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A Review of Passive Design Strategies for Improving Building Energy Performance

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ABSTRACT: It is now necessary to limit the use of conventional energy by buildings in order for them to function properly. Buildings use a significant quantity of energy all throughout the world. Because of the enormous potential of buildings for energy efficiency, the passive design criteria have received a lot of attention. Passive design approaches minimize energy consumption while simultaneously maximizing the use of renewable energy sources, which are widely regarded as the most important path to a low-energy and sustainable future, particularly in the construction industry. By managing heat losses and gains via the building exterior, passive structures can achieve the lowest energy needs. As a result, thermal comfort may be maintained in both winter and summer with little energy inputs, and at peak temperature periods with very minimal energy inputs. The use of passive techniques in the construction industry might be a potential way to improve building energy efficiency. There are a variety of passive design solutions for minimizing a building's energy burden, such as harnessing natural resources and considering climate, especially when planning for heating, cooling, lighting, and ventilation. It reduces the need for additional energy to achieve comfort within the structure.

The main goal of this paper is to critically review and discuss the effects of eight factors of passive design strategies on building energy consumption: "thermal insulation," "thermal mass," "glazing," "window size, shape, and location," "colour of external surfaces," "external shading devices," "building orientation," and "building form." These elements are mostly taken into account during the design phase of the construction process.

KEYWORDS: Passive Design Strategies, Building Energy Performance, Building Thermal Comfort.

INTRODUCTION

Buildings consume over 40% of global energy and emit one-third of global greenhouse gas emissions (Nejat Payam, 2005). The proliferation of heating, ventilation, and air conditioning (HVAC) systems in response to increased demands for enhanced thermal comfort within the built environment accounts for a considerable share of energy consumption (Yang L, 2014). Different governments have undertaken several initiatives to minimize the energy consumption and Greenhouse gas emissions in order to address the issue of rising energy demand. Passive design methods reduce energy consumption while maximizing the use of renewable energy sources, which are widely recognized as the most essential way to a low-energy and sustainable future, especially in the building sector. Passive buildings can achieve the lowest energy consumption by regulating heat losses and gains via the building outside (Sinha & Rastogi, 2017).

As a consequence, thermal comfort may be maintained with little energy inputs in both winter and summer, as well as with extremely little energy inputs during peak temperature periods. In the construction sector, the employment of passive approaches might be a strategy to increase building energy efficiency (Basu et al., 2019).

PASSIVE HOUSE DESIGN PRINCIPLES

Passive House is a construction concept that aims to create pleasant, ecologically friendly, and cheap houses and structures. The Passivhaus Institute in Darmstadt, Germany, founded the "passive house" idea in 1996. It was one of the first low-energy construction concepts and is now a leading building standard. Instead of active heating and cooling systems like air conditioning and central heating, the design focuses on making the most of "passive" effects in a structure, such as sunlight, shade, and ventilation. When combined with extremely high levels of insulation and airtightness, a passive home can consume 90% less energy than a standard dwelling. In this context, (Basu et al., 2017) highlighted that it would be highly beneficial if these value-adding aspects are considered to enhance the construction processes with respect to the passive design principles.

Super Insulated Envelopes

The outer walls, roofs, and floors make up the building envelope, which divides the inside from the exterior. Insulation constructed of low-conductivity materials is put within the wall and roof components to prevent cold/heat loss. As a result, the predicted thermal performance of the building envelope has increased significantly. Greater soundproofing, higher durability, and greater building resiliency—including the capacity to maintain interior comfort for lengthy periods even if there is a power outage—are all advantages of insulating to Passive House standards. The amount of building energy consumption and occupant comfort can be directly influenced by the usage of thermal building insulation.

Airtight Construction

Heat might also escape the envelope due to air leakage. The air barrier of a structure is a layer of material that surrounds the envelope and prevents air from moving in and out. When there is insufficient detailing during construction, when there are multiple ducts or other penetrations in the air barrier, or when the construction is of generally poor quality, gaps in the air barrier can enable uncontrolled air to pass in and out of the structure. Airtightness may help improve a building's energy efficiency by reducing or eliminating hot or cold entry draughts, which reduces the need for space cooling. It is suggested that passive buildings should be exceedingly airtight to prevent heat, moisture, or condensation from penetrating the structure (Klingenberg, 2013).

In addition, while standardization of processes, designs and their required materials can help maximize value and benefit from a building/ project, site constraints and peculiarities compel the designers and project managers to modify and improvise as per requirements pertaining to the passive strategies (Basu et al., 2019, 2017; Seshadhri & Paul, 2018). Further (Seshadhri & Paul, Validation and ranking of user requirement related building performance attributes and sub attributes for government residential buildings, 2018) highlighted the benefits of the airtight construction for the project managers and other stakeholders. According to (Paul et al., 2017; Sawhney et al., 2014), lack of efficient handling and supervision of materials and their storage plays a vital role in such type of construction.

High-Performance Glazing

While the walls make up the majority of a building's façade, the glazing systems can contribute significantly more to space-heating energy. Glazing systems cannot be insulated to the same degree as a wall due to their purpose, resulting in the windows being the most vulnerable portions of the envelope in terms of heat-flow resistance. To lower energy consumption, window design should be done depending on the specific climatic conditions of the structure. Using several forms of glass, such as aerogel glazing (Berardi, 2015), vacuum glazing (Fang, TJ, F, N, & R, 2015), smart glazing, and prismatic glazing, can improve the energy performance of windows.

Eliminating Thermal Bridges

The thermal bridge is defined as the thermally weak regions of the building exterior through which heat reaches the inside and causes energy loss (Ibrahim, PH, & E, 2014). The temperature differential between two parts of the building exterior is the most common cause of thermal bridge. When it comes to architectural interface elements, Passive House designs aspire to be thermal-bridge-free. According to (Seshadhri & Paul, Intervention Strategy for Enhanced User Satisfaction Based on User Requirement Related BPAs for Government Residential Buildings, 2017), the construction projects and buildings are designed and developed to fulfil requirements which are instrumental in mitigating the temperature differentials. Heat tends to move through an element with a higher thermal conductivity than the surrounding materials, resulting in the formation of a thermal bridge. Edges, corners, and connections in structures, such as connections of floors and internal walls with exterior walls, or cantilevered balcony slabs, are possible sites for this phenomenon to occur.

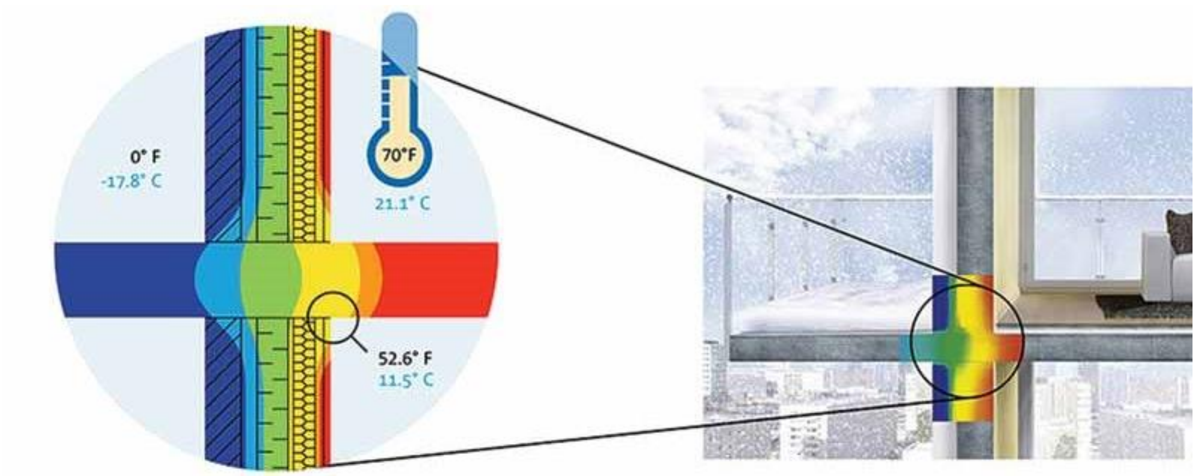

Figure 1: Thermal Bridge (Thermal Bridging Prevention, n.d.)

Ventilation

Because Passive House buildings are airtight, a ventilation system is required to bring in fresh air while exhausting pollutants, smells, CO_2, and moisture that have accumulated. By applying mechanical systems, passive dwellings are able to breathe a regulated volume of air rather than inhaling unmeasurable air volume through uncontrolled leaks. The proper provision of air exchange by a passive house helps ensure that the residents' interior air quality is maintained.

Passive-solar Gains Optimization

The building orientation is one of the most important factors to consider throughout the design process (Klingenberg, 2013). Different building sides should be thoroughly oriented based on climates in order to improve building energy efficiency. The south side of a structure receives the most solar radiation, while the north side receives the least. As a result, fenestrations in the building exterior should be constructed to enable certain radiations to flow into the interior area while maintaining occupant comfort. Other important aspects impacting the building's energy gains include thermal mass, window specs, glass, and the colour of the exterior surfaces.

ENERGY EFFICIENCY AFFECTED BY BUILDING PARAMETERS

Thermal Insulation

Thermal insulation installed properly in the building envelope may reduce energy consumption while also minimizing environmental implications. The environmental implications of three insulation materials, expanded polystyrene (EPS), phenolic foam, and Rockwool insulation, were assessed and compared by (Tingley, A, & B, 2015). Sixteen effect categories were investigated over the course of 30 years to determine which of the insulations had the lowest environmental impact. They claimed that EPS had the least negative environmental impact in fourteen of the sixteen impact categories studied. The embodied carbon associated with PIR (polyisocyanurate) and wood fiber boards was also compared in this study. Woodfibre board has been clearly identified as having the lowest embodied carbon, making it suitable for use in areas where CO_2 reduction is a priority.

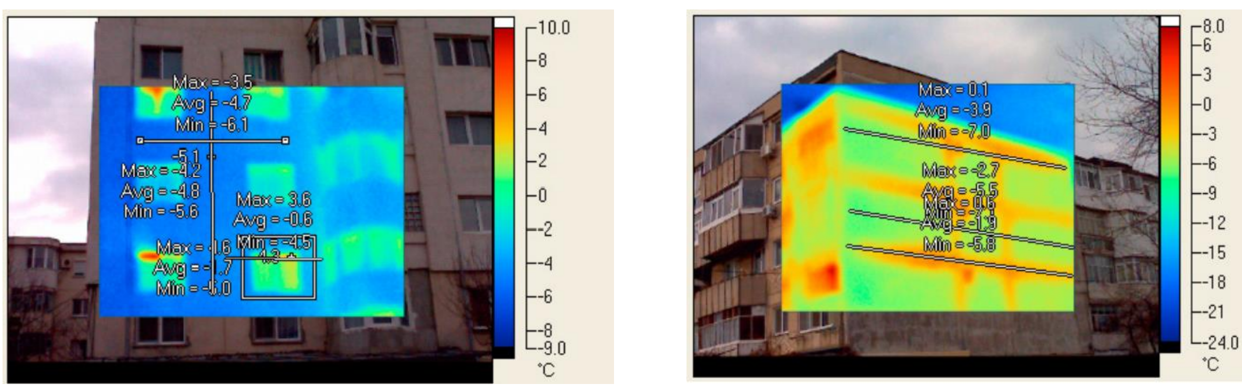

Figure 2: IR visualization of the insulated building VS IR visualization of the uninsulated building. (Tingley, A, & B, 2015)

Thermal Mass

Thermal mass describes a material's ability to absorb and store heat energy during a hot time and then release it during a cold phase. This lag period can result in three significant outcomes (Kalogirou, Florides, & S, 2002):

- The slower reaction time tends to minimize the indoor temperature changes caused by external temperature oscillations.
- In hot or cold climes, it uses less energy than an equivalent low-mass building.
- Because energy storage is managed by proper mass size and interaction with the HVAC system, it shifts building energy demand to off-peak hours.

Glazing Types

Because of its effects on enabling solar radiation to travel through the inner spaces, glazing plays a significant part in building energy management. According to Lee JW, Windows are responsible for 20-40% of a building's lost energy (Lee, Jung, Park, JB, & Y, 2013). Another way to control the amount of solar radiation that enters the structure is to choose the right glazing. The importance of this method may be better understood in areas where there are high needs for heating and cooling. Also, in a study by (Nejat Payam, 2005) there exists an increasing gap in supply and demand of various materials including the glazing types. As a result, while deciding on the kind of glass, the specific climates of the building's location should be considered.

Window Size, Shape and Position

On a case study of 20 terraced passive houses built in Sweden (Persson, A, & M, 2006), evaluated the impact of the size and orientation of the triple glazed, low-e windows on the heating and cooling energy loads. Due to the highly well-insulated walls and excellent ventilation system, the size of the triple glazing made only a tiny contribution to the heating loads. In comparison to the existing dwellings, they offered an ideal design solution with a smaller window area facing south and a bigger window area facing north.

According to ECBC (Ministry of Power, 2017), if the WWR <= 40%, the SHGC requirement is 0.25; however, as the WWR increases, the SHGC requirement becomes stricter. As a result, when 40% < WWR < 60%, SHGC equals 0.20. When using equivalent glass configurations from WWR 10% to 40%, as stated in ECBC, the energy consumption for WWR 40% is the greatest; hence, a life cycle cost analysis for WWR 40% with a conventional window (Base case) and an ECBC suggested window is performed. The graph below depicts the reduction in energy usage for the ECBC window (WWR 40%) when compared to the Base scenario.

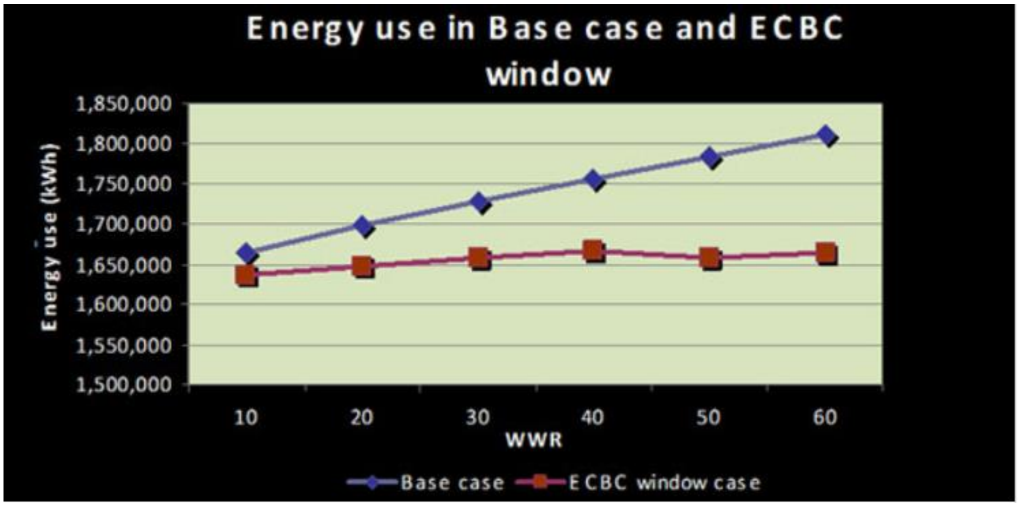

Figure 3: Energy consumption for Base case and ECBC Window Case (WWR 40%) (Ministry of Power, 2017)

Colour of External Surfaces

The use of suitable colours on the outside surfaces of buildings can alter the rate at which solar radiation is received or blocked. Several studies investigated the association between different forms of colour coverings for exterior surfaces and changes in building energy usage.

External Shading Devices

The primary purpose of a shade system is to protect the transparent areas of a structure from harmful sun radiation. Fixed shading systems, moveable shading systems, and other shading systems are three different types of shading systems. By intercepting incoming daylights, a shading device can alter the building's energy use (Bansal N. K., 1988).

CLIMATIC ZONES	REQUIREMENTS
Hot and Dry	Complete year round shading
Warm and humid	Complete year round shading, but design should be made such that ventilation is not affected
Temperate	Complete year round shading but only during major sunshine hours
Cold and cloudy	No shading
Cold and sunny	Shading during summer months only
Composite	Shading during summer months only

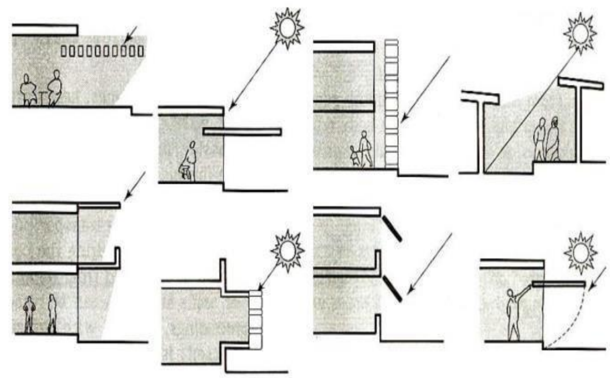

Figure 4: Criteria of Shading for Various Climatic Zones & Different type of shading devices (Bansal N. K., 1988)

Building Orientation

It has an impact on the quantity of sunlight falling on surfaces, daylighting, and wind direction. By utilizing the sun and prevailing winds to our advantage, form and orientation have a substantial influence on a building's energy efficiency. The orientation of the built-form is an important architectural concern, especially in terms of solar radiation and wind. The major orientation of a structure is determined by the sun light route method, which guarantees that natural sunshine resources are used to process daylight, passive solar energy heating, and solar electric power generation.

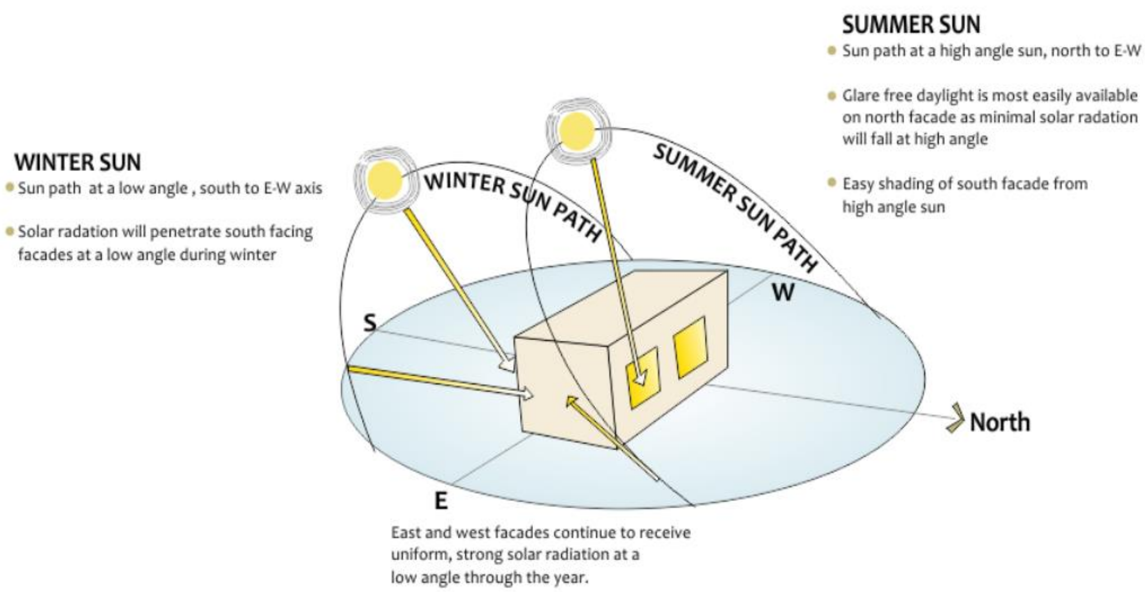

Figure 5: Building orientation as per site condition

The design of a building varies depending on its location and environment. The essential idea, however, remains the same: maximize sun radiation in the winter and minimize it in the summer. Buildings in mostly hot locations should be positioned to minimize solar gains, whereas buildings in predominantly cold regions should be directed to maximize solar benefits.

CONCLUSION

Various strategies have been presented in recent decades to address this problem. To regulate the rising trend of energy consumption in the building industry, several policies have been devised alongside the advancement of new technology. One of these options has been to use passive techniques when developing energy efficient buildings. The basic goal of passive construction is to achieve comfort without the use of a separate active heating system. Passive structures are capable of meeting the lowest energy requirements by finding a balance between heat losses and gains in relation to the climatic condition. Different components of building design, such as thermal insulation, thermal mass, glazing, window size, shape, and location, colour of exterior surfaces, external shading devices, building orientation, and structure form, should all be considered when creating a passive building.

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