International Journal of Design & Nature and Ecodynamics
Vol. 17, No. 6, December, 2022, pp. 831-841
Journal homepage: http://iieta.org/journals/ijdne

An Overview of Thermal Insulation Material for Sustainable Engineering Building Application

Imhade P. Okokpujie[1,2], Victor Essien[3], Omolayo M. Ikumapayi[1,2*], Emeka S. Nnochiri[4], Kennedy Okokpujie[5], Esther T. Akinlabi[6]

[1] Department of Mechanical and Mechatronics Engineering, Afe Babalola University, Ado Ekiti 360101, Nigeria
[2] Department of Mechanical and Industrial Engineering Technology, University of Johannesburg, Johannesburg 2028, South Africa
[3] Department of Mechanical Engineering, Covenant University, Ota112212, Ogun State, Nigeria
[4] Department of Civil Engineering, Afe Babalola University, Ado Ekiti 360101, Nigeria
[5] Department of Electrical and Information Engineering, Covenant University, Ota 112101, Ogun State, Nigeria
[6] Department of Mechanical and Construction Engineering, Northumbria University, Newcastle, NE7 7XA, United Kingdom

Corresponding Author Email: ikumapayi.omolayo@abuad.edu.ng

https://doi.org/10.18280/ijdne.170603

Received: 13 August 2022
Accepted: 13 October 2022

Keywords:
thermal insulation materials, heat transfer, building materials, residential roofing systems, solar radiation, thermal conductivity

ABSTRACT

Residential buildings help to facilitate the occupants against solar radiation and adverse weather conditions. However, the growing increase in climate change in our environment has resulted in different side effects on human's health mostly in the northern region of Nigeria and other parts of the world where high radiation from the sun are experience. This has resulted to the key interests of this research on possible thermal insulation materials that can help resist or absorb the solar radiation effects that can cause damage to lives in our community. This literature review of thermal insulation materials aims to proffer a sustainable solution by evaluating the thermal performance of building materials to provide an eco-friendly environment for building occupants. This research also discusses the Application of Thermal Insulation Materials for Developing Roofing sheets. The classification of thermal insulation materials, heat transfer in insulation materials, factors that influence the choice of building materials and thermal conductivity, resistivity, resistance, and conductance. Advantages of building insulation materials on economic, comfort, and environmental were also studied, and the reviewing of previous and incorporating thermal insulation materials with roofs. From the critical review, the application of insulating materials for developing building materials is highly recommended due to the provision of an eco-friending environment with reduced energy consumption during applications of home appliances.

1. INTRODUCTION

Thermal Insulation materials reduce energy loss in residential and commercial buildings [1]. These insulation techniques can serve year-round by increasing the available heating and cooling systems to full capacity. It also significantly reduces the cost of running electrical water heaters and air conditioning units and the high standing costs of these systems [2]. Electricity consumption can be reduced in the environment when there is a significant reduction in CO_2, which will afford better living standards and a serene environment for individuals [3].

Legal obligations regarding thermal insulation have developed stricter measures to ensure compliance with regular changes being made to existing regulations. The kypto protocol and Paris conference seeks to provide measures in curtailing emissions, stating appropriate insulation as a significant measure to be incorporated in developed buildings and already existing buildings [4]. The clean Development Mechanism (CDM) is one technique that the international community has widely adopted to help reduce the number of carbon emissions released into the environment. Designed to help serve developed countries achieve the commitment to meet domestic greenhouse gas reduction [5].

Many insulation materials are developed from polymers, including integrating certain additives to increase their mechanical strength [6]. The different insulation materials are grouped into four major categories: organic or inorganic, composite, or just typical basic materials. Furthermore, the extensive use of polymers in developing insulating materials is in their naturally stable chemical and physical compositions. However, the mechanical constituents can be improved by adding inorganic fillers [7]. The utilization of air conditioners in most regions results from the hot-humid climate in these regions. In order to achieve thermal comfort, these units would have to be employed, which would invariably reduce the indoor temperature. While most researchers might think that opening windows and doors help to reduce the indoor temperature, this is generally not true, as ventilation typically helps reduce the indoor temperature. Air conditioning units will help achieve a certain level of thermal comfort. However, adverse effects are associated with a continuous and absolute dependence on this system. It increases the amount of money paid by individuals for their electricity tariffs. This is coupled with increased energy consumption and a resulting emission increase from the power plants during power generation [8-10]. This is achieved when the rate at which heat is produced is equivalent to the rate at which it is dissipated. Whenever the ambient temperature is significantly higher in proportion to the body's temperature, this constitutes body heat not being dissipated to the environment and aids thermal discomfort. So in whatever situation where air conditioners are turned on, it helps to reduce the indoor temperature and proper body heat dissipation to attain thermal comfort [11].

As a result of the increasing climate change, the environmental temperature steadily rises [12-15]. From literature, it has been observed that, particularly in the afternoon, solar radiation causes a heat gain in buildings through the envelope and the windows via heat penetration. Alwetaishi [16] highlighted the roof as the component most affected by solar radiation due to direct contact with sunlight. Therefore, is responsible for a greater part of heat gain in buildings.

Naldzhiev et al. [17] climax how much building structures constitute the total emissions of CO_2 in the UK, where it is about 19%. Therefore, measure the crucial need for energy efficiency in buildings to reduce a considerable amount of carbon levels. However, careful examination and investigation have revealed further insulation enhancement in building compartments. This will significantly decrease buildings' heating and cooling requirements by about 20-60%, improving thermal comfort [18-20]. There have been various developed mechanisms to help improve heating and cooling requirements, and better methods are still being tested and developed [21]. While these techniques seek to manage the use of heating and cooling systems, thereby reducing electricity consumption, there are employed in the improvement of building insulation [22]. Improving building insulation will help to reduce energy demands, thereby bringing about quick returns on investment [23-26].

The importance of making better thermal performance levels through the employment of thermal insulation techniques is further stressed through the different comparisons made by energy production and consumption evaluations [27, 28]. Kalair et al. [29] stated that by 2035, only about 15% of the total energy produced would not be gotten from fossil fuels. Furthermore, seeking the actual result to help combat the heat transfer's adverse effect on the environment, various steps, including redirecting appropriate funds. Improvement in buildings will be highly needed for sustainable energy development and efficiency. As this part of the building, the sector has not been fully exploited as of 2012 [30]. Therefore, this research is focus on the review of existing work on thermal insulation materials and to evaluate the thermal performance on building applications. Also, the study proffer solution to the high heat transfer from the sun to the house environment when this materials combination has been determining.

2. APPLICATION OF THERMAL INSULATION MATERIALS FOR DEVELOPING ROOFING SHEET

Incorporating thermal insulation materials in commercial and residential buildings will further improve the management of energy deficits due to energy consumption in building structures [31-33]. This technique will reduce energy loss, which functions for up to a year, and ensures the proper utilization of heating and cooling systems present in the building structure [34]. In addition to these merits, selecting these appropriate materials in developing a building will see a drastic decline in the operational cost of electricity through heating and cooling systems and the cost of insulation of this equipment for heating and cooling [35].

The gains from electricity usage will bring about visible changes in and around the environment through a decline in carbon radiation [36-38]. This additionally moves to create a better atmosphere for living and carrying out work activities. Selecting rather efficient and long-lasting insulating materials is a key determinant that cannot be overlooked. Most of these materials, when adopted, result in several environmental problems, and some of these materials cannot be further processed, especially in plastics [39, 40]. However, this situation was corrected by using a more sustainable approach in the building sector, which helps boost the production of insulation materials using recycled materials. In their research, Monaldo et al. [41] highlighted the cost-effectiveness of thermal insulation materials when combined with the main matrix design, significantly decreasing CO_2 emissions. The majority of these products are currently available for purchase, while others are still in their initial stage of development or being researched. This could be a turning point for developing nations that have not achieved an adequately arranged recycling system coupled with the massive term over by-products from the industries and agricultural by-project. In light of decreasing the building sector's adverse effect on the environment. Ruangpan et al. [42] state that focus should be placed on this area and more efficient optimization techniques available in urban areas.

Many of the available insulation materials are produced with polymer materials, fillers, and other supplements such as composite materials [43]. Building thermal insulation materials are classified under the following primary materials and combinations [44].

(a) Organic: cane, cellulose, cotton, polyethylene, polyurethane, pulpwood, and other polymers.

(b) Inorganic: ceramic products, glass, rock, and slag wool

Polymers have very high insulating properties, which is a result of their balanced physical and chemical characteristics. Its mechanical properties would need further modification, which can be achieved by adding inorganic filters. This will increase the overall strength of the material [45].

2.1 Classification of thermal insulation materials

Thermal insulation materials are engineered to function to a specific constraint while not only considering the thermal conductivity of that material [44]. In order to ascertain its durability, materials are made to undergo a series of test processes, which in the end, prove the levels of stress that the material can attain. While all of this is being carried out, the thermal insulation properties will have to be maintained. There is a list of variables that centre on technical and physical requirements. In contrast, the technical requirements include a method of implementation, how durable the material is, and the manufacturing processes. Then, however, when putting up the physical requirements, it includes fire retardants and their thermal performance [46]. Over time there have been some protocols and guidelines concerning thermal insulation materials. Each protocol is distinctive in defining the various categories of heat insulation from distinctive points of view, testing, and requirements of individual types.

EN 13501-1:2018 illustrates the standard European grouping of construction building materials concerning how there react to fire. Each construction product and building component is given a class, A1, A2, B, C, D, E, and F, representing its affinity to fire. A1 and A2 represent "No contribution to fire," respectively, and products and components with class B show "very limited contribution" to fire growth. Class C products have a "Limited contribution to fire growth" with a "flashover after 10 minutes". However, D stands for "contribution to fire" with "flashover after 10 minutes" after 2-10 minutes". E class construction components have "significant contribution to fire" with "flashover before 2 minutes". While products under the F class have no "performance determined" [47].

The following are the various types of Thermal Insulation Materials available in building structures

(a) Organic materials: These can be further classified into Fibrous and Cellular

i. Fibrous – Cellulose, cotton, pulp, nano-cellulose, wood, cane, pulp, or synthetic fibers,

ii. Cellular– foamed rubber, polystyrene, cork, polyurethane, polyisocyanurate, polyethylene, and other polymers,

(b) Inorganic Materials: like organic materials, they can also have fibrous and cellular sub-classes.

i. Fibrous – rock, slag wool, glass, and

ii. Cellular–bonded perlite, vermiculite, calcium silicate, and ceramic products

(c) Metallic heat insulators or metalized reflective membranes; must have or possess gas-filled, air-filled, or evacuated panels to have any effect.

(d) Aerogels: This used in thermal and acoustic insulations and several other applications such as chemistry (catalyst, Nano-vessels, absorbents, and extracting agents), electronics (insulators and sensors), pharmacy, fillers (varnishes, paints, and functional liquids), and kinetic energy absorber (tank baffles and shock absorption).

(e) Thermal Insulators from waste materials: this is also a solution to waste management issues. Waste materials are reused instead of combustion or disposal. They include coconut husk and bagasse, leather, cotton, textile, natural waste (e.g., natural fibres), rubber, and plastic waste.

(f) Construction and Cement Composite

(g) Materials.

(h) Polymeric and other composites

2.2 Heat transfer in insulation materials

Thermal insulation materials are explicitly employed in their resistance against the passage of heat through materials and media. There are three means through which heat can be transported. This is through conduction or convection, and heat can also be transported through radiation. Therefore, λ_{tot} stands for total conductivity, λ_{gas} represents the conductivity for gas conduction, λ_{solid} is the conductivity for solid conduction, and λ_{rad} signifies the conductivity for radiation [W/(m.K)]. Among these parameters, the solid conduction happens to be the largest. There is high porosity in insulation materials with a little solid structure. A material having a small amount of solid automatically increases the relevance of radiation. This is displayed in Figure 1. The optimal point for a specific material is usually when the solid conduction and radiation contributions are kept at a minimum when all sum together. However, these sums add to the gas conduction but are usually constricted for conventional insulation materials. This gives a value of 30 mW/(mK), which is relatively higher than the air conductivity of 25mW/(mK) when these two parameters are compared. From Figure 1, different materials come with varying solid conduction rates. This qualifies the material and the physical attributes relevant to solid conduction. In a bid to reduce solid conduction, the appropriate solid material should always be selected.

The gas conductivity in a permeable not entirely settled by the quantity of gas particles as move medium as well as by the number of "walls" on the way from the hot to the virus side. At a high strain, when the mean freeway of the gas particles is a lot more modest than the size of the pores, impact between the gas particles is the restricting system for a productive intensity move. Here an expansion in the gas strain with an expansion in the quantity of gas particles is associated with a reduction in the mean freeway. Other than gas conductivity, radiation has additionally to be decreased to arrive at extremely low conductivity values. This is finished by adding opacifiers to the center material.

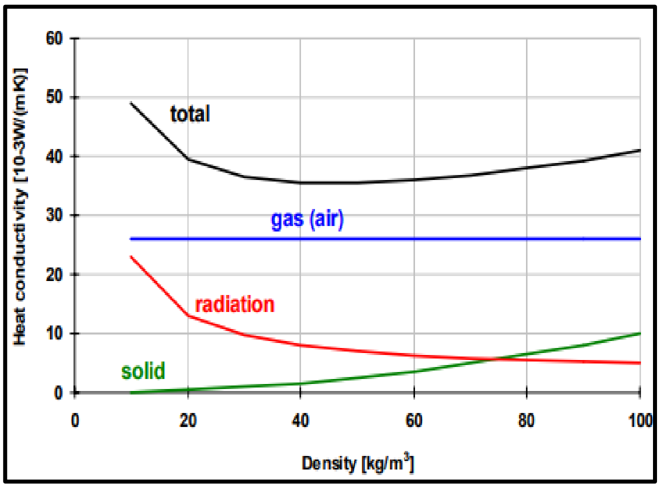

Figure 1. Thermal conductivity through solid conduction, gas phase, and radiation [48]

3. BUILDING ENVELOPE

Building segments create action between the indoor space and surrounding the house's location. The major constituents of a building envelope are the roof, walls, and fenestration usually made up of windows and doors. Other components are the foundation of the building, the insulation, shading devices, finishes, and vapor retarders. This section will cross-examine these components, roof, walls, windows, and the various steps to optimize energy efficiency.

3.1 Energy

Every society requires energy for its daily running of activities [49]. This energy provides a platform for all life processes while also being traded as a commodity for revenue generation. Energy is used for generating new materials when applied to the system. As its importance cannot be overemphasized, its usage should be managed appropriately as its supply is not unlimited. Electrical energy is considered one flexible form of energy. It can as well be easily distributed [50]. However, its use should be appropriately regulated to control waste.

3.1.1 Energy in buildings

The total energy consumed in the world-building structures constitutes a large chunk. Therefore, it has become expedient to develop systems to help curb this significant problem in present-day societies. The building industry takes up 39-40% of the available energy in the world while also emitting 36-38% of CO_2 emissions [51]. In the past decade, energy consumption has been on the rise due to an increase in population alongside other factors, thereby bringing energy conservation in buildings as necessary to be incorporated buildings. More stringent measures should be set up to cut emissions of greenhouse gases and also reduce energy wastage. Cao et al. [52] highlighted this could be realized through the proper design and construction of buildings. It is paramount to have insight into factors that affect energy behaviour in buildings and one major factor contributor to varying weather conditions. While not limiting the factors affecting the energy consumption profile to only weather conditions. There are several other factors, including behavioural patterns of the building occupants and the thermal properties that each building material possesses. A series of research has been carried out regarding energy in buildings and various conservation techniques. The continuous research in this regard will further provide a better understanding of how the materials affect energy consumption and reduce its impact on the environment.

4. FACTORS THAT INFLUENCE THE CHOICE OF BUILDING MATERIALS

Yang et al. [53] stated that various methods adopted over time by professionals have proven to help save energy. This can also be incorporated into already existing buildings. Since thermal comfort is a rather important factor usually considered by persons seeking to take up the building. It is rather suitable to take extra care in selecting materials for the building that also suits that region. With growing interests in real estate, to attract investors confidently, it will only be convenient to identify the best options through choosing by advantages (CBA). In an overview of Patnaik et al. [54] study, the following factors were identified: how durable the material is, the acoustics, the level of insulation, and its impact on climate change. This feasible part of the study was the exemption of cost analysis. There are so many factors that influence the choice of building materials, such as roofing, walls, and windows.

4.1 Roof

The roof is found to be the highest point of the building. Usually, it stands guard in protecting the occupants of the building from any weather not favourable enough, be it rainfall or excessive direct contact with the sun. In some other cases, it improves the beauty of buildings as it adds to the aesthetics. When mentioning roofs, they can be divided into two distinctive categories according to their slope. These steep-slope roofs and the low-slope roofs. The slopes in a steep-slope roof are usually more than 25%, while the slope in a low-slope roof is 25% or less. Steep roofs are usually found in residential buildings, while low-slope roofs are made for industrial buildings. The steep slope has produced just the right amount of gravitational force to take water off the roof. Whenever the slope is not in the right proportion, this results in physical actions from wind and capillary action, leading to water leakages into buildings through the gaps between roofing tiles and sheets (Patterson, 2001). Asides from the slope, roofs can also be categorized based on the construction method. The various types of roofs examined in this section are masonry, lightweight, and advanced energy-efficient roofs, ventilated, solar-reflective and green roofs [55].

4.1.1 Masonry roof, lightweight roof, and ventilated roof

Masonry is usually a construction made of stone or brick. A typical example of masonry is concrete, as it has stone as its major constituent. Reinforced cement concrete (RCC) has resistance to pests and natural calamity [56]. The reinforced cement concrete usually retains a lot of heat during hot periods, and this causes thermal discomfort for the occupants of the building.

A lightweight roof is typically a cheap roofing system found in commercial and government structures. The way this particular roof is built makes it unable to withstand the physical action of wind. Furthermore, another setback experienced with lightweight roofs is their inability to heat resistance, which invariably will lead to the thermal discomfort of the occupants of the building. Especially when specific insulation materials are not incorporated into the system. One way of achieving optimal performance is by using light colours in painting the roof [57].

Ventilated roofs usually have a restricted duct and two slabs, which make up the roof's structure [58]. The duct provided enables free access to air, which helps to reduce the amount of heat transferred through the roof. Ventilation fans can actively induce air through the ventilated roofs while air is passively passed through the stack effect. This type of roof is mostly found in regions under hot climatic zones for low to mid-rise buildings to guard against excessive radiation from the sun.

4.1.2 Solar-reflective roof, green roof

This roof uses reflective surfaces that can reflect sun rays. This helps keep the temperature at a minimum as there is no direct and continuous heating. Infrared radiation is emitted off the surface as well [59]. Achieving a low surface roof temperature leads to a huge amount of heat reduction due to heat transfer. In order to attain this specific property of this roof, materials have to be carefully selected with a high solar reflectance index (SRI) and using reflective paints and coatings.

In this type of roof, a composite layer is used to cover the roof structure, made of a waterproof membrane, growing medium, and vegetation. Green roofs are usually made of a root barrier accustomed to an irrigation system. The natural vegetation typically provides a thermal covering guard against solar radiation. The heat is suppressed when evapotranspiration from the plants forming a part of the vegetation occurs, which helps remove the heat [60].

4.2 Walls

The covering of a building is majorly made up of walls that envelop the building and provides thermal and acoustic comfort for the occupants of the building. It also serves, in most cases, to provide extra beauty to the building. Walls help segment the building into various compartments. These compartments help provide the occupant with the necessary comfort needed in the indoor space [61]. Walls, however, are grouped based on the material used for their construction, which usually are wood-based and masonry-based walls. Asides from the mode of construction, another notable way of classifying walls is the improvement techniques to help produce better characteristics of the wall. In a bid to improve the thermal performance of walls, there are advancements in the systems employed, such as lightweight concrete, passive solar, and double skin.

4.2.1 Passive solar wall and lightweight concrete wall

Passive wall constructions contain solar radiation rather efficiently and are adequately transmitted. In cold regions, a passive solar wall is mainly used to reduce the amount of heat released into the environment. Trombe designed a passive solar wall suitable for transferring through the walls by conduction and air circulation by convection. The various types of Trombe walls developed over time include phase change material (PCM), the photovoltaic (PV) integrated, and fluidized Trombe wall systems [62].

Lightweight concrete walls constitute a lightweight material with a density below 2000kg/m^3. Concrete used in structures is usually between 1600 kg/ m^3 and 2000kg/m^3 and strength of 15MPa. In comparison, concerning thermal insulation, the density is often less than 1450 kg/m^3 having a strength of 0.5MPa. When additives like diatomite, expanded clay, and foamed slag are added to the concrete mix, it helps to improve the thermal insulation properties of the lightweight concrete. The utilization of low-conductivity aggregates also serves for better performance in the insulation properties of concrete. Vermiculite and polystyrene beads are among examples of low-conductivity concrete in engineering applications [63].

4.2.2 Double skin walls

Double skin walls, the significant concept here is the air gap used here as the form of insulation. The thermal performance efficiency is improved with the air gap, which provides air ventilation that helps to suppress heat flow between the walls. Air ventilation present is usually actively induced or, in some cases, naturally due to the stack effect. The double-skin walls are usually found in hot regions as there help to cool buildings and improve the level of thermal comfort [64].

4.3 Windows

Windows are typically openings allowed in buildings for better thermal comfort and increased building illumination. Also, windows help to make a building stand out. Building energy efficiency is better optimized when better-improved glazing technologies are employed in designing the window [65]. This will result in better insulation performance while also, in some cases, being responsible for the number of solar rays allowed into the building. This section presents the various glazing technologies, including aerogel, vacuum, switchable reflective glazing, and optimal design of frames and spacers.

Aerogel Glazing: Aerogel coating comprises granular aerogel capsulized between polycarbonate boards. Aerogels are open-called mesoporous solids comprised of porosity above half in volume, thickness ranges between 1 kg/m^3-150 kg/m^3, and 90% - 99.8% air by volume. The materials utilized in creating aerogel incorporate inorganic and natural polymers, silica, change metal oxides, alumina, metal chalcogenides, and lanthanide. Aerogel frosting weighs 20%, is not precisely comparable to glass units, and has multiple times more effective strength. The use of coating remembers fenestration for the rooftop for rooftop lighting because of its thickness and capacity to diffuse light actually [66]:

i. Vacuum Glazing: A vacuum glaze is accomplished at whatever point two glass sheets have been loaded up with air (vacuum). This assists with checkmating heat conduction and convection between the glass sheets. Covering with low-emissivity is utilized to forestall re-radiation into the indoor space. One significant hindrance of vacuum coating is the necessity of keeping up with the vacuum for broadened periods [67].

ii. Switchable Reflective Glazing: A switchable intelligent coating utilizes a color. In hot locales, the switchable intelligent coating is utilized there to help lessen sun-powered gain in the indoor space of the structure. The various procedures to accomplish this incorporate direct current and the utilization of hydrogen to change over from a white state to a shaded state. Different structures from research utilize intelligent light retires to reflect sun-powered radiation. One of the significant limitations of the switchable intelligent coating is the expense of securing it, the exchanging time, the glare, and the shading delivery issues [68].

iii. Ideal Design of Frames and Parts: Ideal plan casings and spacers are one more way to build energy-productive window coating. Appropriate improvement of the plan of the casings and spacers consolidated combined with cautiously choosing outlines with low conductance gives better warm execution of windows. Limiting warm spanning wiping out penetration misfortunes [69].

iv. Building Insulation Materials and their Properties: Warm protection is characterized as "a material or blends of materials that, when appropriately applied, hinder the hotness stream by conduction, convection, and radiation because of its high warm opposition" [70]. Protection properties are featured in this segment, as well as protection components.

5. THERMAL CONDUCTIVITY, RESISTIVITY, RESISTANCE, AND CONDUCTANCE

Warm conductivity (k-esteem) is "the time pace of consistent state heat stream in Watts (W) through a unit area of 1 meter (m) thick homogeneous material toward a path opposite to isothermal planes actuated by a unit 1 Kelvin (K) temperature contrast across the example". It is regularly communicated in units of W/m-K. The k-worth of a material evaluates the viability in the leading hotness stream: material properties, in particular temperature, dampness content, and thickness, impact k-esteem. Materials with similar properties have a similar k-esteem no matter what their thickness.

The warm resistivity shows the proportion of how compelling a material can oppose heat moving through a material [71]. It is the proportional to the arm conductivity of the material, as displayed in Condition equation (1) Like warm conductivity, the warm resistivity of a material isn't affected by its thickness.

$$\sigma=1/k \tag{1}$$

where, σ addresses the warm resistivity of the material communicated in m-K/W, k represents the warm conductivity of the material communicated in W/m-K.

The warm opposition (R-esteem) of a material is its warm resistivity at a specific thickness. Subsequently, unlike warm resistivity, the R-worth of the material is impacted by its thickness. R-esteem is ordinarily communicated in units of m2K/W. It is utilized as a reason for quantitative correlation among warm protection materials. The R-worth of the material is gotten from its warm conductivity and thickness, as introduced in condition (2). Since warm resistivity is additionally gotten from warm conductivity, R-worth can likewise be determined, as displayed in condition (3):

$$R=x/k \tag{2}$$

$$R=\sigma X \tag{3}$$

where, R is the R-worth of the material communicated in m^2K/W, X is its thickness communicated in m, k is its warm conductivity communicated in W/m-K, and σ is its warm resistivity communicated in m-K/W.

Warm conductance (C-esteem) is "the pace of hotness stream in W through a unit surface region of a part with unit 1 K temperature contrast between the surfaces of the different sides of the part". It is communicated in W/m^2K. It is determined as in condition (4):

$$C=1/\Sigma R \tag{4}$$

where, U is the U-esteem communicated in W/m^2K, and ΣR is the amount of the warm protection of all layers creating that part and the warm protection of within and outside air films.

6. COMPONENTS OF BUILDING INSULATION MATERIALS

Protection materials have countless minute silence cells, which forestall the development of air inside the material construction. The stability of air inside the protection material empowers it to hinder heat movement. The actual material doesn't give the warm obstruction by the protection material exclusively; however, by the air caught inside the material construction. Protection materials likewise impede heat movement by breaking ways of hotness radiation into little distances. Long-wave infrared radiation is assimilated and dissipated by the shut design of little cells of the protection material. In this manner, a high-thickness material with more modest cells can impede heat moved by radiation all the more real. Oppositely, more modest cells don't impede heat movement by conduction well because of the tremendous pace of motor energy moving between little cells in touch with one another. Consequently, the warm opposition of protection material is resolved given its capacity to impede heat movement by three modes: conduction, convection, and radiation [72].

6.1 Advantages of building insulation materials on economic, comfort, and environmental

The establishment of protection materials in structures brings about many advantages. This part talks about three (3) primary advantages, which are prudent and natural, solace, and building security. Protection materials hinder heat movement into the structure and diminish the indoor cooling load. Thus, it decreases the work cost of room AC [73]. Less dependence on room AC prompts diminished power utilization and its related discharges. Subsequently, power bills and poisons from emanations are decreased. The reduced flow of heat into the building due to insulation enables occupants to achieve the desired level of indoor thermal comfort more frequently and for more extended periods.

Insulation materials also suppress the movement of sound into the building. Therefore, noise from neighbours or the outdoor environment is reduced, improving acoustic comfort. The controversies concerning thermal comfort date back as far as 1930, further explaining thermal comfort as gaining satisfaction and happiness with the thermal setting of a place, also highlighting environmental factors being the determinant for this condition aside from cultural settings. Tianzhen et al. [74] also defined thermal comfort as a pleasurable desire of the occupant with the temperature situation. Physicists set in temperature boundaries to limit the magnitude of heating and cooling of structures. The importance of thermal comfort is, however, highlighted below, allowing individuals to a rather conducive environment, enabling proper management of electricity consumption, and prescribing standards to be followed in achieving thermal comfort.

Cruel environmental conditions instigate high-temperature changes that can harm the structure. The high warm obstruction of protection can limit temperature vacillations. Thus, the primary uprightness of structures is safeguarded, and their lifetime is expanded to fabricate structures. Besides, the build-up of fume on building surfaces can prompt the entrance of dampness into the structure. Protection planned and introduced accurately can add to the anticipation of fume build-up. Also, suppose there should be an occurrence of fire. Protection materials can forestall fire migration into the structure, assuming the appropriate protection material is chosen and introduced accurately.

6.2 Review of previous and incorporating thermal insulation materials with roofs

In this particular section, we will be examining past research that has been conducted over time. The review will be done in two distinctive parts. While the first part will look at the thermal performance of building insulation materials, the second area will consider works done in determining optimum insulation thickness. This review can highlight the importance of further developing more high-performance insulation materials with super unique features.

Building insulation materials with propounding solutions can be categorized as either traditional or state-of-the-art [75]. The most common traditionally available building insulation materials with low thermal conductivity are cellulose, cork, EPS, polyurethane, and XPS. This review's present state-of-the-art insulation materials are aerogels, GFP, PCM, and VIP. An insight is given into the development of Nano insulation materials and some other dynamic materials and their massive role in the future in serving as thermal insulation materials. The setup here featured six laboratories, six units' side by side with each other that was situated in an open space, as shown in Figure 2. According to Ong [76], a comparison was carried out between insulated alongside uninsulated tiled and metal deck roof designs, as shown in Figure 3. Each setup unit was stacked with a 2-m long and 1-m wide frame as a means of support. The frames were placed at a 15° inclination from the horizontal plane. The ground platform support was at an angle of 15° from the horizontal plane and rested on a 0.3-m height from the ground on 50-mm long by 50-mm wide and 3-mm thick aluminium angles. 50-mm thick rock wool was used to construct the sidewalls of the base frame. 25-mm thick cement roof tiles were used for the tiled roof designs, while 0.5-mm thick galvanized roofing sheets were utilized for the metal deck roof designs. Aluminium foil is the insulation material for insulated roofs backed with 50-mm rock wool.

The distinguishing factor between the insulated metal deck roof and solar roof collector is the air gap, the type of insulation material used, and the opening on the opposite side of the roof. The air gap provides air circulation. The ceiling temperature is recorded every five minutes for 24-hours over several weeks. The data collected from the result at the end of the research showed that the solar roof collector is responsible for the coolest part of the attic and the ceiling. The part with the highest temperature is the uninsulated metal deck roof. Therefore, this shows that the insulation material kept beneath the roofing sheets can absorb the heat and retard the flow of heat to the ceiling. At the end of the study, the temperatures showed a preference for placing insulation below tiles than above the ceiling.

Figure 2. Units fabricated [76]

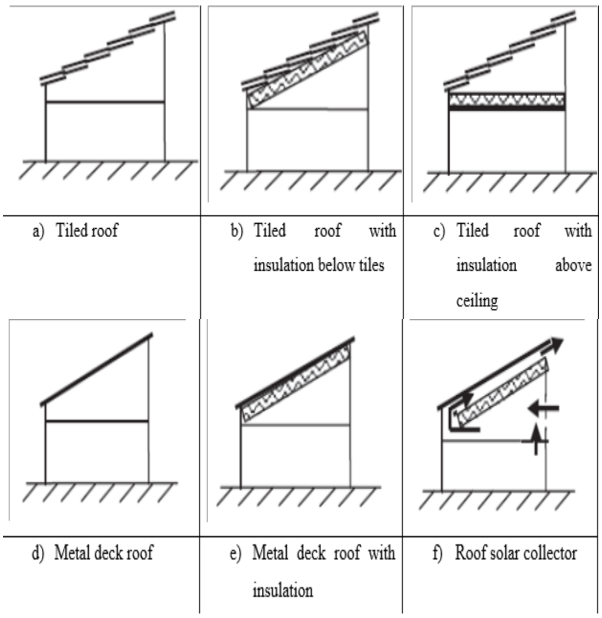

Figure 3. Evaluated roof designs

Halim et al. [77] performed a computer simulation to highlight the importance of insulation underneath the roof pitch and above the ceiling for air-conditioned buildings with Malaysia as the case study. The building model developed for the simulation is shown in Figure 4. A three-case scenario was created with a 950-W split AC installed in each case. The weather file for March was employed for this simulation. The thermal insulation material used here was fiberglass. It effectively reduced the attic temperature by 6.9℃ and the indoor temperature by 0.4℃. From another angle, when the insulation is placed above the ceiling, the attic temperature increases by 2.2℃. However, the indoor temperature goes down by 0.8℃ when placed underneath, causing a 0.4℃ reduction.

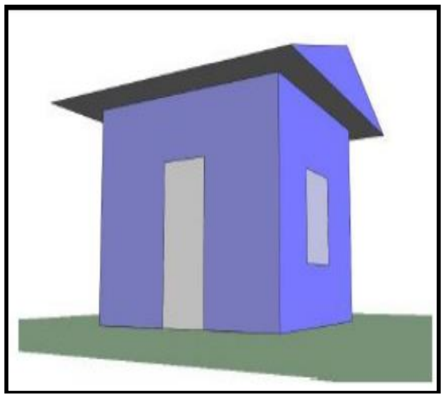

Figure 4. Developed 3-D model [77]

6.3 Determination of optimum insulation thickness

After carefully analyzing past works, it has been established that there are two main methods in determining the optimum insulation thickness, which are the life cycle cost and the P_1-P_2.

6.3.1 Life cycle cost

Yildiz et al. [78] used fiberglass and rock wool in the cities of Izmir and Ankara in Turkey, to calculate the optimum insulation thicknesses. Different types of fuel were used to heat the indoor environment during hot periods. In this study, the types of fuel used include natural gas, liquefied petroleum gas (LPG), and natural gas. The utilization of the air conditioning unit was also considered during cold periods. Fiberglass optimum insulation thickness was found to be from 0.05m to 0.12m. The type of fuel used happens to be a significant influence. Using coal as fuel brings about a 35% emission reduction in the city of Ankara. The study carried out by Bolatturk [79] seeks to find an optimum thickness for polystyrene, and 16 cities in Turkey were used as a case study. Heating fuels used here were oil, LPG, natural gas, and coal. The optimum thickness here ranged from 0.019 to 0.172 m, which was typical for each city and the fuel used for heating. Mahlia and Iqbal [80] obtained the optimum insulation thicknesses for fiberglass-urethane for the building application. Fiberglass (rigid), urethane (rigid), perlite, XPS, and urethane (roof deck). With varying thicknesses ranging from 0.015m – to 0.06m depending on the insulation material and thickness of the air gap. The result showed a 65-77% reduction in emissions.

According to Sisman et al. [81], the optimum thickness for rock wool is the thermal insulation material for external walls and ceilings in Turkey for heating alongside cooling periods. In this research, Izmir, Erzurum, Eskisehir, and Bursa were considered the following locations, all in Turkey, with Tehran in Iran. Coal was the heating fuel employed in this research. The optimal insulation thicknesses gotten were 0.033m, 0.047m, 0.061m, and 0.080m. Daouas et al. [82] research centered on obtaining the optimum thickness of EPS and rock wool for building applications in Tunisia. Cooling the indoor space and the necessary electricity cost will be included in the calculation. The optimum insulation thickness is 0.057m.

Due to their lengthy and unexpected lifespans, significant level of unpredictability, and dangers involved that could have an impact on the decisions made, buildings were viewed as a complicated process [83-85]. Forecasts are less precise as a result of buildings' lengthy lifespans. As a result, the uncertainty of costs throughout the operation and maintenance of buildings depends on a variety of factors, including predictions of the inflation rate, energy prices, laws, local taxes, cost of materials, and labor expenses [86, 87].

7. CONCLUSION AND RECOMMENDATION

This study has reviewed literature cut across the classification of thermal insulation materials, heat transfer in insulation materials, factors that influence the choice of building materials, and thermal conductivity, resistivity, resistance, and conductance. Advantages of building insulation materials on economic, comfort, and environmental and reviewing previous and incorporating thermal insulation materials with roofs. From physical observation along with information from literatures, most existing insulation materials applied for building applications are very heavy which also, has side effects to the buildings, this results to the recommendations in this study.

This study will further recommend the following:

i. The application of insulating materials for roofing, walls, and windows materials for the building is highly recommended;
ii. The variation of thickness of the insulation materials of the insulating materials;
iii. The characterization of the materials to be sure is an eco-friendly material free from any health-related issues.

REFERENCES

[1] Huang, H., Zhou, Y., Huang, R., Wu, H., Sun, Y., Huang, G., Xu, T. (2020). Optimum insulation thicknesses and energy conservation of building thermal insulation materials in Chinese zone of humid subtropical climate. Sustainable Cities and Society, 52: 101840. https://doi.org/10.1016/j.scs.2019.101840

[2] Kumar, D., Alam, M., Zou, P.X., Sanjayan, J.G., Memon, R.A. (2020). Comparative analysis of building insulation material properties and performance. Renewable and Sustainable Energy Reviews, 131: 110038. https://doi.org/10.1016/j.rser.2020.110038

[3] Gupta, A., Dalei, N.N. (2020). Energy, environment, and globalization: an interface. In Energy, environment, and globalization, pp. 1-14. https://doi.org/10.1007/978-981-13-9310-5_1

[4] Cielo, D., Subiantoro, A. (2021). Net-zero energy buildings in New Zealand: Challenges and potentials reviewed against legislative, climatic, technological, and economic factors. Journal of Building Engineering, 44: 102970. https://doi.org/10.1016/j.jobe.2021.102970

[5] Bothun, G. (2021). Greenhouse gases: Properties and evolution. In Affordable and clean energy, pp. 729-745. https://doi.org/10.1007/978-3-319-95864-4_61

[6] Madyaratri, E.W., Ridho, M.R., Aristri, M.A., Lubis, M. A.R., Iswanto, A.H., Nawawi, D.S., Antov, P., Kristak, L., Majlingová, A., Fatriasari, W. (2022). Recent advances in the development of fire-resistant biocomposites—A review. Polymers, 14(3): 362. https://doi.org/10.3390/polym14030362

[7] Ching, Y.C., Gunathilake, T.U., Ching, K.Y., Chuah, C.H., Sandu, V., Singh, R., Liou, N.S. (2019). Effects of high temperature and ultraviolet radiation on polymer composites. In Durability and Life Prediction in Biocomposites, Fibre-Reinforced Composites and Hybrid Composites, pp. 407-426. https://doi.org/10.1016/B978-0-08-102290-0.00018-0

[8] Ahmad, A.D., Abubaker, A.M., Najjar, Y.S., Manaserh, Y.M.A. (2020). Power boosting of a combined cycle power plant in Jordan: An integration of hybrid inlet cooling & solar systems. Energy Conversion and Management, 214: 112894. https://doi.org/10.1016/j.enconman.2020.112894

[9] Khayyam, U., Nazar, U. (2021). Energy production and CO2 emissions: The case of coal-fired power plants under China Pakistan economic corridor. Journal of Cleaner Production, 281: 124974. https://doi.org/10.1016/j.jclepro.2020.124974

[10] Patiño, G.G.E., Rivera, F.N. (2019). Global warming potential and net power output analysis of natural gas combined cycle power plants coupled with CO_2 capture systems and organic Rankine cycles. Journal of Cleaner Production, 208: 11-18. https://doi.org/10.1016/j.jclepro.2018.10.098

[11] Ong, K.S. (2011). Temperature reduction in attic and ceiling via insulation of several passive roof designs. Energy Conversion and Management, 52(6): 2405-2411. https://doi.org/10.1016/j.enconman.2010.12.044

[12] Goshua, A., Gomez, J., Erny, B., Burke, M., Luby, S., Sokolow, S., LaBeaud， A.D., Auerbach, P., Gisondi, M.A., Nadeau, K. (2021). Addressing climate change and its effects on human health: A call to action for medical schools. Academic Medicine, 96(3): 324-328. https://doi:10.1097/ACM.0000000000003861

[13] Shayegh, S., Manoussi, V., Dasgupta, S. (2021). Climate change and development in South Africa: The impact of rising temperatures on economic productivity and labour availability. Climate and Development, 13(8): 725-735. https://doi.org/10.1080/17565529.2020.1857675

[14] Liu, M., Vecchi, G., Soden, B., Yang, W., Zhang, B. (2021). Enhanced hydrological cycle increases ocean heat uptake and moderates transient climate change. Nature Climate Change, 11(10): 848-853. https://doi.org/10.1038/s41558-021-01152-0

[15] Kinnby, A., Toth, G.B., Pavia, H. (2021). Climate change increases susceptibility to grazers in a foundation seaweed. Frontiers in Marine Science, 8: 729. https://doi.org/10.3389/fmars.2021.688406

[16] Alwetaishi, M. (2019). Impact of glazing to wall ratio in various climatic regions: A case study. Journal of King Saud University-Engineering Sciences, 31(1): 6-18. https://doi.org/10.1016/j.jksues.2017.03.001

[17] Naldzhiev, D., Mumovic, D., Strlic, M. (2020). Polyurethane insulation and household products–a systematic review of their impact on indoor environmental quality. Building and Environment, 169: 106559. https://doi.org/10.1016/j.buildenv.2019.106559

[18] Psimopoulos, E., Johari, F., Bales, C., Widén, J. (2020). Impact of boundary conditions on the performance

enhancement of advanced control strategies for a residential building with a heat pump and PV system with energy storage. Energies, 13(6): 1413. https://doi.org/10.3390/en13061413
[19] Rathnayake, U., Lau, D., Chow, C.L. (2020). Review on energy and fire performance of water wall systems as a green building façade. Sustainability, 12(20): 8713. https://doi.org/10.3390/su12208713.
[20] Mostafaeipour, A., Goudarzi, H., Khanmohammadi, M., Jahangiri, M., Sedaghat, A., Norouzianpour, H., ... & Hosseini Dehshiri, S.J. (2021). Techno-economic analysis and energy performance of a geothermal earth-to-air heat exchanger (EAHE) system in residential buildings: A case study. Energy Science & Engineering, 9(10): 1807-1825. https://doi.org/10.1002/ese3.952
[21] Debrah, C., Chan, A.P.C., Darko, A. (2022). Green finance gap in green buildings: A scoping review and future research needs. Building and Environment, 207: 108443. https://doi.org/10.1016/j.buildenv.2021.108443
[22] Nematchoua, M.K., Noelson, J.C.V., Saadi, I., Kenfack, H., Andrianaharinjaka, A.Z.F., Ngoumdoum, D.F., ... & Reiter, S. (2020). Application of phase change materials, thermal insulation, and external shading for thermal comfort improvement and cooling energy demand reduction in an office building under different coastal tropical climates. Solar Energy, 207: 458-470. https://doi.org/10.1016/j.solener.2020.06.110
[23] Esbati, S., Amooie, M.A., Sadeghzadeh, M., Ahmadi, M.H., Pourfayaz, F., Ming, T. (2020). Investigating the effect of using PCM in building materials for energy saving: Case study of Sharif Energy Research Institute. Energy Science & Engineering, 8(4): 959-972. https://doi.org/10.1002/ese3.328
[24] Ikutegbe, C.A., Farid, M.M. (2020). Application of phase change material foam composites in the built environment: A critical review. Renewable and Sustainable Energy Reviews, 131: 110008. https://doi.org/10.1016/j.rser.2020.110008
[25] Prabhakar, M., Saffari, M., de Gracia, A., Cabeza, L.F. (2020). Improving the energy efficiency of passive PCM system using controlled natural ventilation. Energy and Buildings, 228: 110483. https://doi.org/10.1016/j.enbuild.2020.110483
[26] Pessoa, S., Guimarães, A.S., Lucas, S.S., Simões, N. (2021). 3D printing in the construction industry-A systematic review of the thermal performance in buildings. Renewable and Sustainable Energy Reviews, 141: 110794. https://doi.org/10.1016/j.rser.2021.110794
[27] Ngarambe, J., Yun, G.Y., Santamouris, M. (2020). The use of artificial intelligence (AI) methods in the prediction of thermal comfort in buildings: Energy implications of AI-based thermal comfort controls. Energy and Buildings, 211: 109807. https://doi.org/10.1016/j.enbuild.2020.109807
[28] Huang, H., Zhou, Y., Huang, R., Wu, H., Sun, Y., Huang, G., Xu, T. (2020). Optimum insulation thicknesses and energy conservation of building thermal insulation materials in Chinese zone of humid subtropical climate. Sustainable Cities and Society, 52: 101840. https://doi.org/10.1016/j.scs.2019.101840
[29] Kalair, A., Abas, N., Saleem, M.S., Kalair, A.R., Khan, N. (2021). Role of energy storage systems in energy transition from fossil fuels to renewables. Energy Storage, 3(1): e135. https://doi.org/10.1002/est2.135
[30] Asdrubali, F., D'Alessandro, F., Schiavoni, S. (2015). A review of unconventional sustainable building insulation materials. Sustainable Materials and Technologies, 4: 1-17. https://doi.org/10.1016/j.susmat.2015.05.002
[31] Kalnæs, S.E., Jelle, B.P. (2015). Phase change materials and products for building applications: A state-of-the-art review and future research opportunities. Energy and Buildings, 94: 150-176. https://doi.org/10.1016/j.enbuild.2015.02.023
[32] Herrando, M., Cambra, D., Navarro, M., de la Cruz, L., Millán, G., Zabalza, I. (2016). Energy performance certification of faculty buildings in Spain: The gap between estimated and real energy consumption. Energy Conversion and Management, 125: 141-153. https://doi.org/10.1016/j.enconman.2016.04.037
[33] Reilly, A., Kinnane, O. (2017). The impact of thermal mass on building energy consumption. Applied Energy, 198: 108-121. https://doi.org/10.1016/j.apenergy.2017.04.024
[34] Al-Yasiri, Q., Szabó, M. (2021). Incorporation of phase change materials into building envelope for thermal comfort and energy saving: A comprehensive analysis. Journal of Building engineering, 36: 102122.
[35] Abu-Jdayil, B., Mourad, A.H., Hittini, W., Hassan, M., Hameedi, S. (2019). Traditional, state-of-the-art and renewable thermal building insulation materials: An overview. Construction and Building Materials, 214: 709-735. https://doi.org/10.1016/j.conbuildmat.2019.04.102
[36] Cannavale, A., Ayr, U., Fiorito, F., Martellotta, F. (2020). Smart electrochromic windows to enhance building energy efficiency and visual comfort. Energies, 13(6): 1449. https://doi.org/10.3390/en13061449
[37] Alkhatib, I.I., Garlisi, C., Pagliaro, M., Al-Ali, K., Palmisano, G. (2020). Metal-organic frameworks for photocatalytic CO2 reduction under visible radiation: A review of strategies and applications. Catalysis Today, 340: 209-224. https://doi.org/10.1016/j.cattod.2018.09.032
[38] Trovato, M.R., Nocera, F., Giuffrida, S. (2020). Life-cycle assessment and monetary measurements for the carbon footprint reduction of public buildings. Sustainability, 12(8): 3460. https://doi.org/10.3390/su12083460
[39] Shen, M., Song, B., Zeng, G., Zhang, Y., Huang, W., Wen, X., Tang, W. (2020). Are biodegradable plastics a promising solution to solve the global plastic pollution? Environmental Pollution, 263: 114469. https://doi.org/10.1016/j.envpol.2020.114469
[40] Walker, S., Rothman, R. (2020). Life cycle assessment of bio-based and fossil-based plastic: A review. Journal of Cleaner Production, 261: 121158. https://doi.org/10.1016/j.jclepro.2020.121158
[41] Monaldo, E., Nerilli, F., Vairo, G. (2019). Basalt-based fiber-reinforced materials and structural applications in civil engineering. Composite Structures, 214: 246-263. https://doi.org/10.1016/j.compstruct.2019.02.002
[42] Ruangpan, L., Vojinovic, Z., Di Sabatino, S., Leo, L. S., Capobianco, V., Oen, A.M., McClain, M.E., Lopez-Gunn, E. (2020). Nature-based solutions for hydro-meteorological risk reduction: a state-of-the-art review of the research area. Natural Hazards and Earth System Sciences, 20(1): 243-270. https://doi.org/10.5194/nhess-20-243-2020

[43] Zhang, Y., Wu, J., Zhang, X., Zhu, J. (2021). Study on the preparation and application of phenolic resin-based filling composite materials in coal mines. Mining Technology, 130(2): 109-118. https://doi.org/10.1080/25726668.2021.1891807
[44] Torres-Rivas, A., Pozo, C., Palumbo, M., Ewertowska, A., Jiménez, L., Boer, D. (2021). Systematic combination of insulation biomaterials to enhance energy and environmental efficiency in buildings. Construction and Building Materials, 267: 120973. https://doi.org/10.1016/j.conbuildmat.2020.120973
[45] Maggay, I.V., Chang, Y., Venault, A., Dizon, G.V., Wu, C.J. (2021). Functionalized porous filtration media for gravity-driven filtration: Reviewing a new emerging approach for oil and water emulsions separation. Separation and Purification Technology, 259: 117983. https://doi.org/10.1016/j.seppur.2020.117983
[46] Abu-Jdayil, B., Mourad, A.H., Hittini, W., Hassan, M., Hameedi, S. (2019). Traditional, state-of-the-art and renewable thermal building insulation materials: An overview. Construction and Building Materials, 214: 709-735. https://doi.org/10.1016/j.conbuildmat.2019.04.102
[47] Al-homoud, M.S. (2005). Performance characteristics and practical applications of common building thermal insulation materials, 40: 353–366. https://doi.org/10.1016/j.buildenv.2004.05.013
[48] Simmler, H., Brunner, S., Heinemann, U., Schwab, H., Kumaran, K., Mukhopadhyaya, P., Quénard, D., Sallée, H., Noller, K., Kücükpinar-Niarchos, E., Stramm, C., Cauberg, J.J.M., Erb, M. (2005). Vacuum Insulation Panels. Study on VIP-components and panels for service life prediction of VIP in building applications (Subtask A). IEA/ECBCS Annex, 39: 1-153. https://www.osti.gov/etdeweb/biblio/21131463
[49] Kayri, M. (2016). Predictive abilities of bayesian regularization and Levenberg–Marquardt algorithms in artificial neural networks: A comparative empirical study on social data. Mathematical and Computational Applications, 21(2): 20. https://doi.org/10.3390/mca21020020
[50] Okokpujie, I.P., Okonkwo, U. C., Bolu, C.A., Ohunakin, O.S., Agboola, M.G., Atayero, A.A. (2020). Implementation of multi-criteria decision method for selection of suitable material for development of horizontal wind turbine blade for sustainable energy generation. Heliyon, 6(1): e03142. https://doi.org/10.1016/j.heliyon.2019.e03142
[51] Siksnelyte-Butkiene, I., Zavadskas, E.K., Streimikiene, D. (2020). Multi-criteria decision-making (MCDM) for the assessment of renewable energy technologies in a household: A review. Energies, 13(5): 1164. https://doi.org/10.3390/en13051164
[52] Cao, X., Dai, X., Liu, J. (2016). Building energy-consumption status worldwide and the state-of-the-art technologies for zero-energy buildings during the past decade. Energy and buildings, 128: 198-213. https://doi.org/10.1016/j.enbuild.2016.06.089
[53] Yang, J., Santamouris, M., Lee, S.E. (2016). Review of occupancy sensing systems and occupancy modeling methodologies for the application in institutional buildings. Energy and Buildings, 121: 344-349. https://doi.org/10.1016/j.enbuild.2015.12.019
[54] Patnaik, A., Mvubu, M., Muniyasamy, S., Botha, A., Anandjiwala, R.D. (2015). Thermal and sound insulation materials from waste wool and recycled polyester fibers and their biodegradation studies. Energy and Buildings, 92: 161-169. https://doi.org/10.1016/j.enbuild.2015.01.056
[55] 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
[56] Halwatura, R.U., Jayasinghe, M.T.R. (2008). Thermal performance of insulated roof slabs in tropical climates. Energy and Buildings, 40(7): 1153-1160. https://doi.org/10.1016/j.enbuild.2007.10.006
[57] Han, J., Lu, L., Yang, H. (2009). Investigation on the thermal performance of different lightweight roofing structures and its effect on space cooling load. Applied Thermal Engineering, 29(11-12): 2491-2499. https://doi.org/10.1016/j.applthermaleng.2008.12.024
[58] Rupp, S. H., McNeil, S., Plagmann, M., Overton, G. (2021). Hygrothermal characteristics of cold roof cavities in new zealand. Buildings, 11(8): 334. https://doi.org/10.3390/buildings11080334
[59] Liu, Q., Zhang, Y., Xu, H. (2008). Properties of vulcanized rubber nanocomposites filled with nanokaolin and precipitated silica. Applied Clay Science, 42(1-2): 232-237. https://doi.org/10.1016/j.clay.2007.12.005
[60] Lazzarin, R.M., Castellotti, F., Busato, F. (2005). Experimental measurements and numerical modelling of a green roof. Energy and Buildings, 37(12): 1260-1267. https://doi.org/10.1016/j.enbuild.2005.02.001
[61] Khatoon, S., Kim, M.H. (2020). Thermal comfort in the passenger compartment using a 3-D numerical analysis and comparison with Fanger's comfort models. Energies, 13(3): 690. https://doi.org/10.3390/en13030690
[62] Ji, J., Luo, C., Sun, W., Yu, H., He, W., Pei, G. (2009). An improved approach for the application of Trombe wall system to building construction with selective thermo-insulation façades. Chinese Science Bulletin, 54(11): 1949-1956. https://doi.org/10.1007/s11434-009-0353-6
[63] Al-Jabri, K.S., Hago, A.W., Al-Nuaimi, A.S., Al-Saidy, A.H. (2005). Concrete blocks for thermal insulation in hot climate. Cement and Concrete Research, 35(8): 1472-1479. https://doi.org/10.1016/j.cemconres.2004.08.018
[64] Saroglou, T., Theodosiou, T., Givoni, B., Meir, I.A. (2020). Studies on the optimum double-skin curtain wall design for high-rise buildings in the Mediterranean climate. Energy and Buildings, 208: 109641. https://doi.org/10.1016/j.enbuild.2019.109641
[65] Guo, K., Li, Q., Zhang, L., Wu, X. (2021). BIM-based green building evaluation and optimization: A case study. Journal of Cleaner Production, 320: 128824. https://doi.org/10.1016/j.jclepro.2021.128824
[66] Abu-Jdayil, B., Al-Malah, K. (2008). Jordanian clay-based heat insulator composites: Mechanical properties. Journal of Reinforced Plastics and Composites, 27(14): 1559-1568. https://doi.org/10.1177/0731684407087371
[67] Manz, H., Brunner, S., Wullschleger, L. (2006). Triple vacuum glazing: Heat transfer and basic mechanical design constraints. Solar Energy, 80(12): 1632-1642. https://doi.org/10.1016/j.solener.2005.11.003

[68] Papaefthimiou, S., Syrrakou, E., Yianoulis, P. (2006). Energy performance assessment of an electrochromic window. Thin Solid Films, 502(1-2): 257-264. https://doi.org/10.1016/j.tsf.2005.07.294
[69] Gustavsen, A., Arasteh, D., Jelle, B.P., Curcija, C., Kohler, C. (2008). Developing low-conductance window frames: Capabilities and limitations of current window heat transfer design tools—State-of-the-art review. Journal of building physics, 32(2): 131-153. https://doi.org/10.1177/1744259108097672
[70] Huang, L., Zhu, Y., Ouyang, Q., Cao, B. (2012). A study on the effects of thermal, luminous, and acoustic environments on indoor environmental comfort in offices. Building and environment, 49: 304-309. https://doi.org/10.1016/j.buildenv.2011.07.022
[71] Salvador, J.R., Cho, J.Y., Ye, Z., Moczygemba, J.E., Thompson, A.J., Sharp, J.W., König, J.D., Maloney, R., Thompson, T., Sakamoto, J., Wang, H., Wereszczak, A.A., Meisner, G.P. (2013). Thermal to electrical energy conversion of skutterudite-based thermoelectric modules. Journal of electronic materials, 42(7): 1389-1399. https://doi.org/10.1007/s11664-012-2261-9
[72] Peng, L., Su, B., Yu, A., Jiang, X. (2019). Review of clothing for thermal management with advanced materials. Cellulose, 26(11): 6415-6448. https://doi.org/10.1007/s10570-019-02534-6
[73] Souayfane, F., Fardoun, F., Biwole, P.H. (2016). Phase change materials (PCM) for cooling applications in buildings: A review. Energy and buildings, 129: 396-431. https://doi.org/10.1016/j.enbuild.2016.04.006
[74] Tahmasbi, V., Noori, S. (2020). Application of Levenberg–Marquardt Method for Estimation of the Thermophysical Properties and Thermal Boundary Conditions of Decomposing Materials. Heat Transfer Engineering, 41(5): 449-475. https://doi.org/10.1080/01457632.2018.1558010
[75] 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
[76] Ong, K.S. (2011). Temperature reduction in attic and ceiling via insulation of several passive roof designs. Energy Conversion and Management, 52(6): 2405-2411. https://doi.org/10.1016/j.enconman.2010.12.044
[77] Halim, N.H.A., Ahmed, A.Z., Zakaria, N.Z. (2011). Thermal and energy analysis of ceiling and pitch insulation for buildings in Malaysia. In 2011 3rd International Symposium & Exhibition in Sustainable Energy & Environment (ISESEE), pp. 214-220. https://doi.org/10.1109/ISESEE.2011.5977092
[78] Yildiz, A., Gurlek, G., Erkek, M., Ozbalta, N. (2008). Economical and environmental analyses of thermal insulation thickness in buildings. Journal of Thermal Science and Technology, 28(2): 25-34.
[79] Bolattürk, A. (2008). Optimum insulation thicknesses for building walls with respect to cooling and heating degree-hours in the warmest zone of Turkey. Building and environment, 43(6): 1055-1064. https://doi.org/10.1016/j.buildenv.2007.02.014
[80] Mahlia, T.M.I., Iqbal, A. (2010). Cost benefits analysis and emission reductions of optimum thickness and air gaps for selected insulation materials for building walls in Maldives. Energy, 35(5): 2242-2250. https://doi.org/10.1016/j.energy.2010.02.011
[81] Sisman, N., Kahya, E., Aras, N., Aras, H. (2007). Determination of optimum insulation thicknesses of the external walls and roof (ceiling) for Turkey's different degree-day regions. Energy Policy, 35(10): 5151-5155. https://doi.org/10.1016/j.enpol.2007.04.037
[82] Daouas, N., Hassen, Z., Aissia, H.B. (2010). Analytical periodic solution for the study of thermal performance and the optimum insulation thickness of building walls in Tunisia. Applied Thermal Engineering, 30(4): 319-326. https://doi.org/10.1016/j.applthermaleng.2009.09.009
[83] Rathnasiri, P., Jayasena, S., Siriwardena, M. (2020). Assessing the applicability of green building information modelling for existing green buildings. International Journal of Design & Nature and Ecodynamics, 15(6): 763-776. https://doi.org/10.18280/ijdne.150601
[84] Sadia, R. (2018). Group modeling building: how environment, culture and work conditions impact on the process. International Journal of Design & Nature and Ecodynamics, 13(1): 128-135. https://doi.org/10.2495/DNE-V13-N1-128-135
[85] Song, L.Z., Zhu, J., Liu, S.T., Qu, Z.J. (2022). Recent fire safety design of high-rise buildings. J. Urban Dev. Manag., 1(1): 50-57. https://doi.org/10.56578/judm010106
[86] Vulevic, A., Castanho, R.A., Gómez, J.M.N., Quintanova, L. (2022). Tendencies in land use and land cover in Serbia towards sustainable development in 1990-2018. Acadlore Trans. Geosci., 1(1): 43-52. https://doi.org/10.56578/atg010106
[87] Piancastelli, L. (2022). Common mistakes and their fixes in earthquake-resistant buildings. Acadlore Trans. Geosci., 1(1): 12-21. https://doi.org/10.56578/atg010103