ZERO ENERGY BUILDING – A PASSIVE APPROACH

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ABSTRACT

A 'ZERO ENERGY BUILDING (ZEB) is a building with annual net energy consumption nearly equal to zero. With recent advances in building technology ZEB has gained a worldwide attention and it is expected to be delivered and adapted in urban areas on larger scales all around the world by 2025. The reduction in green house gas emission is vital due to exponentially rising global climatic change, hence it is necessary to incorporate passive house designs and renewable energy resources constituting zero energy building. In addition to energy saving, the ZEB also gives comfortable indoor environment to the residents. The basic concept in ZEB is that the heat can be maximum or minimum inside the building envelope based on the outer climatic conditions and this can be achieved by keeping the house airtight and insulated. The basic principle in passive houses is not incorporate heating and cooling systems. ZEB principle is based on the high energy efficiency level and renewable energy systems causing the remaining energy needs of the building seem negligible. This report concentrates on ZEB definitions and various options available in ZEB envelope components such as walls, roofs, glazing, ventilation and also different types of materials that can adopted for thermal comfort and energy efficiency purposes. This review paper emphasizes better ZEB construction, maintenance and adoption in the future.

Keyword: - *Zero Energy Building, Net Zero Energy Building, Thermal comfort, Energy efficiency*

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1. INTRODUCTION

The global climatic change is primarily due to human activities, the excessive use of fossil fuels results in both, depletion of fossil fuels and increased carbon dioxide emission. Since 30% - 40% of the total energy produced is consumed by housing stock [1] [2] [3], incorporating increased regulatory requirements for insulation levels, adjusting coolant parameters and efficient heating system. Existing old buildings consume 200kWh – 400kWh (m^2.year) of thermal energy [4]. The "Zero Energy Building (ZEB)" concept was first proposed by German scholar Wolfgang Feist and Swedish professor Bo Adamson in 1988 [5]. The first passive house was built in Germany in 1990. The "Passivhaus Institut" founded by Dr. Fastom has built more than 15000 low energy buildings across the country [6].

In a developing country like India, the rapid urbanization and industrialization has resulted in high energy demands and is increasing exponentially every year. As per the report by Ministry of Statistics and Program Implementation (Government of INDIA), energy consumption in the country has increased by five times in the last 30 years. The estate developments have contributed to 40% of the Green House Gas (GHG) emissions and the housing stocks contribute to 50% air pollution, 50% water pollution, 42% GHG emissions and 48% solid waste according to various estimates and reports [7].

According to National Renewable Energy Laboratory in Golden, Colorado, the term ZEB refers to a house that produces as much energy as it consumes per annum. Building energy efficiency can be improved by implementing either active or passive energy efficient strategies. Improvements to heating, ventilation and air conditioning (HVAC) systems, electrical lighting, etc. can be categorized as active strategies, whereas, improvements to building envelope elements can be classified under passive strategies [4]. A ZEB design should be a passive sustainable design and this consists of two major steps viz., to reduce building energy demand and to generate electricity at desired standards to achieve energy balance i.e., net zero energy. Thermal insulation is of top priority in maintaining energy efficient building and hence low thermal conductivity materials are developed and existing products are being improvised.

ZEB have gained significant attention post 2010 and by 2020 it is expected that majority of the buildings in the major cities of the world would have adopted alternative renewable energy resources, stepping towards net zero energy. The Green building market worth is expected to be around 364.6 billion dollars by 2022 world-wide [8]; hence it is a driving concept in both residential and non residential sector. In India, the net market status of green buildings is estimated to be between 30 – 50 billion dollars by 2022 [9].

The energy used by the building sector continues to increase, primarily because the new buildings are constructed faster than the old ones being retired. Recent years have seen a renewed interest in environmental-friendly passive building energy efficiency strategies. They are being envisioned as a viable solution to the problems of energy crisis and environmental pollution. Therefore ZEB should become a core concept that needs to be followed by all construction sectors, especially housing stock. Residential building is a simple model to create awareness among the public about new technologies and its benefits. This paper provides the review on various passive energy efficient options available for different building components such as walls, roofs, glazing etc.

1.1 Definitions of Net Zero Energy Building (NZEB)

1.1.1 Net Zero Source Energy Building

A Net Zero Source Energy Building produces as much energy as it uses compared to energy content at the energy source [10]. Source energy refers to the primary energy used to generate and deliver the energy to the site. To calculate a building's total source energy, imported and exported energy is multiplied by the appropriate site-to-source conversion multipliers.

1.1.2 Net Zero Site Energy Building

A Net Zero Site Energy Building produces as much energy as it uses when measured at site [11] i.e., for example, if a building consumes 5000kWh, it must produce 5000kWh or more ideally on site within the building footprint. It tends to encourage energy efficient designs and this type does not account for type of fuel used.

1.1.3 Net Zero Energy Cost Building

A Net Zero Energy Cost Building is one in which the building earns as much money from selling electricity produced as it pays for bought [12]. In this case every user would like to break even i.e., net zero or be better (profit). The issue is that the utility rates can vary widely. A building with consistent energy performance could meet the cost ZEB one year and not the next. Sometimes utility companies often pay their avoided cost rather than the same amount of money the owner pays for them for the kWh the owner buys i.e., the owner should produce more on site productions in reality. Breaking even in this case is difficult.

1.1.4 Net Zero Emission Building

A Net Zero Emissions Building achieves net zero energy based on zero emissions, produces at least as much emissions - free renewable energy as it uses from emission producing resources. This feature greatly depends on type of resource used, site location and ZEB design. Emissions vary greatly depending on the source of electricity, ranging from nuclear, coal, hydro, and other utility generation sources. One could argue that any building that is constructed in an area with a large hydro or nuclear contribution to the regional electricity generation mix would have fewer emissions than a similar building in a region with a predominantly coal-fired generation mix. Therefore, an emission ZEB would need a smaller Photo Voltaic (PV) system in areas with a large hydro or nuclear contribution compared to a similar building supplied by a utility with a large coal-fired generation contribution.

2. LITERATURE REVIEW

According to Energy Performance of buildings Directive (EPBD) [13] [14], in recent years, the rapid growth of energy consumption and CO_2 emissions in building sector has made energy efficiency a priority objective in various countries by developing new building regulations and certification schemes targeting towards minimum energy performance requirements. The elaboration of the country by country worldwide statistics provided by the International Energy Agency (IEA) [15] highlights an higher global energy consumption for residential buildings compared to commercial ones, due to the wider portion both in terms of number of buildings and floor area. Meanwhile, commercial sector presents the highest Energy Use Intensity (EUI) due to the high consumption for lighting and appliance The EUI varies from 79.0 to 404.3 kWh/m^2 for the residential and from 75.9 to 567.6 kWh/m^2 for the commercial buildings and are affected by several factors viz., climate, social, cultural, technological and economic conditions. Moreover, within the European Union, the recently adopted EPBD recast states that by the end of 2020 all new buildings should be Nearly Zero Energy Buildings (NZEB). Crawley et al [16] [17] reviewed the goals for the implementation of ZEBs at the international level, in the USA within the Energy Independence and Security Act of 2007 (EISA 2007) and, at the European level within the recast of the EPBD adopted in May 2010. The EISA authorizes the Net - Zero Energy Commercial Building initiative to support the goal of net zero energy for all new commercial buildings by 2030. It further specifies a zero energy target for 50% of USA commercial buildings by 2040 and net zero for all USA commercial buildings by 2050. The EPBD establishes the NZEB as the building target from 2018 for all public owned or occupied by public authorities buildings and from 2020 for all new buildings.

Adhikari et al [18] conducted a technical – economic analysis on a zero energy residential building and concluded that energy performance of ZEB is consistent and also ZEB’s are economically convenient in comparison to ordinary building. Elena et al [19] conducted a real time case study where a building was designed with energy consumption close to zero and planned to be built on the Polytechnic University territory (RUSSIA). The observation was that the optimal building orientation to the side of light and presence of the vestibule at the entrance avoided additional heat loss. Alanne et al [20] performed an investigation on zero energy for buildings and communities including personal mobility and concluded that the energy consumption of building sector amounts to about 40%, which is a predominant portion of the total energy consumption. Moreover, the percentage considered could be further increased by including other aspects in the energy balance, such as the consumption related to people mobility or the fraction of heat and power generation produced by the industry related to the construction of buildings. Bosseboeuf [21] conducted a review of energy consumption data in various EU countries and stated that the EU statistics show a great variance in energy use in building construction sector due to the large spectrum of the climatic conditions, with values lower than 100 kWh/m^2 in southern countries and up to values higher than 200 kWh/m^2 in northern countries. Although these values are still high, they have decreased over the years, due to the improved energy policies promoting both technological development and changes in the user’s behavior. Chan et al [22] reported that, in hot and humid climate of Hong Kong, in high rise apartment energy savings of 31.4% and peak load savings of 36.8% were recorded due to adoption of passive strategies like Extruded Polystyrene (EPS) walls, reflective coated glass window glazing and wing wall to all windows. In Greece, adaption of thermal insulation in walls, roofs and floors reduced energy consumption by 20% - 40% and low infiltration strategies reduced energy demand by 20%. Awnings and light colored roof reduced cooling demand by 2% - 4%. The review conducted by Lorenzo et al [23] reported on performance of ZEB adopting either active or passive technology for cooling and heating and stated that the use of innovative materials like aerogel is vital in ZEB concept. Reshmi [24] conducted a review on importance of ZEB and reported that the ZEB do not increase the GHG emissions in the environment and ZEB are an active part of the renewable energy infrastructure and latter also accounted that present buildings are merely meeting the ZEB standards. Isamu [25] studied on embodied CO_2 evaluation of a Zero Life Cycle CO_2 ($ZLCCO_2$) homes and reported that the $ZLCCO_2$ houses have lower annual energy expenditure and higher solar energy production i.e., the photovoltaic energy production substantially exceeds total annual energy consumption. The researcher also accounted that the annual absorption of CO_2 by photovoltaic system surpasses the annual emission. Nicole [26] carried out a design work on ZEB with incorporation of mixed mode ventilation system which provides greater thermal comfort to the residents. The study mainly focused on easily accessible materials and its impact on rational consumption of energy with minimum environmental impact. Noguchi et al [27] developed Eco-Terra housing prototype which was designed to be energy- efficient and to minimize the negative impact on environment. The analysis indicates that the house experiences nearly net - zero energy consumption and the house provides its occupants with comfortable and healthy indoor living environment. Summarizing the literature review, it has been well demonstrated that it is possible to considerably improve the buildings performance by adopting passive energy saving measures and renewable.

3. PASSIVE HOUSE – A MAJOR BRANCH OF ZEB

The most practical and comfortable houses are those that have been built in response to the surrounding climate i.e., taking into account the temperature variations over a year. A Passive house is a standard example that gives specific recommendations in regard to the achievement of heating or cooling energy savings. A Passive house is the one in which a comfortable and moderately cool climate can be maintained by not involving active heating and cooling systems. The passive houses allow for heating and cooling related energy savings of up to 90% compared with typical building stock and over 75% compared with average new builds [28]. Appropriate windows with good insulation and building shell consisting of good insulated exterior walls, roof and floor slab keep the heat inside during winter and keeps it out during summer. The vast energy savings in passive houses are achieved by using energy efficient building components and a quality ventilation system.

3.1 PASSIVE HOUSE CHARACTERISTICS

3.1.1 Design without Thermal Bridges

A thermal bridge or bypass is an area or component of an object which has higher thermal conductivity than the surrounding materials, creating a path of least resistance for heat transfer [29]. In case of buildings, heated air inside the house will follow through the path of least resistance and out of the house. Due to improper design of windows, poorly insulated walls, crack under the doors etc., all these factors add to the thermal bridge formation. Since the passive house designs concentrates on high insulated walls and airtight windows and doors, virtually there will be minimum or no thermal bridges.

3.1.2 Insulation

During cold periods, the temperature inside the building envelope is usually higher than it is outside. As a result, heat is lost through the envelope, unless this heat is replaced, the inside of the building cools down adjusting to the outdoor temperature. The inverse applies during hot climates with excessive heat entering the building through its envelope. In passive buildings, the entire building envelope is well insulated. Its main purpose is to provide a comfortable indoor condition, irrespective of the outdoor climate. During cold periods, the heat generated inside the building during the day is not allowed to get out and hence no matter the outside climate the interior temperature is warm. This leads to a high level of comfort and reliable prevention of building damage due to moisture build up. In warmer climates or during summer months, good insulation also provides protection against heat. Effective sunshades for the windows and sufficient ventilation are also essential to ensure a maximum level of comfort during hot periods.

3.1.3 Airtight Construction

The indoor air has higher water vapour content than the outside air. In a cold climate, indoor air is cooled during the flow inside - out. The colder air cannot keep the high amount of water vapour, condensing will occur at certain places within the construction leading to serious damage. Inversely during hotter climates, the airflow will be dominated in the direction outside – in and will cause the same problem. Therefore airtight construction is a must in passive houses, a good airtight construction results in negligible airflows, thus ensuring better house life and comfort level. An airtight construction is a draught free building, meaning no air is allowed to get in or out of the building.

3.1.4 Ventilation

Another important characteristic of passive house design is its efficient central ventilation system, which continuously exchanges moist indoor air for fresh filtered outside air to maintain a comfortable, consistent temperature and humidity level.

3.1.5 Passive solar gains

Passive solar gain refers to the use of the solar energy for the heating and cooling of living spaces by exposure to sun. When the solar light strikes the passive house, the building materials can reflect, transmit or absorb solar radiation. The solar gain depends upon the orientation of the building, glazing position, extensions of roof etc.

3.2 ZEB OR PASSIVE HOUSE WALLS

The chief fraction of the building envelope is the walls and it is expected to provide thermal and acoustic comfort in the building. Ensuring that the walls are well insulated will provide residents low heating and cooling costs, preservation of natural resources and also comfortable indoor climate. Thermal resistance value (R) of wall plays a significant role, since majority of the energy demand is depended on it, especially in high rise buildings, where the wall area and total envelope area is high. The R value depends on material with which wall is constructed, for example, wood walls, metal based walls and masonry walls.

3.2.1 Passive Solar Wall

The walls that trap and transit solar energy efficiently into the building are known as passive solar walls. It is popularly known as Trombe wall. It is a wall built on the winter sun side of a building with an external glass layer and a high heat capacity internal layer separated by a layer of air. Few effective design inputs to a classical Trombe wall resulted in a wall with an operating efficiency of 56% that of a classical Trombe wall.

3.2.2 Latent Heat Storage Wall

Latent heat storage is a direct heat storage system which has the advantage of high storage density and ability to store energy with only small temperature variations. This type of wall mainly uses a phase change material for passive heat gain. The working principle of phase change material (PCM) is that, a specific amount of thermal energy is absorbed while solidifying and similarly specific amount of energy is released while liquefying [30]. Porous material such as plasterboard has better PCM impregnation potential. Recent years have seen the advent of composite materials that can encapsulate PCM up to 60% by weight. PCM based wall lowers the room temperature by 4°C and reduces the heating demand by night [31].

3.2.3 Thermal Mass Wall

Thermal mass is the ability of the material to absorb and store heat energy [32]. Concrete blocks, burnt bricks etc., require high amount of heat energy to change the temperature and are categorized under high thermal mass units, whereas lightweight materials such as timber have low thermal mass. In climates where there are cool winters and a reasonable variance between temperatures during day and night, a wall built with material having high thermal mass can be used to keep the indoor environment fairly static. Thermal mass walls consist of 4 inches of concrete facing the interior, 2 inches of concrete on the exterior and 2 inches of Styrofoam extruded polystyrene board insulation sandwiched in between. Fiber composite connectors, spaced 16 inches on centre, hold the assembly together. These plastic connectors are one of the keys to achieve the optimal energy efficiency of the thermal mass walls.

3.2.4 Living Green Wall

Green walls are vertical structures that have different types of plants or other greenery attached to them. Green walls are built the same way as normal walls. Greenery helps to reduce heat transmittance into a building through direct shading and evapotranspiration. Evapotranspiration refers to the movement of water into the air (evaporation) and the movement of water within a plant and the subsequent loss of water as vapour through its leaves (transpiration) [33]. The intent of installing vertical greenery is to study the effectiveness of these systems on reducing the heat transfer through the building walls into the interior building space and the possible energy savings.

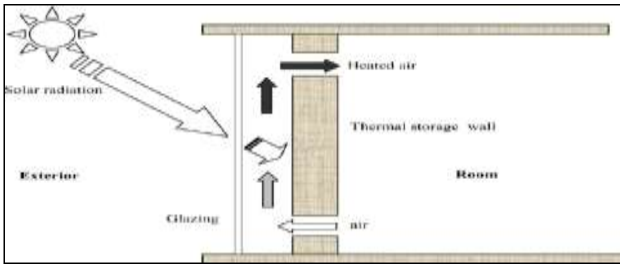

Fig -1: Trombe Wall [34]

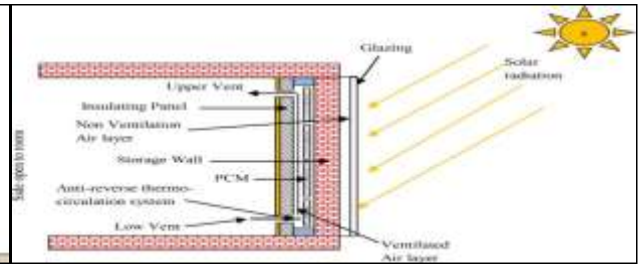

Fig -2: Latent Heat Storage Wall [35]

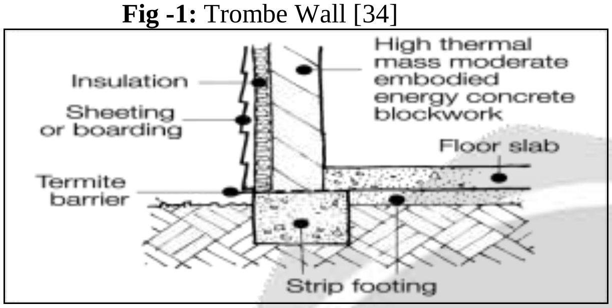

Fig-3: Thermal Mass Wall [36]

Fig -4: Green Wall [37]

3.3 ZEB OR PASSIVE HOUSE ROOFS

Roofs are a critical part of the building envelopes that are highly susceptible to solar radiation and other environmental changes, thereby, influencing the indoor comfort conditions of the residents. Roofs account for large amounts of heat gain or loss, especially, in buildings with large roof area such as sports complexes, auditoriums, exhibition halls etc. In accordance with the UK building regulations [38], the upper limits of U-value (heat energy lost per square meter for every 1° change in temperature) for flat roofs in 1965, 1975 and 1985 were 1.42 W/m^2 K, 0.6 W/m^2 K and 0.35 W/m^2 K respectively. Currently, 0.25 W/m^2 K or less is required for all new buildings in the UK. This reduction in the U-value over the years emphasizes the significance of thermal performance of roofs in the effort to increase the overall thermal performance of buildings.

3.3.1 Lightweight Roof

Lightweight Aluminum Standing seam roofing systems (LASRS) are popularly used on commercial and government buildings as they are economical. There are two easy ways to improve thermal characteristics of these roofs, by adding thermal insulation and using light colored roof paint. It was determined that the lighter colored surfaces such as white, off-white, brown and green yielded 9.3%, 8.8%, 2.5% and 1.3% reduction in cooling loads compared to an black-painted LASRS surface [39]. Cost savings in budget and materials without compromising on quality, savings on core foundation design, increased durability and extreme weather performance are the benefits of lightweight roofing.

3.3.2 Cool Roof

A cool roof is one that has been designed to reflect more sunlight and absorb less heat than a standard roof. Cool roofs can be made of a highly reflective type of paint, a sheet covering or highly reflective tiles. Standard roofs can reach temperatures of 65° C or more during summer. A cool roof under the same conditions will only heat up to 40° degree C and thus using less air conditioning, in turn resulting in saving of vital amounts of energy [40]. Two surface properties that affect the thermal performance of these roof surfaces are reflectivity and emissivity. Special roof coatings can raise the emissivity of bare metal roofs.

3.3.3 Living Green Roof

A living roof or a green roof is a roof of a building that is partially or completely covered with vegetation and a growing medium, planted over a waterproofing membrane. Often, green roofs also include a root barrier layer, drainage layer and an irrigation system. There are two types of green roofs viz., intensive and extensive, the former has a deeper substrate layer and allows to cultivate deep rooting plants such as shrubs and trees; while the latter with thinner substrate layer allows to grow low level planting such as lawn or sedum [41]. A green roof system incurs higher annual savings when installed on a poorly insulated roof rather than a well-insulated roof. The moisture content in growing media of the green roof influences its insulating properties. Wetter the medium, poorer is the insulating capacity of the growing media. Therefore green roofs reflect solar radiation more efficiently than most conventional roofs.

3.3.4 PV Roof

There have been significant efforts in recent years in integrating photovoltaic's (PV's) into the building envelope. PV roof tiles replacing roofing material are installed directly on to the roof structure. Ceramic tiles or fiber - cement roof slates have crystalline silicon solar cells glued directly on them [42]. Another type of roof integrated system has a PV element (glass-glass laminate) placed in a plastic supporting tray which is anchored to the roof [43]. PV roofs are one time installation and their durability is very high. Solar radiation from the sun is often consistent throughout the day and in the summer; hence both energy and insulation can be obtained using PV roofs.

Fig-5: Lightweight Roof [44]

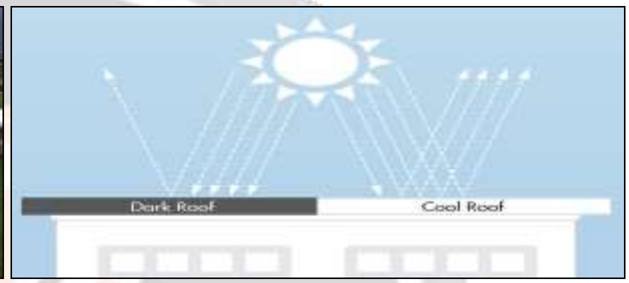

Fig -6: Cool Roof [45]

Fig-7: Living Green Roof [46]

Fig -8: PV Roof [47]

3.4. ZEB OR PASSIVE HOUSE GLAZING

Windows open up possibilities for heat gain through solar radiation. Therefore, windows in a passive house play an excellent role in reducing the heat loss despite having large glass areas. U - value of passive windows is as low as 0.4 W/m^2K. Windows in passive houses are triple glazed and frames are also very well insulated in order to fulfill high requirements of thermal insulation. As 30% - 40% of the window opening consists of the frame, the quality of the frame is paramount. Heat loss and heat gain through windows occurs at 20–30 times the rate that occurs through walls. Proper window performance can ensure that the heating and cooling equipment can maintain a reasonable level of comfort without excessive operating costs. The action of installing windows is known as glazing.

3.4.1 Aerogel Glazing

Aerogels are solid materials of extremely low density, produced by removing the liquid component from a conventional gel. Aerogel can also be referred to a category of open celled meso – porous (diameter of pores varies from 2nm – 50nm) solids with a volume porosity of greater than 50%. They have a density in the range of 1–150 kg/m^3, and are typically 90–99.8% air by volume [48]. They can be formed from a variety of materials, including silica, alumina, lanthanide, transition metal oxides, organic and inorganic polymers and carbon. Aero-gel glazing entered the contemporary glazing market in the year 2006 and is, essentially, a granular aerogel encapsulated between polycarbonate construction panels that weigh less than 20% of the equivalent glass unit and has 200 times more impact strength [49]. Their high performance, low density and outstanding light diffusing properties make them an appropriate choice for roof-light applications.

3.4.2 Vacuum Glazing

Vacuum space is created between two glass panes to eliminate the conductive and convective heat transfers between the glass panes reducing the centre-of-glass U - value to as low as 1 W/m^2 K [50]. Most often, low - emissivity coating is applied on one or both sides of the glass panes to reduce the re-radiation into the indoor space. With the width of single glazing, vacuum glazed windows offer the same thermal insulation as their double glazed counterparts. The mechanics of vacuum glazing is that, instead of using air or other gas combinations between the panes of glass, vacuum glazing has nothing between the glasses i.e., vacuum, thus not allowing the heat transfer between the panes. This result in no heat loses thus keeping the interior of the building cool.

Fig-9: Aerogel Glazing [51]

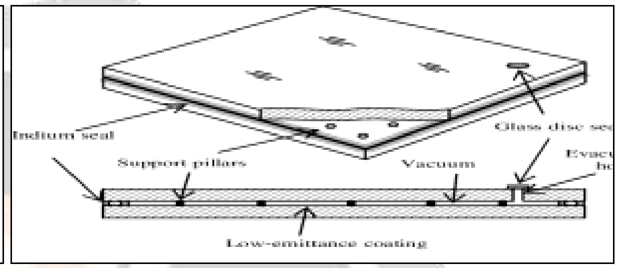

Fig -10: Vacuum Glazing [52]

3.4.3 Smart Glazing

Smart glass or glazing is a switchable phenomenon where the light transmission properties are altered when voltage, light or heat is applied to the glazing [53]. The glass changes from transparent to translucent and vice versa. During summer, these smart glasses block the sun radiations and during winter, the glasses let the solar radiations to pass through them.

3.4.4 Double and Triple Glazing

Generally the windows of the building were single glazed, having just one layer of glass, resulting in substantial heat loss. Therefore multi layered glazing were developed like double and triple glazing to ensure minimum heat loss. Double glazing comprises of two layers of glass separated by a spacer bar. A spacer bar is a continuous hollow frame typically made of low heat conducting metal such as aluminum. The spacer bar is bonded to the panes using a primary and secondary seal. Gases like argon are filled between the panes cavity, which further improves the thermal properties of the window. A desiccant in the spacer bar absorbs any residual moisture within the cavity, preventing internal misting as a result of condensation. Typically the U - value of single glazing varies from 4.8 W/m^2K – 5.8 W/m^2K. Double glazing offers U - value around 1.2 W/m^2K – 2.7 W/m^2K and triple glazing can achieve U - value less than 1 W/m^2K [54].

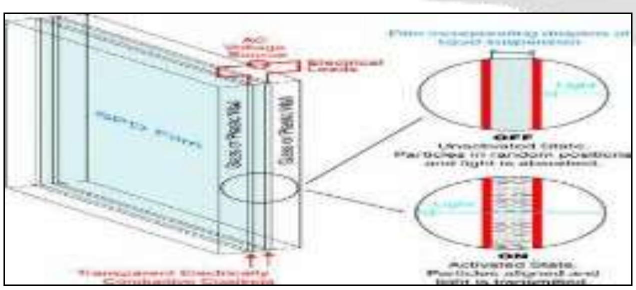

Fig-11: Smart Glazing [55]

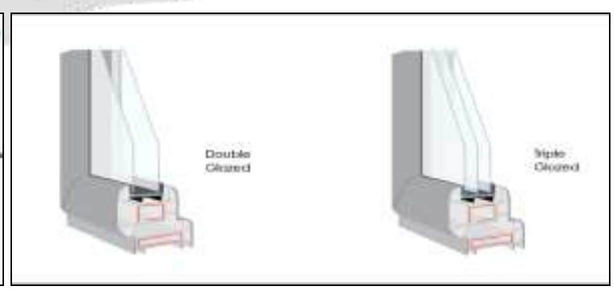

Fig -12: Double and Triple Glazing [56]

3.4.5 Building Integrated Photo – Voltaic Glazing

Building Integrated Photo – Voltaic (BIPV) have dual purpose, since they serve as both the outer layer of the structure and generate electricity for on - site use and export to the grid [57]. BIPV systems can provide savings in material costs, electrical costs, reduce pollution and add to architectural appeal of a building. The BIPV will come in two main forms viz., partially opaque (light transmitting) and transparent. At present era, light transmitting BIPV consists of solar cells made from thick crystalline silicon either as single or poly-crystalline wafers. These deliver about 10 W / ft² - 12 W / ft² of PV array under full sun. This type of glazing technology is best suited for areas with no light transmission requirements, for example spandrels or shading areas such as overhangs and sunshades.

Fig -13: Building Integrated Photo - Voltaic Glazing [58]

3.5 Insulation Materials

The thermal insulation materials have a low thermal conductivity which serves to limit the flow of heat energy between one side of the insulation and the other. In the building environment thermal insulation is typically used to reduce the passage of heat between the inside of the building and the outside. Insulation materials have developed significantly with technological advancements. Insulation materials vary in terms of color, surface finish, texture, core composition and performance [59]. Different types of insulation materials are reviewed below.

3.5.1 Conventional Insulation Materials

3.5.1.1 Mineral Wool

Mineral wool is a non – metallic, inorganic product manufactured from a carefully controlled mix of raw materials, mainly comprising either stone or silica which are heated to a high temperature until molten. This molten silica is later mixed with molten glass and formed into flexible, fibrous mat [60]. It is a very versatile material that can be manufactured to many different densities to give varying properties as they offer excellent thermal, fire and acoustic properties. The thermal performance of wool is mainly due to prevention of convection by the entrapment of air in the material's open cell matrix. Conduction is reduced because there is a very little solid material to provide pathways and the trapped, static air has a low thermal conductivity. Heat transfer is also reduced because the material acts as a physical barrier to radiation process. The thermal conductivity value of mineral wool varies from is 0.035 W/mK – 0.04 W/mK..

3.5.1.2 Expanded Polystyrene and Extruded Polystyrene

The Expanded Polystyrene (EPS) is a synthetic aromatic polymer made from the monomer styrene, which is derived from benzene and ethylene. EPS is composed of small plastic beads that are fused together and it is a colorless, transparent thermoplastic and is extensively used in insulation field. EPS can be used as a thermal insulation material in cavity walls, roofs and floors. The thermal conductivity value of EPS is 0.03 W/mK – 0.04 W/mK [61]. The Extruded Polystyrene (XPS) is a synthetic aromatic polymer also derived from petroleum products such as benzene and ethylene. The XPS begins as a molten material that is pressed out of a foam into sheets and is commonly used as foam board insulation. The thermal conductivity value of XPS is 0.025 W/mK – 0.04 W/mK [62].

3.5.1.3 Cellulose

Cellulose insulation is composed of 75% - 85% fiber, from recycled paper and is one of the most environmental friendly insulation currently available and the remaining 25% - 15% is composed of natural fire retardants and anti fungal agents such as boric acid and ammonium sulfate. Cellulose insulation is often blown into building spaces through hoses from special blowing equipment mounted inside a truck. The thermal conductivity value of cellulose insulation is around 0.04 W/mK [63].

3.5.1.4 Polyurethane

The polyurethane is formed by mixing an isocyanate such as methylene diphenyl di – isocyanate (MDI) with a polyol blend. These components are mixed to form a rigid cellular foam matrix; the resulting material is an extremely lightweight polymer with superior insulating properties. Compared to other building insulation materials, polyurethane has the lowest thermal conductivity value of 0.022 W/mK – 0.028 W/mK. For a given thermal conductivity value, polyurethane sheets have the lowest thickness compared to all other insulating materials mentioned above.

Fig-14: Mineral Wool [64]

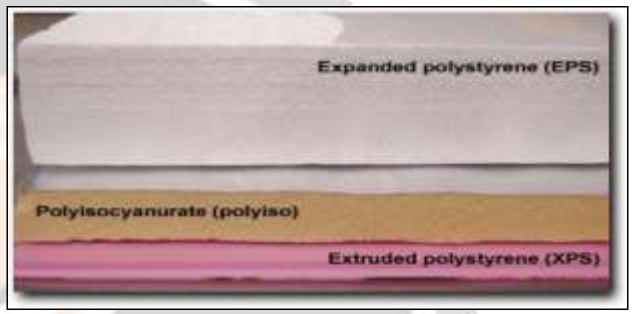

Fig -15: EPS and XPS [65]

Fig-16: Mineral Wool [66]

Fig -17: EPS and XPS [67]

3.5.2 Modern Insulation Materials

3.5.2.1 Vacuum insulation Panel

A Vacuum Insulation Panel (VIP) is a form of thermal insulation comprising of gas tight enclosure surrounding a rigid core from which the air has been evacuated. VIP's consists of membrane walls, used to prevent air from entering the panel. A panel of a rigid, highly porous material, such as fumed silica, aerogel etc., support the membrane walls against atmospheric pressure once the air is evacuated. The thermal conductivity value achieved by VIP is 0.004 W/mK across its centre part of the panel and at the edges it varies from 0.006 W/mK – 0.008 W/mK [68].

3.3.2.2 Vacuum Insulation Material

A Vacuum Insulation Material (VIM) is basically a homogeneous material with a closed small pore structure filled with vacuum with an overall thermal conductivity of less than 0.004mW/mK in pristine condition [69]. The VIM can be cut and adapted at the building site with no loss of thermal conductivity. Perforating the VIM with a nail would only result in a local heat bridge, i.e. no loss of low thermal conductivity.

3.3.2.3 Nano Insulation Material

The Nano Insulation Material (NIM) is basically a homogeneous material with a closed or open small nano pore structure [70]. The development from VIP's to NIM is the recent trending technological advancement. In the NIM the pore size within the material is decreased below a certain level, i.e. 40nm or below for air, in order to achieve an overall thermal conductivity of less than 0.004 W/mK in its pristine condition.

3.2.2.4 Dynamic Insulation Material

A dynamic insulation material (DIM) is a material where the thermal conductivity can be controlled within a desirable range. The thermal conductivity control is governed by:

a) The inner pore gas content or concentration including the mean free path of the gas molecules and the gas-surface interaction.

b) The emissivity of the inner surfaces of the pores.

c) The solid state thermal conductivity of the lattice.

The thermal insulation regulating abilities of DIM's give these conceptual materials a great potential. The thermal conductivity value less than 0.004 W/mK can be achieved.

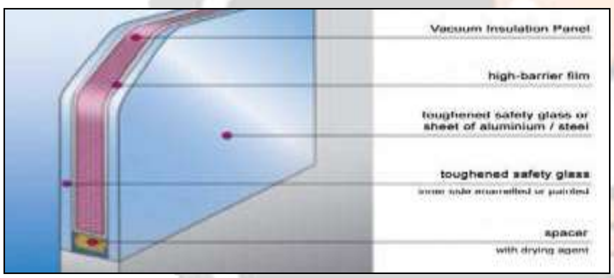

Fig-18: Vacuum Insulation Panel [71]

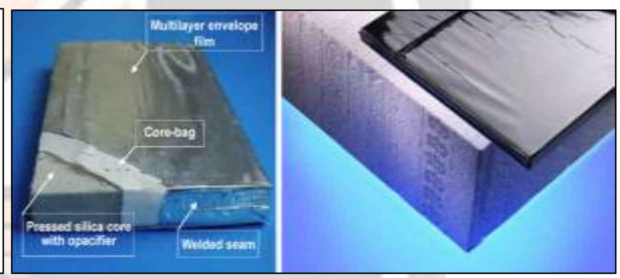

Fig -19: Vacuum Insulation Material [72]

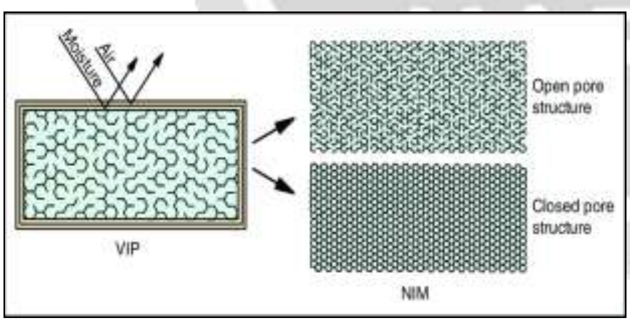

Fig-20: Nano Insulation Material [73]

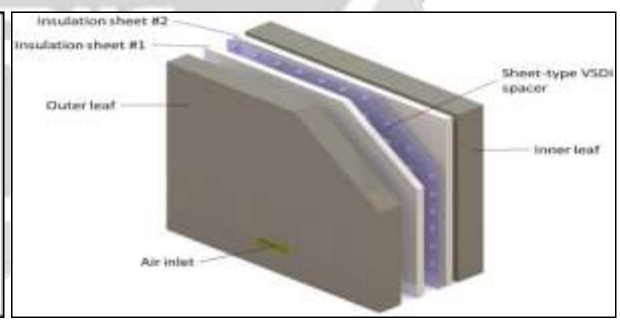

Fig -21: Dynamic Insulation Material [74]

4. CONCLUSIONS

This report concentrates on passive means that can be adopted in various building envelope components such as walls, roofs, glazing, ventilation and also discusses on different types of energy efficient materials that can be adopted in ZEB. Few conclusions based on the review are listed below

- **Combat Climate Change:** The combination of design, building techniques and technologies that go in to the ZEB, all result in a building that produces net zero green house gas emissions i.e., the building is not contributing to global climatic change.

- **Healthy Indoor Environment:** Since the ZEB's are built with air tight passive walls, they incorporate energy efficient fresh air systems. The higher advanced ventilation system helps in frequent replacement of indoor air with outdoor pure, thus aiding cleaner, fresher and healthier indoor environment.

- **Passive Solar Profits:** ZEB's are designed and built using passive solar design principles, making the most of natural daylight and gives energy throughout the day contributing to lower or no use of electricity from the outside grid and it is a one-time installation, having low maintenance.

- **Live Anywhere:** ZEB are found in hot deserts and in cold climes and are built according to location specific data, ZEB are built accordingly to the region's climatic condition, providing total comfortable living anywhere in the world.

- **Clean Energy Resource:** Living in a ZEB gives the freedom from polluting fossil fuels. The energy used in the building is extracted from clean, renewable resources like solar panels on the roof of the building.

- **Cost Savings:** The cost savings are the result of no energy bills incurred on the home, hence the residents can save the monthly energy bills instead of paying it to the utility company.

- **Durable Home:** The building techniques and materials used in ZEB are more durable than those used in conventional buildings and hence last longer and also require lesser upkeep.

- **Year Round Comfort:** A ZEB has a highly energy efficient, quiet and easy to use comfort system for heating and cooling, making the ZEB exceptionally comfortable to live all year around.

- **Acoustic Comfort:** A ZEB has very well insulated walls, multi pane windows and is built airtight resulting in nice and quiet indoor environment, free from outside noises and sounds.

- **Low Maintenance:** The durability of a ZEB is high and also has less complicated indoor design resulting in easy cleaning and maintenance. Due to airtight construction, there is no water damage, fresher air means low dust resulting in easy cleaning.

- **Positive Energy:** The ZEB must be primarily designed and built to produce excess amount of energy than consumed, resulting positive energy can be exported to utility companies, contributing to the society.

- **Pioneer the Future:** With a ZEB, we can lead the way to a better future, global climatic change and depleting non renewable energy resources can be minimized, paving better way for the future generations.

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