conventional building material can be enhanced using nanotechnology. It further considers the conservation of energy in residential buildings through the building integrated nano-wood technology.

Keywords: Energy efficiency, nanotechnology, composite materials, wood composites.

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1. INTRODUCTION

Building construction and materials processes has a great impact on the general global energy. It is projected about 40% of the global electric energy is disbursed by building construction and exploitations. Construction industry alone contributed about 50% of the general global problems such as global warming, which is caused as a result of deflection of Ozone layer in the atmosphere (O_3) (Gellings, 2016). Recently the general publics are becoming aware of the environmental problems that are being caused in the built environment. Wood is one of the oldest building materials in the world, and it's considered as sustainable in nature due to its embodied energy efficiency. This embodied energy is the energy that is being required in the exploitation and production of wood and also the energy required for transportation. It is considered a low level energy based building material when compared with other building material such as concreate, aluminium, steel etc (Lei et.al 2007). The use of this conventional building material is limited by some problems such as weak mechanical strength, water absorption, fungal attack etc. Application of nanotechnology to this material will make it a better building material (Klein, n.d.).

Nanotechnology is not a new science or technology, but rather a continuation of has been in existence for a long period. It is regarded as a science of manipulating matter at nanoscale and produces a large scale material. It was first introduced in 1959 by a physicist R. P. Feynman while delivering a lecture "*There is plenty of room at the bottom*" which held in American Physical Society's meeting (Sev & Ezel, 2014). He explained that a technology might develop that will enable manipulations of atoms at nanoscale and produce materials with better and enhanced properties. This research tends to study how wood as a conventional and energy efficient building material can be enhance using nanotechnology and produce a nano-wood composite material that can be use in residential constructions.

2. WOOD COPOSITES

Timber is one of man's oldest building materials. It is easily worked, structurally strong, and warm and inviting to touch**.** It is a renewable, naturally occurring organic polymer, unique in a world of synthetic and composite building materials (Jiang & Kamdem, 2004). Today, timber is derived from sustainably managed forests and is one of our most environmentally friendly building materials (Rowell, 2012). Wood grown primarily with solar energy inputs, wood sequesters carbon, even after harvest and processing into lumber products. Timber, arguably the original building material, retains its prime importance within the construction industry because of its versatility, diversity and aesthetic properties (Sacui Et.al, 2014).

Compared to the other major construction materials, timber as a renewable resource is environmentally acceptable (see figure 1). The wide distribution of timber, its ready availability, variety of uses and relative ease of handling and conversion, have all contributed to its wide acceptance in the building industry (Klein, n.d.).

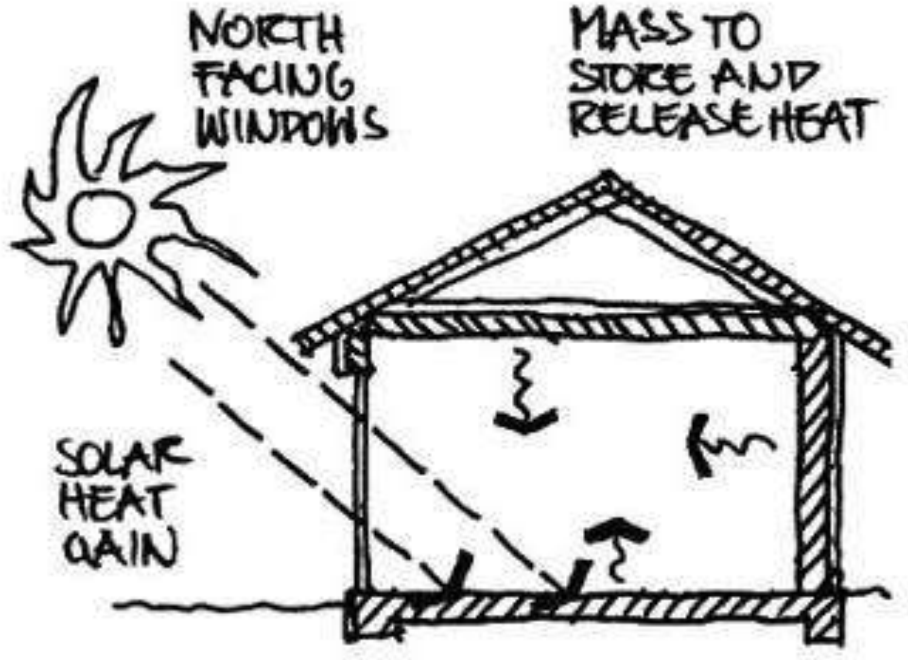

Figure 1 High thermal mass property. (Source: Gellings, 2013)

Benefits of wood over other building materials include:

- Renewable resources, recycling and reuse
- Design flexibility, versatile design options.
- Rational construction, offering light weight construction alternative.
- Reducing maintenance
- Low energy consumption, embodied energy and thermal efficiency and comfort Low internal emissions.

2.1. Introduction

Composites of woods are made up of several parts or elements of wood combined together with other material or element. These elements includes a variety of wood products which are produced by binding and fixing of wood fibres, veneers etc. together with adhesives or any other system to produce a composite materials. Examples of wood composites materials include:

a) Wood Plastic composite

Wood plastic composite is a fusion of materials from natural wood fibre, plastic fibre and thermoplastics which includes PE, PVC, and PP etc. This process involves the mixture of wood fibre dust and waste of plastic powder (Jiang & Kamdem, 2004). These materials are mixed together to achieve a desired relative thickness using condiments such as pigments, binding and reinforcing agents (Rowell, 2012). This product has a highest property of flexibility in order to achieve a unique scale and proportion. In some years ago, wood plastic composites evolved as an essential engineering and innovative material. This innovation became dominant in numerous building applications such as fencing, facades, landscaping timber etc., this is because there was a need to replace conventional timber in the construction industries. Wood plastic composites are currently obtaining a great attention in construction sectors due to their economical, structural and mechanical advantages with sustainability (see figure 2.0) (Rowell, 2012).

Figure 2 Natural wood-plastic composites materials. (Source: Greendotpure, 2016)

According to (Jiang & Kamdem, 2004), (Beecher, 2007)

Advantages

1. Corrosion and decay resistant
2. Good workability
3. Sustainable in nature
4. Flexibility
5. Good texture

Disadvantages

1. Lower strength
2. Moisture absorption
3. Frequent maintainace
4. Fungal attack

b) Medium-density fibreboard (MDF)

Medium Density Fibreboard is a wood composite that is made by breaking down of hardwood and softwood residuals into fine particles, combing it with wax and a binder (resin) forming panels under high temperature and pressure. MDF is comparably denser and stronger than ordinary plywood (Beecher, 2007). MDF does not comprise knots, this makes it more identical than ordinary woods during the process. This composite is not isotropic, this is because fibres are pressed firmly together through the sheet (see figure 3.0). MDF has the properties of flat, smooth and hard surface that will makes it perfect for utilization. This composite is glued and lamented (Jiang & Kamdem, 2004)

Figure 3 Medium-density fibreboard (MDF). (Source: (Beecher, 2007)

Advantages

1. Economically cheaper than conventional plywood
2. Good and smooth texture for painting
3. Flexibility in shape and proportion

Disadvantages

1. High density
2. Change under low humidity
3. Water absorption when exposed to water

3. ENERGY EFFICIENCY AND NANOTECHNOLOGY

Nanotechnology is in the process of revolutionising construction industries. This innovational development in construction industry is widely considered in energy efficiency and conservation due to global climate change. 40% of the global energy is consumed by built environment (Fels & Stram, 1986). With introduction and advancement of nanotechnology, buildings with a vital insulation capacity and thermal efficiency could be produced, as such a huge amount of energy could be hoarded (Beecher, 2007).

Nanotechnology has provided the ability to enhance energy efficiency in the building. According to Lei et.al (2007), there are some factors to consider in when dealing with energy efficiency and nanotechnology. These factors are as follows:

- Energy source

Nanotechnology provides a significant improvement in the devolvement of both traditional (conventional) such as fossils and renewable energy sources such as nano-coated, sun, water etc. However, nanotechnology has provided further development and enhancement of substitute cell types such as thin layer solar cells like silicon materials, copper, materials etc. another example include dye solar cells or polymer based solar cells which will ultimately advance from nanotechnology (Beecher, 2007). This enhancement could contribute to the enhancement of the layer based design and morphology of organic semiconductor compound mixtures in chemical mixtures. It is in this continuous process, the exploitation of nanostructures, like quantum which could allow for energy efficiency of about 60% (Jiang & Kamdem, 2004).

- Energy conversion

A conversion primary energy source to electric energy requires a huge amount of energy efficiency. With an increase in this energy efficiency, the amount of carbon dioxide emitted to the atmosphere ultimately increased (Lei et.al 2007). Similarly, big power plant efficiencies require high functional temperatures. With these, potential improvements and advancements are possible through nanotechnology products and possibilities such as nano-scale heat and corrosion protection through nano-coatings protection (Beecher, 2007).

- Energy distribution

During energy transmissions, there are reduction and energy losses in current transmission, with hope that through nanotechnology special electric conductivity of nanomaterials. Nanotechnology presented opportunities for enhancement of superconductive materials through nanotechnology. Nanotechnology could contribute resolutely to the realization of this vision (Beecher, 2007).

- Energy storage

Utilization of nanotechnology for the enhancement of electrical energy stores such as capacitors, batteries and super capacitors will lead to energy efficiency. Similarly, the capacities and safety of batteries could be enhanced though application of nanotechnology materials (Lei et.al 2007). Numerous nanomaterials based on Nano-porous metal-organic components of organic compounds offer potential development which is believed to be economically dependent on both operation and application (Klyosov, 2007).

- Energy usage

For a sustainable energy supply, the supply source should also be optimized and enhanced through nanotechnology. It is mandatory to advance the efficiency of energy use and to avoid redundant energy utilization. Energy can also be saving through use of lightweight construction materials when integrated with nanocomposites such as wood-composites materials (Beecher, 2007).

4. NANO-WOOD COMPOSITES

Nanotechnology is not new science, but it is new to some extent in the construction industry. Building material properties such as their mechanical strength, energy efficiency and the general concept of sustainability can be achieve to its maximum capacity when nanotechnology is incorporated in the construction industry. Common environmental problems such as global warming and greenhouse effects can be tackled in a sustainable way (Klyosov, 2007).

Introduction

Nanotechnology is applied in wood structural material, composites and wood base materials in two strategic forms: These strategies as follows:

a. Use of Nanomaterials, Nano sensors and embrace them to the forest products, therefore enlightening prevailing products enactment. This strategy enhances the wood structure and its properties and increased its coating for resistance water and provide.

b. This exploits the nanoscale properties of wood to develop completely a new material like a light weight material and economical that could compete with concrete and steel.

Wood which is a conventional building material is naturally made up of nanofibers and fibrils that have strength which is 25% stronger then concrete and twice stronger then steel (Sev & Ezel, 2014). These wooden composites materials performed excellently perfect under climatic conditions. Nevertheless, they can be predisposed to fungal attack and deterioration under misty circumstances (Klein, n.d.). But all this constraints could be protected using nanotechnology materials. These materials include ZiO_2, TiO_2 and Silver nanoparticles. Another important feature could be achieved in wood, which fire resistance by using nanodimentional particles such as TiO_2 (Kashef & Sabouni, 2010).

Nanotechnology and wood composites

Nanotechnology is still advancing globally in terms of awareness, innovations and technological advancements. Nanomaterials offer many improved performance properties for adhesives, concrete, coatings, flooring, glass, lighting equipment, plumbing fixtures and other construction products. Building Industry has undergone tremendous change in the past two centuries (Beecher, 2007). What affected it most were the industrial revolution and resultant outcome in terms of wood, wood composites, steel, cement and other building materials. The twentieth century saw further refinement in the same with even more sophisticated techniques and devices. Now, it has to move in the next phase where inputs are less and lighter, they are smooth and sturdier, they are cost effective, cleaner and sustainable. It has to move towards more sophistication with the help of emerging technologies like the Nanotechnology (Beecher, 2007). In this aspect, nanomaterials and particles will be critically studied with respect to application and integration with wood composites materials to produce better composites using the same materials with an enhancement (Nano wood composites) (Beecher, 2007).

Nanomaterials

In the earlier example of wood composites mentioned above, wood plastic composites (WPC) was one of the common wood composites that are widely used. These composites are part of the innovative and recent materials which combine the characteristics of wood and plastic using nanomaterial such as nanoclays to enhance the performance of these composites especially the water absorption problem, which is reduction of moisture absorption content (Lei et.al 2007). Physically, this composite is similar to wood; nevertheless, the low toughness of plastic contents in the composite makes the composites modulus considerably lower than that of conventional solid wood. Similarly, increasing the content ratio of wood to plastic in the composites will also lead to an increase in toughness; however the water absorption also rises up (Beecher, 2007). To overcome these challenges a nanomaterial known as *Nanoclays* will be introduce. This nanomaterial or nanoparticle will be compounded with plastic and wood using a compound mixture based on their ratio to form a three based composite component. This three based composite components will increase stiffness as well as increase in strength mechanically and structurally and at the same time an increase in rate of water or moisture absorption in the composites (Klyosov, 2007).

Nanoclays

Nanoclays are clay based nanomaterials of coated mineral silicates. The clay minerals enhanced for application in clay nanocomposites materials with numerous features that are meant for a specific application. Depending on the compound composition and morphology of the nanoparticle, nanoclays are structured in different classes such as bentonite, kaolinite, montmorillonite etc. (Beecher, 2007).

Montmorillonite which is the most common nanoclays materials is mostly used in materials based application. This nanoclays material consists of 1nm thickness of alumiosilicate coatings on a surface ancillary with metal cations and stacked in 10μm sized multicoated piles (see figure 4.0).

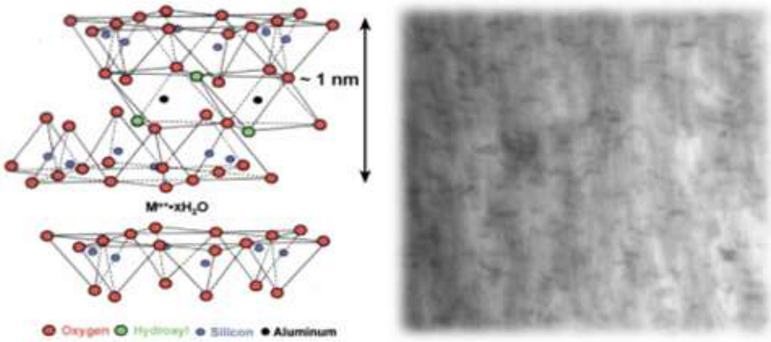

Figure 4 Chemical structure of montmorillonite nanoclays based material. (Source: Sev & Ezel, 2014)

Advantage of nanoclays materials/particles on wood plastic composites

1. Reduction in moisture and water absorption.
2. Increase in mechanical strength without increasing the bulk volume
3. Environmentally suitable/ sustainable in nature
4. Resistant to fungal and fire attack
5. No health risk

Disadvantage of nanoclays materials/particles on wood plastic composites

1. Economically expensive
2. Lack of availability
3. Lack of awareness

5. INTEGRATION OF NANO-WOOD COMPOSITES WITH ENERGY EFFICIENCY

Wood plastic composites are made from wood fibres and plastic thermosets. These composites were developed as an important member of engineering materials. According to (Yadav & Yusoh, 2015), "*wood floor is gaining more acceptance as a type of filler for polymers due to its easy availability, low density, biodegration, sustainability, low cost and high stuffiness.*" Because of these attributes wood fibre, the fabrication of wood plastic composites and there application has engrossed responsiveness for long period of time (Lei et.al 2007). Nevertheless, while mixing thermoplastic with wood fibres in a traditional system, the vastly hydrophilic natures of the lignocellulose materials make the compounds irreconcilable with the thermoplastic which are vastly hydrophobic in nature. This irreconcilability manifest to weak interfacial adhesion in between wood filler and the thermoset and that leads to weak and poor composites characteristics (Candan & Akbulut, 2013).

With the advance of nanotechnology, an innovative system has been provided in development and production of wood-plastic composites, with enhanced physical, chemical, structural and other properties using nano-fillers. The enhancement comprises of an increased in tensile and flexural strength, increased in biodegradability and decreased in water and moisture absorbance (Lei et.al 2007). The common example of these nano-fillers is nano-clay which is commonly used as filler in the wood-plastic composites production. This nano-clay is a particle based materials of layered mineral silicates, with a weathering product produced by disintegration and chemical decomposition of igneous rocks (Klyosov, 2007).

In developing energy efficient buildings, one of the furthermost significant objectives is during the design stage, in which a special consideration of structural performance and building materials as well be monitored. Similarly, the natural resources used and operational energy are also the subject of consideration (Beecher, 2007).

Aspen Aerogels

Recent nanotechnology innovations such as Aspen Aerogels (see figure 5.0), has led to the production of ultra-thin wall insulations which uses a hydrophobic nonporous aerogel materials that repels moisture and provide effective heat barrier (Gellings, 2016).

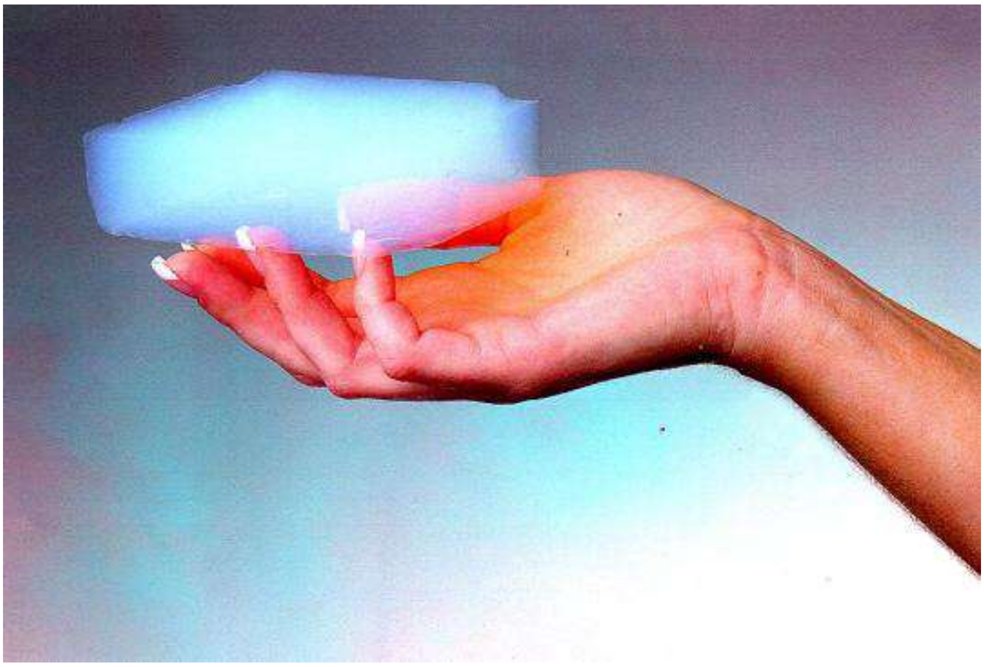

Figure 5 Aspen Aerogel. (Source: Sev & Ezel, 2014)

This nanoparticles could be apply to a wood which naturally has an insulation property could makes the wooden material repels moisture and provide an ultimate heat insulation to the building. Nano-Wood composites which naturally has the insulation property has the advantage of an easy integration with aerogels for an enhance energy efficiency in buildings (Beecher, 2007). Structurally, conventional insulating materials depend on ensnaring air within their structure in order to develop an insulation property (Candan & Akbulut, 2013). Even though, nano-wood composites are newly innovated with an enhanced advantages, their performance by thermal property can be advance further for energy efficiency in the buildings thorough aerogel materials. This aerogel material has more than twice the insulating performance of still air. It's developed to have an open structure that allows vapour to freely diffuse thorough its matrix. Incorporating aerogel particles or materials with Nano-wood composites would move air and immediately replace it with an incredible performance

(Beecher, 2007). This aerogel particle empowers Nano-wood composites to achieve and efficient thermal performance. Aerogel also will enhance moisture management in terms of building breathability. Similarly, it also has good design flexibility when integrated with nano-wood composites (Candan & Akbulut, 2013).

Figure 6 Residential building façade showing application of Aspen Aerogel nanoparticles on wooden spaceloft insulation-cap. (Source: Gellings, 2016)

Figure 7 Integration process. (Source: Developed by the author)

Application of this nanoparticles also could maximizes space and minimize heat loss in the wooden structure. This product has increase energy efficiency in the buildings by 15%, while increasing spaceloft insulation-cap (see figure 6.0) at the same time reducing noise within the building (Gellings, 2016).

6. CONCLUSION

Based on the literature review of this study, wood which is a conventional building material is naturally made up of nanofibers and fibrils that have strength which is 25% stronger then concrete and twice stronger then steel. Wooden composites materials performed excellently perfect under climatic conditions due its sustainability in nature. It is learned that those properties can be enhanced when to or more materials are mixed or join together to form a composites such wood and plastic (wood-plastic composites). Even though, some properties such mechanical strength, resistance to moisture, fire and fungal attack were originally the common problems that are aimed to tackle, but the aim was not achieved. With an advent of nanotechnology those properties were achieved, example of nanotechnology materials such as nanoclays that were integrated with wood composites and form a Nano-wood composites. Integration of nano-wood composites with aerogel and nanoclays, an energy efficient building will be generated.

REFERENCES

[1] Adedeji, Y. M., & Taiwo, A. A. (2012). Sustainable Building Finishes: Use of Renewable Standardized Wood-Based Material in Nigeria. AMR, 587, 134-138.

[2] Ashori, A., & Nourbakhsh, A. (2009). Effects of nanoclay as a reinforcement filler on the physical and mechanical properties of wood-based composite. Journal of composite materials, 43(18), 1869-1875.

[3] Bari, E., Taghiyari, H. R., Schmidt, O., Ghorbani, A., & Aghababaei, H. (2015). Effects of nano-clay on biological resistance of wood-plastic composite against five wood-deteriorating fungi. Maderas. Ciencia y tecnología, 1(1).

[4] Beecher, J. F. (2007). Organic materials: Wood, trees and nanotechnology. Nature nanotechnology, 2(8), 466.

[5] Candan, Z., & Akbulut, T. (2013). Developing environmentally friendly wood composite panels by nanotechnology. BioResources, 8(3), 3590-3598.

[6] Dányádi, L., Móczó, J., & Pukánszky, B. (2010). Effect of various surface modifications of wood flour on the properties of PP/wood composites. Composites Part A: Applied Science and Manufacturing, 41(2), 199-206.

[7] Fabiyi, J. S., McDonald, A. G., Wolcott, M. P., & Griffiths, P. R. (2008). Wood plastic composites weathering: Visual appearance and chemical changes. Polymer Degradation and Stability, 93(8), 1405-1414.

[8] FARUK, O., & MATUANA, L. (2008). Nanoclay reinforced HDPE as a matrix for wood-plastic composites. Composites Science and Technology, 68(9), 2073-2077.

[9] Fels, M. F., & Stram, D. O. (1986). The effect of burning wood on saving electricity. Energy and Buildings, 9(1-2), 119-126.

[10] Gellings, C. W. (2013). Back to Basics. Energy Efficiency, 1(1), 375-417.

[11] Gellings, W. C. (2016). Efficient use and conservation of energy in buildings. Electric power research institute (EPRI), USA, 1(1).

[12] Gong G., & Et.al. (2009). Preparation of nanocellulose with high aspect ratio from wood.Fokusomradet Materialvetenskap 4:e konferensen om maerialforskning pa LTU.

[13] Greendotpure. (2016, May 14). Wood Plastic Composite - Green Dot. Retrieved from http://www.greendotpure.com/materials/wood-composites/

[14] Hincapié, I., Künniger, T., Hischier, R., Cervellati, D., Nowack, B., & Som, C. (2015). Nanoparticles in facade coatings: a survey of industrial experts on functional and environmental benefits and challenges. Journal of Nanoparticle Research, 17(7). doi:10.1007/s11051-015-3085-3

[15] Jelle, B. (2015). Building Integrated Photovoltaics: A Concise Description of the Current State of the Art and Possible Research Pathways. Energies, 9(1), 21.

[16] Jiang, H., & Kamdem, D. P. (2004). Development of poly (vinyl chloride)/wood composites. A literature review. Journal of Vinyl and Additive Technology, 10(2), 59-69.

[17] Jiao, Y., Zhang, F., & Meng, S. (2011). Dye Sensitized Solar Cells Principles and New Design.Solar Cells - Dye-Sensitized Devices, 1(1).

[18] Kashef M., & Sabouni A. (2010). Nanotechnology and the Building Industry. Proceedings of the International Conference on Nanotechnology: Fundamentals and Applications Ottawa, Ontario, Canada, 1(1), 550.

[19] Klein A. (n.d.). Energy Code Compliance in Wood-Frame Buildings. Klein Engineering, PLLC.

[20] Klyosov, A. A. (2007). Wood-plastic composites. John Wiley & Sons.

[21] Ktron. (2016, May 13). Wood-Plastic Composites production requires high formulation quality the feeding system. Retrieved from http://www.ktron.com/industries_served/plastics/woodplastic.cfm

[22] Lei, Y., Wu, Q., Clemons, C. M., Yao, F., & Xu, Y. (2007). Influence of nanoclay on properties of HDPE/wood composites. Journal of Applied Polymer Science, 106(6), pp.3958-3966.

[23] Nanowerk. (2016, May 26). Carbon Nanotubes 101 - an overview. Retrieved from http://www.nanowerk.com/nanotechnology/introduction/introduction_to_nanotechnology_21.php

[24] Ndiaye, D., Fanton, E., Morlat-Therias, S., Tidjani, A., & Gardette, J. L. (2008). Durability of wood polymer composites: Part 1. Influence of wood on the photochemical properties. Composites Science and Technology, 68(13), 2779-2784.

[25] Rowell, R. M. (Ed.). (2012). Handbook of wood chemistry and wood composites. CRC press.

[26] Sacui, I. A., & Et.al. (2014). Comparison of the Properties of Cellulose Nanocrystals and Cellulose Nanofibrils Isolated from Bacteria, Tunicate, and Wood Processed Using Acid, Enzymatic, Mechanical, and Oxidative Methods. ACS Appl. Mater. Interfaces, 6(9), 6127-6138.

[27] Sev A., & Ezel M. (2014). Nanotechnology Innovations for the Sustainable Buildings of the Future. World Academy of Science, Engineering and Technology International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering, 8(8), 886-896.

[28] Taşdemır, M., Biltekin, H., & Caneba, G. T. (2009). Preparation and characterization of LDPE and PP-wood fiber composites. Journal of applied polymer science, 112(5), pp.3095-3102.

[29] Thomasnet. (2016, May 14). Wood Plastic Composite. Retrieved from http://www.thomasnet.com/articles/plastics-rubber/composite-wood-plastic

[30] Yadav, S. M., & Yusoh, K. B. (2015). Mechanical and Physical Properties of Wood-Plastic Composites Made of Polypropylene, Wood Flour and Nanoclay. Proceeding - Kuala Lumpur International Agriculture, Forestry and Plantation September 12 - 13, 2015. Hotel Putra, Kuala Lumpur, Malaysia, 1(1), 1-10.

[31] Amira Mersal, Green Building: Energy Efficiency Strategy. International Journal of Architecture (IJA), 3(1), 2017, pp. 46–60.

[32] M. Vinay Kumar Reddy, Ch. Mamatha,K. L. Raghavender Reddy, Dr. V Anandam and Md. Ashfaqul Hasan, Sensing Devices For Energy Efficiency In Smart Cities Environment, International Journal of Mechanical Engineering and Technology 8(12), 2017, pp. 684–688.

[33] Kirill Evgenievich Karpukhin, Aleksey Stanislavovich Terenchenko, Aleksey Fedorovich Kolbasov and Vladimir Nikolaevich Kondrashov, Using Photoelectric Converters in Road Transport in Order to Improve Energy Efficiency in Russia, International Journal of Mechanical Engineering and Technology 8(10), 2017, pp. 529–534.

[34] Dr. Sonali Dasgupta, Improve Energy Efficiency of Electrical System by Energy Audit (Data Logging), International Journal of Electronics and Communication Engineering & Technology (IJECET), Volume 3, Issue 3, October- December (2012), pp. 240-245