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Optimization of Building Energy Performance through Passive Design Strategies

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Passive buildings are capable of achieving the lowest energy requirements by optimizing heat losses and gains through the building envelope. Therefore, the thermal comfort in winter and summer can be maintained mostly without requiring the energy inputs and during the peak temperature periods with only minimum amounts of energy inputs. Application of passive strategies in building sector can be a promising measure to enhance the building energy efficiency. This paper is aimed at reviewing studies utilized passive strategies to optimize building energy utilization. The findings demonstrate that, usage of passive strategies in the building sector enhances sustainability measures predominantly through mitigating building's negative environmental impacts besides optimizing its energy performance.

Keywords: Passive building; building energy performance; building environmental impacts; passive strategies.

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1. INTRODUCTION

Buildings account for approximately 40% of global energy consumption and one-third of global GHG emissions [1]. A significant proportion of the energy utilization is due to the spread of the heating, ventilating, and air conditioning (HVAC) installations in response to the growing demands for better thermal comfort within the built environment [2]. The statistics reported by '*International Energy Agency*' indicating an upward trend in global energy consumption between the years of 1984 and 2004 [3]. This report claimed that, primary energy has grown by 49% and CO_2 emissions by 43%, with an annual average increase by 2% and 1.8%, respectively. '*The International Energy Outlook 2013*' also predicted that, energy consumption will be globally increased from 106 quadrillion Btu between the years of 2010 and 2020 to 820 quadrillion Btu in 2040 [4]. This report stated that, 85% of this increase will occur in developing countries due to pursuing economic growth and responding to population increase.

In order to tackle the issue of growing demand for energy, many efforts have been made by different countries to reduce the energy consumption and GHG. In US, the 'National Global Change Research Plan of 2012- 2021' was approved by US government in 2012 aiming to monitor, investigate, and report the current status of CO_2 emissions and energy consumption, and also providing solutions for preventing the climate change [5]. European Union (EU) also adopted the first mandatory Directive on Energy Efficiency in Building in 2002 to curb the climate change [6]. One of the primary objective of this Directive is to reduce the energy consumption and CO_2 emissions by 20% up to 2020 [7]. Moreover, China is set out an object in its "Twelfth Five- Year Plan" (2012) to mitigate the energy consumption by 32% comparing to that defined in its "Eleventh Five-Year Plan" [4]. Furthermore, in 2010, the world leaders reached to an agreement in Cancun, Mexico, at the 2010 United Nations Climate Change Conference to commit to a maximum temperature rise of 2ºC above pre-industrial levels, and to consider lowering this temperature to maximum 1.5 degrees in the near future [8]. However, King D et al. [9] believed that, commitments made during this conference have a slim chance to realize this goal. They stated that, the concentration of CO_2 in the atmosphere will exceed the critical level for a 2ºC rise in temperature by 2035, and on current policies the temperature will eventually reach 4ºC above the pre-industrial level.

Additionally, various strategies are globally developed to control the increase of energy consumption and GHG emissions. Among them, Passive Building Design (PBD) has been widely identified as one of the most effective strategies for decreasing the energy demand in building [10-13]. A passive building is defined as '*a building which is constructed to achieve a comfortable interior climate without a separate active heating device*' [14]. The passive buildings are capable of achieving the lowest energy requirements through striking a balance between the heat losses, and the heat gains with respect to the particular climatic condition of building's location [14]. A proper practice of passive design involves various aspects of building design [15], such as orientation of the main façades and windows, wall thickness, thermal insulation, window details, sunroom for passive solar heating, shading devices, etc. [16].

Several studies are carried out aiming to address the impacts of implementing passive strategies on diminishing the building energy use [13,17-20]. For example, Al-Obaidi KM et al. [19] reviewed passive cooling techniques that can be employed to regulate the indoor air quality by consuming the minimum energy. They mainly focused on adopting two passive roof types, the reflective and radiative, and discussed about their capabilities to attenuate the heat transmission between inside and outside of the building. Pérez G et al. [20] conducted a comprehensive literature review on the application of Vertical Greenery Systems (VGS) to be used as passive tool for energy savings in buildings. Sadineni SB et al. [13] also provided an exhaustive technical review on the different building envelope components and respective improvements from an energy efficiency perspective. The gap identified by this study is the lack of existing a structured literature review addressing the effects of most influential passive strategies on reducing the building energy consumption. The main aim of this paper is to critically review and discuss the effects of eight factors of passive design strategies, 'thermal insulation', 'thermal mass', 'glazing', 'window's size, shape, and position', 'color of external surfaces', 'external shading devices', 'building orientation', and 'building form' on the building energy consumption. These factors can be mainly taken into considerations at the designing phase of the building construction process.

2. PRINCIPLES OF PASSIVE HOUSE DESIGN

The concept of PHD is based on achieving critical objectives in buildings such as cost-effective, high quality, healthy and sustainable construction [21]. These objectives can be obtained through following six basic principles.

2.1 Superinsulation (Depending on Climate)

Application of thermal insulation in the building envelope is one of the basic principle of designing a passive house. Using insulation in the building shell can retard or block the heat transmission between inside and outside of building. Moreover, the employment of insulation can help the indoor air temperature to be remained at a relatively constant level. Klingenberg [21] believed that, the entire envelope of a passive house building should be well- insulated based on the particular climatic conditions of building's location. The proper use of thermal building insulation can directly determine the level of building energy consumption and occupants' comfort.

2.2 Eliminating Thermal Bridges

Thermal bridge is defined as the thermally weak areas of the building envelope, by which the heat penetrates into the interior by passing through these areas and cause the energy loss [22]. The chief reason for occurring thermal bridge is the thermal difference between two areas in the building envelope [21]. Generally, the heat tends to pass through an element that has a higher thermal conductivity than the adjacent materials, and results in happening the thermal bridge. The potential points for this phenomenon to be happened are the edges, corners, or connections in buildings, such as connections of floors and internal walls with external walls, or cantilevered balcony slabs. Significance of thermal bridge has been widely studied in the literature [22-24]. Regarding to the passive buildings, it is stated that, there should be few or no thermal bridges in passive houses [21]. The thermal bridge coefficient for a passive house should be less than 0.01 watts per meter per Kelvin (W/mK) or 0.006 British Thermal Units per hour foot and degree Fahrenheit (BTU/h ftoF) [21].

2.3 Airtight Construction

Airtightness can associate to enhance the building energy performance through minimizing, or eliminating the hot or cold ingress drafts, thereby decreasing the demands for space conditioning. It is argued that, passive houses should be extremely air- tighten in order to prevent the penetration of warmth, moisture, or condensation into the house [21]. Airtight construction can be realized through employing a continuous layer of airtight materials around the entire building envelope [21]. Different materials can be utilized to isolate the building envelope, namely membranes, tapes, plasters, glues, shields, and gaskets.

2.4 Ventilation

Hermetically air- tighten building does not mean disabling the building to breath [21]. Passive houses are able to breathe a controlled volume of air by employing mechanical devices rather than breathing unmeasurable air volume through uncontrolled leaks. The use of mechanical ventilation leads to consistently circulate a measured amount of fresh air throughout the passive house and help exhausting measured quantities of stale air from the house. Air ventilation of passive house is based on utilizing a balanced mechanical ventilation system, in which this system must be extremely energy efficient. Proper provision of air exchange by passive house can assure maintaining the indoor air quality for occupants.

2.5 High-performance Windows

Windows are responsible for wasting a notable percentage of total building energy loss approximately by 20-40% [25]. Designing window should be practiced based on the particular climatic condition of buildings to reduce the energy demand. Recently, several studies proposed effective solutions for increasing the energy performance of windows by utilizing different types of glazings such as aerogel glazing [26-28], vacuum glazing [29,30] smart glazing [31,32] and prismatic glazing [33,34].

2.6 Optimization of Passive- solar Gains

One of the primary factor requiring to be considered at the designing stage is the building orientation [21]. Based on the climates, different building sides should be thoroughly orientated aiming to enhance the energy efficiency of buildings. For example, south side of building generally receives maximum solar radiations, while the north side receives minimum sunlight. Therefore, fenestrations in the building envelope should be designed to allow passing specific radiations into the interior space without compromising the occupants' comfort. Additionally, there are other significant factors affecting the building energy gains such as, thermal mass [35,36], windows specifications (windows' shape, orientation, and size) [37,38], glazing [39-41], and color of external surfaces [42,43].

The core concept of these principles are based on minimization of the heat wastes, and maximization of the heat gains. Combination of these parameters can be promising to enhance the building energy efficiency. The current study aims to review the effects of eight factors of passive design strategies, and discuss about their effects on diminishing the building energy consumption.

3. IMPACT OF BUILDING PARAMETERS ON ENERGY EFFICIENCY

3.1 Thermal Insulation

Thermal insulation is known as a material or a combination of materials used in the building shell to retard the rate of inward or outward heat flows through conduction, convection, and radiation [44]. This section is reviewed studies that addressed the impacts of employing thermal insulations on the improvement of environmental, and energy performances of building.

Proper application of thermal insulation in building envelope can result in reducing the building energy consumption as well as decreasing the amount of environmental impacts. Tingley, D.D. et al. [45] quantified and compared the environmental impacts of three insulation materials, expanded polystyrene (EPS), phenolic foam and rockwool insulation. Sixteen impact categories were examined during 30 years in order to find out which one of the insulations could have the lowest environmental contribution. They stated that, EPS had the lowest environmental impacts in fourteen out of the sixteen impact examined categories. This study also made a wider comparison of embodied carbon associated with PIR (polyisocyanurate) boards and woodfibre boards. Woodfibre board was conclusively identified to have the lowest embodied carbon which is capable of being utilized where reduction of CO_2 is the priority. Comakli & Yuksel [46] investigated the environmental impact of heat insulation used for the reduction of heat losses in building. It was found that, the optimum thickness applied for the insulation can result in reducing CO_2 emission by 27%. In another attempt, Dombayci O.A. [47] studied the environmental impact of optimum insulation thickness in Denizli, Turkey. He used coal as the fuel source and the expanded polystyrene as the insulation material in the case study. It was stated that, when the optimum insulation thickness (0.095m Denizli) was applied for the building, the emissions of CO_2 and SO_2 were decreased by 41.53%. Additionally, a reduction of 46.6% in energy use was also reported when the optimum thickness was used in the building. Carreras J. et al. [48] also presented a methodology to determine the optimal insulation thickness for external building surfaces. They used a multi-objective model capable of simultaneously minimizing the cost and environmental impacts associated with both the energy consumption over the operational phase of building life cycle, and production of the construction materials. Afterwards, this model was applied to assess a building's performance located in Lleida, Spain. The results of this study indicated a reduction of 40% in both cost and environmental impacts.

Several endeavors are also made to investigate the possibility for energy savings through utilizing the thermal insulation in buildings. Fang Z. et al. [49] investigated the impacts of using external wall insulation on energy consumption, and the indoor thermal environment. Two types of chambers were constructed in this study; an energy efficient chamber with thermal insulation used in the external wall, and a basic chamber according to the common design principles for residential buildings in the 1980s and 1990s. The results showed that, the energy consumption of the energy efficient chamber was lower than the basic chamber, offering a savings up to 23.5% in consuming energy during the summer. Moreover, Dongmei P. et al. [50] carried out a research on the impacts of wall insulation thickness on the annual cooling and heating energy uses under different Chinese climates. The annual cooling and heating energy uses were simulated for the four different exterior zones at different external wall insulation thicknesses under three different climates in China, Guangzhou, Shanghai and Beijing. The results reported that, a significant percentage of energy saving was achieved by increasing the external wall insulation thickness in exterior zones facing all orientations under Beijing's climate. In another attempt, the effects of using a proper insulation on the energy saving in Iranian buildings were studied [51]. An integrative modelling was used to simulate the buildings' energy consumption. The results of this study showed that, a reduction up to 35.2% in energy consumption per square meter of buildings can be realized when the thermal insulation applied for the external walls. Kolaitis, DI et al. [52] performed a comparative assessment of internal versus external thermal insulation systems for energy efficient retrofitting of residential buildings by means of detailed numerical simulations. The outcomes of this study indicated a significant reduction in the total energy requirements achieved as a result of utilizing both external and internal thermal insulation configurations. They also stated that, external insulation generally outperforms the internal insulation configuration by 8%.

Several researchers also proposed innovative solutions for using natural materials as the building insulation [53-56]. Balo [53] produced insulation materials through using clay, fly ash, rice husk ash, and epoxidized tall oil. The analysis showed that, the impacts of fly ash and epoxidized tall oil was significant on the thermal conductivity. They stated that, insulation materials produced by clay, fly ash, rice husk ash, and epoxidized tall oil ETO can be used as the insulation materials. Corscadden KW et al. [54] investigated the possibility of using sheep's wool as a building insulation. The results showed that, thermal insulation produced by wool is competitive with other insulation products in terms of thermal properties. Patnaik A et al. [56] also produced different samples out of waste wool and recycled polyester fibers (RPET), and analyzed their thermal, acoustic, moisture and fire properties. The results indicated that, two layers comprising of 50% waste wool and 50% RPET mat can provide the best performance in terms of thermal insulation, acoustic and fire properties, and moisture absorption.

Thermal insulation plays a significant role in optimizing the building energy as well as mitigating the building environmental impacts. The employment of thermal insulation should be coupled with other passive strategies to realize further enhancements in building energy efficiency. Technical characteristics of building insulations, such as thickness should be thoroughly designed with respect to the particular climate of building location.

3.2 Thermal Mass

Thermal mass refers to the ability of materials to absorb (convectively and radiatively), and store the heat energy during a warm period and release it during a cool period. This lag time can have three important results [35]:

- The slower response time tends to moderate the fluctuations of indoor temperature under outdoor temperature swings.
- In hot or cold climates, it reduces energy consumption in comparison to that for a similar low-mass building.
- It moves building energy demand to off-peak periods because energy storage is controlled through correct sizing of the mass and interaction with the HVAC system.

Thermal mass can be divided into two categories [57]. I) the external thermal mass which are exposed directly to the ambient and indoor temperature. Generally, the external components which are in connection with the outdoor environment and inner spaces such as walls and roofs are belonged to this category. II) the internal thermal mass which are not connected to the outdoor environment, namely furniture, or internal concrete partitions.

Working principle of thermal mass is based on absorbing the heat from indoor air when the temperature of thermal mass is lower than the indoor air temperature and releasing the absorbed heat into the indoor air when the its temperature is higher than the indoor air temperature [58]. Material mass of buildings can be designed to store the internal solar heat gains in order to moderate the temperature swings, and thereby reducing the energy use for space conditioning. The effectiveness of thermal mass in buildings depends on the interactions of several parameters including climate, orientation, window area, insulation, ventilation, load profile and occupancy pattern of buildings [59,60]. Thermal mass is more effective to be implemented, where the diurnal range of temperature is high.

Several studies addressed the effects of thermal mass on the energy use of buildings [35,36,61,62]. Kalogirou SA et al. [35] conducted a study to investigate the effects of thermal mass on the heating and cooling loads of buildings in Cyprus. It was found that, the use of thermal mass can considerably reduce the heating loads and slightly increase the cooling loads of buildings. However, Aste N et al. [36] explored the effects of thermal mass in an Italian building by analyzing the energy performance of wall systems with the same U-values but different thermophysical properties including heat transfer surface, specific heat capacity, thermal conductivity and solar control factor. They found that, the walls which performed best in terms of energy had an effective combination of dynamic thermophysical properties, mainly greater heat transfer surface, and not necessarily the best thermophysical properties. Thus, the heat transfer surface influences the effectiveness of thermal mass for saving energy, and careful design and control strategies are required for effective use of thermal mass. Gregory K, et al. [61] also presented a comparative analysis on the influence of thermal mass in simplified building modules in Australia. They found that, thermal mass significantly reduced the space heat demands, particularly where the thermal mass was placed at the interior side of the insulation.

3.3 Glazing Types

Glazing plays an important role in building energy management due to their influences on allowing the solar radiations to pass through the inner spaces. Lee JW et al. [25] opined that, windows are responsible for 20-40% wasted energy in the building. Window is an indispensable part of building configuration, which has an influential impacts on the overall building energy performance. The energy performance of a window depends on its thermal transmittance, the glazing solar transmittance, and the air leakage due to the frame and installation airtightness. Among all these parameters, glazing system can be considered as a major determinant in energy performance of window.

Visual transmittance of the glazing unit is important, as it determines the amount of daylight passing through the glazing unit. One of the basic characteristics for glazings is to have a higher transmittance in visible spectrum and lower transmittance in infrared region. Ihara T et al. [39] evaluated the energy performance of aerogel granulate glazing systems used in an office facade consisting of a translucent aerogel granulate glazing system at spandrels. They concluded that, application of such glazing façade can achieve a lower energy demand compared to a double glazing facade in cooling dominated climates, such as Tokyo and Singapore. In heating dominated climates, a combination of aerogel and triple glazing systems was suggested as an energy efficient façade to offer increasing the building energy optimization. De Forest N et al. [40] also presented a simulation study of the energy and CO_2 benefits of a transparent, near- infrared switching electrochromic (NEC) glazing for building applications. NEC glazings are an emerging dynamic window technology that can modulate the transmission of near-infrared (NIR) heat without affecting transmission of visible light. In this study, a hypothetical NEC glazing was simulated on clear and tinted glass in six building models in 16 US climate regions using EnergyPlus. The total annual energy consumption for lighting, heating, cooling, and ventilation for the NEC glazings were compared with high performance static windows and conventional tungstenoxide EC glazings. The results of this study revealed that, 50% of the total energy savings can be realized by deploying NEC glazings in only 18% of the total window stock, and 75% of the savings in only 39% of the stock. Warwick, ME et al. [41] also used building simulation to examine the effect of the thermochromic transition gradient on the energy demand characteristics of a model system in a variety of climates. The results were compared against current industry standard glazing products. They suggested that, in a warm climate with a low transition temperature and sharp hysteresis gradient, energy demand can be reduced by up to 51% compared to a conventional double glazing approach.

Proper selection of the glazing is another measure to regulate the ingress solar radiation to the building. The significance of this strategy can be more sensed, where the excessive demands for heating and cooling are existed. Therefore, the particular climates of building's location should be taken into account in order to decide the type of glazings.

3.4 Window Size, Shape, and Position

Besides glazing systems, the size, shape and position of windows are considered as significant parameters which can have an influential impact on the wasted energy in buildings. Therefore, an optimum design of a window can be a careful trade-off between all properties of window's components such as its particular characteristics, orientation, shape, size, glazing, and external elements. Persson ML et al. [63] evaluated the influence of size and orientation of the triple glazed, low-e windows on the heating and cooling energy loads on a case study of 20 terraced passive houses built in Sweden. The results showed that, the size of triple glazed made a minor contribution to the heating loads due to the extremely well- insulated walls and the efficient ventilation system. They proposed an optimal design solution with smaller window area facing south, and larger window area facing north comparing to the already built houses. The outcomes of this study showed that, in passive houses, it was not necessary to decrease the areas of window facing north.

Gasparella A et al. [37] studied the influence of windows type and size on the heating and cooling energy demands, and peak loads for a case study of a well-insulated house with two stories located in, Italy. They reported that, using the large glazings can enhance the window performance in terms of saving energy, but deteriorate slightly the peak of winter loads. Moreover, they found that, the use of windows with low thermal transmittance is useful, if accompanied by high solar transmittance, though higher solar transmittance considerably hinders the summer performance. Jaber & Ajib [64] performed a parametric study using TRNSYS to determine the effects of the windows type, size and orientation on the annual heating and cooling energy demands of a single-story house located in three different climate zones, Amman, Jordan and Germany. The results indicated that, the heating load was highly sensitive to windows type and size as compared with the cooling load. Furthermore, Acosta I et al. [38] conducted a research to quantify the daylight factors produced inside a room for different models of windows. They stated that, the square windows produced daylight factors slightly higher than those obtained with horizontal windows and noticeably higher than those measured with vertical windows, considering the same surface of openings. Furthermore, they found that the windows in the upper position allowed higher luminance at the back of the room than those in centered locations.

Windows are an influential component of the building configuration in determining the level of energy consumption. They can be applied as a leverage to regulate the indoor air quality by allowing, or preventing the outdoor air and light to pass through, with respect to the particular climates of building location. Position, size, and shape of the windows are needed to be considered for practicing an energy efficient design, because they largely specify the amount of ingress radiations. It can be mentioned that, the final volume of receiving solar radiation is a definite trade-off between four critical parameters, windows' size, shape, position, and proper selection of the window glazing.

3.5 Color of External Surfaces

Use of appropriate colors on the external surfaces of buildings can influence the receiving, or blocking rate of solar radiations. Several researchers studied the relationship between covering the external surfaces with different types of colors and changing the building energy consumption [42,43,65-68]. Givoni & Hoffman [65] claimed that, the unventilated small buildings with white-colored walls in Israel were approximately 3ºC cooler in summer than the same buildings painted with gray color. Saber HH et al. [42] also simulated the hygrothermal performance of roofing systems under different North American climates. They found that, black roofs always performed with lower moisture than white roofs. For a 5 years period, the white roofs could lead to long-term moisture-related problems in the cities with cold climate, where the moisture content exceeded the acceptable limit of 19%. Sheikhzadeh GA et al. [43] investigated the effects of using a new type of painting on the reduction of energy consumption in various climates. The new used type of paintings was contained of mineral micro particles in lieu of regular acrylic paint. It was observed that, coatings containing mineral micro particles act as thermal insulation and reduce energy consumption by 20%. Moujares & Brickman [66] developed a model using temperature nodes and energy balance equations to describe the roof heat transfer. An 11% reduction in the daily heat transfer was achieved, when a reflective paint to the roof was applied. Furthermore, Uemoto KL et al. [68] analyzed the application of cool-colored acrylic paints for roofs. When the cool paints were exposed to infrared radiation, the surface temperature remained about 10ºC lower than the conventional paints. With respect to the untreated roof, the cool paints reduced the heat flux between 26 and 37%.

The results of reviewed studies indicating the impacts of external colors on the building energy utilization. This influence can be delivered by using the light- colored coatings to reflect solar radiations, or applying the black-colored coatings to absorb the radiations. Decision on selecting the suitable color for exposed surfaces should be made based on the climatic condition of buildings. Combination of this factor with suitable thermal insulation can significantly decrease the volume of receiving radiations, where the cooling demands is prominence. The efficiency of these strategies can be further increased by being integrated with new technologies such as Photovoltaic (PV) modules. The outcome of these strategies is to improve the efficiency of building energy utilizations.

3.6 External Shading Devices

The main function of a shading system is to protect the transparent parts of building against entering the unwanted solar radiations. Various types of shading systems can be categorized into fixed shading systems, movable shading systems, and other shading systems (Figs. 1 and 2). Shading device can influence the building energy consumption through intercepting the incoming daylights. Palmero-Marrero & Oliveira [69] studied the effects of using shading devices on the building thermal performance in different cities with various latitudes and climatic conditions. It was shown that, shading devices have a great impact on saving energy and improving thermal performance in offices in different climatic conditions. Manzan [70] performed genetic optimization (GO) on an office room with a south facing window in order to design a fixed shading device for two climates, Trieste and Rome. The performance of shading device was investigated in winter and summer by considering the shades provided over the window to reduce the cooling loads in summer, but also affected heat loads in winter by limiting the sun gains. A reduction in primary energy consumption up to 19% for Trieste, and 30% for Rome were achieved compared to the unshaded window. Chou DC et al. [71] developed a prototype integrating horizontal louver shading devices with solar collectors, and evaluated its influences on enhancing the building energy efficiency. They stated that, under sufficient solar radiation, this system can have an excellent absorption performance without requiring auxiliary heating equipment. It was concluded that, using the proposed prototype can decrease the cooling loads.

The use of shading device in building envelope to protect the transparent components is a reliable measure to mitigate the incoming solar radiations. This part requires to be carefully designed considering the most suitable size, position, and type for installation. Shading device systems can be integrated with new technologies such as PV panels to increase the energy efficiency. PV modules can be used as a shading device to simultaneously intercept the receiving radiations, and generate the electricity power.

3.7 Building Orientation

The effects of building orientation on the energy use has been frequently studied in the literature [73-77]. The amounts of direct radiation hitting the building facade depends on the azimuth in the wall, and building's angle [78]. The Southern side of a building generally receives the maximum level of solar radiation, and Northern side receives the minimum amounts of radiations. Based on this fact, a southern building orientation can be considered as an optimal orientation for receiving the highest level of sun's rays in the winter, and controlling ingress lights in the summer.

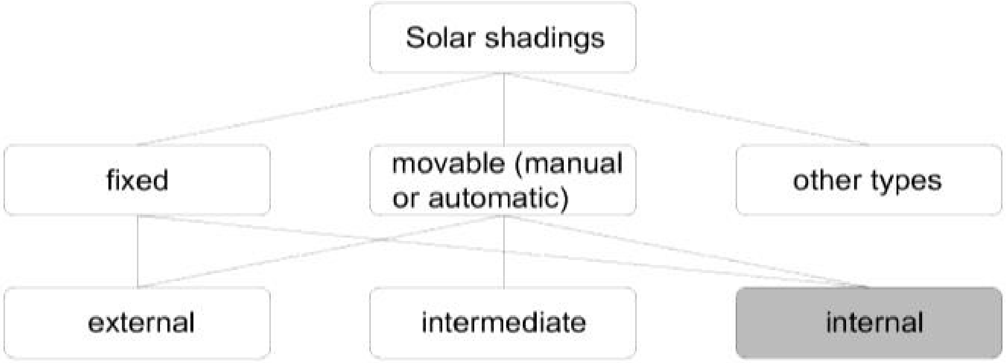

Fig. 1. Possible classification for solar shading systems [72]

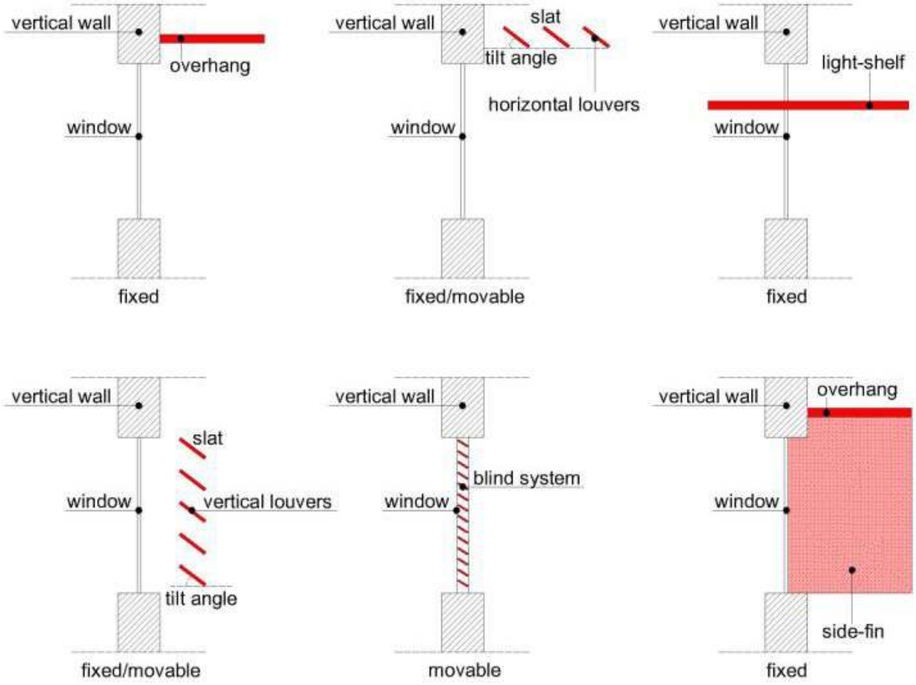

Fig. 2. Main shading types [72]

Gupta & Ralegaonkar [79] proposed an equation Eq. (1) to optimize building orientation for various shape factors. Where A is the surface area; H is the monthly mean daily global radiation on a horizontal surface; i is the incidence angle; dw is the hour angle at sunrise or sunset; θ_z is the zenith angle or polar angle. The goal of this study was to diminish the ingress solar radiation in summer and increase sunlight in the winter. They successfully optimized the value of the solar radiation received during the months with the most extreme climate conditions (June and December). They used different shape values and varied the orientation angle from 0º to 180º. This method can be utilized to discover the optimal orientation angle for receiving the minimum solar radiation in summer and maximum in winter. It was concluded that, the optimal building orientation can be achieved, when the longest wall sections were oriented toward the north and south.

$$E = A \times \int_{\omega_1}^{\omega_2} (0.834 \times H) \times \left(\frac{\cos\ i}{\cos\ \theta_z}\right) d\omega \qquad (1)$$

In another study, Faizi F et al. [74] investigated the effects of building orientation on the energy reduction for four different types of residential buildings locating in Tehran, Iran. They used Ecotect software to analyze the building behaviors in four major fields; shadows and overshadowing, solar radiation, lighting access and thermal simulation. It was concluded that, building orientation is one of the most important factor in determining the volume of receiving solar energy. They also stated that, the best building orientation is where, the building would be orientated with having 0º angle between the main axis of building and the North. The optimal selection of building orientation should be performed at the designing stage with respect to the particular climatic condition of building.

Huang J et al. [80] highlighted the importance of house orientation, windows-to-wall ratio, types of insulation materials and windows in renovating the building envelope. They proposed a mathematical model to determine the economical thickness of thermal insulation, and optimize the thermal properties of building envelope with respect to the aforementioned criteria. It was concluded that, the optimization design project for envelope renovation can be determined by the technical and economic analyses considering the impact of house orientation, windows-to-wall ratio, types of insulation materials and windows.

3.8 Building Form

Practicing an energy efficient design to minimize the building energy use requires thorough articulation of the building's form. Building geometry is considered as a significant factor influencing the building energy consumption [81-83]. Hemsath & Bandhosseini [84] presented a methodology to evaluate the building form to compare the energy consumption of geometric variations and material considerations through conducting two types of sensitivity analyses. They stated that, the both vertical and horizontal geometric proportion is equally as sensitive as certain material aspects related to building energy use.

When a building is designed, the ratio between its outer surface and the total constructed volume should be as small as possible, tending towards the ideal case of a hemisphere [85]. There are different variables pertaining to the building shape which can affect the heating and cooling demands [86]. These factors are briefly explained as follow:

- *Compactness index*; defines as 'the ratio between the volume of a building (V) and its the outer surface of the building façade ($A_{ext.}$)' [86]. This ratio represents the building's capacity to store the heat and prevent the heat loss through its façade. A building with the high compactness index is the one which has a high volume/ surface ratio, where the surface exposes to the possible heat losses or gains is as small as possible. The relative compactness of a building is defined as the ratio between its compactness index and the compactness index of a reference building as shown in Eq. (2). The effect of compactness on energy savings varies depending on climate [84]. In one study, the analysis conducted by Gratia & Herde [87] showed that, a 18.6% heating loads difference existed between the highest and lowest compactness ratio (1.24-0.84) of the targeted case study. Bekkouche SMA et al. [88] studied the impact of compactness index on the building's thermal behavior in a hot dry climate. They also highlighted the importance of considering the geometry parameters at the designing stage of construction due to their significance in minimizing the energy consumption and improving the indoor temperature. Simulated results of this study indicated that, the higher compactness in building can result in comforting the indoor temperature.

$$RC = \frac{(V / Aext)Building}{(\mathrm{V/Aext})\mathrm{ref}} \tag{2}$$

- *Shape factor;* defines as 'the proportion of a building's length to its width' [15,86]. The importance of this criterion has been always considered alongside with the building orientation. There can be found several studies in the literature that addressed these two factors to optimize the energy usage in the building [78,15,89]. For example, Aksoy & Inalli [15] stated that, an energy saving by 36% in heating loads can be achieved as a result of optimizing the building orientation and shape. Mingfang [78] also studied the impact of building shape parameters such building length, depth, and width on receiving the solar radiation by a parallelepiped-shaped building. They concluded that, the most optimum orientation is the south, as the building receives maximum radiation in the winter and controlling the heat in the summer. Mingfang also presented an equation (Eq. (3)) to calculate the optimal building proportions, where q_S, q_N, q_E, q_W, q_H are the solar radiation receive by the walls located in the South, North, East, West, and Roof, respectively. Moreover, ƛ is the building length and β is the height. By applying this method, the total solar radiation on the building will decrease as much as 4% in comparison with radiation on a cubic building.

$$\frac{Q}{Q_0} = \frac{(q_s + q_N)^3\sqrt{\lambda\beta} + (q_E + q_w) \times \sqrt[3]{\lambda^{-2}\beta} + q_H \times \sqrt[3]{\lambda\beta^{-2}}}{q_s + q_N + q_E + q_w + q_H} \tag{3}$$

- *Climate;* the building shape should be responsive to the particular climatic conditions of building's location. This is the main reason to explain why, one particular building shape has been more pervasive than other probable forms in particular regions. For example, in the regions where the average of annual rains is high, buildings' form are different from dry and hot regions. Additionally, building shape should be designed in a way to be also responsive towards the prevention of energy loss through the envelope [86].

4. FUTURE DIRECTION FOR ADOPTING PASSIVE BUILDING

One of potential direction for the future development of passive building is to improve the disintegrated process of building design existing in current practice of architectural mindset. Butera [90] believed that, execution of a building is based on a linear path consisting of three steps; architectural design, mechanical systems design, and the construction (Fig. 3). The architects –due to their training – usually have a limited knowledge about the building physics. Consequently, the choices made by architects regarding to the building's envelope for optimizing the energy usage often have a negative impact on the building's energy performance. For instance, in order to design a building in the cold climates, the primary choice to improve the building energy performance is to increase the insulation thickness, or improving the performance of windows' glasses. Although these measures are considered as the part of passive strategies, improper employment of these measures can associate with increasing the cost, and environmental issues related to production of insulation materials. Therefore, it is necessary to alter the mindset of building design through making use of the integrated design model by introducing new professional expertise in the cycle of building design, namely the energy, or environmental experts [90-91]. New areas of expertise can be introduced in building science to meticulously address the two long-standing issues (energy and environmental performances) concerning to building sector. These analysts can directly contribute to the process of building design alongside with the other experts involved in designing procedure such as architects, mechanical, electrical engineers, and so on.

Fig. 3. Usual design process [92]

The integration of new technologies with buildings are reported to be successful in reducing the energy consumption, cost, as well as mitigating the environmental impacts [93-95]. However, integration of PV, or other similar technologies with buildings still has a long way to go to fully guarantee the reduction of building energy and environmental issues [96]. The future of passive building can be intertwined with the upsurge in the presence of new technological advancements such as PV, or glazing technologies to increase the building energy efficiency. These technologies should possess the capability to be easily integrated with the new buildings as well as existing building stocks.

Various policies are established in different countries to augment the building energy efficiency by supporting the implementation of PBD. Several researches also conducted to review and highlight the importance of these efforts [97-101]. One of the future-oriented trend for passive buildings is to support this concept by the building regulations. The importance of PBD can be reflected in national building regulations in order to obligate the practitioners to consider passive strategies in their designs. Additionally, the use of PBD can be also highlighted by globally well-recognized building rating systems such as LEED, or BREEAM. Moreover, various mandatory and incentive schemes can be introduced by the governments aiming to ameliorate the awareness about the potential benefits delivering through practicing the passive strategies.

5. CONCLUSION

Building sector is one of the major determinants in consuming energy worldwide. Regarding to the upward trend of world population and the extreme needs for increasing building construction, it can be expected that, building sector will be one of the most significant energy consumer in the near future. In recent decades, different solutions have been proposed in order to tackle this issue. Several policies are established alongside with advancing new technologies to control the increasing trend of energy consumption in building sector. Adopting passive strategies for designing the energy efficient buildings has been of one these solutions. This paper attempted to review the recent studies utilized the passive strategies to optimize the building energy consumption. Accordingly, eight important criteria were identified and their results were discussed.

Application of passive strategies in the construction industry enhances sustainability measures predominantly through mitigating building's negative environmental impacts, besides optimizing its energy performance. This statement can be confirmed by the outcomes of reviewed studies indicating reductions in the energy and environmental impacts that were achieved as a result of using passive strategies.

The primary intention of passive building is to realize the comfortability without employing a separate active heating device. Passive buildings are capable of achieving the lowest energy requirements through striking a balance between the heat losses, and the heat gains with respect to the climatic condition. Proper practice of designing a passive building should be involved in adopting various aspects of building design, such as thermal insulation, thermal mass, glazing, window's size, shape, and position, color of external surfaces, external shading devices, building orientation, and building form.

To further increase the application of passive buildings in the construction industry, alteration in architectural mindset is demanded. New areas of expertise needs to be introduced to meticulously address the two long-standing issues (energy and environmental performances) concerning to the building sector. Energy and environmental analysts can directly contribute to the process of building design alongside with the other experts in order to assess the energy, and environmental impacts of building. Additionally, the concept of passive building requires to be supported by the building regulations. Different incentive-based programs and mandatory schemes can be initiated by governments in order to obligate and encourage the practitioners for using passive strategy. The importance of using PBD can be also highlighted by the most renowned sustainable building rating systems such as LEED, or BREEAM. In their scoring systems, credits can be allocated to the buildings utilized passive techniques to optimize the energy use, and diminish the environmental impacts. Moreover, the future of passive building can be intertwined with the upsurge in the presence of new technological advancements. Integration of technological advancements with passive buildings will further enhance the building energy efficiency, and reduce the building environmental effects. These technologies should have the capability to be readily integrated with the new buildings as well as existing building stocks.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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