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Research Article

Building Solar Shading

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ABSTRACT

This paper proposes a novel approach to building solar shading, aiming to reduce energy consumption by up to one-third (E/3 model). Through a comprehensive literature review, this paper explores passive solar building designs that maximize thermal comfort while minimizing auxiliary power needs. The methodology involves reviewing existing literature, designing a potential building skin model for buildings, and exploring further actions needed to complete a specific design. This research addresses concerns about investment cost and payback period for environment-friendly net-zero houses, aiming to retrofit existing architectures and promote sustainability.

Keywords: Building solar shading, Energy efficiency, Passive solar buildings, Sustainability, Building skins

1. Introduction

In today's world, we all seek more energy efficiency, and we must. We have relied on fossil fuel for so long, not thinking about the dire consequences of the eventual depletion of fossil fuel supplies. This is one of the cultural constraints M. King Hubbert, a famous geologist, mentioned when he predicted in 1962 that the oil and natural gas production of the United States of America would peak in 1967[1]. Exponential production of oil and natural gas fostered extravagant energy consumption, believing that exponential production would persist forever. The second constraint Hubbert described has to do with bell curve behavior. Once the resource has been discovered, the production will first grow exponentially, then peak, and afterward, it will decline exponentially, too, making a symmetrical production curve[1]. Since we have already peaked, we need to be more careful and focus more on energy-efficient designs and non-carbon energy sources. Most important is a focus on energy-efficient designs since it will have more impact, specifically regarding the design of the building itself. There are buildings everywhere. From the Empire State Building to Eiffel Tower to Burj Khalifa- they all consume energy. We need to understand the importance of reducing the large consumption of energy by buildings.

When we are talking about building thermal control, one question that arises is why do we need to develop thermal management? Because the outside environment is always changing. Sometimes it is too hot outside, and sometimes it is too cold out, and people inside the building need to be in a specific temperature range to be at comfort. This need points to the importance of thermal control. A building is thermally controlled if it can heat or cool the internal environment to maintain comfort. Now, how can we define comfort? It has two factors- one is humidity, and the other is temperature. To be in an allowed range of humidity and temperature, we use sophisticated technologies such as air conditioners and heaters. However, these technologies generally consume carbon-based resources, i.e., active technologies with a significant amount of carbon footprint. In 2019, the total utility-scale electricity generation in the U.S.A. was about 4,118 billion kilowatt-hours of electricity, and 63% of the electricity generation was from carbon-based sources[2]. Also, in 2018 commercial and residential buildings accounted for forty percent (40 quadrillion British thermal units) of the total energy consumption of the U.S.A[3]. So we can connect the information and see that the building is leaving a significant amount of carbon footprint.

We are not currently making use of smart energy-efficient building design. Historically, some buildings were built in harmony with the environment to decrease the use of energy. But nowadays, we apply the same model of building design at every location regardless of the environmental surroundings. We compensate for inefficient building designs by supplying high amounts of external energy to the building. Thus, we are increasing our carbon footprint. Due to using high amounts of energy through fossil fuels, we face global warming. The consequences of global warming that many believe will occur during this century are severe, such as 1) Approximately half of the habitat that supports fish in Ohio and nationwide will no longer survive by the time we reach 2100 because of rising water temperatures and more extreme storms caused by climate change[4]. 2) In India, summer days exceeding 95 F (with high humidity levels) result in a skyrocketing mortality rate, which is 5 (currently) to 75 (predicted by the end of the century)[5]. 3) Projections from research suggest a reduction in rainfall in the subtropics, and an increase in precipitation in sub-polar latitudes and some equatorial regions, i.e., dry areas at present will, in general, become even more dehydrated. In contrast, areas that are currently wet will, in general, become even more humid[6]. Most of the world will increase 16-24% in heavy precipitation intensity by 2100[7]. 4) Sea level rise of three meters could be a reality by the end of the century. Rising sea levels can put millions of people at risk in low-lying coastal areas in countries such as China, Bangladesh, India, and Vietnam[8] . Buildings are responsible for contributing nearly 70 percent to the city's carbon emissions through their high demands for heating, cooling, ventilation, and air conditioning, especially older structures that are inefficient due to either poor insulation or window design[9]. There are two effective ways in which we can decrease carbon footprint: 1) We must rely less on fossil fuel and use more renewable energy; 2) Energy Efficient design and implementation also helps in reducing carbon dioxide levels in the atmosphere as well as saving a lot of energy which would otherwise be used by burning fossil fuels.

A good building design's characteristic quality is that the building needs to accept solar heat in winter and reject solar heat during summer months. Historical buildings utilized solar resources in this way. For example, the Newgrange World Heritage site (Ireland) was built in 3000 BC. It was so designed that on the winter solstice (December 22) at noon, the sunlight comes inside the structure and illuminates it[10]. Even in Ancient Greece around 400 BCE, Aristotle postulated, in houses with a south aspect, the sun's rays penetrate 5 the entrances in the wintertime, but in the summertime, the path of the sun is right above the heads and above the roofs, so there is the shade[11]. Also, we have excellent examples of the building by the Pueblo and Anasazi. They built houses at a certain height in the mountains to get shading in summer and sun in winter[12].

Most buildings that will exist by 2030 have already been built. So if we want to reduce energy consumption on buildings, we have to retrofit the existing building. Retrofits are an essential thing if we are going to make all buildings energy efficient. Building energy efficiency retrofit refers to changing existing facilities with innovative and efficient technologies in building envelope, energy systems, lighting, and other electrical appliances. In this area, researchers mainly focus on modeling and planning for providing stakeholders guidelines for real-world projects. Technologies that can be easily installed on existing buildings must be developed[13].

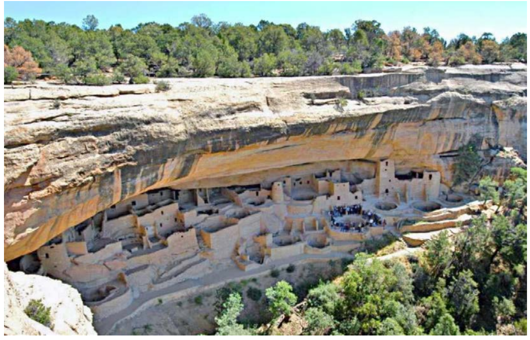

Figure 1: Cliff Palace, Mesa Verde National Park[12].

It is fascinating to ponder whether the building shell can adjust to solar heat loads. To find a building shell set at an optimum angle would conserve a significant amount of energy. Building skins that can adapt themselves using actuators according to the sun's location will be much more optimum but expensive. To this effect, this paper proposes a passive solar technology- a building shell to maximize absorption in summer and reflection in winter to reduce building carbon footprint. The proposed solution can be implemented for buildings in Dayton, Ohio.

Conventionally, a building envelope has been considered a thermal barrier to prevent heat loss or shade to control solar gain. Most of the building envelopes are constructed to provide static design solutions, and conventional solutions for building envelopes could not also adapt to contextual issues and needs. It was found that most dynamic systems utilize mechanical actuators that require maintenance and consequently increase their susceptibility to failure. As a result, a new system should be developed for future adaptive building skins. This is the need of the hour that can be addressed by proposing a passive solar technology to adjust building solar energy absorption. To optimize the building energy saving in a building that already exists, there is a need of a design solution for the building that can be easily retrofitted without much cost damage. **Figure 2** shows plausible passive solar building skin model design with different plausible orientation angles for different weather conditions.

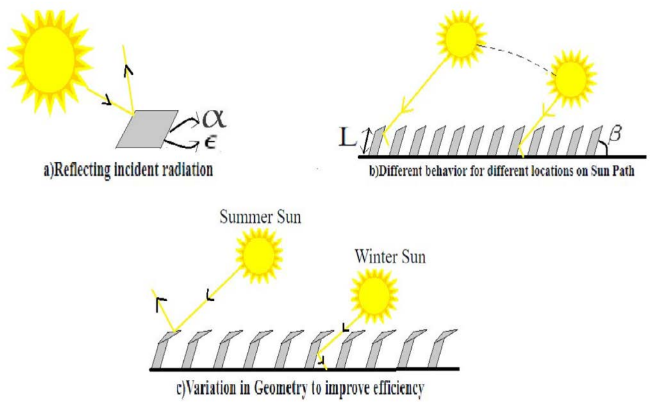

Figure 2: Passive Building Skin Model.

2. Technology Analysis

Passive solar technologies use sunlight with no active mechanical systems. Such technologies convert sunlight into useful heat (in water, air, and thermal mass), cause air-movement for ventilating, or future use, with little help from other energy sources. Passive solar technologies have both direct and indirect solar gain for space heating, solar water heating systems based on the thermosiphon, thermal mass use, phase-change materials for slowing indoor air temperature swings, and solar cookers solar chimney for enhancing natural ventilation and earth sheltering.

Several technologies currently exist or are in development that utilizes the idea of solar building designs. This paper is proposing passive solar skin technology, but other technologies can also reduce the building's energy consumption. Achieving an optimized cost/performance solution requires careful, holistic, system integration engineering of these scientific principles. Modern refinements through computer modeling and the application of lessons learned after the 1970s energy crisis can achieve significant energy savings and reduce environmental damage without sacrificing functionality or aesthetics. Passive-solar design features like greenhouse and solarium can effectively enhance the livability, daylight, views, and value of a building at a low cost per unit of space. The top three developed techniques in the published literature include Kinetic Solar skin, Dynamic Shading, and Biomimicry.

A. Kinetic Solar Skin

As the name suggests, kinetic solar skin adjusts its shape dynamically rather than maintaining a fixed shape so that there is movement on the building surface. This kinetic facade is used to 7 manage light, air, and energy information. It can act to reduce solar gain and allow the passage of fresh air into the building, helping to alter the interior environment [14]. Kinetic Solar Skin utilizes origami concepts, as shown in the below image. It is different from my proposed solution because my project is about static technology, whereas, in this case, the building skins would be moving. This is an active technology with actuators and motor mechanisms for its skin to follow the sun's path and adjust its orientation according to location and weather. It can be designed to be more effective than our passive technology, but the only obvious drawback is that of practicality. A multiple-actuator mechanism would have many problematic issues like money-saving vs. money invested, its protection from bad weather conditions like rain and snow, and the skill required to install them.

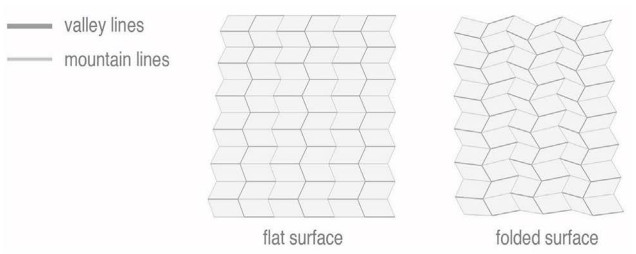

Figure 3: Kinetic Solar Skin utilizing origami concepts[14].

B. Dynamic Solar Shading

This technique only focuses on the heat transfer that takes place through windows. However, in this project, it can work on heat transfer through the medium of roofs and walls. As the name suggests, the technology is about dynamic windows shading according to the outside environment to accomplish the defined comfortable environment inside the office or residential building[15]. It will work on some algorithms and would be automatic rather than manually controlled. It can be defined as an intelligent system that calculates the amount of shading needed to achieve the required temperature and lighting level. It automatically shades that much. It is an exciting idea if we want to deal with heat transfer taking place through the window.

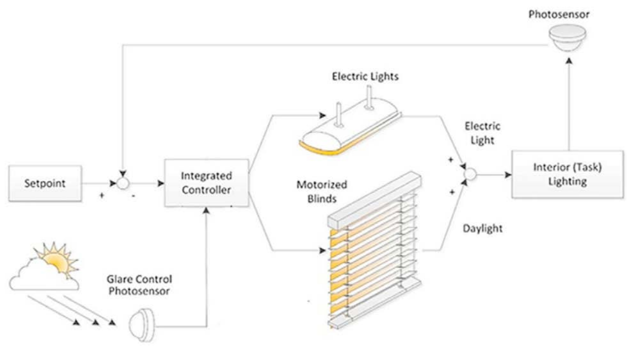

Figure 4: Integrated lighting and shading control systems[16].

C. Biomimicry

Biomimicry is the process of learning from biological environments and implements what is known in our real-life solutions. If we look at our problem statement, it deals with building skin design. So one might wonder, are there any designs available in nature which we can profitably learn from. This is the question of biomimicry, and it has inspired many solutions to engineering problems for over thirty years. If one looks at the resemblance between the problem statement and nature, they will see that building skin is like natural skin as it consists of various filters and layers that react to light, air, moisture, sound, and heat[17]. The building skin, identical to natural skin, is the boundary of the controlled and uncontrolled environment. They both should act as filtration in the process of allowing what is allowed to enter and exit[17]. For example, The Council House 2 building in Melbourne has been inspired by a tree's design. It offers fully filtered air, saving natural lighting and ventilation cost by sixty-five percent, and has shading mechanisms for visual comfort[17].

Figure 5: Council House 2 building in Melbourne[17].

3. Passive Solar Building Skins implementation

Usually, Passive solar systems don't have a large investment cost or long payback period, which can be seen in active solar heating systems. Increased user comfort is another benefit of passive solar heating[18].

Technically, Passive solar heating is highly efficient. Direct-gain systems can utilize (i.e., convert into "useful" heat) 65-70% of solar radiation energy that strikes the aperture or collector. Passive solar fraction (PSF) is the percentage of the required heat load met by Passive solar heating and represents a potential reduction in heating costs. RETScreen International has reported a PSF of 20-50%. Within sustainability, energy conservation, even of the order of 15%, is considered substantial. Other sources say the following PSFs: 5-25% for modest systems, 40% for "highly optimized" systems, Up to 75% for "very intense"[19].

4. Conclusion

This paper proposes a passive solar building skin model to solve the massive amount of external energy that is supplied to the building to compensate for their inefficient design, not following the location and weather conditions. To develop an efficient passive building skins model, various geometric variations can be considered for an optimum inclination angle. This research can be continued to develop a mathematical model in which the inputs are emissivity of the material used to make the panel, the panel's length, the panel's thickness, and The Angle of inclination. This model's desired output should include heat absorption and reflection of summer and winter seasons. It can help find the optimum angle at which there is maximum summer reflection and winter absorption. This can be the objective function = [(heat absorbed in summer)/(heat absorbed in winter)]. The model should minimize the value of this objective function to find the optimum angle of inclination. This can either be done in Python or Matlab. The heat transfer model should consider diffuse and direct energy and how they are absorbed.

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