QATAR UNIVERSITY

COLLEGE OF ARTS AND SCIENCES

# DATE PITS BASED NANOMATERIALS FOR THERMAL INSULATION APPLICATIONS - TOWARDS ENERGY EFFICIENT BUILDINGS IN QATAR

BY

MOZA ALI AL MARRI

A Project Submitted to

the Faculty of the College of Arts and Sciences

in Partial Fulfillment of the Requirements for the Degree of

Masters of Science in

Environmental Sciences

January 2019

COMMITTEE PAGE

The members of the Committee approve the Project of Moza Ali Al Marri defended on 28/11/2018.

Dr. Mohammad A. Al-Ghouti

Thesis/Dissertation Supervisor

Dr. Bilal Mansoor

Committee Member

Prof. Nabil Zouari

Committee Member

Prof. Yousef Hijji

Committee Member

# ABSTRACT

AL MARRI, MOZA, A., Masters : January : 2019, Environmental Sciences

Title: Date Pits Based Nanomaterials for Thermal Insulation Applications - Towards Energy Efficient Buildings in Qatar

Supervisor of Project: Dr. Mohammad A. Al-Ghouti.

Air-conditioning systems make the most significant part of energy consumption in the residential sector. There is no denying that it is essential to produce a comfortable indoor thermal environment for residents in a building. The actual goal is to achieve thermal comfort level without putting too much cost on the ecological system. An effective way to help achieve such a goal is by incorporating thermal insulation in buildings. Thermal insulations help reduce thermal energy gained during the implementation of a desired thermal comfort level. This project aims to study a new, environmentally friendly nanomaterial containing nanoparticle of date-pits to create thermal insulations. In addition, fly ash and different ratios of the nanoparticle of date pits and sand composite were investigated. Fourier transform infrared (FTIR) spectroscopy and scanning electron microscopy (SEM) were used to characterize the new materials. The material with nanoparticle of date pits and 50% by-volume epoxy provide good thermal insulation with thermal conductivity of 0.26 $W/_{mK}$ that may be used in existing buildings. This has the potential to reduce the overall energy consumption by 4,494 $kWh$ and thereby to reduce $CO_2$ emissions of a 570 $m^2$ house by 1.8 tons annually. The use of fly ash as an insulation material was not found to be as efficient compared to nanoparticle of date pits. In conclusion, the future of using nanoparticle of date pits in construction is bright and promising due to their promising initial results.

# ملخص

يعتبر حفظ الطاقة في المباني، من أكثر المجالات أهمية في الوقت الراهن؛ ويرجع ذلك لارتفاع استهلاك الطاقة في القطاع المنزلي، نتيجة لاستخدام مكيفات الهواء، ووسائل التبريد، لتأمين الارتياح الحراري في البيئة الحرارية المحيطة بالإنسان. يُعد استعمال المواد العازلة حرارياً في المباني من أنجع الوسائل المتبعة تقنياً واقتصادياً وبيئياً. وذلك لقيمة العازل الحراري في خفض الاستهلاك المتزايد للطاقة، إذ يوفر قدراً لا بأس به من الطاقة المستهلكة في التبريد. ونظراً لأهمية العوازل الحرارية في ترشيد الطاقة، هدفت هذه الرسالة إلى البحث عن مادة عازلة حرارياً، باستخدام نواة التمر، والرماد المتطاير من محارق النفايات والمقارنة بينهما؛ للحصول على أعلى مردود؛ عن طريق بلوغ مستوى توصيل حراري منخفض عما هو متوفر في السوق. وقد جاء هذا البحث، كمحاولة لتعزيز رؤية قطر ٢٠٣٠ من المنظور الاقتصادي والبيئي، وهو ما ذكر سابقاً من خلال تحقيق أفضل أداء حراري للمبنى. ولإدراك هدف الرسالة فقد اعتمدت المنهجية لدراسة الخصائص الفيزيائية والحرارية للمادة، والبحث عن مدى فعاليتها ومقارنتها بأقرانها من المواد المتوفرة في السوق. حيث أكدت الرسالة بفاعلية استخدام نواة التمر المركب بالإيبوكسي كعازل حراري بوجود ناقلية حرارية منخفضة تقدر بـ 0.26 واط لكل متر كلفن. استخدام عازل نواة التمر أثبت فعاليته باستخدام برامج المحاكاة بالتقليل من استخدام الطاقة بـ 6.49 ٪ والحد من انبعاثات ثاني أكسيد الكربون لبيت مساحته 570 متر مربع بما يقدر بـ 1.8 طن سنوياً. العزل الحراري المكون من الرماد المتطاير لم يكن بنفس كفاءة نواة التمر من حيث الناقلية الحرارية. انتهت الرسالة إلى جملة من النتائج والتوصيات والاقتراحات في مجال البحث ومستقبله.

# DEDICATION

*To my beloved Parents,*

*Who gave me my start.*

*To my siblings and friends,*

*Who supported me.*

*To Qatar,*

*as Qatar deserves the best from us.*

ACKNOWLEDGMENT

First and foremost, I would like to give thanks to God to Whom without I would not have been able to complete this thesis. Unconditional gratitude to my family and friends for providing me with immense support and continues encouragement throughout my years of studying and the entire process of this thesis.

My sincere thanks to my supervisor Dr. Mohammad Al-Ghouti and the committee members Dr. Nabil Zouari from Qatar University, and Dr. Bilal Mansoor from TAMU, Qatar. Dr. Vasanth Shunmugasamy from TAMU at Qatar; without his passion and patience during the experiments, this work would not have been possible.

I am also grateful to the Center of Advanced Material (CAM) in Qatar University, with a very special thanks to Dr. Nasser AlNuaimi and Eng. Mohamed Salih and all the technicians for their outstanding efforts.

This acknowledgment would not be complete without recognizing the Qatar Environment and Energy Research Institute (QEERI), especially Dr. Said Mansour for their continued patience and help.

TABLE OF CONTENTS

# LIST OF TABLES

LIST OF FIGURES

# CHAPTER ONE: INTRODUCTION

Qatar is one the fastest growing economies in the world. Qatar is involved in several infrastructure development megaprojects, including the hosting of 2022 FIFA World Cup. Therefore, Qatar is continually facing a rising demand for energy. In recent years, many countries including Qatar have increasingly become aware of the risks posed by climate change. This has put much emphasis on reducing the use of fossil fuels, reducing energy consumption and finding ways to use energy more efficiently (Rostam, Mahdavinejad, & Rostam, 2015).

Currently, environmental sustainability is a crucial area of focus in Qatar; it involves management of non-reproducible resources. One of the critical solutions to reach environmental sustainability goals involves sustainable development, i.e., finding ways to reduce the consumption of fuels in every which way we live (Rostam et al., 2015). In Qatar, cooling, heating and air-conditioning systems for buildings pose a significant hurdle to achieve the concept of sustainable development (Agoudjil, Benchabane, Boudenne, Ibos, & Fois, 2011). Air-conditioning, cooling systems use the most energy of all building services. It is estimated that about 80% of the energy in Qatari buildings is utilized to provide thermal comfort to the occupants. This number is extremely high, in-fact this is the most significant fraction in any country in the world (Meier, Darwish, & Sabeeh, 2013). A study found that human comfort indoor temperature is around 31°C, which is the stark contrast to what is typically used in Qatar, i.e., standard comfort temperature is between 20-22°C (Indraganti, 2010).

The best way to reduce the overall energy usage to achieve the thermal comfort level in a building is to use effective insulation strategies. (Agoudjil et al., 2011) studied natural material in the manufacture of thermal insulations for buildings. They investigated the thermo-physical, chemical and dielectric properties of three varieties of date palm wood. They concluded that the effect of the fiber’s orientation was significant on the relative permittivity when compared to the thermal conductivity of the date palm wood.

Nowadays, the focus in sustainable buildings research is on examining reliable methods for producing, assessing and verifying insulation materials. Considering this, the argument of the use of materials is increasingly being perceived through their ecological aspects that take in to regard various characters of material and their interplay with the environment (Kini, Garg, & Kamath, 2017).

Embedded energy and pollution, waste production and recycling opportunities are top of the list. Present-day sustainable aims recreate ways for reducing waste and loss of materials, which drives to a decrease in environmental contamination. If waste is becoming a source to be supplied to the economy as a raw material, then greater priority needs to be given to the reuse and incorporation of waste into new materials for buildings (Yoada, Chirawurah, & Adongo, 2014).

Nano thermal insulation materials commonly have lower thermal conductivity coefficient than other used materials. The coefficient of thermal conductivity is reduced in nano-based materials; due to the ways of heat flow are blocked between the particles because of the high surface area corresponding to volume ratio in the particles other than other sizes of particles, in addition to the slower movement of the thermal radiation (Bozsaky, 2016). These advantages give an excellent opportunity to investigate nanoparticles date pits as a candidate material for thermal insulations. Date pits as a lignocellulosic material mainly composed of cellulose, hemicellulose and lignin as major components, while oil, protein, ashes, fats, and carbohydrates are minor components. In addition, they contain several minerals including potassium, magnesium, calcium, phosphorus, sodium and iron.

Nanomaterials such as nano-activated carbon and nanoparticle of date pits are often used in the field of environmental remediation due to their huge effects on remediation

(Al-Ghouti, Hawari, & Khraisheh, 2013). Nanomaterials have recently gained popularity, which deals with various applications, and it is considered very efficient, eco-friendly and cost-effective due to unique functionalities of the nano-materials. There are various analytical techniques that can be used for characterization of materials and determining which functional groups exist on their surface, one of these techniques is Fourier Transform Infrared (FTIR) Spectroscopy. Scanning electron microscope (SEM) can also be used to study the morphological characteristics of the adsorbent surfaces.

## 1.1. Research Objectives

Below are the objectives of the study:

- Study the physical and chemical characterization of the date pits and sand.
- Produce nanoparticle of date pits by using a simple and convenient means to produce particles arbitrarily such as the planetary ball mill and examine the physical disintegration of the date pits.
- Investigate the thermal conductivity characteristic of the produced nanoparticle composite materials using different configurations and different combinations e.g. powdered date- pits, suitable size sand particles, and binder.
- Perform statistical analysis.
- Use a simulation program to analyze the role of the proposed insulation materials in performing the energy consumption in a warm and humid climate.

Detailed below are the expected outcomes of the study:

- Minimize the usage of energy for cooling by enhancing the thermal insulating of the building's coating.

- Compare the result characteristics of varying composites of the proposed insulation materials.
- Reduce unwanted waste by creating new thermal insulation.

### 1.2. Novelty of the Research

Date pits were studied as they are more sustainable and environmentally friendly. Thus, solving the issue of carbon dioxide emitting into the atmosphere from excess using of energy, where the rising level of atmospheric $CO_2$ will lead to an increase in global air temperatures and shifts in precipitation patterns. This completely defeats the propose of having thermal insulation system, $CO_2$ will raise the temperature correspondingly will increase, which will go in a never-ending circle where keeping the buildings cool brings earth's temperature up. Therefore, using the bio insulation material can help reduce the problems caused by the conventional thermal insulation systems. Moreover, helping the environment by recycling the date pits, in addition to, reducing the dependency on mechanical cooling systems and so lowering the building usage of energy.

Distinguished from other thermal insulation, the proposed material in this project can be used on existing buildings. Conventional thermal systems cannot be installed into an existing building but are required to be put during the construction of the building. Other solutions to this issue only work with a new building that is being built. However, the project can also be used on old buildings that can save time and energy.

This project satisfies the pillars of Qatar National Vision 2030. First, the economic development where it helps the country's economy and ensuring a stable and sustainable business environment. Secondly, environmental Development in which it encourages to put in place measures to decrease the adverse environmental effects of pollution arising from development activities and evaluating the impact of climate change and decreasing its negative impacts. The rising of the $CO_2$ is a serious matter, not only does it affect the temperature of the atmosphere. Bearing in mind that switching to the bio-based thermal insulation can help prevent many of the predicaments as mentioned above from occurring.

# CHAPTER TWO: LITERATURE REVIEW

## 2.1. Thermal Insulation Materials

### *2.1.1. Thermal Insulation Materials' History*

The story of thermal insulation started just as that of other building materials, although in the past thermal insulation was not a separate layer in building's construction because it was not required to create other coating materials to secure the building (Mahdavinejad, Ghaedi, Ghasempourabadi, & Ghaedi, 2012). Construction activity began when people in ancient times first started building houses (Rostam et al., 2015). The main aim of building houses at that time was to protect the inhabitants from wild animals and natural weather conditions, such as cold winters and hot summers: in other words, buildings served to insulate people from their surroundings (Mahdavinejad et al., 2012). Therefore, the need for sufficient thermal insulation can be assumed to be an essential requirement for building construction (Dávid Bozsaky, 2011).

Historically houses were built from the same materials that people used for clothes. Conventional materials were animal fur, wool, and plant-related materials such as reeds, flax, or straw, but the problem was the lifespan of these materials is limited (Rostam et al., 2015). Various synthetic materials were later created during the Industrial Revolution, which held numerous benefits over those of natural materials, including stability as well as water and fire resistance; these materials became increasingly popular during the first third of the last century (Dávid Bozsaky, 2011).

### *2.1.2. Background of the Thermal insulation Materials*

The primary feature of thermal insulation in construction is thermal conductivity, where the aim is to reach the lowest possible thermal conductivity. Low thermal conductivity, $(^{W}/_{mK})$, allows builders to create thin walls with a very high thermal resistance,

($^{W^2K}/_{W}$), while keeping the U-value, thermal transmittance or ($^{W}/_{m^2K}$), as low as possible (Al-Homoud, 2005).

However, total thermal conductivity, $\lambda\ tot$ (i.e., the width of the material classified by thermal resistance), is a system made up of various contributions (A. N. Raut, 2017):

$$\lambda_{tot} = \lambda_{Solid} + \lambda_{gas} + \lambda_{rad} + \lambda_{conv} + \lambda_{coupling} + \lambda_{leak} \quad (1)$$

where $\lambda_{tot}$ is total thermal conductivity, $\lambda_{solid}$ is solid phase thermal conductivity, $\lambda_{gas}$ is gas state thermal conductivity, $\lambda_{rad}$ is radiation of thermal conductivity, $\lambda_{conv}$ is convection of thermal conductivity, $\lambda_{coupling}$ is the result of differences between the thermal conductivities in Equation (1), and $\lambda_{leak}$ is leakage of thermal conductivity (Heinemann, 2008).

Therefore, to yield the lowest possible thermal conductivity, all of the contributions mentioned above should be minimized. Usually, leakage of thermal conductivity, $\lambda_{leak}$, expresses the air and moisture leaks forced by the difference between pressures. The coupling expression, $\lambda_{coupling}$, could be accounted for by consequence effects among the different thermal conductivities in Equation (1). In some studies, the coupling effect was neglected (Jelle, 2011).

Materials have inherent properties of thermal insulation, and their specifications must satisfy a range of conditions concerning features other than thermal conductivity. Some of these conditions may limit the degree to which thermal conductivity can be easily lowered, so it is important to choose the right materials and solutions (Jelle, 2016).

#### *2.1.3. Thermal Insulation Material for Hot and Humid Climates*

Well-designed building insulation not only promotes energy conservation in buildings but also enhances economic profits by taking advantage of daylighting and reducing the need for air-conditioning (Saffari, de Gracia, Ushak, & Cabeza, 2017). Insulation materials and their components are the principal determinants of the quantity of heat gain and loss in buildings as well as capacity for air ventilation. Insulation protects the interior and the inhabitants from climate conditions. The design characteristics of insulation greatly affect the thermal comfort of people as well as the building's energy consumption (A. N. Raut, 2017).

Thermal insulation can be explained as a material or mixture of materials that slows the flow of conduction, convection, and radiation of heat. It impedes the flow of heat into buildings, which determines the thermal resistance of the building itself (Al-Homoud, 2005). In hot and humid regions, such as Qatar, insulation is a substantial investment that carries both economic and environmental profits. The indoor thermal index is affected by the difference between high outdoor temperatures and low air movement. To maintain comfortable indoor temperature, most of today's buildings have a mechanism technique to cool the indoor environment, which undoubtedly consumes huge amounts of energy. A very recent paper by Aditya et al. (2017) pointed out that good insulation can minimize energy use by 64% in typical buildings as well as decrease $CO_2$ emissions. Insulation also creates comfortable thermal conditions, even without the use of air-conditioning (Pérez, 2016).

#### *2.1.4. Advantages of Thermal Insulation*

Al-Homoud (2005) showed in his study several benefits of thermal insulation, such as (a) increased environmental profits, where the application of insulation not only saves energy costs but also affects environmental profits due to decreased dependence on mechanical systems (e.g., air conditions) and reductions in pollutant emissions; (b) increased energy and resource savings, where applying insulation in buildings lowers dependence on the electrical and mechanical systems used to maintain a comfortable indoor environment; (c) reduced economic costs, where insulation conserves energy and lowers not only operation costs (i.e., how much energy is consumed in typical Qatari residential house) but also initial the air-conditioning cost; (e) thermally comfortable zones, where insulation in buildings extends the duration of indoor thermal comfort; (f) reduced noise pollution, whereby insulation decreases the noise pollution from surroundings and improves indoor acoustic comfort (Guzel Kaya, Yilmaz, & Deveci, 2018).

#### *2.1.5. Thermal Insulations'' Types*

The thermal insulation types can be summarized as:

- *Synthetic Insulation Materials*

Synthetic insulation materials are non-natural; they are made from human-engineered processes. One of the most common types of synthetic insulation materials is fiberglass, which is manufactured through the process of weaving strands of glass into materials with thermal insulation properties. Other types of synthetic insulation materials include polyethylene and phenolic foams (Bianco, Pollo, & Serra, 2017). While it may not be among the most popular insulation materials, polyethylene foam is an excellent, lightweight insulator with additional benefits including durability and resilience. Phenolic foam, on the other hand, makes use of a phenolic resin that is both chemically and thermally stable (Chen, Chen, Yang, & Chen, 2017). Calcium silicate is another primary type of thermal insulation material. It is an optimal alternative to asbestos because it is rigid and highly dense, making it suitable as high-temperature insulation. Polystyrene is also a synthetic insulation material with both excellent sound and temperature insulation properties. It has optimal utility because it is available in two forms that differ in cost and performance ratings: extruded and expanded forms (Schiavoni, D'Alessandro, Bianchi, & Asdrubali, 2016).

- *Natural Insulation Materials*

These insulation materials are made from materials that occur naturally. The first dominant type of natural insulation material is mineral wool (Aditya et al., 2017), which describes two other insulation materials: slag wool manufactured from slag in steel mills, and rock wool made from basalt. Another type of natural insulation material is cellulose. Cellulose is arguably the eco-friendliest insulation material. It can be produced from paper or cardboard that has been duly recycled (Sagbansua & Balo, 2017). Natural fiber is also a source of natural insulation comprising products like cotton, straw, hemp, and sheep's wool. Apart from being excellent thermal insulators, these products are also both waterproof and readily available (Palumbo, Lacasta, Giraldo, Haurie, & Correal, 2018). Cork and vermiculite are two other significant natural thermal insulation materials. Cork occurs naturally from trees. It is an excellent thermal insulator mainly because of the abundance of air that fills its cells (Zach, Slávik, & Novák, 2016). Vermiculite, on the other hand, is a naturally occurring mineral that offers thermal insulation once heated to temperatures above 27 ℃. At this high temperature, vermiculite often expands, hence exhibiting low heat conductivity and bulk density. Both of these are admirable qualities for a thermal insulation material (Palumbo, Avellaneda, & Lacasta, 2015).

#### *2.1.6. Thermal Insulations' Uses*

Experience has shown that the emergence of new technologies has made it a necessity to look for alternative materials that are capable of protecting humankind from outside threats. Proper use of techniques related to thermal insulation is sure to offer protection from elements, such as heat. Materials with favorable thermal insulation properties offer protection from heat by absorbing it either directly or indirectly (Conley, Cruickshank, & Baldwin, 2018). This section discusses the uses of these materials below:

(1) Heat insulation: Insulating from heat is the main purpose of thermal insulation materials in any form of application. These materials are often incorporated on the exterior assemblies of buildings during construction. In return, they either reduce heat loss or heat gain as a way of achieving energy conservation. Thermal insulation materials act as energy conservation agents by inhibiting the rate of heat transfer and converting heat energy to other necessary forms through convention, conduction, and radiation (Jelle, 2011). Buildings in particular lose heat energy through floors, roofs, windows, wall, doors, and ventilation systems. The application of these materials to prevent heat loss ensures that the loss of heat energy is reduced by as much as 50% in a building of any type. In the end, a building constructed with proper thermal insulators has lower electrical costs that come with the use of air conditioners and similar electrical appliances (Muizniece, Blumberga, & Ansone, 2015).

(2) Environmental protection: This is the second most significant use of thermal insulation materials. Constructing buildings with thermal insulators helps protect the environment by limiting the effects of several harmful gases, including carbon dioxide, chlorofluorocarbon, and nitrogen oxide, among other greenhouse gases. The abundance of these gases results in what is commonly known as the greenhouse effect (Parthenopoulou & Malindretos, 2016). This phenomenon is brought about by human activities that emit greenhouse gases in large quantities, thus resulting in adverse climatic changes. The use of appliances such as air conditioners in buildings brings about the emission of gases like carbon dioxide and chlorofluorocarbon (Luo et al., 2014). This implies that in a bid to regulate heat energy and keep indoor conditions comfortable, people end up releasing large amounts of greenhouse

gases into the atmosphere, hence rapidly depleting the ozone layer. Therefore, thermal insulation materials were introduced in part to reduce the effects of some of these appliances. Recent studies have predicted that continuous use of heat regulation appliances in buildings in the next decades will contribute to a significant increase in the presence of greenhouse gases in the atmosphere (Sadineni, Madala, & Boehm, 2011). The same study illustrated that proper use of thermal insulation materials in the course of construction is set to reduce these emissions by 8% if other factors are held constant. It is therefore reasonable to conclude that the application of thermal insulation materials not only makes buildings thermally comfortable but also protects the environment from the effects of greenhouse gases that come with thermal regulation appliances (Parthenopoulou & Malindretos, 2016).

(3) Reduction of condensation on building surfaces: Certain thermal insulation materials, such as polyethylene films and chlorinated rubber in the form of treated paints, either prevent or reduce condensation on the surface of buildings. In areas where surface condensation diminishes the durability of buildings, these materials play a significant role during construction. Buildings fitted with internal insulation materials tend to experience a falling dew point (Al-Homoud, 2005). Because the temperature gradient falls from the interior to the exterior of structures, the temperature on the cold side of insulation materials often falls below the dew point, resulting in surface condensation (Wang, Liang, Tang, Chen, & Chen, 2014). Therefore, thermal insulation materials, like the ones listed above, act as barriers to water vapor. In specific structures, such as those with timber flat roofs and high-raised factory roofs, surface condensation is eliminated with the use of ventilation

fitted above the interior insulation. Ventilation, in this case, eliminates water vapor (Jelle, 2016).

(4) Prevention of structure damage by fire: Certain thermal insulation materials can counter the effects of excess heat resulting from fires inside or outside building structures. Currently, many commercial structures have been fitted with thermal insulation materials with the aim of reducing or entirely preventing the adverse effects of fires. When these buildings are constructed, their surfaces are sprayed with a particular form of noncombustible insulating lining (Cabeza, Rincón, Vilariño, Pérez, & Castell, 2014). The use of thermal insulation materials for this purpose was discovered in a study conducted at a fire research station involving the flashover time of fire incidences. The results suggested that the use of thermal insulation materials, such as hardboards and other insulating boards, led to a longer flashover time and reduced the impacts of fire on structures. Therefore, it is worth concluding that the application of thermal insulation materials in buildings can reduce fire risk. It would be an essential construction code to stipulate that all new building projects should consider using these materials (Pérez, 2016).

(5) Use in mechanical systems of commercial and industrial buildings: Thermal insulation materials are heavily applied in the mechanical systems of buildings in schools, hospitals, shopping centers, and hotels. Here, they are used to lower energy consumption in temperature regulation systems, hot and cold water supply systems, and refrigerated systems, such as ducts in the buildings (Papadopoulos, 2005). In the case of industrial establishments, like paper mills, refineries, and power plants, thermal insulation materials are embedded in the mechanical systems to regulate the loss and gain of heat

energy during industrial processes that involve condensate and steam distribution in facilities such as boilers, precipitators, bag houses, and storage tanks (Pérez-Lombard, Ortiz, & Pout, 2008).

(6) Acoustic control in buildings: One of the unique uses of thermal insulation materials is in sound insulation. Thermal insulation materials embedded in the mechanical systems of buildings often act as sound insulators as well. These materials are often characterized by high sound attenuation or resistance. Installing a thermal insulation material between the source of the noise and the surrounding areas often greatly inhibits the transmission of sound. Therefore thermal insulation materials are used not only in building thermal regulation but also in mechanical systems of both industrial and commercial buildings for purposes of noise insulation among others (Iannace, 2017).

## 2.2. Waste Management

### *2.2.1. History of Waste Management*

Throughout history, the low population density saw to it that waste generation was very insignificant. This together with the low level of natural resource exploitation played a role in the insignificant accumulation of waste materials. Waste materials during premodern times were mainly constituted of ashes and human biodegradable waste (Lin, Huang, & Shern, 2008). These waste materials were disposed of locally with minimal environmental impacts. Tools and machinery were made of metal and wood. They were generally reused and passed down generations (Morrissey & Browne, 2004). Some civilizations, however, accumulated larger amounts of waste than others. The Maya of Central America, in particular, had a waste management ritual where they would burn their waste monthly.

But with the coming of industrialization and the exponential growth of the population, waste materials began accumulating at a fast rate. Low levels of sanitation were witnessed in areas with no elaborate waste management techniques. Urban areas during those times were choked with waste material (Tchobanoglous, Theisen, & Vigil, 1993). Corbyn Morris made the first call for waste management in 1751 in the city of London. This was the advent of waste management techniques and policies (Bystrzejewska-Piotrowska, Golimowski, & Urban, 2009).

### *2.2.2. Waste Management's Importance*

Waste management is important because it eliminates waste material. Waste management is a valuable resource when it is actualized through practice and policy, boasting numerous advantages. Because there are particular types of waste that have been categorized as hazardous, waste management techniques eliminate the possibility of the environment being contaminated (Tchobanoglous et al., 1993). The absence of waste management exposes both animals and plants to diseases.

### *2.2.3. Types of Waste Managements*

There are three main types of waste management strategies currently applied across the globe: spreading awareness of waste management, recycling, and dumping (Sun, Fujii, Tasaki, Dong, & Ohnishi, 2018). In terms of spreading awareness, people are made aware of the need to manage waste with the aim of either reducing the amount of waste material produced or encouraging proper disposal. Recycling as a type of waste management deals with resource recovery in the form of the collection, processing, and reuse of waste material. Dumping, on the other hand, is the oldest type of waste management. This is where a site is designated for the disposal of waste material by burial.

### *2.2.4. Uses Of Waste Management*

The uses of waste management are categorized in terms of economic, social, environmental benefits. From the economic perspective, waste management is used to improve economic efficiency through the use, treatment, and disposal of resources. It also creates markets for recycled material. From the social perspective, waste management is used to reduce the adverse health effects of waste material. Waste material endangers the health of civic communities (Tchobanoglous et al., 1993). Apart from that, implementation of waste management techniques creates new sources of employment for the community. From the environmental perspective, waste management is used to eliminate the negative impacts that waste material has on the environment. Techniques that reuse, recycle, and reduce the extraction of resources improve the quality of the air and water (Tomovska & Radivojević, 2017).

### 2.2.5. *Waste Management's Measures*

There are many measurements of waste management, including (a) disposal measures, (b) recycling measures, (c) reuse measures, and (d) avoidance and reduction measures. The two major waste disposal measures are the use of landfills and incineration. Landfills are areas designated for the disposal of waste material. Incineration, on the other hand, is where solid organic wastes are combusted into residue products and gas (Yoada et al., 2014). Recycling measures are a resource recovery waste management measure (Gálvez-Martos, Styles, Schoenberger, & Zeschmar-Lahl, 2018) aimed at collecting and processing waste material for reuse. Reuse measures involve putting waste materials that are still in good shape to another use without disposing of them. One type of technique in this waste management measure is biological reprocessing. In this technique, organic waste is often recovered by passing it through processes such as composting and recycling. Finally, avoidance and reduction measures are crucial in waste management because they significantly reduce the amount of waste produced. Techniques applied in this waste management technique include the reuse of second-hand products, the repair of broken products, and encouraging people not to make use of disposable products (Morrissey & Browne, 2004).

### 2.2.6. *Fly Ash*

In power plants, the very fine particles secured in electrofilters as they pass by the flue draught are called fly ash. A significant amount of fly ash waste is generated across the world, and the majority of this type of waste is abandoned (Cretescu et al., 2018). Fly ash is characterized as a hollow ferroaluminosilicate material and is considered as a heterogeneous composite of amorphous and crystalline phases with predominant elements including aluminum, calcium, iron, sodium, and silicon (Adriano, Page, Elseewi, Chang, & Straughan, 1980; Sajwan, Alva, & Keefer, 2003). The fly ash that has been emitted from the flue draught into the environment is controlled by particulate devices like mechanical electrostatic precipitators and scrubbers (Kumari, 2009).

Fly ash can be classified by carrying out some tests in the laboratory. The major parameters of its physical and chemical properties are size distribution, morphology, surface area, hydraulic condition, pH, solubility, leachability, toxicity, and radioactivity (Lokeshappa, 2012). Nevertheless, fly ash is basically categorized into two main classes, C and F, based on the amount of $CaO$ and the characteristics of the burned coal (Bicer, 2018).

#### 2.2.6.a. *Fly ash toxicity*

Fly ash usually carry complex organic molecules, like Polychlorinated dibenzofurans, Polychlorinated Biphenyls, poly-chlorinated dibenzo-p-dioxins, Polyaromatic hydrocarbons, monomethyl, and dimethyl sulfate. It contains also various heavy metals such as Lead (Pb), Zinc (Zn), Nickel (Ni), Cadmium (Cd), Arsenic (As), Chromium (Cr), and Copper (Cu). Which may damage the circulatory system and creates carcinogenic changes (Jambhulkar, Shaikh, & Kumar, 2018). However, in order to use the fly ash clean and without toxicity it will be through long and costly process.

## 2.3. Biomaterials

### *2.3.1. Biomaterials' Importance*

The history of using biomaterials in construction is quite lengthy, which illuminates their importance in the industry. Biomaterials, such as timber, have been used in construction since before memory or record. Timber is known for its irreplaceable role in framing, roofing, and boarding. Other popular biomaterials that continue to be used in flooring and roofing are straws and reeds. Biomaterials have replaced synthetic materials in areas where their uses have been well established and their performance known and proven (Papadaki, 2017).

Biomaterials have numerous advantages, making them extremely valuable not only in the field of construction but also in other fields. These materials provide people with the opportunity to facilitate the capture and exploitation of certain valuable properties that have evolved naturally and hence possess valuable performance traits (Khitab et al., 2016). First, biomaterials come with high quantities of carbon harvested from the atmosphere, lending to biomaterials their durability. In addition, biomaterials are often readily available because their production is both sustainable and continuous. They are therefore important given the sustainability they offer in construction (Bardage, 2017). Biomaterials are also important because they are biodegradable at the end of their lifespan. In instances where structures are not expected to exist to perpetuity, the use of biomaterials is valuable. Biomaterials are also important because of their low to zero linear coefficients of thermal expansion (Pilla, 2011). This implies that in the event of excess heat or long spells of high temperature, structures constructed with biomaterials suffer little to no effects of the heat. Thermal expansion has been known to cause the deformity and even destruction of buildings. This is something that structures built with biomaterials rarely exhibit. Biomaterials are also important for their ability to regulate both temperature and humidity in enclosed spaces. Temperature and humidity regulation are valuable in any form of building. Biomaterials are also known to exhibit high Fickian vapor dispersion and diffusivity, both of which are valuable to temperature and humidity regulation, in turn ensuring structure longevity. Other valuable properties of these materials include low embodied energy, high specific heat capacity, adequate performance-to-weight ratios, and low thermal diffusivity (Khitab et al., 2016).

The application of biomaterials in any sector allows humankind to make use of non-synthetic alternatives. Through them, people are able to deploy nature's answers for adhesion and preservation. Biomaterials are used in cooperation with synthetic materials to facilitate the production of different structures and achieve different performance levels. The sustainability of biomaterials is expressed in their environmental, social, and economic benefits. Sustainability requires the construction of future infrastructure that meets present requirements without compromising the capability of future generation to meet their own requirements (Fırat, Kinuthia, & Abu-Tair, 2018). This goal is well met with the use of biomaterials. The advances in the field of chemistry represent some of the greatest breakthroughs in history. Chemical processes have brought about synthetic materials that are optimal in various functions. However, these advancements have continued to compromise the well-being of the environment. In this case, the use of biomaterials is currently very important, because these materials offer solutions to a myriad of environmental problems. The use of biomaterials has significantly reduced the emission of greenhouse gases, hence offering a less toxic collection of alternatives to their synthetic counterparts (Ong, Shatkin, Nelson, Ede, & Retsina, 2017).

The use of reusable and sustainably managed biomaterials is one of the major strategies to ensure the progression of green sustainable construction (Khitab et al., 2016). Sustainability in construction focuses on the importance of the application of biomaterials together with the incorporation of finishes manufactured from by-products, such as agricultural waste. Due to their biodegradability, biomaterials have taken up numerous roles that had been dominated by synthetic materials. The dumping of synthetic materials has a history of causing environmental problems in the long run, because they are nonbiodegradable. Therefore the use of biomaterials is any form solves the dumping dilemma by eliminating waste production (Weber, Calaf-Forn, Puig-Ventosa, Cabras, & D'Alisa, 2018).

#### *2.3.2. Types of Biomaterials*

Some of the major types of biomaterials applied in the construction industry are:

1) Bio-concrete: Apart from being the most durable material, concrete is one of the strongest materials used in construction. And the addition of the bio component in its constituents has only served to make concrete stronger. Despite its reputable strength, standard concrete has been known to crack, reducing its overall durability. A technique known as autogenic healing is known to develop a special type of bio-concrete that rarely exhibits cracks (Williams, Lawrence, & Walker, 2016).
2) Bio-plastics: Plastics are highly versatile while in use. Construction engineers and architects make use of plastics to maximize the durability, energy efficiency, and performance of buildings (Pilla, 2011). Plastic has therefore been applied in solutions for walls, roofs, fences, windows, and pipes. The emergence of bio-plastics has provided not only renewable and biodegradable alternatives but also sustainable ones. Their bio components substitute the petroleum-based composites of standard plastics. Because of their optimal strength-to-weight ratio, bio-plastics are good alternatives in fencing, framing, decoration, insulation, walling, and railing (Nwabue, Unah, & Itumoh, 2017).
3) Bio-admixtures, such as lignosulfonate, are known for increasing the workability and compressive strength of inputs like concrete. Lignosulfonate is derived from a

natural polymer of wood. Apart from concrete, bio-admixtures for asphalt, gypsum, grouts, and paints are also currently in application (Oliveira, Ramires, Frollini, & Belgacem, 2015).

4) Bio-mediated soil: Bio-mediated soil is a valuable type of biomaterial currently being applied in the construction industry. Bio-mediated soils have had better application results than those of regular soil because the bacteria component induces cementation optimally. Apart from this, it is also a cost-effective construction material (DeJong, Mortensen, Martinez, & Nelson, 2010).
5) Bio-asphalt: This is a valuable alternative to regular asphalt because it is derived from renewable sources that are not petroleum based. These bio-sources include vegetable oils, natural gum and gum resins, molasses, peanut oil, canola oil waste, natural latex rubber, rice, sugar, and dried sewage effluent among others. Bio-asphalts provide better shear strength of soil, increased structure stiffness, and reduced dilative tendencies (Su, Xiao, Wang, Cong, & Amirkhanian, 2018; Zhang, Wang, You, Jiang, & Yang, 2017).

### *2.3.3. Uses of Biomaterials*

Biomaterials are currently applied in the construction industry in several different forms. These materials are used either directly or indirectly through chemical modification in a bid to optimize materials' performance. Biomaterials are derived from a wide variety of natural sources, such as plants, animals, biotechnical processes, and soil. Apart from common biomaterials such as wood, agricultural crops are currently being prepped for use in construction despite their limitations. This points to significant progression in the application of biomaterials (Razavi, 2018).

One of the valuable applications of biomaterials is in concrete reinforcement. In this use, natural fibers are embedded into walls through hemp-shive and ultimately bonded by lime (Bardage, 2017). Concrete reinforced in this manner is more durable than conventional reinforced concrete. Another valuable application of biomaterials is in paint, where paint is laced with linseed oil. Such paints are sustainable due to the limited quantities of synthetics they contain (Khitab et al., 2016).

Another valuable use of biomaterials is as an insulation material in construction. The straw bale farmhouse located in Wales is a noteworthy example. The structure is made out of pieces of wood and enormous bales of straw that have been tightly compacted on the farmhouse's concrete base (Binici, Aksogan, & Demirhan, 2016). The compacted bales of straw provide a great insulation cover as compared to traditional manufactured blocks. In addition, the wool material embedded on the farmhouse's roof extends insulation to the upper parts of the building (Liu et al., 2017).

Biomaterials also provide alternatives for construction materials that use high levels of embodied energy. Synthetic materials often need great amounts of embodied energy due to the number of chemical processes and reactions required during their production. Biomaterials offer not only similar functionalities to synthetic materials but require lower levels of embodied energy (Bianco et al., 2017).

Sustainable thermal regulation represents one of the major uses of biomaterials. Biomaterials can effectively regulate temperature for long periods of time. Apart from making living spaces thermally comfortable, they are also cost effective in that end (Khitab et al., 2016). As mentioned earlier, biomaterials are also proven to be effective fire retardants. Biomaterials derived from plants oils and animal fats are known to have high latent heat, hence their ability to resist the adverse effects of fire. And they offer not only durable and stable solutions but also nontoxic benefits (Razavi, 2018).

The final use of biomaterials in this context is in the optimization of the performance of construction materials, as is the case of admixtures. The addition of the bio component as a functional molecule improves admixtures' performance. Similar cases are found in asphalts and concrete, as previously discussed. The use of biomaterials can be traced back to the times of the Sumerians and the ancient Roman Empire. Advances in Roman architecture were in fact made possible by the use of construction materials made from chemicals derived from natural sources (Plank, 2004).

#### *2.3.4. Biomaterial Insulations*

Thermal insulation was categorized as one of the major uses of biomaterials (Cárdenas-R et al., 2018). Biomaterial insulation is applied in various approaches with the use of various materials, with the common factor that the materials are all derived from natural sources. Apart from these biomaterials having thermal conductivities similar to those of mineral wool, they also have other valuable properties like fire resistance; resistance to pests, fungi, and rodents; and durability (Palumbo et al., 2018). As a result of their hygroscopic properties, these materials are currently being relied upon in the construction of optimally insulated buildings. Their low embodied energy requirement makes them even more attractive for this function. Biomaterial products are currently available in different forms, such as boards, slabs, and fleeces. A recent report attributed the 20% increase in insulation seen in green buildings to the existence of biomaterial insulation (Nguyen, Grillet, Bui, Diep, & Woloszyn, 2018). This level of thermal insulation is considered greater than that provided by traditional materials.

Bio-based insulators have several environmental advantages. Most of these insulators, including stalks and straws, are derived from agricultural processes. Builders make the most of natural resources by using these materials, thus presenting a sustainable alternative from an environmental perspective (Ong et al., 2017). Apart from this, biomaterial insulators provide other solutions by having low embodied energy requirements as opposed to conventional insulation materials that must be produced through high-energy, intensive processes and shipped across continents. The main idea of insulation is to find a solution that needs low embodied energy (Khitab et al., 2016; Razavi, 2018).

Bio-based insulators have also proven to be viable economically for both homeowners and builders. The capital expenditure perspective currently drives the cost of construction. In this case, the cost of raw materials is the determinant of the overall construction cost. Due to the availability of bio-based insulators, their use has not only improved building insulation by over 20% but also reduced the overall cost of construction by 15%, thus making bio-based insulators economically viable (Palumbo et al., 2018).

Despite the progressive accumulation of the advantages of bio-based insulators, they are still being widely applied as small niche products. One of the main reasons for this is the unavailability of economies of scale (Nguyen et al., 2018). The cost perspective has made it difficult for builders to exclusively embrace biomaterial insulation. But from the consumer's perspective, the use of biomaterials in insulation is an attractive idea mainly because of the increasing cost of procuring thermal regulation appliances. As a result, private homeowners have resorted to rebuilding their homes with the better insulation characteristics provided by biomaterials (Binici et al., 2016).

One of the various types of biomaterials used in insulation is hemp. This biomaterial insulator is available as either hempcrete or fiber slabs and used as a straightforward insulation solution in homes. In application, is it often embedded between studs of timber. Hemp can also be applied in structural floors and walls. Hempcrete is typically laid as blocks before casting is done. Hemps are optimal thermal insulators because of their low thermal conductivity. They can adequately insulate the buildings in which they are applied (Dhakal, Berardi, Gorgolewski, & Richman, 2017).

The other type of biomaterial insulator is sheep's wool. This material is available in the form of slabs and rolls. Sheep's wool in all of its forms constitutes a significant portion of polyester fibers. Its low conductivity of 0.039 $W/_{mK}$ makes it a good thermal insulator. The material is capable of absorbing and releasing large amounts of water without coming undone. However, long-term exposure to humidity and radiation is capable of degrading its insulation value (Bosia et al., 2015).

The other type of biomaterial insulator is wood fiber. This biomaterial is characterized by a thermal conductivity as low as 0.038 $W/_{mK}$ (Khitab et al., 2016). Its low thermal conductivity together with its flexibility makes it ideal for insulating buildings with irregular walls. In addition, certain types of wood fibers are known for their ability to prevent structural problems by absorbing any condensed precipitate that forms within the batt. Like most biomaterial insulators, wood fibers contain neither CFCs nor VOCs (Cetiner & Shea, 2018).

The other major type of biomaterial insulators is straw. Straws are currently being availed as either finished boards or pre-compressed blocks. However, they can also be normal field bales derived from food crops and compressed with the use of baling machines. Due to their density, these materials are not susceptible to rodent attacks and are also fire resistant. Their major disadvantage is their high load bearing. This constraint is often overcome with the use of timber frames that can withstand their loading conditions. Long-lasting straw buildings have been able to survive due to the waterproof nature of the straws (Belayachi, Hoxha, & Ismail, 2017).

The other types of biomaterial insulators are cotton, cork bark, and flax and rice fibers. The extension of cotton as a bio-based insulation material is limited due to the unavailability in certain areas in the world. It has proven to be an insulation solution with a relatively higher embodied energy (Khitab et al., 2016). Its production makes use of processes that are characterized by high amounts of chemicals and energy. The only sustainable type of cotton insulation is provided by recycled cotton. Cork bark, on the other hand, has proven to be sustainable insulator in loose fill application. It is applied in two forms: granulated cork and insulation board. Cork is extremely sustainable in countries such as Portugal, where its production is abundant. Rice and flax fibers are applied in ways similar to straw and hemp. All of the above-discussed types of biomaterial insulators have clear sustainability benefits (Marques et al., 2018; Pérez, 2016; Sierra-Pérez, García-Pérez, Blanc, Boschmonart-Rives, & Gabarrell, 2018).

#### 2.3.4.a. *Historical Development of Bio-insulation*

Investigating the history of bio-insulation is important to gain an accurate perception of this biomaterial. Overall, the articles published in this field explain the level of bio-insulation's development.

As Liu et al. (2017) pointed out, the very first research on bio-insulation was conducted in 1974; consequently the historical development of bio-insulation is quite short. Only a few articles released were before 1998, which indicates the limited work done from 1974 to 1998 (Al-Juruf, Ahmed, Alam, & Abdel-Rahman, 1988; Etris et al., 1974; Sampathrajan, Vijayaraghavan, & Swaminathan, 1992; Wagner, 1978).

Some judgment drove the absence of consideration of bio-insulation before 1998. In Liu et al.'s (2017) opinion, a building's purpose is limited to living. They made no consideration regarding energy savings or adjusting the environmental effects of the building. Hence not only bio-insulations but also other thermal insulations created using local materials drew limited attention (Dávid Bozsaky, 2011).

Attention to bio-insulation grew notably beginning from 2003 and, remarkably, after 2010 (Hajj et al., 2011; Latif, Ciupala, & Wijeyesekera, 2014; Nicolajsen, 2005; Taoukil, El bouardi, Ajzoul, & Ezbakhe, 2012). This was in part due to increased interest in protecting the environment and saving energy. Environmental protection and energy savings became the focus of the public perspective broadly—and unexpectedly–

–by the beginning of this century. Another reason, aside from population growth, was that the need for good indoor air quality became greater, which drove the fast rise of energy use (Binici, Gemci, Kucukonder, & Solak, 2012; Latif, Ciupala, Tucker, Wijeyesekera, & Newport, 2015; Mansour, Srebric, & Burley, 2007; Palumbo et al., 2015; Srinivasan, Rajendra Boopathy, Sangeetha, & Vijaya Ramnath, 2014; Taoukil et al., 2012; Zhou, Zheng, Li, & Lu, 2010).

Consequently, there is a definite interest in conserving energy in buildings. Thermal insulation is considered an efficient technique to decrease energy consumption, and especially when considering as environmental-friendly, bio-insulation started to attract more awareness (Wei et al., 2015).

### *2.3.5. Epoxy mixing with Biomaterials*

Increasing economic and environmental concerns together with the uncertainty that comes with limited petroleum resources have catalyzed research activities aimed at creating renewable material resources. An example of such materials is epoxies resins. Epoxy resins refer to a set of common prepolymers employed in various sectors (Baroncini, Kumar Yadav, Palmese, & Stanzione, 2016). To change epoxy resins into cross-related networks that have useful mechanical and thermal properties, the resin ought to be mixed with biomaterials, such as coconut shell powder or tamarind shell powder (Somashekhar, Naik, Nayak, Mallikappa, & Rahul, 2018). Therefore manufacturers are aiming to substitute petroleum-based materials using naturally occurring biomaterials to achieve the industrial target for developing products and processes that are friendly to the environment and improve sustainable development (Guzel Kaya et al., 2018).

Epoxy resin is a vital type of thermosetting polymer with a history that extends over 60 years. Today the most important and frequent type is known as the epoxy resin produced from epichlorohydrin and bisphenol A: Bisphenol A diglycidyl ether whose chemical compound is shown in Figure 1 (Yang et al., 2017). Before the healing process, oligomers or epoxy monomers comprise at least two epoxy sets. However, after curing, they transform into cross-related networks because of the reaction with an appropriate catalyst or curing agent. Materials and chemicals resulting from renewable sources have received extensive attention in recent years as environmental problems and petroleum depletion are becoming increasingly serious. As a result, numerous bio-based epoxy-curing catalysts have been developed (Somashekhar et al., 2018). For instance, a polyamine derived from a novel vegetable oil was developed using grapeseed oil and cysteamine chloride. An utterly bio-based epoxy resin was created from maleopimaric acid and terpene-maleic anhydride, which shows similar or even improved mechanical characteristics and thermal stability as compared to the bisphenol A class epoxies cured using agents derived from petroleum (Yang et al., 2017).

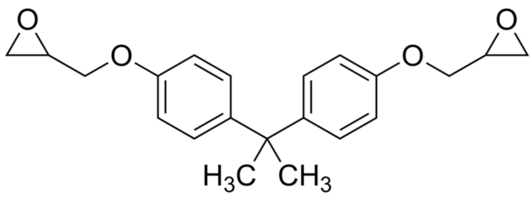



*Figure 1*: Chemical structure of Bisphenol A diglycidyl ether "epoxy DER 332" (Pham & Marks, 2005).

According to Somashekhar et al. (2018), directly mixing epoxy resin and tamarind shell powder, coconut shell powder, or both improves epoxy's strength characteristics and can be applied a broad spectrum of uses. From the results of their study, they established that the best mixture is obtained when the coating comprises 45% epoxy resin, 50% powder from coconut shell, and 5% powder from tamarind shell. They further added that to prepare the various classes of coatings, epoxy, tamarind shell powder, and coconut shell powder are mixed as per the percentage proportions presented below.

Table 1:

*Directly Mixing Epoxy Resin and Tamarind Shell Powder, Coconut Shell Powder, or Both Improves Epoxy's Strength Characteristics and Can Be Applied in a Broad Spectrum of Uses (Somashekhar et al., 2018).*

| Class | Powder from coconut shell (%) | Powder from tamarind shell (%) | Epoxy resin (%) |
|---|---|---|---|
| A | 30 | 0 | 70 |
| B | 40 | 0 | 60 |
| C | 50 | 0 | 50 |
| D | 30 | 15 | 55 |
| E | 40 | 10 | 50 |
| F | 50 | 5 | 40 |

Organic coatings are used to manage the corrosion of steel materials placed in highly acidic areas (Xu, Wang, Han, Wang, & Liu, 2018). DER-332-epoxy resin is the principal vital as well as commercial epoxy polymer. It has high alkali and acid resistant properties, and it usually acts as a barrier between the solution and the metal substrate to prevent the infiltration of energetic ions and water (Baroncini et al., 2016). Nonetheless, energetic ions, particularly robust ions, can attack coatings through pores. Owing to the incidence of inherent brittleness and porosity of the polymer, various coatings put to use under these conditions cannot withstand strong acids at high temperatures, resulting in early failures. The challenge therefore is to formulate a product that meets the desired lifespan and target cure temperature (Honcoop & McNamee, 2010).

Coatings must meet many requirements to be characterized as environmentally friendly: their materials ought to be produced sustainably from biomaterials. As highlighted in this case study, many studies are being done globally to create improved coatings from bio-based sources (Gupta, Ahmad, & Dev, 2011).

#### *2.3.5.a. Toxic effects of bisphenol A diglycidyl ether*

Bisphenol A is a hazardous chemical -while liquid- as defined by the OSHA Hazard Communication Standard (The Dow Chemical Company, 2012). It may cause skin irritation with redness and eye irritation. There is no evidence of Bisphenol A is carcinogenic.

### ***2.3.6. Date Pits as a Biomaterial***

Phoenix dactylifera L., or the date palm, is a broadly consumed fruit everywhere in the world. In the Middle East, there are many date palm farms that breed dates for local consumption and export (Maqsood, Kittiphattanabawon, Benjakul, Sumpavapol, & Abushelaibi, 2015). The date palm pit forms about 10% of the date fruit's mass, which is a by-product of the fruit processing industry and can be reused for different value-added products. Carbohydrates (0.85 g/g date pits) and oil (0.12 g/g date pits) are considered the main solids elements in the pits (Suresh et al., 2013). According to a report by the Food Authorization Organization (FAO) of United Nations, the mass composition of date pits worldwide in 2014 was 750,000 tons (FAO, 2014).

Although most of the date pit generated becomes waste material, the pits have a notable number of natural fibers (Al-Farsi & Lee, 2008). The primary purpose of this study to optimize the powder produced from date pits for application as coating paste of existing buildings.

Phoenix dactylifera L. is the Latin name for the date palm, which is considered one of the most important species of the family Arecaceae. There are over 2,000 types of dates around the world, which differ in size, weight, and form. Normally, they have an oval-cylindrical form, although some types are round. Regularly, lengths vary from 1.8 to 11.0 cm, with a diameter from 0.8 to 3.2 cm. On average a date weighs 2 to 60 g (Al-Farsi & Lee, 2011; Besbes, Blecker, Deroanne, Drira, & Attia, 2004; Mostaan, 2016). The pits do not look much different than the fruit; they also vary depending on the variety of the fruit, environmental circumstances, and growing techniques. An average pit weighs from 0.5 to 4 g, and its length ranges from 1.2 to 3.6 cm, with a width between 0.6 and 1.3 cm (Al-Farsi, 2011). The pits are usually oval-cylindrical, grooved ventrally, and have a tiny embryo and a hard endosperm coated by cellulose on the core of cell's walls (Mostaan, 2016).

Cellulose, hemicellulose, and lignin are the three major chemical components of date pits as well as other minor constituents such as protein, oil, and lipids (Shayeb, Alharbi, Baloch, & Rahman Alsamhan, 2017). Cellulose counts as a linear polymer of b-D-glucopyranose units and is insoluble in water, while hemicellulose is vaguely defined as a polysaccharide of low molecular weight, and is therefore soluble in water (El-Hendawy, 2006). However, both cellulose and hemicellulose accommodate major functional groups of oxygen, which are evident in the lignocellulosic material, some of which are hydroxyl, ether, and carbonyl, as illustrated in Figure 2 (Al-Ghouti et al., 2013). Lignin is complicated, systematically polymerized, and is considered a high aromatic substance, which also behaves as a cementing matrix that keeps both cellulose and hemicellose units together (Alsewailem & Binkhder, 2010).

### 2.3.6.a. *Chemical composition*

Table 2 presents the average chemical compositions of date pits from different articles (Besbes et al., 2004; Nehdi, Omri, Khalil, & Al-Resayes, 2010). Date pits composed 90.20% of dry matters, 1.17% ash, 77.85% carbohydrate, and crude protein and the fat contents (dry weight basis) were 5.67% and 10.28%, correspondingly. The concertation of potassium was the highest, followed in order magnesium, calcium, phosphorus, sodium and iron.

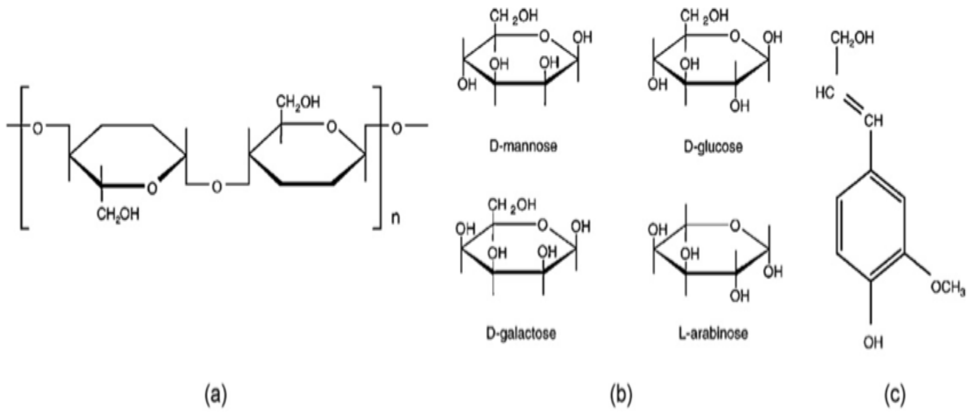



*Figure 2:* (a) cellulose molecule, (b) sugar residues of hemicellulose, (c) phenylpropanoid (Al-Ghouti et al., 2013).

Table 2:

*Chemical composition (dry basis) of date pits.*

| Component | (Nehdi et al., 2010) | (Besbes et al., 2004) |
|---|---|---|
| Dry Matter (%) | 89.80 | 90.60 |
| Fat (%) | 10.36 | 10.19 |
| Protein (%) | 5.77 | 5.56 |
| Ash (%) | 1.18 | 1.15 |
| Potassium (mg/100 g of dry matter) | 255.43 | 229.00 |
| Magnesium (mg/100 g of dry matter) | 62.78 | 51.70 |
| Calcium (mg/100 g of dry matter) | 48.56 | 38.80 |
| Phosphorus (mg/100 g of dry matter) | 41.33 | 68.30 |
| Sodium (mg/100 g of dry matter) | 8.77 | 10.40 |
| Iron (mg/100 g of dry matter) | 3.21 | 2.30 |
| Carbohydrate (%) | 72.59 | 83.10 |

#### 2.2.6.b. *Flammability of Cellulose-Based Fibers*

The flammability of cellulose-based materials was studied by (Salmeia et al., 2016); it shows that the rate of the flammability varies from chemical composition to another. It was proven the cellulose -based fibers congaing lignin, burn slowly compared to others.

## 2.4. Nano-Technology

Nanotechnology is one of the rising technologies of the present era, because of the universal focus on nanosciences. Nanotechnology has made it possible to create materials from an atomic source, which has had a tremendous impact on the quality of life. Nanotechnology proposes techniques to produce lighter, stronger, and more economical materials with unique properties that can be used in innovative applications, using fewer resources and far less energy (Li, Xiao, Amirkhanian, You, & Huang, 2017).

Various studies have shown that the use of nanomaterials would reduce the annual cooling load from 15% to 30% (Boostani & Modirrousta, 2016). The importance of nanotechnology in architecture is broad and ranges from the initial stages of drafting up to the last touches of decorating. Particularly in terms of materials selection, nanotechnology is influential not just in design but also in the thinking of architects, given the new extensive selections that nanotechnology offers (Mohamed, 2017).

Nanoarchitecture is the merging of nanotechnology with architecture by applying nanomaterials, nanoproducts, and nanoshapes. Such union has significant benefits, including additional performance, economic benefits, and market needs concerning product improvement. Great design is based on interest and participation in the development of both nanomaterial and the resulting nanoproduct (Liu, Zeng, & Wei, 2018).

### *2.4.1. Importance of Nanotechnology in Buildings*

The construction sector is one of the most significant industries globally, so it stands that nanomaterials will have a growing role in architecture (Vyas & Jha, 2016). Many building materials integrate nanotechnology, from self-cleaning windowpanes to adjustable solar cells, self-healing concrete, and materials that block infrared and ultraviolet radiation (Porro, 2004). Because the construction sector plays a vital part in resource depletion, thermal insulation is considered a critical solution that can support communities' efforts to build without wasting energy. Various natural and artificial materials could be created for use in thermal insulation, including nano insulation, nano silica, fiberglass, nano-TiO2, rock wool, polystyrene, and polyurethane. Nanomaterials are expected to reduce carbon emissions in three primary capacities: transportation, buildings, and renewable photovoltaic energy (Boostani & Modirrousta, 2016; Rostam et al., 2015). For example, the durability and compressive strength of cement-based materials is higher when using nano silica Bozsaky, 2016; David Bozsaky, 2015), which can increase the fluidity of concrete. New low-cost materials with excellent thermal insulating would be an exciting solution given their mechanical and economic advantages and the essential plan for sustainable environments and buildings (Rostam et al., 2015; Schlanbusch, 2013).

The application of nanomaterials in architecture offers great possibilities to solve dilemmas and enhance the quality of buildings, their efficiency, and the way they are associated with the environment (Acharya, Giri, & Gokhale, 2017). Nanomaterials can open up design opportunities for both interior and exterior areas. Their application creates new potentialities for sustainable design approaches and allows for a new pattern of functions that would improve the interaction between residents and buildings (Lau, Jian, Yu, & Hui, 2018).

Nanomaterials can combine practical features with new breakthrough characteristics, such as enhanced tensile strength, self-cleaning capabilities, fire protection, heat absorption for windowpanes, and energy coating solutions, for optimal solutions regarding energy and light (Acharya et al., 2017). The most captivating reason to employing nanotechnology in architecture is to achieve higher energy efficiency.

Nanotechnology provides new technological means to mitigate climate change and decrease greenhouse gas emissions in the future (Rostam et al., 2015).

### *2.4.2. Thermal Insulation and Nanotechnology*

The use of nanotechnology has the potential to create excellent thermal insulation materials. The focal point of nanotechnology is to manage matter in regular particles, with a diameter from 0.1 nm to 100 nm (i.e., at the scale of atomic and molecular particles). But to create optimal thermal insulation materials, nanotechnology's target shifts from the particles themselves to the pores on the particle at a nano scale (Jelle, 2016). These characteristics are shown in Figure 3; where nanoparticles have nanopores with the high surface area to volume ratio, the nanoparticle will result in blocking and slowing down the heat flow.

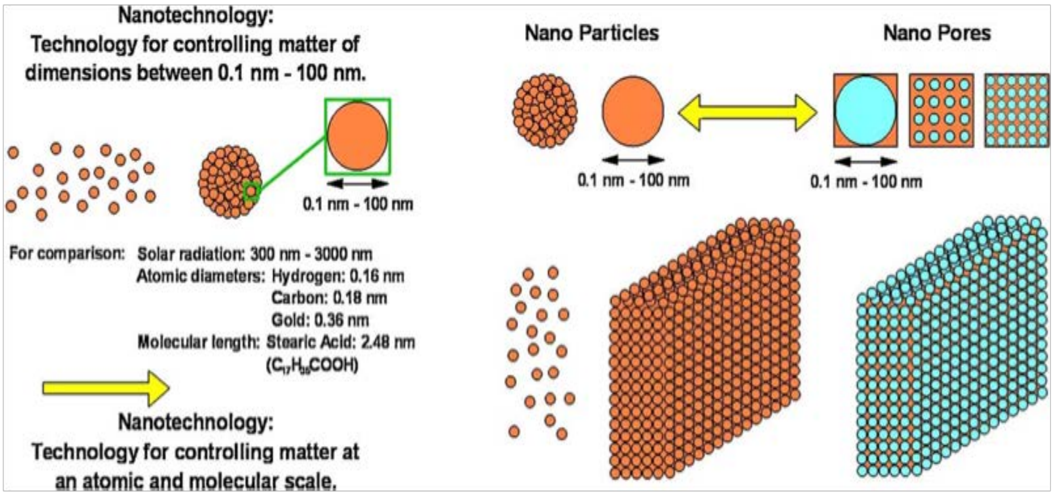



*Figure 3:* The application of nanotechnology in high-performance thermal insulation (Jelle, 2011).

### 2.5. Qatar National Vision 2030

By 2030, Qatar intends to be a leading community, capable of sustaining its expansion and implementing a higher standard of living. Qatar's national vision describes long-term development goals for the state and provides a framework through which national development plans and implementation strategies can be developed.

Qatar National Vision 2030 is established based on the guidelines of Qatar's permanent constitution, and four interconnected pillars support it:

1) Human development is the process that develops the abilities and opportunities of those who live in Qatar to empower them to sustain a promising community.
2) Social development is the process of tending society through exceptional moral standards and encouraging cultural approaches, and where Qatar plays an essential role in the international community.
3) Economic development aims to guarantee a diversified and competitive economy that is able to satisfy the needs of, and ensure a high standard of living for, those currently living in Qatar as well as for the next generation.
4) Environmental development aims to control the environment through the combination of economic, social and environmental aspects—the three aspects of sustainable development.

### 2.6. Building Energy Simulation

A building energy simulation makes use of a computer-based program to predict the energy aspects of a building. The main aim is to create a pragmatic model that accurately represents the actual building (Kim, Jeong, Clayton, Haberl, & Yan, 2015). As in the literature, the evolution of the building energy simulation can be described as the simulation of building thermal performance using computers focusing on load calculations and analyzing the use of energy, where a graphical interface simulates the heat and mass transfer in the layers of the building (Spitler, 2006).

The primary goal of a building energy simulation is to promote innovation by implementing a high-integrity representation of the building. To achieve the best design, a model is used to indicate the most accurate achieved model within the investigation. Based on Shiel, Tarantino, and Fischer (2018), the best model design group had nine parameters identified as major possible change points, depending on where in the process the data were sourced. A summary of the nine parameters is shown in Table 3. Several designs, layouts, and energy modeling software are available, as open-source or commercial programs, including Autodesk Revit, HEED, EnergyPlus, OpenStudio, and Trimble SketchUp (Fukuda, Yokoi, Yabuki, & Motamedi, 2018).

Briefly, an energy system model is an analytical model illustrating the behavior of the building system and materials. As presented in Figure 4, the input variables are the building mass of the modeling system that acts on the energy system of the building. There are internal variables, such as heat gain and the set point of the thermostat. Other inputs include solar radiation, outside temperature, and the wind speed, where these characteristics are not controllable but can be forecast. Regarding the output variables, they can be grouped into indoor temperature and indoor humidity (Harish & Kumar, 2016).

Table 3:

*Design Stages in the Building Energy Simulation Model to Obtain the Best Design*

| High-Level Categories | | Selected Parametric Group |
|---|---|---|
| Design | 1 | Geometry |
| | 2 | Materials |
| | 3 | Glazing System |
| System | 4 | HVAC System |
| Use | 5 | Lighting System |
| | 6 | Plug Loads System |
| | 7 | Occupancy System |
| Context | 8 | Building Adjacencies Geometry |
| | 9 | Statistical Weather Data |

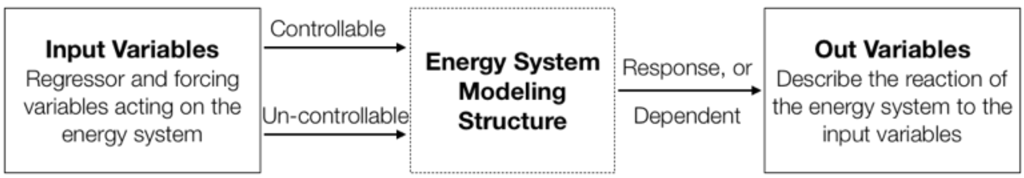



*Figure 4:* Modeling structure of building energy simulation.

The evaluation of the building energy load can be classified into five aspects: a) the building envelope and coating, b) air ventilation and conditioning, c) water heating system, d) equipment inside the building, and e) lighting (Egwunatum, Joseph-Akwara,

& Akaigwe, 2016). The building envelope is the physical separator between the indoor and outdoor environment, which includes the exterior walls, roofs, and floors. Thermal insulation is a major component of the building envelope; it is considered as a barrier for heat flow (Natephra, Yabuki, & Fukuda, 2018). The thermal properties of the building's envelope are defined by wall mass, thermal resistance, insulation placement, exterior wall color, texture, and size.

# CHAPTER THREE: MATERIALS AND METHODS

## 3.1. Introduction

This chapter addresses the aim and objectives of the project defined in the first chapter. For the sake of understanding the thermal performance of the new biomaterial, some experimental investigations were conducted. Figure 5 shows a flow diagram involving the different steps for developing the thermal insulation material.

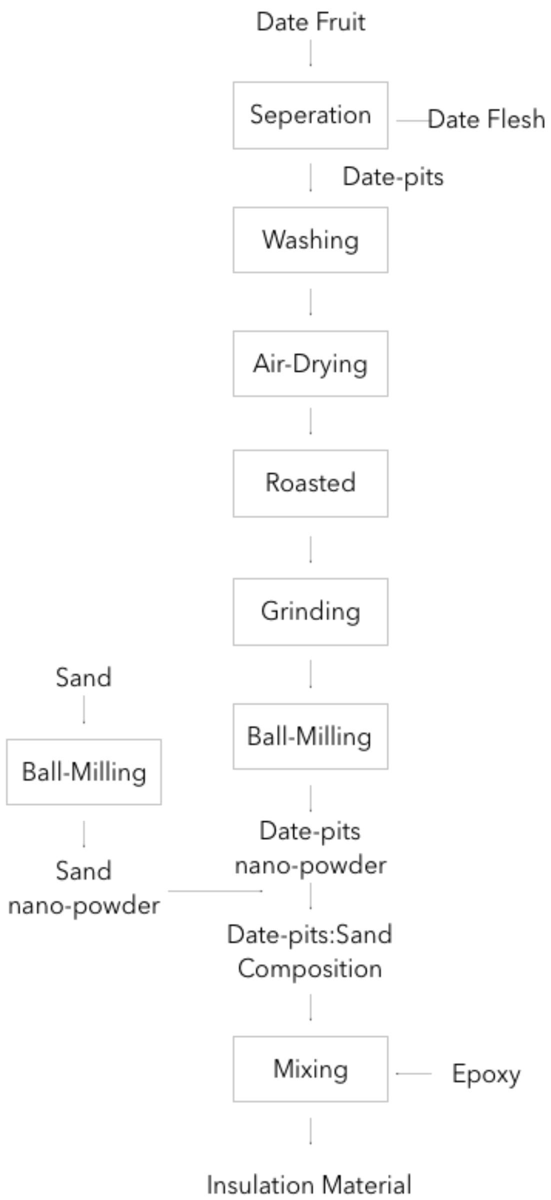



*Figure 5:* Flow diagram showing the development of date pits into insulation material.

## 3.2. Materials collection and preparation

### *3.2.1. Date pits*

The date pits (DP) samples were collected from different sources. In order to remove impurities, the samples were rinsed several times with deionized water. Then, the samples were left to air dry for 24 hours at 105°C. The samples were then roasted at 130°C for 5 h. The roasted date pits (RDP) were crushed and grounded into powder using grinder and then transferred to coffee machine where it was grinded further to obtain particles size ranging from coarse particles to fine particles. One particle size range (0.250 mm - 0.125 mm) were then further processed to the nanoscale using the MSK-SFM-1 Bench-Top Planetary Automatic Ball Mills at 50 Hz for 3 hours; these new materials were referred to as nanoparticle of date pits in this study.

Planetary ball mills process samples into ultrafine particles (Figure 6); this method has been known for more than 100 years. Usually the mill has two or four jars, and the jars are connected to a plate, which turns on its axis. The high speed of the rotation of the plate and jars transfers energy to the milling balls inside the rotating jars, achieving efficient grinding (Stolle, Szuppa, Leonhardt, & Ondruschka, 2011). There are many advantages to using a planetary ball mill because it (a) is quick and powerful, grinding down to the nanoscale; (b) is adequate for long-term experiments; and (c) has the ability to grind both wet and dry materials (Noor, 2017).

### *3.2.2. Sand*

Sand samples were taken from southeastern Qatar at a sand dune (25.0856 °N and 51.3689 $°E$). Sand samples were collected from the dune's surface and stored in a plastic container. The sand particles were then processed to the nanoscale using the MSK-SFM-1 Bench-Top Planetary Automatic Ball Mills at 50 Hz for 3 hours.

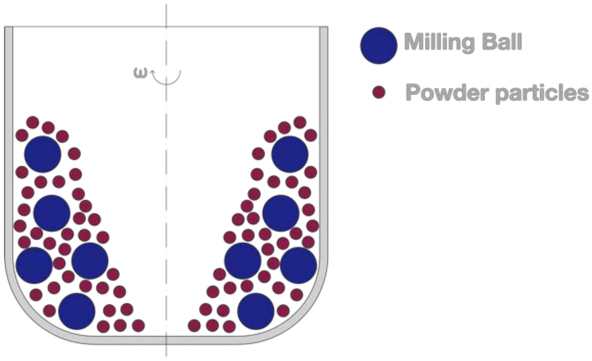



*Figure 6:* A schematic diagram of a planetary ball mill (cross-section).

### *3.2.3. Nanoparticle of Date Pit and Sand Composites*

The prepared nanoparticle sand was mixed to the prepared nanoparticle of date pits powder at different ratios (0%, 10%, 20%, 30%, and 40%) and labeled as (DP0S, DP10S, DP20S, DP30S, and DP40S), respectively, to reach a final weight of 20 $g$.

### *3.2.4. Fly Ash*

Fillite 160 fly ash cenospheres were obtained from Omya UK Ltd. The Fillite 160 fly ash has chemical properties as shown in Table 4, with an average loos bulk density of 0.35 to 0.48 $^{g}/_{cm^3}$. The Fillite fly ash has a neutral pH, with a very low reactivity and high melting point (1200 - 1400 °C). One of the advantages of the Fillite fly ash that it has a low thermal conductivity of 0.11 $^{W}/_{mK}$ (Omya UK Ltd., 2014).

Table 4:

*Chemical Properties of Fillite 160 Fly Ash Cenospheres (Omya UK Ltd., 2014).*

| Oxides | Percentage (%) |
|---|---|
| $SiO_2$ | 55–65 |
| $Al_2O_3$ | 27–33 |
| $Fe_2O_3$ | ≤ 6 |
| $CO_2$ | 70 |
| $N_2$ | 30 |
| Loss in ignition (1000°C) | ≤ 2 |

Table 5:

*Composition Volume with Respect to Epoxy.*

| Composite | Filler Volume Added to Epoxy (%) |
|---|---|
| Control Epoxy | 0 |
| DP0S50E | 50 |
| DP10S50E | 50 |
| DP20S50E | 50 |
| DP30S50E | 50 |
| DP40S50E | 50 |
| FA60E | 60 |

### 3.3 Polymer Compositions

Five different sizes of composition, or filler, were taken for study at a time and mixed with epoxy and hardener; the epoxy resin reacted with a special hardener, polymerizing to form a plastic-like product (Kang & Hussin, 2008). The mixing of the epoxy and date pit–sand composite (DP0S, DP10S, DP20S, DP30S, DP40S) with epoxy and fly ash composition is described as follow. First, the dry composition was weighed according to mix proportion and put in a clean, dry container until the epoxy and hardener was prepared. The proposed amount of epoxy resin was weighed, and hardener was added thoroughly in the same container as the filler. The mixture was continuously mixed for 3 minutes to achieve a uniform mixture. The cylindrical mold has a radius of 12.25 $mm$ and height of 21 $mm$. The hardener-to-epoxy ratio is optimally 1:7, which is required to achieve adequate strength. The epoxy was added to the date pit–sand composite with ratio 1:1 of epoxy, and ratio of 2:3 the fly ash to epoxy resin, as shown in Table 5. All composites were exposed to air curing in the lab with an average temperature of 22.5 ℃ ± 0.5℃ , and 45 % ± 5 % relative humidity.

#### *3.3.1. Morphology Scanning Electron Microscopy-Energy Dispersive X-ray Spectroscopy (SEM-EDX) Analysis*

The morphology of the powdered date pits was examined using a field emission scanning electron microscope (SEM). SEM (JEOL JSM-7600F) uses a stream of electrons to yield high-resolution images of a targeted sample as it is and as well suspending the particles in solvent and spread on glass slide. Images are created when the sample's particles interact with the electron beam (Newbury & Ritchie, 2013). The morphology of the resin composite was also scanned using an emission scanning electron microscope to determine its composition after mixing with epoxy.

### *3.3.2. Particle Size Analyzer*

A particle size analyzer allows researchers to study the distribution of sizes of a selected sample in a liquid particulate material. This technique is vital in characterizing the variety of particle sizes of samples (Ferng, Chen, & Lin, 2011). In this study, the particles of the sample were suspended in water and stirred at 2000 rpm; light energy is diffracted by the suspended particles or the light intensity is absorbed by the material, giving a measure of the size of the particles (Mahasukhonthachat, Sopade, & Gidley, 2010; Storti & Balsamo, 2010). The analysis was performed using laser diffraction (Malvern Mastersizer 2000 MU) to determine the size of particles.

### *3.3.3. Measuring Density*

The composition's density was measured using a traditional method. The composition was pressed into a known cylindrical mold's dimension to reach volume

$$V = \pi r^2 h \tag{2}$$

The mold was tared to determine the composition's weight:

$$m_{compostion} = m_{compostion+mold} - m_{mold} \tag{3}$$

The equation to determine density is

$$\rho = {}^{m}/_{V} \tag{4}$$

Where density, ρ, is equal to mass, m, divided by volume, V.

### *3.3.4. Fourier Transform Infrared Spectroscopy*

Fourier transform infrared spectroscopy (FTIR) is very sensitive to the chemistry of nanoparticles. However, FTIR investigates the chemistry of the sample's surface and electron properties in addition to the stability, biocompatibility, and fluorescence properties of the particles' core (Petit & Puskar, 2018).

The measurement depends on the absorption of infrared radiation as it catches the specimen; this method is called transmission. Transmission depends on the thickness of the specimen with the reduction in light intensity following the Beer-Lambert law (Griffiths, 2010). To prepare the measurement, the Hot Disk TPS 2500 S device was used. The powdered date pit was distributed on a Styrofoam plate. After several trials, it was found that the Styrofoam plates could be used as a container to run the test. The plate's depth, height, and width are $2.5\ x\ 4\ x\ 4\ mm$, respectively. During the measurement, the sensor was sandwiched inside the powdered date pits. The implemented output power to the sensor was 0.4 $W$. FTIR was performed to identify the different functional groups that are present on the resin surface. A range of 400–4000 $cm^{-1}$ was used in the scanning with a step size of 4 $cm^{-1}$ and a scanning rate of 40.

### *3.3.5. Optical Microscopy*

Light optical microscopy is a method in which the quantitative information of a material is captured (Koval, Krahenbuhl, Warren, & O'Brien, 2018). Images of the specimen's surface are captured by a calibrated reflected white LED light source at 50x total magnification with a digital pixel resolution using Nikon Eclipse Model L200N. The photomicrography of the DP0S50E composition was scanned using the Nikon Eclipse Model L200N to determine the date-pit compositions after mixing with epoxy.

### *3.3.6. Thermal Conductivity Measurement*

The test was carried out using standard hot disc technique applied with the Hot Disk TPS 2500 S device that have a sensor which is fixed between two halves of specimens, and the experimental specification is set to similar previous values. Heat was produced by the desk run through the two halves of the sample, and the temperature of the sensor and samples are increased over time. The rate by which the temperature increases depends on the sample's materials; if the thermal conductivity of the sample is low, then the flow of temperature is high (Gustafsson, 1991; Mihiretie et al., 2017).

### *3.3.7. Thermal Analysis*

Thermogravimetric scales are used to characterize biomass; they evaluate the weight loss of a sample when temperature increases in a controlled environment. This environment could be an oxidizing atmosphere (e.g., air) or an inert atmosphere (e.g., nitrogen or helium; Velázquez- Martí, Gaibor-Chávez, Niño-Ruiz, & Cortés-Rojas, 2018).

This method also allows investigators to observe the thermal stability of the specimen where the TGA is obtained. A T50 decomposition temperature is when the material loses 50% of its original mass (Alabdulkarem, Ali, Iannace, Sadek, & Almuzaiqer, 2018).

The TGA analysis was done using the TGA 8000 in an inert atmosphere to measure the thermal stability of the biomass and the pyrolysis reaction. The TGA analyzer was raised from 0 °C to 900 °C at a rate of 10 $^{\circ C}/_{min}$ under a flow of nitrogen gas at 60 $^{cm^3}/_{min}$.

### *3.3.8. UV Aging Test*

UV exposure is a test performed in the laboratory to determine changes in the functional properties of a certain material and to define its aging mechanism (Guiheneuf et al., 2017). Epoxy resin might deteriorate after long exposure to the environment, which would affect the reliability and properties of the specimens (Wang et al., 2018). A test involving long exposure of the material in-situ would take too much time, but accelerated aging methodologies can be applied to predict the durability of the material in a very short time (Muhamad et al., 2019; Wang, Lu, & Zhang, 2016). In the accelerated aging test, the tested material is examined at a high aging rate by accelerating one of the affecting circumstances of the environment, and then the aging test parameters are transformed into real-time properties using mathematical equations. It is well known that the longevity of epoxy resin mainly depends on moisture diffusion, which can be obtained by the TGA test. In the case of coatings, this involves exposure to UV irradiation, which can be easily examined by using accelerated the aging test using QUV Accelerated Weathering Tester (Yan et al., 2018).

The examined samples are listed in Table 6. The specimens were cut into three long rectangular prisms of 10 cm, with a width of 5 mm, to prepare them for the aging process. The QUV Accelerated Weathering Tester was used to predict the long-term performance of the samples under weather stress.

As mentioned in Section 2.7.5, the laboratory UV accelerated aging test allows researchers to study the long-term effects and changes of material properties within a very short period of time as compared to actual outdoor weathering aging. Exposure levels were chosen to meet Qatari weather circumstances and also to accelerate the aging process within the available testing time. As is well known, the most critical climate conditions that act as aging agents for building and construction materials are solar radiation and extreme temperatures (Jelle, 2012).

The QUV chamber was set to 60 ℃ with a maximum irradiation of UBA-340 (1.55 $W/_{m^2}$ @ 340 $nm$) continuously for 2 days, which is equals to almost two years of harsh, extreme weather conditions.

Table 6:

*List of Examined Samples for UV Aging Test.*

| | Filler | Volume of Filler to Epoxy (%) |
|---|---|---|
| 1 | DP0S50E | 50 |
| 2 | FA60E | 60 |

### *3.3.9. TPS Method Measuring Thermal Conductivity*

The standard hot disk technique was applied using the Hot Disk TPS 2500 S device, where thermal conductivity and thermal diffusion were measured using same technique as used to measure the plain powdered date pits. The Hot Disk TPS 2500 S device was used to apply the standard hot disc technique for the five different resin mixtures to measure their thermal conductivity and thermal diffusion.

## 3.4. Building Thermal Simulation

A conceptual residential home design was chosen to run the building energy simulation. Qatari architect Arch. Asmaa Al-Mohannadi designed the house. As Arch. Asmaa described, the house is divided into five units: majlis, living unit, main core, bedrooms, and services (Al-Mohannadi, 2016). The area of the chosen house design is 570 $m^2$.

Some conceptual 3D renders by the architect are shown in Figure 7. The architectural plans of the house are given in Figure 8, showing the ground floor, first floor, and sectional plan of the house.

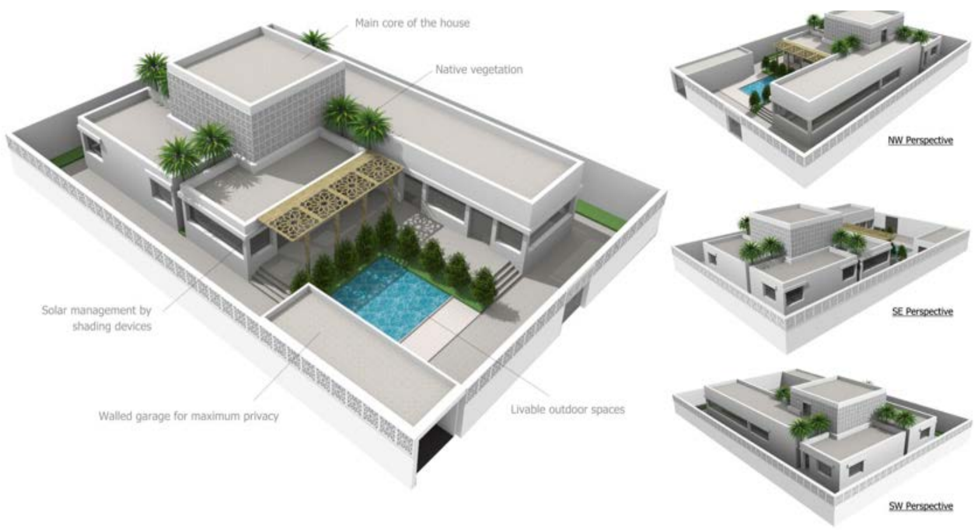



*Figure 7:* 3D rendering of the conceptual house (Al-Mohannadi, 2016).

The house design has been transferred to Revit software, which is associated with the building information modeling (BIM) system software. The model is capable of determining and visualizing the building's energy performance with or without the proposed material of DP0S50E and FA60E. A user interface plug-in is used in Revit software to integrate the data to calculate the thermal properties of different building materials and structures, such as concrete walls, reinforced columns, reinforced beams, bitumen insulation paints, and plaster. The house's location is chosen in the Baaya neighborhood in Ar-Rayyan.

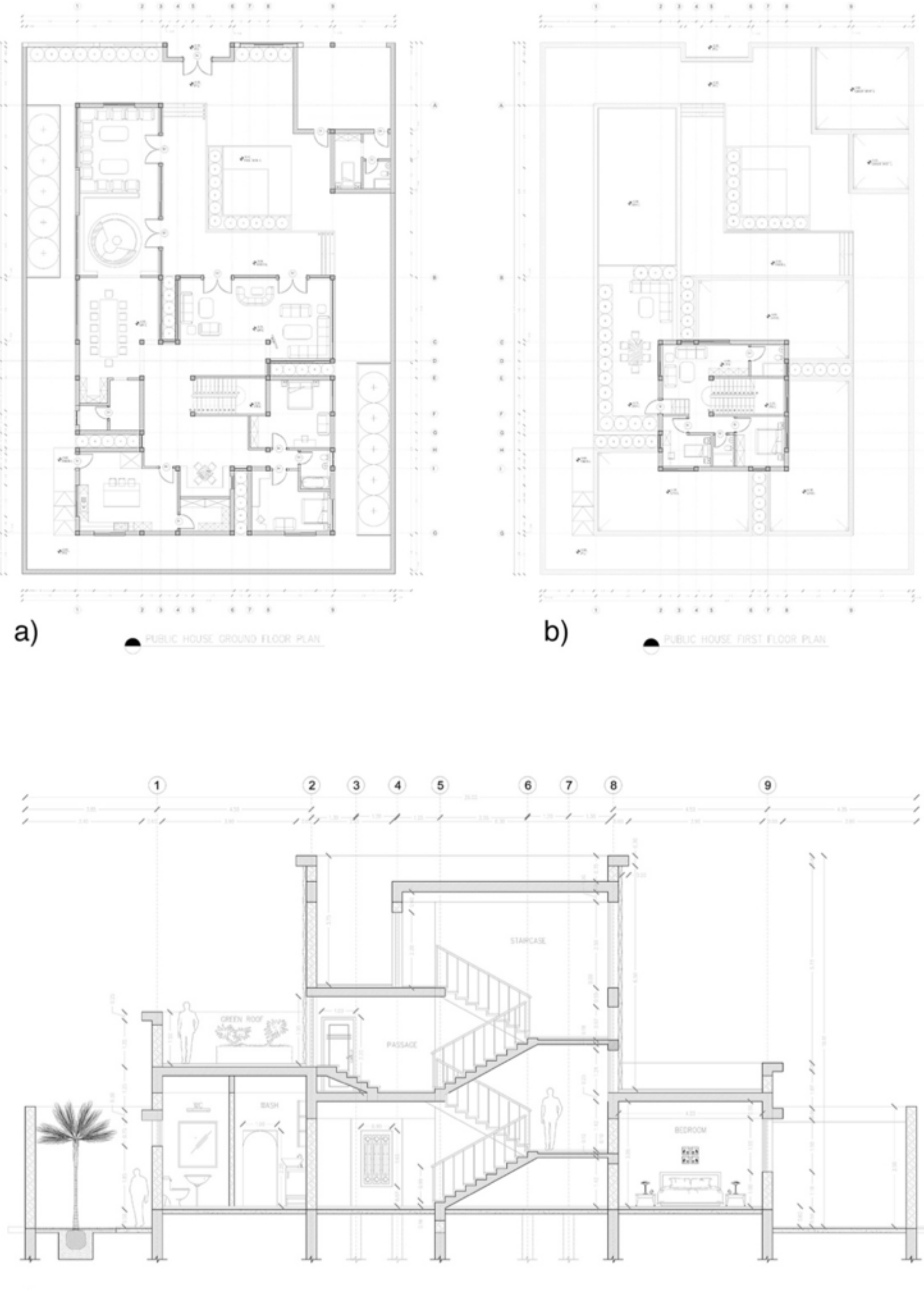



*Figure 8:* Architectural drawing of the house's a) Ground Floor Plan, b) First Floor Plan, and c) Section Plan (all plans are not to scale) (Al-Mohannadi, 2016).

# CHAPTER FOUR: RESULTS AND DISCUSSION

## 4.1. Date pits and sand composition

### *4.2.1. Morphology of nanoparticle of date-pit powder particles*

The investigation using SEM by the default method shows an agglomeration in the particles, as shown in Figure 9. The agglomeration state and the stability state of the nanoparticles can be determined by the sum of the repulsive and attractive forces between individual nanoparticles. The attraction forces between the nanoparticles are a result of Van der Waal forces. Cellulose nanoparticles usually form an interaction of electric double layers that coat each particle, which is called an electrostatic repulsive force (Eremin & Ananikov, 2017). Two critical characteristics of the electric double layer are the zeta potential and the thickness of the electrical double coating (Dickinson, 2015). The main reason nanoparticle agglomeration occurs is because of the high surface energy of the particles, surface energy, which tends to decrease the massive energy by agglomeration. Agglomeration was visible masking smaller particles as shown in Figure 10 and Figure 11. To measure the size of the date-pit particles, the particle size analyzer shows that the majority of the particles were - as shown in Figure 11 and Figure 12- in the range of 4 $\mu m$ to 63 $\mu m$.

### *4.2.1. Particles Density*

The measured density using equation

$$\rho = {}^{m}/_{V} \tag{4}$$

Where density, ρ, is equal to mass, m, divided by volume, V.

For DP0S, DP10S, Dp20S, DP30S, and DP40S was 841 ${}^{kg}/_{m^3}$, 938.5 ${}^{kg}/_{m^3}$, 943.79 ${}^{kg}/_{m^3}$, and 894.3 ${}^{kg}/_{m^3}$, respectively.

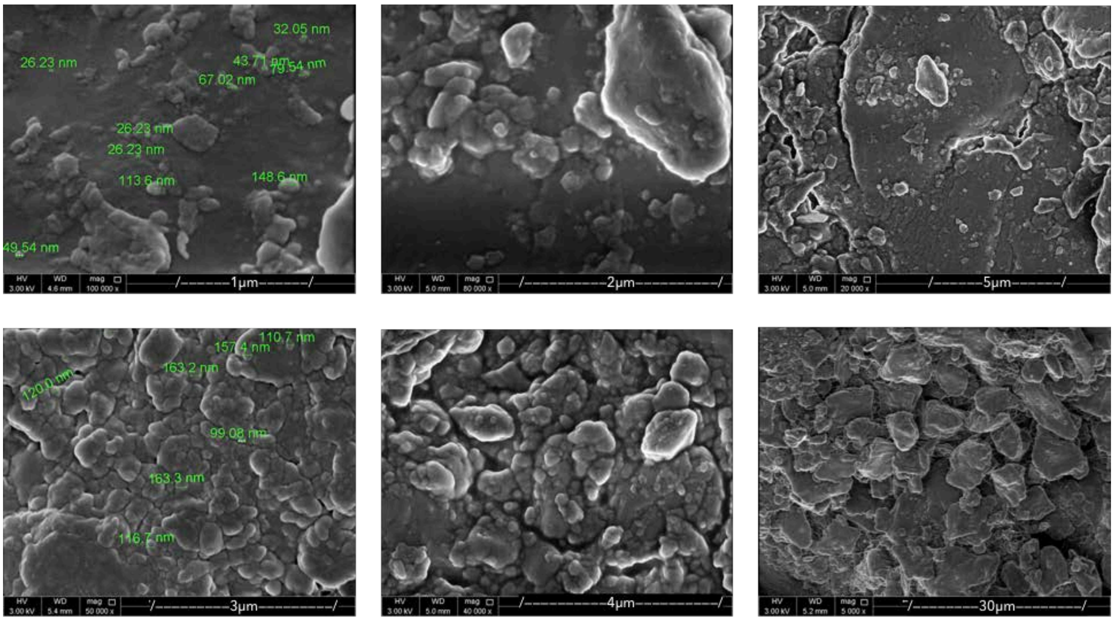



*Figure 9:* SEM images show agglomeration in date-pit particles by using the default method.

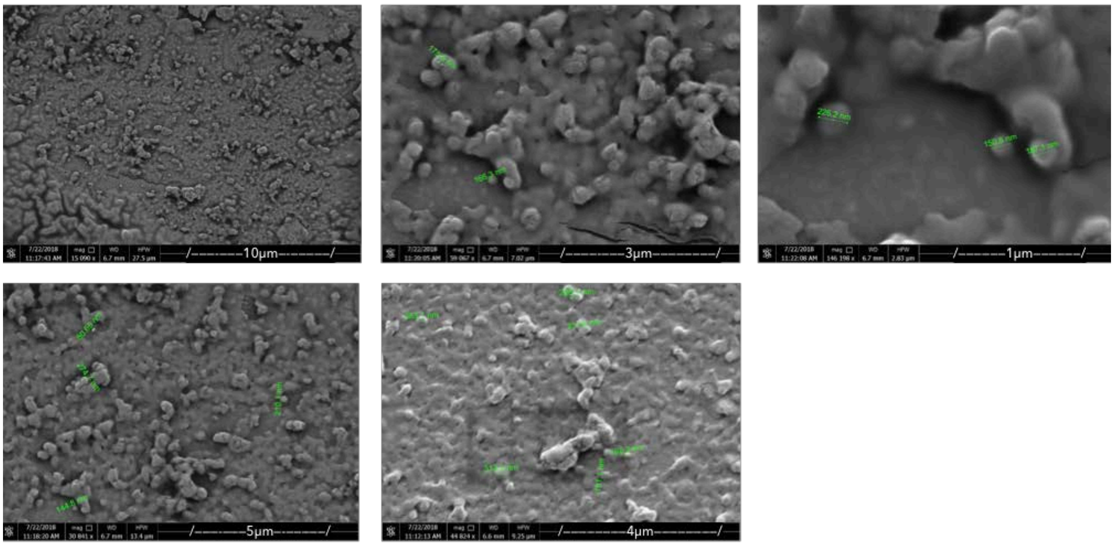



*Figure 10:* Images of sample particles suspended in ethanol and left to dry on a glass slide. Agglomeration was visible, masking smaller particles.

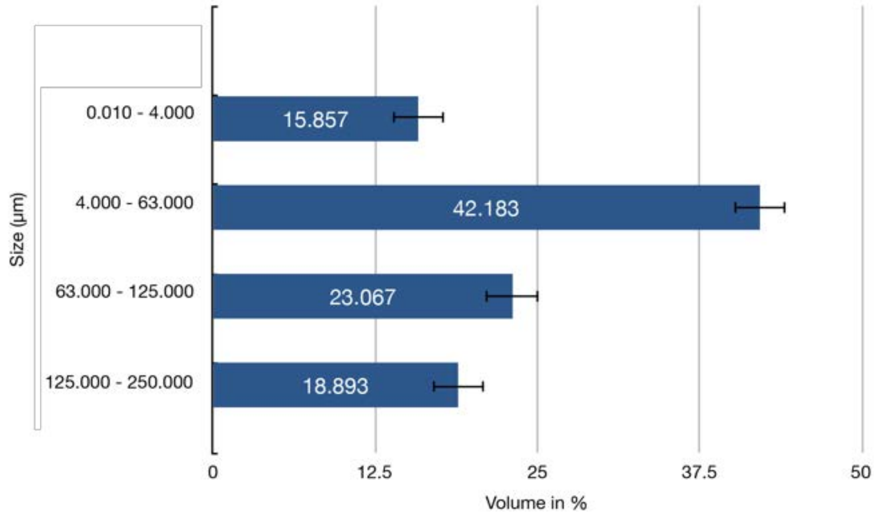



*Figure 11:* The size distribution of the date-pit particles' using particle analyzer.

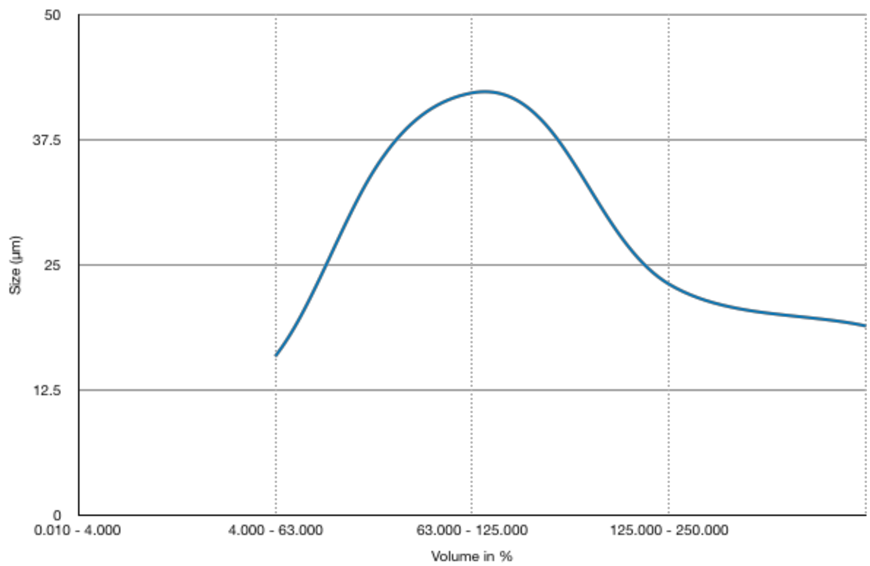



*Figure 12:* The curve of size distribution of the date-pit particles' using particle analyzer.

(Issa, Obaidat, Albiss, & Haik, 2013) investigated the agglomeration on Gd-substituted Mn–Zn ferrite nanoparticles. Figure 12 shows a serve agglomeration where the identification of the size and the shape of particles are almost not possible, which is the same case as DP0S. In the case of (Issa et al., 2013) the phenomenon of agglomeration occurs because of the size of the particles with large fractions of all the atoms and the applied magnetic field that the particles have.

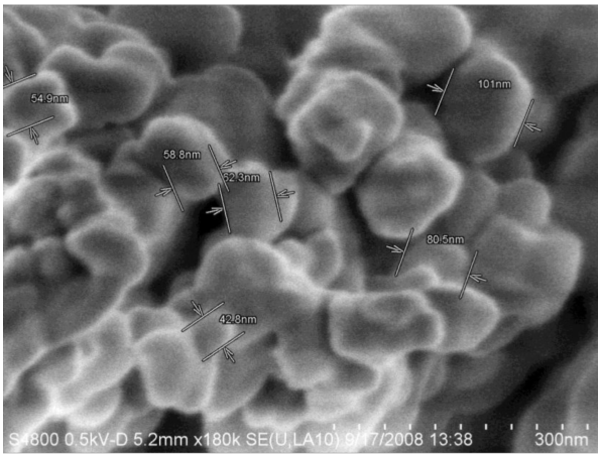



*Figure 13:* Severe degree of agglomeration of nanoparticles that provides the representation of particle morphology and size very difficult (Issa et al., 2013).

### *4.2.2. Thermophysical properties of the nanoparticle of date pits and sand composition*

Table 7 shows the average thermal conductivity for each composition. As presented in Table 7, the sand-to-date-pits ratio has a positive effect on insulation until the ratio of 30 and 40% of sand to date pits by weight were having the same thermal conductivity as shown in Figure 13. This was due to the low $\lambda$ of the specimens. Although it was compacted powder but because of agglomeration and high porosity, which was due to the poor filling of pores and voids that carry air. The lower the thermal diffusivity, the lower the penetration (Agoudjil et al., 2011). Low thermal diffusivity values are good for minimizing heat and thermal conduction.

Table 7:

*Thermophysical characterization of the samples with its standard deviation.*

| Material | Average Thermal Conductivity $\lambda$ [W / mK] | Average Thermal Diffusivity $\alpha$ [$m^2$/ s] | Standard Deviation of U-Value [$\sigma$] |
|---|---|---|---|
| DP0S | 0.09600 | 0.70500 | 0.00029 |
| DP10S | 0.09240 | 0.19800 | 0.00005 |
| DP20S | 0.08306 | 0.40290 | 0.00056 |
| DP30S | 0.07963 | 0.25195 | 0.00032 |
| DP40S | 0.07855 | 0.32350 | 0.00015 |

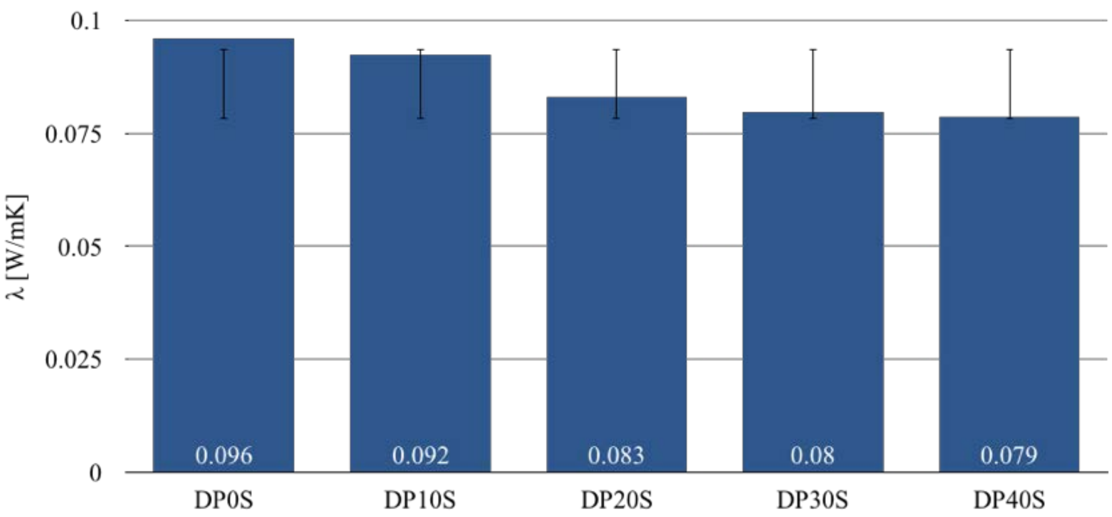



*Figure 14:* The thermal conductivity of the powder compositions (DP0S, DP10S, DP20S, DP30S, and DP40S).

Same thermal conductivity trend was also observed by (Nguyen et al., 2018). The bamboo particles having a diameter of 0.1–0.2 $mm$ was crushed from bamboo fibers, having a value of 0.101 $W/mK$. While in the study investigated by (Abu-Jdayil, Mourad, & Hussain, 2016) was focused on placing the formulation polyester - filler composite as insulation material using waste rubber particles as filler in ratio 0 - 40 % by volume, the investigation shows a low value of thermal conductivity 0.144–0.113 $W/mK$. Comparing to the data carried in this study there is a small difference where DP30S and DP40S were the lowest among them.

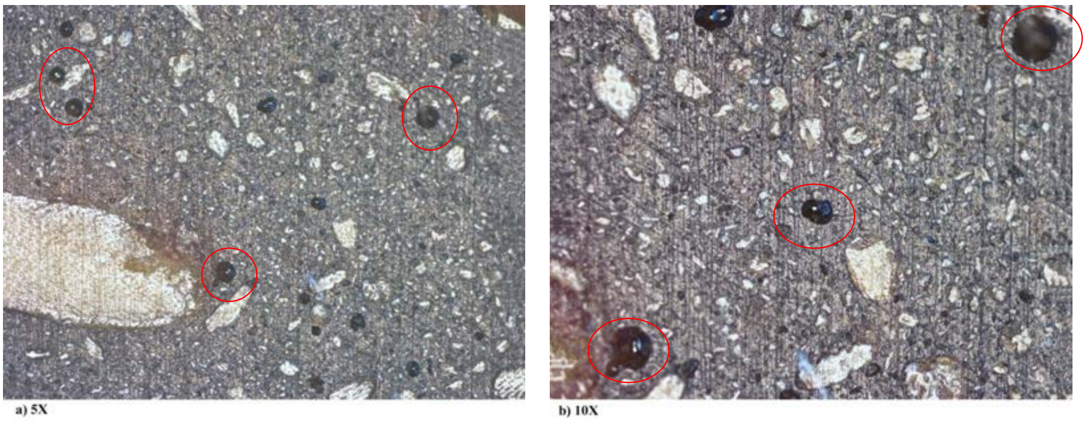



*Figure 15:* Microscopic images marking the air voids of DP0S50E with a) 5X magnification and b) 10X magnification.

*Figure 16:* Cross-sectional image of the of wood polypropylene particulate bio composite panels.

## 4.2. The polymer epoxy with nanoparticles of the date pits and sand composition

### *4.3.1. Morphology of polymer DP0S50E*

Figure 14 shows the images of DP0S50E before exposure to the UV aging test with two different magnifications: 5X and 10X. The images show the date-pit particles with few voids due to the traditional method of polymer preparation. The microscopic photos show a semi-homogenous mixture of DP0S50E with epoxy (Figure 14), unlike the photo of FA60E that shows the fly ash particles clearly with no voids as in Figure 19. (Echeverria, Pahlevani, Gaikwad, & Sahajwalla, 2017) studied hybrid wood polypropylene particulate bio composite in figure 15 an obvious uniform mixture with the bio filler distribution, was observed. This characteristic might have included an identical reinforcement to the wood polypropylene particulate bio composite. Some voids were hardly visible due to mixing the filler with epoxy.

### *4.3.2. Fourier transform infrared spectroscopy FTIR*

FTIR spectroscopy shows the specimens (DP0S50E, DP10S50E, DP20S50E, and DP30S50E) registered some peaks -as illustrated in Figure 16- in the following ranges: 827 $cm^{-1}$ indicate for $C-H$ 1,4-disubstituted or 1,2,3,4-tetrasubstituted, the peak at 915

$cm^{-1}$ due to alkene $C = C$ monosubstituted, the observed band at 1250 - 1050 $cm^{-1}$ is assigned to $C - O - C$ stretch group, the band from the range 1600 - 1400 $cm^{-1}$ may be due to the $NO_2$ stretch or $C = C$ aromatic, 1607 $cm^{-1}$, 1744 $cm^{-1}$ due to carboxylic acid $C = O$ stretch, and the broad and strong band was situated at 2900 - 2800 $cm^{-1}$, which is attributed to the $C - H$ aldehydic. While the wide band between 1100 – 1250 $cm^{-1}$ are attributed to the quartz in sand.

In the study done by (Al-Ghouti et al., 2010), there was some similarities for analyzing raw date pits, the similarities found in the frequencies of 1744 $cm^{-1}$ indication of unconjugated $C - O$ in xylans (hemicellulose), 1449 $cm^{-1}$ for $C\text{–}H$ found in lignin and carbohydrates, 1246 $cm^{-1}$ for syringyl ring and $C\text{–}O$ in lignin and xylan, 156 $cm^{-1}$ for $C\text{–}O\text{–}C$ vibration in cellulose and hemicellulose, 1058 $cm^{-1}$ attribute for $C\text{–}O$ stretch in cellulose and hemicellulose and 869 $cm^{-1}$ due to $C\text{–}H$ distortion in cellulose. Similarly, (Mechri, Chihi, Mahdadi, & Beddiaf, 2017) investigated dunes sand in Ouargla, Algeria. The study showed some FTIR similarities; the matches peaks found in the following frequencies; the wide band between 1100 – 1250 $cm^{-1}$ are due to the quartz in the dunes sand. In addition to that, the peak in 1607 $cm^{-1}$ is due to gypsum. As well as some organic compounds (the $C - H$ aldehydic) found in 2923 - 2852 $cm^{-1}$.

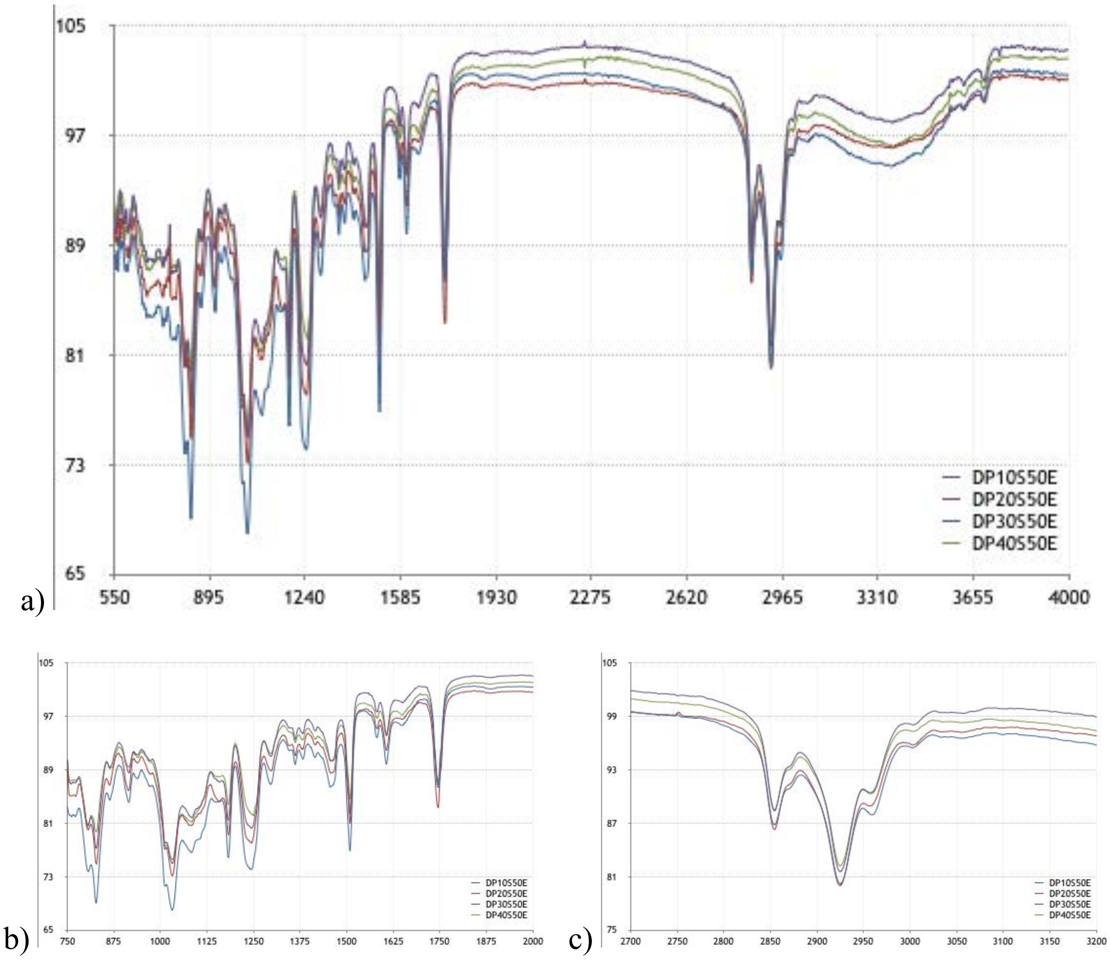



*Figure 17:* FT-IR spectra of DP10S50E, DP20S50E, DP30S50E, and DP40S50E. a) full frequency b) from 750–2000 $cm^{-1}$ c) frequency from 2700–3200 $cm^{-1}$.

### *4.3.3. Thermogravimetric analysis TGA*

The thermograms of the samples exhibited the weight loss of the specimens. Similarly, Figures 17a, 17b, 17c, and 17d show the TGA curves and their derivatives of the TGA curves, which can be used to determine the exact temperature ranges of weight loss of specimens. It was noticed that the distinct peaks were at 375.70℃, 374.96℃, 374.02℃, and 375.13℃ for DP10S50E, DP20S50E, DP30S50E, and DP40S50E respectively. These peaks presented 50% of the weight loss of each sample.

A similar research was studying the thermal degradation for an epoxy polymer using bio filler by (Yew et al., 2018). It showed that the polymers loss the 50% of their weight was below 400 ℃, which is almost similar to the study case in this paper. Which also may indicate better fire protection performance evolution.

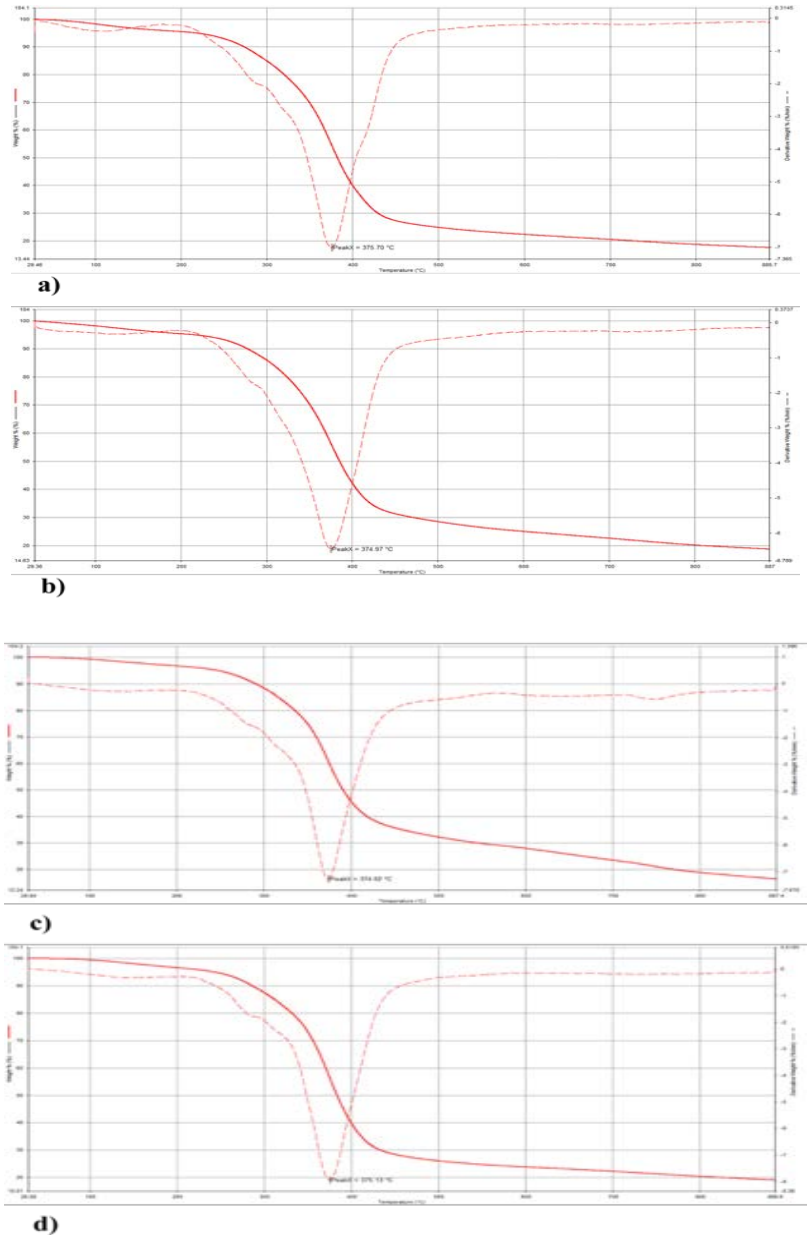



*Figure 18:* Average TGA curves and their first derivative curves for a) DP10S50E, b) DP20S50E, c) DP30S50E, and d) DP40S50S.

#### *4.3.4. Thermophysical properties of the polymer composition*

The thermophysical properties of DP0S50E, DP10S50E, DP20S50E, DP30S50E, and DP40S50E revealed that the average thermal conductivity for each composition is as shown in Table 8. Each reading repeated three times to eliminate the reading's error. As illustrated in Table 8 and Figure 18, the sand-to-date-pits ratio is no longer effective at insulating.

The rise in thermal conductivity values has two possible causes: the first was referred to in section 4.2.2, and the second is the thermal conductivity of the epoxy itself. The DP0S composed was performed with different epoxy and different preparation; the epoxy we used was cold-mounting resin, and the polymer coded as DP0S50ECM. The thermophysical test showed the same values as DP0S50E.

A thermally enhanced sustainable hybrid brick was developed by (A. Raut & Gomez, 2018). The component materials for the developed bricks were glass powder, palm oil fly ash, oil palm fibers, crusher dust, lime, and water. The study showed that it had a thermal conductivity of 0.3812 $W/_{mK}$; the $\lambda$ value is slightly higher than DP0S50E.

In a study done by (Lee, Kim, & Na, 2015) an insulation material was used formed from foamed concrete for cast-in-site having a thermal conductivity of 0.66 $W/_{mK}$.

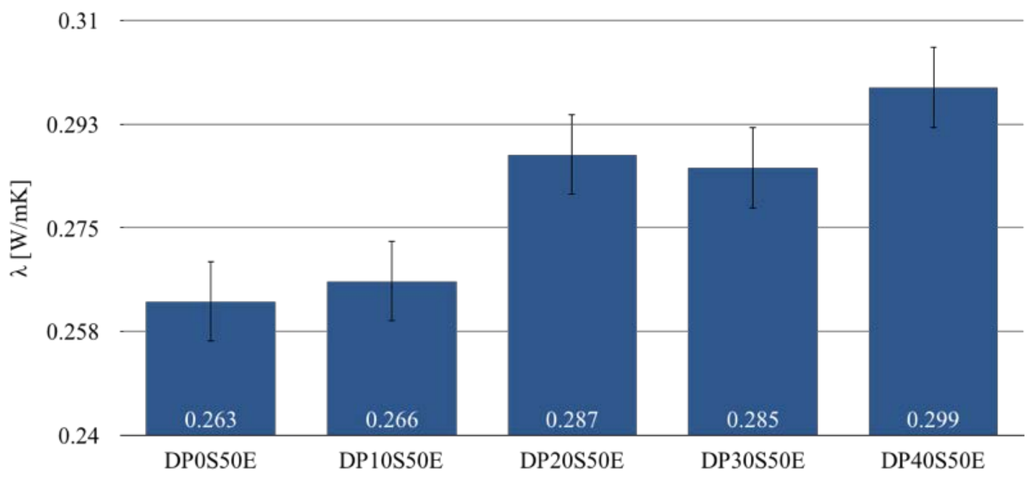



*Figure 19:* A comparison of the average values of thermal conductivity of polymer samples (DP0S50E, DP10S50E, DP20S50E, DP30S50E, and DP40S50E).

Table 8:

*Thermophysical characterization of the polymers with its standard deviation.*

| Polymer | Average Thermal Conductivity λ [W / mK] | Average Thermal Diffusivity α [$m^2$/ s] | Standard Deviation of Thermal Conductivity [σ] |
|---|---|---|---|
| DP0S50E | 0.26256 | 0.16362 | 0.00017 |
| DP10S50E | 0.26600 | 0.12666 | 0.00084 |
| DP20S50E | 0.28731 | 0.16429 | 0.00028 |
| DP30S50E | 0.28511 | 0.16547 | 0.00095 |
| DP40S50E | 0.29868 | 0.15595 | 0.00053 |

#### *4.3.5. Polymer Density*

The density of polymers where found using equation

$$\rho = \frac{\lambda}{\alpha \cdot C_p} \tag{5}$$

Where; ρ is the density ( ${kg}/{m^3}$ ) , $\lambda$ is thermal conductivity ( ${W}/{mK}$ ), $\alpha$ is thermal diffusivity ( ${m^2}/{s}$ ), and $C_p$ is specific heat capacity ( ${J}/{(kg \, . K)}$ ).

The density of the polymers; DP0S50E, DP10S50E, DP20S50E, DP30S50E, and DP40S50E, are, 0.997 ${kg}/{m^3}$, 1.026 ${kg}/{m^3}$, 0.997 ${kg}/{m^3}$, and 1.000 ${kg}/{m^3}$, respectively.

## 4.3. The polymer epoxy with fly ash

### *4.3.1. Morphology of polymer FA60E*

Microscopic image inspection with 10X magnification of FA60E is shown in Figure 19. The photo clearly shows the mixture of epoxy resin and fly ash cenosphere's shape. In Figure 20, an image using SEM showed the same crystal particles that is shown in figure 19 (Wang, Ishida, & Gu, 2018).

### *4.3.2. Thermogravimetric analysis TGA*

The TGA curve of FA60E is presented in Figure 21 with its derivatives. It determined the temperature where 50% of the specimens' weight was lost. The peak was marked at 370.47℃. The result of thermal degradation is clearly as the values discussed in section 4.3.3.

### *4.3.3. Thermophysical properties of the polymer composition*

Here, the thermophysical properties of the studied sample were determined and compared them to DP0S50E in section 4.7. As shown in Table 9, λ was equal to 0.29 $W/_{mK}$ and $\alpha$ was 0.57 $m^2/_{s}$. The value is a bit higher than results of the thermal conductivity of DP0S50E, DP10S50E, DP20S50E, DP30S50E, and DP40S50E which was discussed in section 4.3.4. Unlike the outputs from (Sunil & Manavendra, 2017) where the thermal conductivity of the fly ash composed to epoxy with a ratio of 1:1 was 0.194 $W/_{mK}$. Which is less than the value that was in this study, this may occur because of the fly ash used in the study by (Sunil & Manavendra, 2017) was bagasse ash which is basically a waste by-product generated by combustion of sugar cane bagasse in thermal power stations.

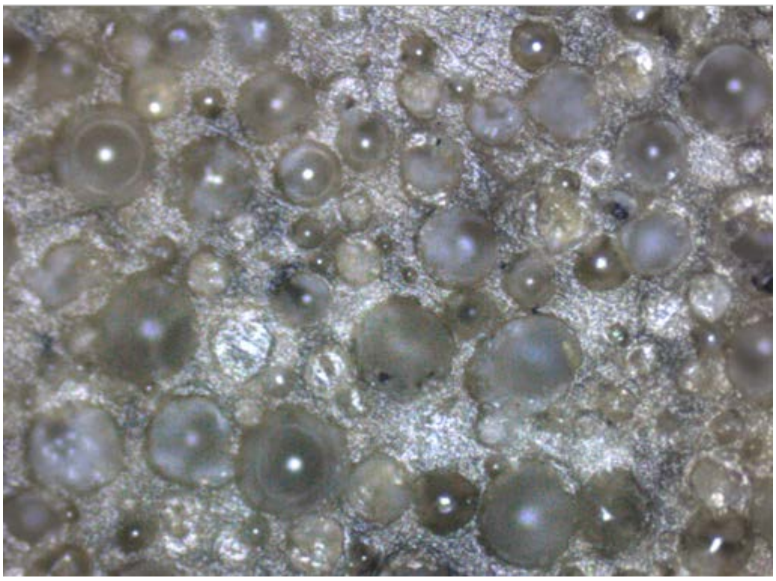


*Figure 20*: Microscopic image shows 10X magnifcation of FA60E using Nikon Eclipse Model L200N.

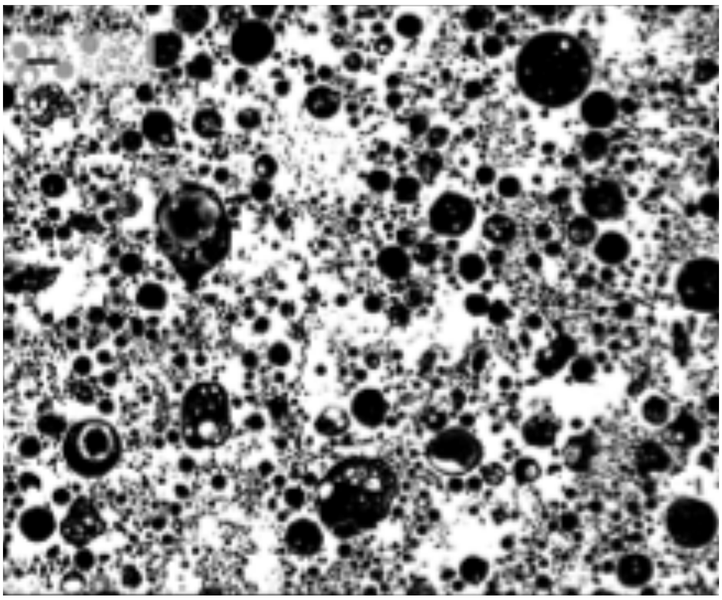


*Figure 21*: SEM image of fly ash (T. Wang et al., 2018).

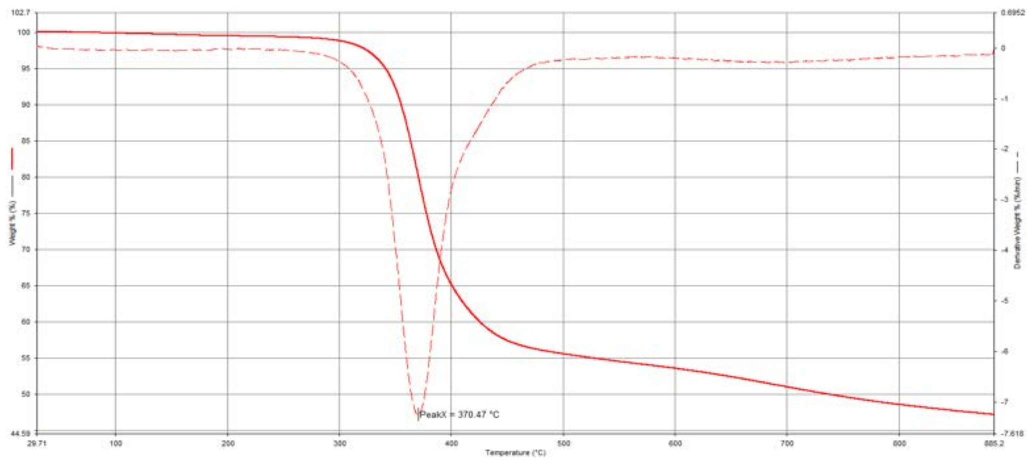



*Figure 22:* Average TGA curve and its first derivative curve for FA60E.

Table 9:

*Thermophysical characterization of the polymers with its standard deviation.*

| Polymer | Average Thermal Conductivity λ [W / mK] | Average Thermal Diffusivity α [$m^2$/ s] | Standard Deviation of Thermal Conductivity [σ] |
|---|---|---|---|
| FA60E | 0.28789 | 0.57025 | 0.00131 |

### 4.4. The polymers DP0S50E and FA60E UV aging test

The UV aging test shows a slight pigmented in FA60E, while no changing occurs in DP0S50E -see figure 22-.

a) b)

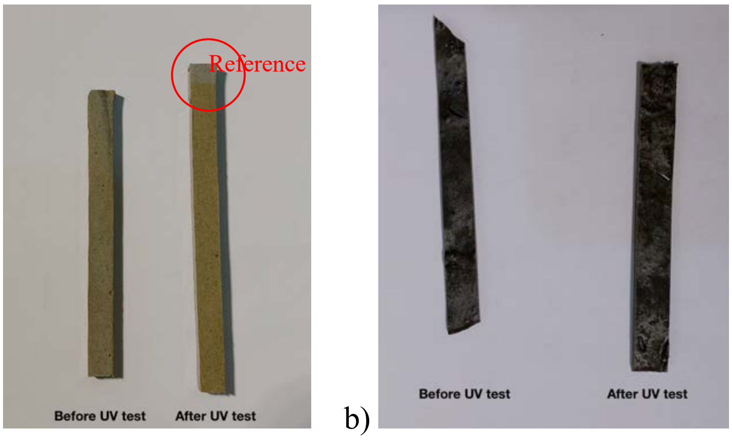
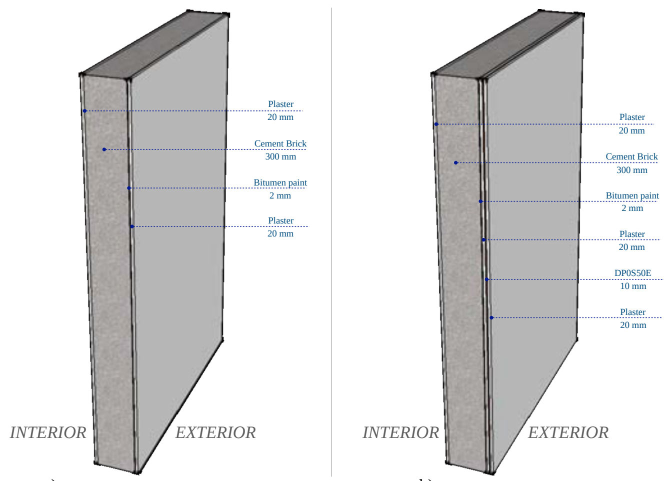



*Figure 23:* Changing in color pigmentation before and after UV aging test for a) FA60E and b) DP0S50E.

## 4.5. Building energy simulation

Energy use of buildings varies across a wide range. The key to operating a good building simulation are weather data and building masses, while other parameters control the energy usage in buildings, like: building operation; maintenance; occupant behavior; and the activities inside the building. The simulation using Autodesk Revit 2017 with a small house design of 570 $m^2$ - explained in section 3.7 - and the input location was $25.28152°N$, $51.39164°E$ was conducted. Three simulation models were running: a house with typical wall layers TH1; a house with added DP0S50E as a layer in exterior walls, coded in this study as PHDP; and a house with a layer of FA60E in the exterior, was encoded as PHFA. The exterior wall area for the three models was $506m^2$.

The three models took into consideration the typical wall construction layers, which are illustrated in Table 10 with their insulation conductivity. The 3-D section of the exterior walls in typical Qatari houses is shown in Figure 23 with a comparison of layers in exterior walls of existing houses using the proposed materials.




a) b)

*Figure 24:* 3-D sections illustrate a) the layers in typical Qatari houses and b) how to locate the proposed material in existing houses.

Table 10:

*Construction wall layers used in three models of the building energy simulation.*

| | Layer | Layer Thickness [mm] | Average Thermal conductivity λ [W / mK] | TH1 | PHDP | PHFA |
|---|---|---|---|---|---|---|
| 1 | Plaster | 20 | 1.49 | ✓ | ✓ | ✓ |
| 2 | Cement Brick | 300 | 0.98 | ✓ | ✓ | ✓ |
| 3 | Bitumen paint | 2 | 0.49 | ✓ | ✓ | ✓ |
| 4 | Plaster | 20 | 1.49 | ✓ | ✓ | ✓ |
| 5 | DP0S50E | 10 | 0.26 | | ✓ | |
| 7 | FA50E | 10 | 0.29 | | | ✓ |
| 6 | Plaster | 20 | 1.49 | | ✓ | ✓ |

#### *4.6.1. Energy usage simulation of TH1 model*

Running the simulation of TH1 shows that the regular Qatari house with area of 570 $m^2$ uses 73,692 $kWh$ per year of energy: 53% of this energy is used to cool down the house to reach a comfortable indoor temperature, as presented in Figure 24 (a breakdown of energy use building as given by an Autodesk Revit 2017 simulation). Figure 25 shows the monthly electricity consumption by TH1, showing that May through August has the highest energy usage.

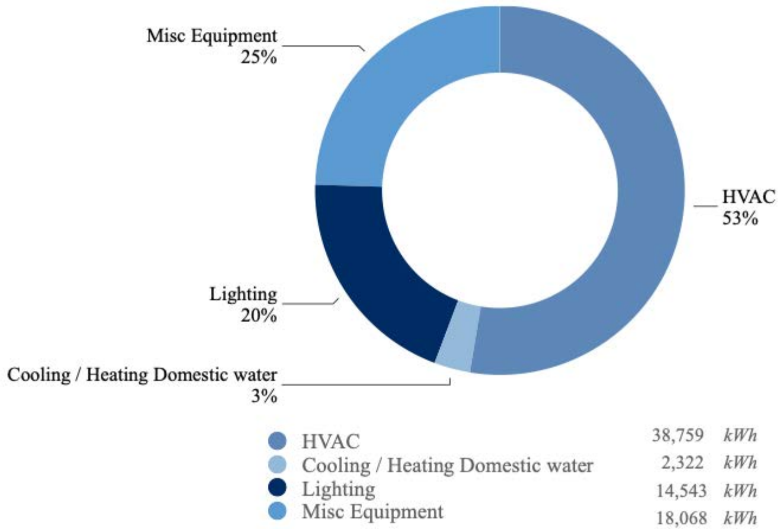



*Figure 25:* The breakdown of annual energy usage for TH1.

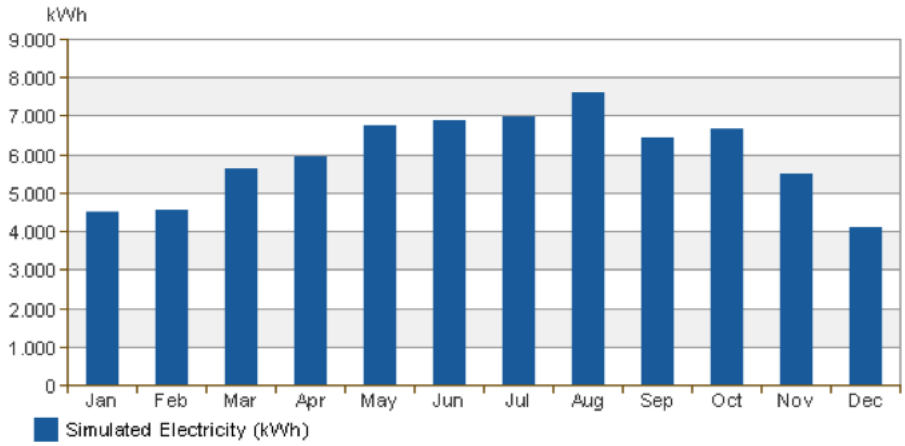



*Figure 26:* The monthly electricity consumption of TH1.

### ***4.6.2. Energy usage simulation of PHDP model***

The simulated model of PHDP shows that the annual energy consumption of the same 570 $m^2$ house using DP0S50E as a coating material in the external walls is 69,198 $kWh$, which is 4,494 $kWh$ less than TH1, meaning it is 6.49% more energy efficient than TH1.

Saving 4,494 $kWh$ of energy means reducing the $CO_2$ produced by a 570 $m^2$ house by 1.8 tons annually. Figure 26 shows that 52% of energy consumption is a result of using HVAC system. The monthly energy usage by PHDP is shown in Figure 27, wherein August has the highest energy usage in order to cool down the building to a comfortable indoor temperature.

#### *4.6.1. Energy usage simulation of PHFA model*

We simulated PHFA using the same parameters used in TH1 and PHDP and using FA60E as a coating material in the external walls. The simulation shows that the annual energy usage is 69,203 $kWh$, which is slightly higher than PHDP by 5 $kWh$ and eliminates 1.78 tons of $CO_2$ emitted by TH1. Figure 28 shows that 52% of energy consumption is a result of using HVAC. Consumption of energy per month by PHFA is as shown in Figure 29.

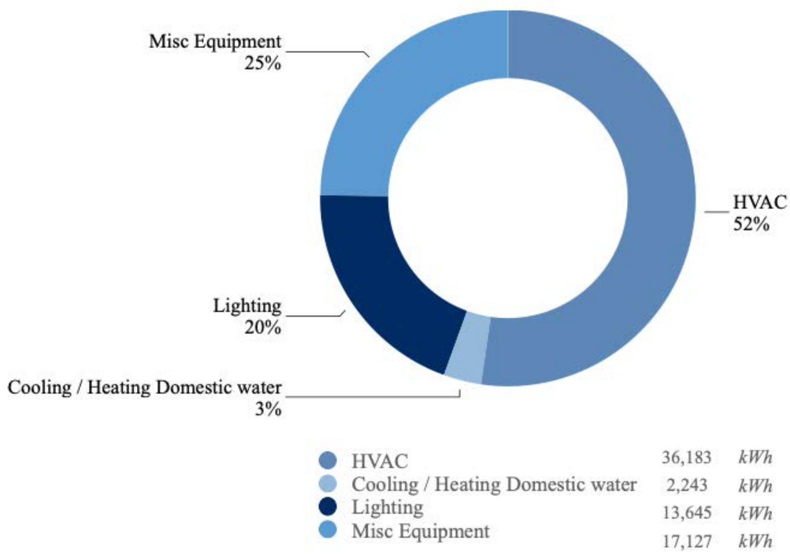



*Figure 27:* The breakdown of annual energy usage for PHDP.

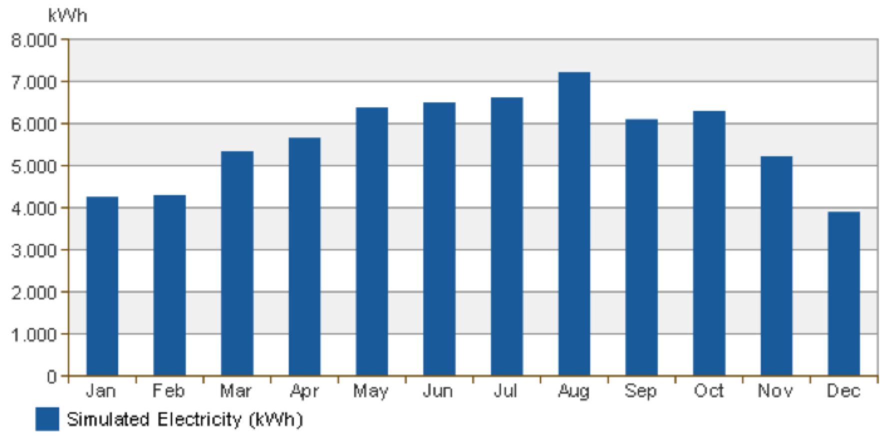



*Figure 28:* The monthly electricity consumption by PHDP.

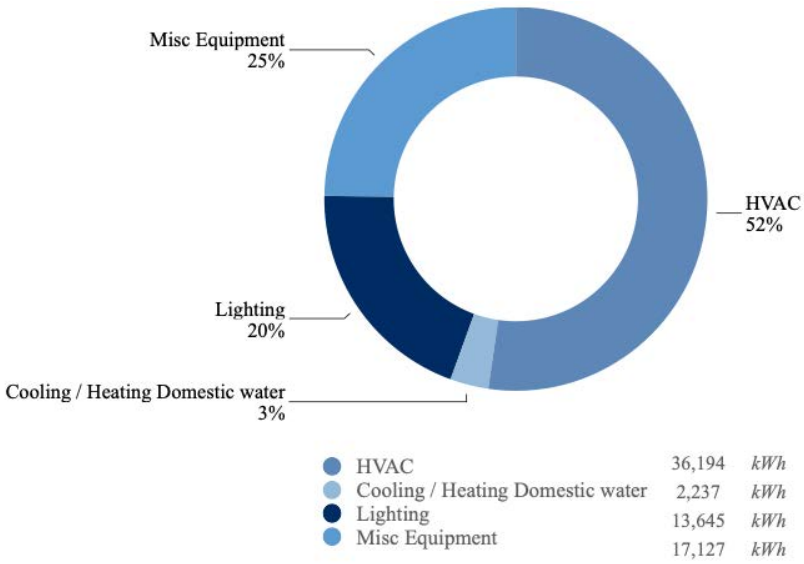



*Figure 29:* The annual energy usage by PHFA.

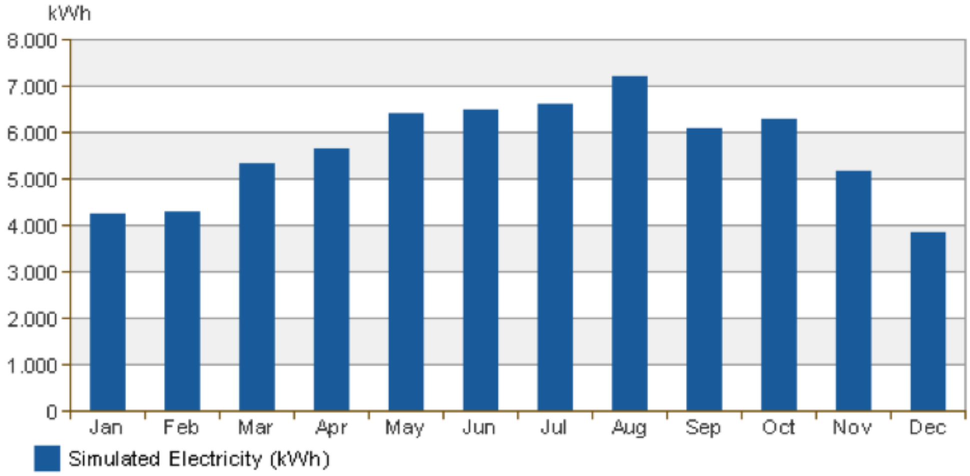



*Figure 30:* The simulated consumption energy usage per month of PHFA.

### 4.6. Comparison of DP0S50E and FA60E

DP0S50E can be defined as a polymer of epoxy and nanoparticles of date pits with a ratio of 1:1. It is lightweight and low density and has low thermal conductivity - see Table 11. Used date pits pose no harm to the environment because they are bio-composites, as well as a material usually considered a solid waste that rarely recycles. FA60E is also a polymer of epoxy and Fillite 160 fly ash cenospheres with a ratio of 2:3, respectively. Fly ash has leaching characteristics; therefore, more investigation of using FA60E in residual buildings must be taken into consideration (J. Wang, Ban, Teng, Wang, & Ladwig, 2006; Zhao et al., 2018). DP0S50E has less thermal conductivity than FA60E, which indicates that DP0S50E is a better insulation. Its reduced thermal diffusivity strengthens DP0S50E, allowing the heat to penetration slower.

Table 11:

*A summary of characteristics of DP0S50E and FA60E.*

| Proposed Material | Average Thermal Conductivity $\lambda$ [W / mK] | Average Thermal Diffusivity $\alpha$ [$m^2$/ s] | Density [ Kg / $m^3$] | Proposed Thickness [cm] |
|---|---|---|---|---|
| DP0S50E | 0.2626 | 0.1636 | 0.95 | 1 |
| FA60E | 0. 2879 | 0.5703 | 1 | 1 |

Based on previous and recent literature building energy simulation is broadly carried in researches (Abdul Mujeebu, Ashraf, & Alsuwayigh, 2016; Lee, Kim, & Na, 2015; Raut & Gomez, 2018; Shoubi, Shoubi, Bagchi, & Barough, 2014). Many software programs were used in the simulation of energy performance of different building types to analyze the performance of different materials programmatically. In Table 12, summarizes and compares all the relevant information analyzed using building energy simulation.

All the evaluated models estimate energy consumption, where the highest performance in saving energy among them all is the study conducted by (Raut & Gomez, 2018) using thermally enhanced sustainable hybrid brick, the decreased in the usage of energy was 9.40%. Although, the surveyed studies conducted into having new buildings to obtain these values in saving energy, unlike the proposed model in this thesis that can be used in existing buildings aiming to save time and the cost. (Abdul Mujeebu et al., 2016) studied the enrichment of having new modified insulation material using nano vacuum insulation panel where the panels should be installed between two 100 mm bricks on the external walls, although the decrease in consuming the energy was only 0.57%.

These results strengthen the ability to use DP0S50E as insulation material as a coating for existing buildings.

Table 12:

*Summarizes and compares all the relevant information analyzed using building energy simulation.*

| Reference | Research Building Type | Area ($m^2$) | Location | Software | Aim | Type of modification | Energy saving potential (%) | Applicable in existing building? |
|---|---|---|---|---|---|---|---|---|
| Present study | Residential House | 570 | Qatar | Autodesk Revit | Cooling energy and carbon emission | Nanoparticles of date pits insulation on external walls only | 6.49 | yes |
| Present study | Residential House | 570 | Qatar | Autodesk Revit | Cooling energy and carbon emission | Fly ash insulation on external walls only | 6.48 | yes |
| (Abdul Mujeebu et al., 2016) | Office Building | 200 | Saudi Arabia | Autodesk Revit and Autodesk Ecotect | Cooling energy and total energy consumption | Nano-vacuum insulation panels on external walls only | 0.57 | no |
| (Raut & Gomez, 2018) | Residential House | 234 | Malaysia | Ansys | Energy consumption, electricity consumption and Carbon emission | Thermally enhanced sustainable hybrid brick | 9.40 | no |
| (Shoubi et al., 2014) | Residential House | 400 | Malaysia | Autodesk Revit and Autodesk Ecotect | Operational energy consumption | Double brick cavity plaster | 6.02 | no |
| (Lee et al., 2015) | 20 Story Housing | 70,824 | Korea | IES VE | Operational energy and life cycle cost | Glass fiber reinforced concrete | 0.43 | no |
| (Lee et al., 2015) | 20 Story Housing | 70,824 | Korea | IES VE | Operational energy and life cycle cost | Cellulose fiber reinforced concrete | 0.55 | no |

# CHAPTER FIVE: CONCLUSION AND FUTURE WORK

## 5.1. Conclusion

The outcomes of this study confirm that date pits have the ability to play a role in the building industry as a thermal insulation material. It was proposed and simulated the polymer DP0S50E as a coating material for existing buildings with a thickness of 1 cm. The use of DP0S50E as a coating material has been proven in this project efficient regarding energy usage by 6% and eliminating the emission of $CO^2$ by 6% as well. Although DP0S50E was used in an existing building, rather than in the construction of a new building, it conserves the environment and constrains the costs of generating energy; because of the properties of biomaterial DP0S50E has a low thermal expansion which will give it more durability. Surprisingly, the use of fly ash as an insulation material was not as efficient as the use of date pits. In conclusion, the future of using date pits in construction is bright and promising due to their special characteristics.

Polymeric insulators are now a trend in the replacement of coating insulations. The use of this promising technology offers many advantages to the construction sector; nevertheless, in a polluted environment with high humidity levels, (i.e. Qatar, as a case study), nanoparticles developed the surface of the insulation. However, with the limited amount of filler that can be added for the processability of the epoxy, it becomes difficult and expensive in cost.

Some examinations should be followed in future such as study the flammability, how to extract the oil from the nanoparticle of the date pits, and the mechanical properties of the material itself.

## 5.2. Suggestions for future work

- Improvements due to the addition of sand need to be tested on different particle samples.

- Experimental calculations and modeling should be done to determine the exact reduction of energy caused by the use of the proposed material.
- Chemical analysis needs to be carried out for both DP0S50E and FA60E to better understand the role of the interface in polymer samples.
- Bio-binders need to be studied to replace epoxy and give a better result.
- Long term effects of UV and thermal aging studies on the coating materials.
- Peel tests of coating from adhering surface.
- Changes in mechanical properties after seawater immersion tests to study exposure to local climatic conditions existing in Qatar.
- Cost analysis.
- Using Microwave instead of roasting method; for a speed and economic benefits.

REFRENCES

Abdul Mujeebu, M., Ashraf, N., & Alsuwayigh, A. H. (2016). Effect of nano vacuum insulation panel and nanogel glazing on the energy performance of office building. *Applied Energy*, *173*, 141–151. https://doi.org/10.1016/j.apenergy.2016.04.014

Abu-Jdayil, B., Mourad, A. H., & Hussain, A. (2016). Thermal and physical characteristics of polyester-scrap tire composites. *Construction and Building Materials*, *105*, 472–479. https://doi.org/10.1016/j.conbuildmat.2015.12.180

Acharya, A., Giri, S., & Gokhale, V. (2017). Nano Technology in Architecture: Exploring Possibilities. *IOSR Journal of Applied Chemistry*, *10*(2), 44–47. https://doi.org/10.9790/5736-1002014447

Aditya, L., Mahlia, T. M. I., Rismanchi, B., Ng, H. M., Hasan, M. H., Metselaar, H. S. C., … Aditiya, H. B. (2017). A review on insulation materials for energy conservation in buildings. *Renewable and Sustainable Energy Reviews*, *73*, 1352–1365. https://doi.org/10.1016/j.rser.2017.02.034

Adriano, D. C., Page, A. L., Elseewi, A. A., Chang, A. C., & Straughan, I. (1980). Utilization and Disposal of Fly Ash and Other Coal Residues in Terrestrial Ecosystems: A Review1. *Journal of Environment Quality*, *9*(3), 333. https://doi.org/10.2134/jeq1980.00472425000900030001x

Agoudjil, B., Benchabane, A., Boudenne, A., Ibos, L., & Fois, M. (2011). Renewable materials to reduce building heat loss: Characterization of date palm wood. *Energy and Buildings*, *43*(2–3), 491–497. https://doi.org/10.1016/j.enbuild.2010.10.014

Al-Farsi, M. (2011). *Date seeds: Usage of date seed extract in health*.

Al-Farsi, M. A., & Lee, C. Y. (2008). Optimization of phenolics and dietary fibre extraction from date seeds. *Food Chemistry*, *108*(3), 977–985.

https://doi.org/10.1016/j.foodchem.2007.12.009

Al-Farsi, M. A., & Lee, C. Y. (2011). Usage of date (phoenix dactylifera l.) seeds in human health and animal feed. *Nuts and Seeds in Health and Disease Prevention*, (January 2011), 447–452. https://doi.org/10.1016/B978-0-12-375688-6.10053-2

Al-Ghouti, M. A., Hawari, A., & Khraisheh, M. (2013). A solid-phase extractant based on microemulsion modified date pits for toxic pollutants. *Journal of Environmental Management*, *130*, 80–89. https://doi.org/10.1016/j.jenvman.2013.08.045

Al-Ghouti, M. A., Li, J., Salamh, Y., Al-Laqtah, N., Walker, G., & Ahmad, M. N. M. (2010). Adsorption mechanisms of removing heavy metals and dyes from aqueous solution using date pits solid adsorbent. *Journal of Hazardous Materials*, *176*(1–3), 510–520. https://doi.org/10.1016/j.jhazmat.2009.11.059

Al-Homoud, D. M. S. (2005). Performance characteristics and practical applications of common building thermal insulation materials. *Building and Environment*, *40*(3), 353–366. https://doi.org/10.1016/j.buildenv.2004.05.013

Al-Juruf, R. S., Ahmed, F. A., Alam, I. A., & Abdel-Rahman, H. H. (1988). Development of Heat Insulating Materials Using Date Palm Leaves. *Journal of Thermal Insulation*, *11*(3), 158–164. https://doi.org/10.1177/109719638801100304

Al-Mohannadi, A. (2016). Affordable House Design.

Alabdulkarem, A., Ali, M., Iannace, G., Sadek, S., & Almuzaiqer, R. (2018). Thermal analysis, microstructure and acoustic characteristics of some hybrid natural insulating materials. *Construction and Building Materials*, *187*, 185–196. https://doi.org/10.1016/j.conbuildmat.2018.07.213

Alsewailem, F. D., & Binkhder, Y. A. (2010). Preparation and characterization of polymer/date pits composites. *Journal of Reinforced Plastics and Composites*, *29*(11), 1743–1749. https://doi.org/10.1177/0731684409337339

Bardage, S. L. (2017). *Performance of buildings*. *Performance of Bio-based Building Materials*. Elsevier Ltd. https://doi.org/10.1016/B978-0-08-100982-6.00006-9

Baroncini, E. A., Kumar Yadav, S., Palmese, G. R., & Stanzione, J. F. (2016). Recent advances in bio-based epoxy resins and bio-based epoxy curing agents. *Journal of Applied Polymer Science*, *133*(45). https://doi.org/10.1002/app.44103

Belayachi, N., Hoxha, D., & Ismail, B. (2017). Impact of fiber treatment on the fire reaction and thermal degradation of building insulation straw composite. *Energy Procedia*, *139*, 544–549. https://doi.org/10.1016/j.egypro.2017.11.251

Besbes, S., Blecker, C., Deroanne, C., Drira, N. E., & Attia, H. (2004). Date seeds: Chemical composition and characteristic profiles of the lipid fraction. *Food Chemistry*, *84*(4), 577–584. https://doi.org/10.1016/S0308-8146(03)00281-4

Bianco, L., Pollo, R., & Serra, V. (2017). Wood Fiber vs Synthetic Thermal Insulation for Roofs Energy Retrofit: A Case Study in Turin, Italy. *Energy Procedia*, *111*, 347–356. https://doi.org/10.1016/j.egypro.2017.03.196

Bicer, A. (2018). Effect of fly ash particle size on thermal and mechanical properties of fly ash-cement composites. *Thermal Science and Engineering Progress*, *8*, 78–82. https://doi.org/10.1016/j.tsep.2018.07.014

Binici, H., Aksogan, O., & Demirhan, C. (2016). Mechanical, thermal and acoustical characterizations of an insulation composite made of bio-based materials. *Sustainable Cities and Society*, *20*, 17–26. https://doi.org/10.1016/j.scs.2015.09.004

Binici, H., Gemci, R., Kucukonder, A., & Solak, H. H. (2012). Investigating sound insulation, thermal conductivity and radioactivity of chipboards produced with cotton waste, fly ash and barite. *Construction and Building Materials*, *30*, 826–

832. https://doi.org/10.1016/j.conbuildmat.2011.12.064

Boostani, H., & Modirrousta, S. (2016). Review of Nanocoatings for Building Application. *Procedia Engineering*, *145*, 1541–1548. https://doi.org/https://doi.org/10.1016/j.proeng.2016.04.194

Bosia, D., Savio, L., Thiebat, F., Patrucco, A., Fantucci, S., Piccablotto, G., & Marino, D. (2015). Sheep Wool for Sustainable Architecture. *Energy Procedia*, *78*, 315–320. https://doi.org/10.1016/j.egypro.2015.11.650

Bozsaky, D. (2011). The historical development of thermal insulation materials. *Periodica Polytechnica Architecture*, *41*(2), 49–56. https://doi.org/10.3311/pp.ar.2010-2.02

Bozsaky, D. (2015). Laboratory Tests with Liquid Nano-ceramic Thermal Insulation Coating. *Procedia Engineering*, *123*, 68–75. https://doi.org/10.1016/j.proeng.2015.10.059

Bozsaky, D. (2016). Application of Nanotechnology Based Thermal Insulation Materials in Building Construction. *Acta Technica Jaurinensis*, *9*(1), 29. https://doi.org/10.14513/actatechjaur.v9.n1.391

Bystrzejewska-Piotrowska, G., Golimowski, J., & Urban, P. L. (2009). Nanoparticles: Their potential toxicity, waste and environmental management. *Waste Management*, *29*(9), 2587–2595. https://doi.org/10.1016/j.wasman.2009.04.001

Cabeza, L. F., Rincón, L., Vilariño, V., Pérez, G., & Castell, A. (2014). Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: A review. *Renewable and Sustainable Energy Reviews*, *29*, 394–416. https://doi.org/10.1016/j.rser.2013.08.037

Cárdenas-R, J. P., Cea, M., Santín, K., Valdés, G., Hunter, R., & Navia, R. (2018). Characterization and application of a natural polymer obtained from Hydrangea macrophylla as a thermal insulation biomaterial. *Composites Part B:*

*Engineering*, *132*, 10–16. https://doi.org/10.1016/j.compositesb.2017.07.086

Cetiner, I., & Shea, A. D. (2018). Wood waste as an alternative thermal insulation for buildings. *Energy and Buildings*, *168*, 374–384. https://doi.org/10.1016/j.enbuild.2018.03.019

Chen, Y.-Y., Chen, S.-Y., Yang, C.-J., & Chen, H.-T. (2017). Effects of insulation materials on mass concrete with pozzolans. *Construction and Building Materials*, *137*, 261–271. https://doi.org/10.1016/j.conbuildmat.2017.01.059

Conley, B., Cruickshank, C. A., & Baldwin, C. (2018). 2.24 Insulation Materials. In *Comprehensive Energy Systems* (pp. 760–795). Elsevier. https://doi.org/10.1016/B978-0-12-809597-3.00252-2

Cretescu, I., Harja, M., Teodosiu, C., Isopescu, D. N., Chok, M. F., Sluser, B. M., & Salleh, M. A. M. (2018). Synthesis and characterisation of a binder cement replacement based on alkali activation of fly ash waste. *Process Safety and Environmental Protection*, *119*, 23–35. https://doi.org/10.1016/j.psep.2018.07.011

DeJong, J. T., Mortensen, B. M., Martinez, B. C., & Nelson, D. C. (2010). Bio-mediated soil improvement. *Ecological Engineering*, *36*(2), 197–210. https://doi.org/10.1016/j.ecoleng.2008.12.029

Dhakal, U., Berardi, U., Gorgolewski, M., & Richman, R. (2017). Hygrothermal performance of hempcrete for Ontario (Canada) buildings. *Journal of Cleaner Production*, *142*, 3655–3664. https://doi.org/10.1016/j.jclepro.2016.10.102

Dickinson, E. (2015). Structuring of colloidal particles at interfaces and the relationship to food emulsion and foam stability. *Journal of Colloid and Interface Science*, *449*, 38–45. https://doi.org/10.1016/j.jcis.2014.09.080

Echeverria, C., Pahlevani, F., Gaikwad, V., & Sahajwalla, V. (2017). The effect of microstructure, filler load and surface adhesion of marine bio-fillers, in the performance of Hybrid Wood-Polypropylene Particulate Bio-composite. *Journal of Cleaner Production*, *154*, 284–294. https://doi.org/10.1016/j.jclepro.2017.04.020

Egwunatum, S., Joseph-Akwara, E., & Akaigwe, R. (2016). Optimizing Energy Consumption in Building Designs Using Building Information Model (BIM). *Slovak Journal of Civil Engineering*, *24*(3), 19–28. https://doi.org/10.1515/sjce-2016-0013

El-Hendawy, A.-N. A. (2006). Variation in the FTIR spectra of a biomass under impregnation, carbonization and oxidation conditions. *Journal of Analytical and Applied Pyrolysis*, *75*(2), 159–166. https://doi.org/10.1016/j.jaap.2005.05.004

Eremin, D. B., & Ananikov, V. P. (2017). Understanding active species in catalytic transformations: From molecular catalysis to nanoparticles, leaching, "Cocktails" of catalysts and dynamic systems. *Coordination Chemistry Reviews*, *346*, 2–19. https://doi.org/10.1016/j.ccr.2016.12.021

Etris, S., Fiorini, Y., Lieb, K., Moore, I., Batik, A., & Tye, R. (1974). Heat Transmission in Cellulosic Fiber Insulation Materials. *Journal of Testing and Evaluation*, *2*(3), 176. https://doi.org/10.1520/JTE10095J

FAO. (2014). *Statistical Databases - Food and Agricultural Organization of the United Nation*.

Ferng, L.-H., Chen, S.-H., & Lin, Y.-A. (2011). Effect of steam jet cooking on the destruction of corn starches. *Procedia Food Science*, *1*, 1295–1300. https://doi.org/10.1016/j.profoo.2011.09.192

Fırat, S., Kinuthia, J., & Abu-Tair, A. (Eds.). (2018). *Proceedings of 3rd International Sustainable Buildings Symposium (ISBS 2017)* (Vol. 6). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-63709-9

Fukuda, T., Yokoi, K., Yabuki, N., & Motamedi, A. (2018). An indoor thermal environment design system for renovation using augmented reality. *Journal of Computational Design and Engineering*. https://doi.org/10.1016/j.jcde.2018.05.007

Gálvez-Martos, J.-L., Styles, D., Schoenberger, H., & Zeschmar-Lahl, B. (2018). Construction and demolition waste best management practice in Europe. *Resources, Conservation and Recycling*, *136*, 166–178. https://doi.org/10.1016/j.resconrec.2018.04.016

Griffiths, P. R. (2010). Introduction to the Theory and Instrumentation for Vibrational Spectroscopy. In E. C. Y. Li-Chan (Ed.), *Handbook of Vibrational Spectroscopy*. Chichester, UK: John Wiley & Sons, Ltd. https://doi.org/10.1002/0470027320.s8935

Guiheneuf, V., Delaleux, F., Pouliquen, S., Riou, O., Logerais, P.-O., & Durastanti, J.-F. (2017). Effects of the irradiance intensity during UV accelerated aging test on unencapsulated silicon solar cells. *Solar Energy*, *157*, 477–485. https://doi.org/10.1016/j.solener.2017.08.044

Gupta, A. P., Ahmad, S., & Dev, A. (2011). Modification of novel bio-based resin-epoxidized soybean oil by conventional epoxy resin. *Polymer Engineering & Science*, *51*(6), 1087–1091. https://doi.org/10.1002/pen.21791

Gustafsson, S. E. (1991). Transient plane source techniques for thermal conductivity and thermal diffusivity measurements of solid materials. *Review of Scientific Instruments*, *62*(3), 797–804. https://doi.org/10.1063/1.1142087

Guzel Kaya, G., Yilmaz, E., & Deveci, H. (2018). Sustainable nanocomposites of epoxy and silica xerogel synthesized from corn stalk ash: Enhanced thermal and acoustic insulation performance. *Composites Part B: Engineering*, *150*(May), 1–6. https://doi.org/https://doi.org/10.1016/j.compositesb.2018.05.039

Hajj, N. El, Mboumba-Mamboundou, B., Dheilly, R.-M., Aboura, Z., Benzeggagh, M., & Queneudec, M. (2011). Development of thermal insulating and sound absorbing agro-sourced materials from auto linked flax-tows. *Industrial Crops and Products*, *34*(1), 921–928. https://doi.org/10.1016/j.indcrop.2011.02.012

Harish, V. S. K. V., & Kumar, A. (2016). A review on modeling and simulation of building energy systems. *Renewable and Sustainable Energy Reviews*, *56*, 1272–1292. https://doi.org/10.1016/j.rser.2015.12.040

Heinemann, U. (2008). Influence of Water on the Total Heat Transfer in 'Evacuated' Insulations. *International Journal of Thermophysics*, *29*(2), 735–749. https://doi.org/10.1007/s10765-007-0361-1

Honcoop, E., & McNamee, W. (2010). *Toughening of epoxy coating systems with novel bio-based materials* (Vol. 26).

Iannace, G. (2017). The acoustic characterization of green materials. *Building Acoustics*, *24*(2), 1–6. https://doi.org/10.1177/1351010X17704624

Indraganti, M. (2010). Thermal comfort in naturally ventilated apartments in summer: Findings from a field study in Hyderabad, India. *Applied Energy*, *87*(3), 866–883. https://doi.org/10.1016/j.apenergy.2009.08.042

Issa, B., Obaidat, I. M., Albiss, B. A., & Haik, Y. (2013). Magnetic nanoparticles: Surface effects and properties related to biomedicine applications. *International Journal of Molecular Sciences*, *14*(11), 21266–21305. https://doi.org/10.3390/ijms141121266

Jambhulkar, H. P., Shaikh, S. M. S., & Kumar, M. S. (2018). Fly ash toxicity, emerging issues and possible implications for its exploitation in agriculture; Indian scenario: A review. *Chemosphere*, *213*, 333–344. https://doi.org/10.1016/j.chemosphere.2018.09.045

Jelle, B. P. (2011). Traditional, state-of-the-art and future thermal building insulation materials and solutions - Properties, requirements and possibilities. *Energy and*

*Buildings*, *43*(10), 2549–2563. https://doi.org/10.1016/j.enbuild.2011.05.015

Jelle, B. P. (2012). Accelerated climate ageing of building materials, components and structures in the laboratory. *Journal of Materials Science*, *47*(18), 6475–6496. https://doi.org/10.1007/s10853-012-6349-7

Jelle, B. P. (2016). *Nano-based thermal insulation for energy-efficient buildings*. *Start-Up Creation: The Smart Eco-Efficient Built Environment*. Elsevier Ltd. https://doi.org/10.1016/B978-0-08-100546-0.00008-X

Kang, L. S., & Hussin, M. W. (2008). Effect of Filler on Strength Development of Epoxy Grout. *Malaysian Journal of Civil Engineering*, *20*(1), 38–46. Retrieved from http://civil.utm.my/mjce/?s=Effect+Of+Filler+On+Strength+Development+Of+Epoxy+Grout%5Cnhttp://www.researchgate.net/profile/Siong_Kang_Lim

Khitab, A., Anwar, W., Mehmood, I., Khan, U. A., Kazmi, S., Minhaj, S., & Munir, M. J. (2016). Sustainable Construction with Advanced Biomaterials: an Overview. *Science International*, *28*(3), 2351–2356.

Kim, J. B., Jeong, W., Clayton, M. J., Haberl, J. S., & Yan, W. (2015). Developing a physical BIM library for building thermal energy simulation. *Automation in Construction*, *50*, 16–28. https://doi.org/10.1016/j.autcon.2014.10.011

Kini, P., Garg, N. K., & Kamath, K. (2017). Exploring Energy Conservation in Office Buildings with Thermal Comfort Criterion Towards Sustainable New Developments in Warm and Humid Climate. *Energy Procedia*, *111*(September 2016), 277–286. https://doi.org/10.1016/j.egypro.2017.03.029

Koval, S., Krahenbuhl, G., Warren, K., & O'Brien, G. (2018). Optical microscopy as a new approach for characterising dust particulates in urban environment. *Journal of Environmental Management*, *223*, 196–202. https://doi.org/10.1016/j.jenvman.2018.06.038

Kumari, V. (2009). Physicochemical Properties of Fly Ash from Thermal Power Station and its Effect on Vegetation, *3*(2), 102–105.

Latif, E., Ciupala, M. A., Tucker, S., Wijeyesekera, D. C., & Newport, D. J. (2015). Hygrothermal performance of wood-hemp insulation in timber frame wall panels with and without a vapour barrier. *Building and Environment*, *92*, 122–134. https://doi.org/10.1016/j.buildenv.2015.04.025

Latif, E., Ciupala, M. A., & Wijeyesekera, D. C. (2014). The comparative in situ hygrothermal performance of Hemp and Stone Wool insulations in vapour open timber frame wall panels. *Construction and Building Materials*, *73*, 205–213. https://doi.org/10.1016/j.conbuildmat.2014.09.060

Lau, D., Jian, W., Yu, Z., & Hui, D. (2018). Nano-engineering of construction materials using molecular dynamics simulations: Prospects and challenges. *Composites Part B: Engineering*, *143*, 282–291. https://doi.org/10.1016/j.compositesb.2018.01.014

Lee, S., Kim, S., & Na, Y. (2015). Comparative analysis of energy related performance and construction cost of the external walls in high-rise residential buildings. *Energy and Buildings*, *99*, 67–74. https://doi.org/10.1016/j.enbuild.2015.03.058

Li, R., Xiao, F., Amirkhanian, S., You, Z., & Huang, J. (2017). Developments of nano materials and technologies on asphalt materials – A review. *Construction and Building Materials*, *143*, 633–648. https://doi.org/10.1016/j.conbuildmat.2017.03.158

Lin, C., Huang, C. L., & Shern, C. C. (2008). Recycling waste tire powder for the recovery of oil spills. *Resources, Conservation and Recycling*, *52*(10), 1162–1166. https://doi.org/10.1016/j.resconrec.2008.06.003

Liu, L., Li, H., Lazzaretto, A., Manente, G., Tong, C., Liu, Q., & Li, N. (2017). The development history and prospects of biomass-based insulation materials for buildings. *Renewable and Sustainable Energy Reviews*, *69*, 912–932. https://doi.org/10.1016/j.rser.2016.11.140

Liu, Y., Zeng, Z., & Wei, J. (2018). Nanoarchitectured electrodes for supercapacitance energy storage. In *Fundamentals of Nanoparticles* (pp. 215–244). Elsevier. https://doi.org/10.1016/B978-0-323-51255-8.00008-2

Lokeshappa, B. (2012). Disposal and Management of Flyash. *2011 International Conference on Life Science and Technology*, *3*(2011), 11–14.

Luo, Z., Wang, Z., Xu, B., Sarakiotis, I. L., Laing, G. Du, & Yan, C. (2014). Measurement and characterization of engineered titanium dioxide nanoparticles in the environment. *Journal of Zhejiang University SCIENCE A*, *15*(8), 593–605. https://doi.org/10.1631/jzus.A1400111

Mahasukhonthachat, K., Sopade, P. A., & Gidley, M. J. (2010). Kinetics of starch digestion in sorghum as affected by particle size. *Journal of Food Engineering*, *96*(1), 18–28. https://doi.org/10.1016/j.jfoodeng.2009.06.051

Mahdavinejad, M., Ghaedi, A., Ghasempourabadi, M., & Ghaedi, H. (2012). The Role of Vernacular Architecture in Design of Green Sidewalk (Case Study: Iran, Shushtar). *Applied Mechanics and Materials*, *260–261*, 65–68. https://doi.org/10.4028/www.scientific.net/AMM.260-261.65

Mansour, A., Srebric, J., & J Burley, B. (2007). *Development of Straw-cement Composite Sustainable Building Material for Low-cost Housing in Egypt*. *Journal of Applied Sciences Research* (Vol. 3).

Maqsood, S., Kittiphattanabawon, P., Benjakul, S., Sumpavapol, P., & Abushelaibi, A. (2015). Antioxidant activity of date (Phoenix dactylifera var. Khalas) seed and its preventive effect on lipid oxidation in model systems. *International Food Research Journal*, *22*(3), 1180–1188.

Marques, D. V., Barcelos, R. L., Silva, H. R. T., Egert, P., Parma, G. O. C., Girotto, E., … Magnago, R. F. (2018). Recycled polyethylene terephthalate-based boards for thermal-acoustic insulation. *Journal of Cleaner Production*, *189*, 251–262. https://doi.org/10.1016/j.jclepro.2018.04.069

Mechri, M. L., Chihi, S., Mahdadi, N., & Beddiaf, S. (2017). Diagnosis of the heating effect on the electrical resistivity of Ouargla (Algeria) dunes sand using XRD patterns and FTIR spectra. *Journal of African Earth Sciences*, *125*, 18–26. https://doi.org/10.1016/j.jafrearsci.2016.10.007

Meier, A., Darwish, M., & Sabeeh, S. (2013). Complexities of saving energy in Qatar. *ECEEE 2013 Summer Study Proceedings*, 41–46. Retrieved from http://www.eceee.org/

Mihiretie, B. M., Cederkrantz, D., Rosén, A., Otterberg, H., Sundin, M., Gustafsson, S. E., & Karlsteen, M. (2017). Finite element modeling of the Hot Disc method. *International Journal of Heat and Mass Transfer*, *115*, 216–223. https://doi.org/10.1016/j.ijheatmasstransfer.2017.08.036

Mohamed, A. S. Y. (2017). Smart Materials Innovative Technologies in architecture; Towards Innovative design paradigm. *Energy Procedia*, *115*, 139–154. https://doi.org/10.1016/j.egypro.2017.05.014

Morrissey, A. ., & Browne, J. (2004). Waste management models and their application to sustainable waste management. *Waste Management*, *24*(3), 297–308. https://doi.org/10.1016/j.wasman.2003.09.005

Mostaan, A. (2016). Framework to develop the mechanisation of date palm cultivation. *Biosystems Engineering*, *147*, 26–38. https://doi.org/10.1016/j.biosystemseng.2016.02.016

Muhamad, I. I., Zahan, K. A., Pa'e, N., Salehudin, M. H., Khairuddin, N., Mohd Marsin, A., … Salleh, E. (2019). Accelerated testing methodology for long-term life prediction of cellulose-based polymeric composite materials. In *Durability and Life Prediction in Biocomposites, Fibre-Reinforced Composites and Hybrid Composites* (pp. 149–171). Elsevier. https://doi.org/10.1016/B978-0-08-102290-0.00008-8

Muizniece, I., Blumberga, D., & Ansone, A. (2015). The Use of Coniferous Greenery for Heat Insulation Material Production. *Energy Procedia*, *72*, 209–215. https://doi.org/10.1016/j.egypro.2015.06.030

Natephra, W., Yabuki, N., & Fukuda, T. (2018). Optimizing the evaluation of building envelope design for thermal performance using a BIM-based overall thermal transfer value calculation. *Building and Environment*, *136*, 128–145. https://doi.org/10.1016/j.buildenv.2018.03.032

Nehdi, I., Omri, S., Khalil, M. I., & Al-Resayes, S. I. (2010). Characteristics and chemical composition of date palm (Phoenix canariensis) seeds and seed oil. *Industrial Crops and Products*, *32*(3), 360–365. https://doi.org/10.1016/j.indcrop.2010.05.016

Newbury, D. E., & Ritchie, N. W. M. (2013). Is Scanning Electron Microscopy/Energy Dispersive X-ray Spectrometry (SEM/EDS) Quantitative? *Scanning*, *35*(3), 141–168. https://doi.org/10.1002/sca.21041

Nguyen, D. M., Grillet, A. C., Bui, Q. B., Diep, T. M. H., & Woloszyn, M. (2018). Building bio-insulation materials based on bamboo powder and bio-binders. *Construction and Building Materials*, *186*, 686–698. https://doi.org/10.1016/j.conbuildmat.2018.07.153

Nicolajsen, A. (2005). Thermal transmittance of a cellulose loose-fill insulation material. *Building and Environment*, *40*(7), 907–914. https://doi.org/10.1016/j.buildenv.2004.08.025

Noor, L. (2017). *Internship on Ferrite Sample Preparation, Planetary Ball Milling* *and Calcination*.

Nwabue, F. I., Unah, U., & Itumoh, E. J. (2017). Production and characterization of smokeless bio-coal briquettes incorporating plastic waste materials. *Environmental Technology & Innovation*, *8*, 233–245. https://doi.org/10.1016/j.eti.2017.02.008

Oliveira, F. de, Ramires, E. C., Frollini, E., & Belgacem, M. N. (2015). Lignopolyurethanic materials based on oxypropylated sodium lignosulfonate and castor oil blends. *Industrial Crops and Products*, *72*, 77–86. https://doi.org/10.1016/j.indcrop.2015.01.023

Omya UK Ltd. (2014). *Fillite: Product Overview – Standard Range*. East Riding of Yorkshire.

Ong, K. J., Shatkin, J. A., Nelson, K., Ede, J. D., & Retsina, T. (2017). Establishing the safety of novel bio-based cellulose nanomaterials for commercialization. *NanoImpact*, *6*, 19–29. https://doi.org/10.1016/j.impact.2017.03.002

Palumbo, M., Avellaneda, J., & Lacasta, A. M. M. (2015). Availability of crop by-products in Spain: New raw materials for natural thermal insulation. *Resources, Conservation and Recycling*, *99*, 1–6. https://doi.org/10.1016/j.resconrec.2015.03.012

Palumbo, M., Lacasta, A. M., Giraldo, M. P., Haurie, L., & Correal, E. (2018). Bio-based insulation materials and their hygrothermal performance in a building envelope system (ETICS). *Energy and Buildings*, *174*, 147–155. https://doi.org/10.1016/j.enbuild.2018.06.042

Papadaki, D. (2017). Tha Environmental Performance of Photocatalytic Materials for Energy Save, (April).

Papadopoulos, A. M. (2005). State of the art in thermal insulation materials and aims for future developments. *Energy and Buildings*, *37*(1), 77–86.

https://doi.org/10.1016/j.enbuild.2004.05.006

Parthenopoulou, N. K., & Malindretos, M. (2016). The Use of Innovative Materials in Innovative Architectural Applications. Combining Forces for High Performance Structures. *Materials Today: Proceedings*, *3*(3), 898–912. https://doi.org/10.1016/j.matpr.2016.02.023

Pérez-Lombard, L., Ortiz, J., & Pout, C. (2008). A review on buildings energy consumption information. *Energy and Buildings*, *40*(3), 394–398. https://doi.org/10.1016/j.enbuild.2007.03.007

Pérez, J. S. (2016). *The introduction of eco-design for promoting the use of eco-materials: the cork as building material*. Universitat Autònoma de Barcelona. Retrieved from https://ddd.uab.cat/pub/tesis/2016/hdl_10803_400141/jorsieper1de1.pdf

Petit, T., & Puskar, L. (2018). FTIR spectroscopy of nanodiamonds: Methods and interpretation. *Diamond and Related Materials*, *89*, 52–66. https://doi.org/10.1016/j.diamond.2018.08.005

Pham, H. Q., & Marks, M. J. (2005). Epoxy Resins. In *Ullmann's Encyclopedia of Industrial Chemistry*. Weinheim, Germany: Wiley-VCH Verlag GmbH & Co. KGaA. https://doi.org/10.1002/14356007.a09_547.pub2

Pilla, S. (2011). *Handbook of Bioplastics and Biocomposites Engineering Applications*. (S. Pilla, Ed.). Hoboken, NJ, USA: John Wiley & Sons, Inc. https://doi.org/10.1002/9781118203699

Plank, J. (2004). Applications of biopolymers and other biotechnological products in building materials. *Applied Microbiology and Biotechnology*, *66*(1), 1–9. https://doi.org/10.1007/s00253-004-1714-3

Porro, A. (2004). Integration of European Nanotechnology Research in Construction. In *Nanotechnology in Construction Special Publication* (pp. 25–30).

https://doi.org/10.1039/9781847551528-00025

Raut, A., & Gomez, C. (2018). Assessment of thermal and energy performance of thermally efficient sustainable wall system for Malaysian low cost housing. *Applied Thermal Engineering*, *136*(September 2017), 309–318. https://doi.org/10.1016/j.applthermaleng.2018.03.017

Raut, A. N. (2017). DEVELOPMENT OF SUSTAINABLE MATERIAL FOR HYBRID WALL SYSTEM TO, (May).

Razavi, M. (2018). Bio-based nanostructured materials. In *Nanobiomaterials* (pp. 17–39). Elsevier. https://doi.org/10.1016/B978-0-08-100716-7.00002-7

Rostam, N. G., Mahdavinejad, M. J., & Rostam, M. G. (2015). Commercializing Usage of Nano-insulating Materials in Building Industry and Future Architecture. *Procedia Materials Science*, *11*, 644–648. https://doi.org/10.1016/j.mspro.2015.11.004

Sadineni, S. B., Madala, S., & Boehm, R. F. (2011). Passive building energy savings: A review of building envelope components. *Renewable and Sustainable Energy Reviews*, *15*(8), 3617–3631. https://doi.org/10.1016/j.rser.2011.07.014

Saffari, M., de Gracia, A., Ushak, S., & Cabeza, L. F. (2017). Passive cooling of buildings with phase change materials using whole-building energy simulation tools: A review. *Renewable and Sustainable Energy Reviews*, *80*(January), 1239–1255. https://doi.org/10.1016/j.rser.2017.05.139

Sagbansua, L., & Balo, F. (2017). Ecological impact & financial feasibility of Energy Recovery (EIFFER) Model for natural insulation material optimization. *Energy and Buildings*, *148*, 1–14. https://doi.org/10.1016/j.enbuild.2017.05.015

Sajwan, K. S., Alva, A. K., & Keefer, R. F. (2003). *Chemistry of Trace Elements in Fly Ash*. (K. S. Sajwan, A. K. Alva, & R. F. Keefer, Eds.) (1st ed.). Boston, MA: Springer US. https://doi.org/10.1007/978-1-4757-4757-7

Salmeia, K. A., Jovic, M., Ragaisiene, A., Rukuiziene, Z., Milasius, R., Mikuioniene, D., & Gaan, S. (2016). Flammability of cellulose-based fibers and the effect of structure of phosphorus compounds on their flame retardancy. *Polymers*, *8*(8). https://doi.org/10.3390/polym8080293

Sampathrajan, A., Vijayaraghavan, N. C., & Swaminathan, K. R. (1992). Mechanical and thermal properties of particle boards made from farm residues. *Bioresource Technology*, *40*(3), 249–251. https://doi.org/10.1016/0960-8524(92)90151-M

Schiavoni, S., D׳Alessandro, F., Bianchi, F., & Asdrubali, F. (2016). Insulation materials for the building sector: A review and comparative analysis. *Renewable and Sustainable Energy Reviews*, *62*, 988–1011. https://doi.org/10.1016/j.rser.2016.05.045

Schlanbusch, R. D. (2013). A New Nano Insulation Material for Applications in Zero Emission Buildings. *Norwegian University of Science and Technology NTNU*, 1–94.

Shayeb, M. A., Alharbi, T., Baloch, M. A., & Rahman Alsamhan, O. A. (2017). Transfer factors for natural radioactivity into date palm pits. *Journal of Environmental Radioactivity*, *167*, 75–79. https://doi.org/10.1016/j.jenvrad.2016.11.014

Shiel, P., Tarantino, S., & Fischer, M. (2018). Parametric analysis of design stage building energy performance simulation models. *Energy and Buildings*, *172*, 78–93. https://doi.org/10.1016/j.enbuild.2018.04.045

Shoubi, M. V., Shoubi, M. V., Bagchi, A., & Barough, A. S. (2014). Reducing the operational energy demand in buildings using building information modeling tools and sustainability approaches. *Ain Shams Engineering Journal*, *6*(1), 41–55. https://doi.org/10.1016/j.asej.2014.09.006

Sierra-Pérez, J., García-Pérez, S., Blanc, S., Boschmonart-Rives, J., & Gabarrell, X.

(2018). The use of forest-based materials for the efficient energy of cities: Environmental and economic implications of cork as insulation material. *Sustainable Cities and Society*, *37*, 628–636. https://doi.org/10.1016/j.scs.2017.12.008

Somashekhar, T. M., Naik, P., Nayak, V., Mallikappa, & Rahul, S. (2018). Study of Mechanical Properties of Coconut Shell Powder and Tamarind Shell Powder Reinforced with Epoxy Composites. *IOP Conference Series: Materials Science and Engineering*, *376*, 012105. https://doi.org/10.1088/1757-899X/376/1/012105

Spitler, J. (2006). Editorial: Building Performance Simulation: The Now and the Not Yet. *HVAC&R Research*, *12*, 711–713. https://doi.org/10.1080/10789669.2006.10391194

Srinivasan, V. S., Rajendra Boopathy, S., Sangeetha, D., & Vijaya Ramnath, B. (2014). Evaluation of mechanical and thermal properties of banana–flax based natural fibre composite. *Materials & Design*, *60*, 620–627. https://doi.org/10.1016/j.matdes.2014.03.014

Stolle, A., Szuppa, T., Leonhardt, S. E. S., & Ondruschka, B. (2011). Ball milling in organic synthesis: solutions and challenges. *Chemical Society Reviews*, *40*(5), 2317. https://doi.org/10.1039/c0cs00195c

Storti, F., & Balsamo, F. (2010). Particle size distributions by laser diffraction: sensitivity of granular matter strength to analytical operating procedures. *Solid Earth*, *1*(1), 25–48. https://doi.org/10.5194/se-1-25-2010

Su, N., Xiao, F., Wang, J., Cong, L., & Amirkhanian, S. (2018). Productions and applications of bio-asphalts – A review. *Construction and Building Materials*, *183*, 578–591. https://doi.org/10.1016/j.conbuildmat.2018.06.118

Sun, L., Fujii, M., Tasaki, T., Dong, H., & Ohnishi, S. (2018). Improving waste to energy rate by promoting an integrated municipal solid-waste management system. *Resources, Conservation and Recycling*, *136*, 289–296. https://doi.org/10.1016/j.resconrec.2018.05.005

Sunil, E. M., & Manavendra, G. (2017). Experimental Investigation on Thermal Properties of Bagasse Fly Ash Reinforced Epoxy Composite. *International Research Journal of Engineering and Technology(IRJET)*, *4*(9), 444–450. Retrieved from https://irjet.net/archives/V4/i9/IRJET-V4I977.pdf

Suresh, S., Guizani, N., Al-Ruzeiki, M., Al-Hadhrami, A., Al-Dohani, H., Al-Kindi, I., & Rahman, M. S. (2013). Thermal characteristics, chemical composition and polyphenol contents of date-pits powder. *Journal of Food Engineering*, *119*(3), 668–679. https://doi.org/10.1016/j.jfoodeng.2013.06.026

Taoukil, D., El bouardi, A., Ajzoul, T., & Ezbakhe, H. (2012). Effect of the incorporation of wood wool on thermo physical proprieties of sand mortars. *KSCE Journal of Civil Engineering*, *16*(6), 1003–1010. https://doi.org/10.1007/s12205-012-1470-3

Tchobanoglous, G., Theisen, H., & Vigil, S. (1993). *Integrated Solid Waste Management: Engineering Principles and Management Issues*. Singapore: McGraw-Hill,.

Tomovska, R., & Radivojević, A. (2017). Tracing sustainable design strategies in the example of the traditional Ohrid house. *Journal of Cleaner Production*, *147*, 10–24. https://doi.org/10.1016/j.jclepro.2017.01.073

Velázquez- Martí, B., Gaibor-Chávez, J., Niño-Ruiz, Z., & Cortés-Rojas, E. (2018). Development of biomass fast proximate analysis by thermogravimetric scale. *Renewable Energy*, *126*, 954–959. https://doi.org/10.1016/j.renene.2018.04.021

Vyas, G. S., & Jha, K. N. (2016). Identification of green building attributes for the development of an assessment tool: a case study in India. *Civil Engineering and Environmental Systems*, *33*(4), 313–334.

https://doi.org/10.1080/10286608.2016.1247832

Wagner, R. (1978). Reclamation of carpet waste for building insulation. *Conservation & Recycling*, *2*(2), 131–135. https://doi.org/10.1016/0361-3658(78)90052-8

Wang, F., Liang, J., Tang, Q., Chen, C., & Chen, Y. (2014). Preparation and performance of thermal insulation energy saving coating materials for exterior wall. *Journal of Nanoscience and Nanotechnology*, *14*(5). https://doi.org/10.1166/jnn.2014.8034

Wang, J., Ban, H., Teng, X., Wang, H., & Ladwig, K. (2006). Impacts of pH and ammonia on the leaching of Cu(II) and Cd(II) from coal fly ash. *Chemosphere*, *64*(11), 1892–1898. https://doi.org/10.1016/j.chemosphere.2006.01.041

Wang, S., Lu, A., & Zhang, L. (2016). Recent advances in regenerated cellulose materials. *Progress in Polymer Science*, *53*, 169–206. https://doi.org/10.1016/j.progpolymsci.2015.07.003

Wang, T., Ishida, T., & Gu, R. (2018). A comparison of the specific surface area of fly ash measured by image analysis with conventional methods. *Construction and Building Materials*, *190*, 1163–1172. https://doi.org/10.1016/j.conbuildmat.2018.09.131

Wang, Y., Zhang, X., Cai, G., Wan, B., Waldmann, D., & Qu, Y. (2018). A new thickness-based accelerated aging test methodology for resin materials: Theory and preliminary experimental study. *Construction and Building Materials*, *186*, 986–995. https://doi.org/10.1016/j.conbuildmat.2018.07.245

Weber, G., Calaf-Forn, M., Puig-Ventosa, I., Cabras, I., & D'Alisa, G. (2018). The role of environmental organisations on urban transformation: The case of waste management in Esporles (Mallorca). *Journal of Cleaner Production*, *195*, 1546–1557. https://doi.org/10.1016/j.jclepro.2017.08.241

Wei, K., Lv, C., Chen, M., Zhou, X., Dai, Z., & Shen, D. (2015). Development and performance evaluation of a new thermal insulation material from rice straw using high frequency hot-pressing. *Energy and Buildings*, *87*, 116–122. https://doi.org/10.1016/j.enbuild.2014.11.026

Williams, J., Lawrence, M., & Walker, P. (2016). A method for the assessment of the internal structure of bio-aggregate concretes. *Construction and Building Materials*, *116*, 45–51. https://doi.org/10.1016/j.conbuildmat.2016.04.088

Xu, W., Wang, Z., Han, E.-H., Wang, S., & Liu, Q. (2018). Corrosion Performance of Nano-ZrO2 Modified Coatings in Hot Mixed Acid Solutions. *Materials*, *11*(6), 934. https://doi.org/10.3390/ma11060934

Yan, G., Crivoi, A., Sun, Y., Maharjan, N., Song, X., Li, F., & Tan, M. J. (2018). An Arrhenius equation-based model to predict the residual stress relief of post weld heat treatment of Ti-6Al-4V plate. *Journal of Manufacturing Processes*, *32*, 763–772. https://doi.org/10.1016/j.jmapro.2018.04.004

Yang, X., Wang, C., Li, S., Huang, K., Li, M., Mao, W., … Xia, J. (2017). Study on the synthesis of bio-based epoxy curing agent derived from myrcene and castor oil and the properties of the cured products. *RSC Advances*, *7*(1), 238–247. https://doi.org/10.1039/C6RA24818G

Yew, M. C., Yew, M. K., Saw, L. H., Ng, T. C., Durairaj, R., & Beh, J. H. (2018). Influences of nano bio-filler on the fire-resistive and mechanical properties of water-based intumescent coatings. *Progress in Organic Coatings*, *124*, 33–40. https://doi.org/10.1016/j.porgcoat.2018.07.022

Yoada, R. M., Chirawurah, D., & Adongo, P. B. (2014). Domestic waste disposal practice and perceptions of private sector waste management in urban Accra. *BMC Public Health*, *14*(1), 697. https://doi.org/10.1186/1471-2458-14-697

Zach, J., Slávik, R., & Novák, V. (2016). Investigation of the Process of Heat Transfer in the Structure of Thermal Insulation Materials Based on Natural

Fibres. *Procedia Engineering*, *151*, 352–359. https://doi.org/10.1016/j.proeng.2016.07.389

Zhang, R., Wang, H., You, Z., Jiang, X., & Yang, X. (2017). Optimization of bio-asphalt using bio-oil and distilled water. *Journal of Cleaner Production*, *165*, 281–289. https://doi.org/10.1016/j.jclepro.2017.07.154

Zhao, S., Duan, Y., Lu, J., Gupta, R., Pudasainee, D., Liu, S., … Lu, J. (2018). Chemical speciation and leaching characteristics of hazardous trace elements in coal and fly ash from coal-fired power plants. *Fuel*, *232*, 463–469. https://doi.org/10.1016/j.fuel.2018.05.135

Zhou, X., Zheng, F., Li, H., & Lu, C. (2010). An environment-friendly thermal insulation material from cotton stalk fibers. *Energy and Buildings*, *42*(7), 1070–1074. https://doi.org/10.1016/j.enbuild.2010.01.020

**APPENDIX A**

Collected Date-Pits Samples

# APPENDIX B

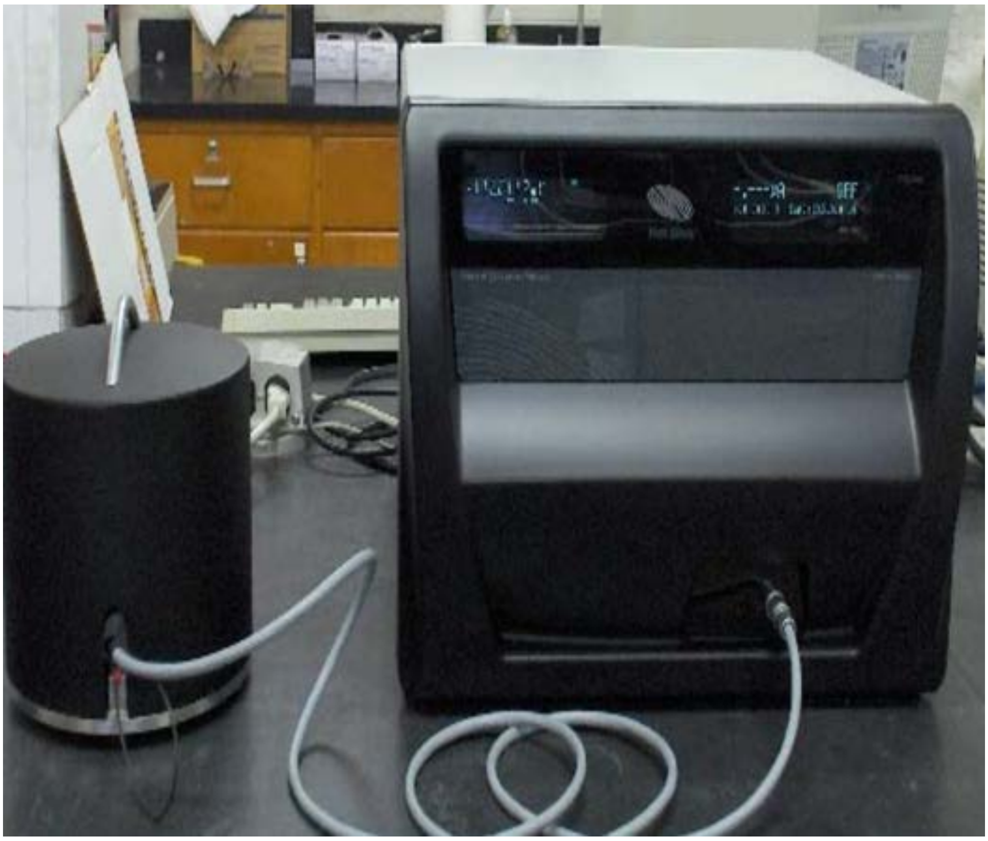
Collected Powdered Date-Pits in Micron

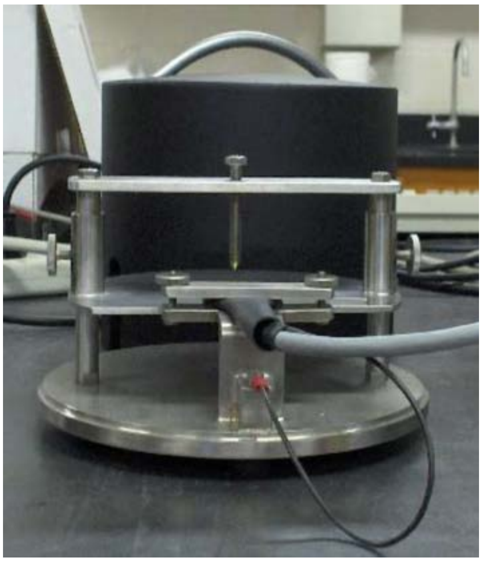
# APPENDIX C

Malvern Mastersizer 2000MU Particle Size Analyzer

# APPENDIX D

The Hot Disk TPS 2500 S Device, Side and Top View of The Sensor and Holder of The Hot-Disk Device





**APPENDIX E**

Date-Pits:Sand Composition (DP0S50E) Mixed with Epoxy Resin in Mold; Prepared in The Lab