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Environmental Control System (ECS): A Review of the Effectiveness of Shading Devices as Environmental Control System's Component in Enhancing Thermal Comfort in Buildings

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Abstract

Environmental Control System is a means for achieving comfort in the design of the environment. Architecture stand out as one of the systems, as architecture provides for creation of thermally comfortable indoors and radiation is a known element working against the noble attainment of architectural goals towards thermal comfort in buildings. Radiation which is experienced as heat transfer from zone of higher temperature to areas of lower temperature is the major cause of heating up of indoor spaces in buildings. When indoor spaces of buildings heats up, it causes thermal discomfort and will require cooling to return to comfort zone. Cooling consumes energy and energy is scares and expensive. Besides the thermal discomfort, and cooling cost, Ultra Violet (UV} radiations are known to cause skin cancer. This paper reviewed shading devices with an aim of pinning down how effective they are in enhancing thermal comfort in buildings. It noted shading devices could be external or internal, fixed or movable, and to cover a range that include, overhangs, fins, awnings, sun breakers, blinds and curtains, landscape features like trees, lawns. It was found that good application of shading devices lowers the temperature of the indoor spaces of a building as well as the cooling load and cost appreciably. Effective shading can block 80% of sun's ray into a building interior, 75% of UV rays and reduce up to 30% air conditioning cooling load. The paper affirmed that when effectively applied that shading devices are effective in enhancing thermal comfort in buildings and strongly recommend that architects specify them as a passive measure of enhancing thermal comfort in buildings. The paper concluded by requesting architects to understand the climate prevailing in their project areas and specify on design inception the volume and kind of shading their projects will be needing.

Keywords: *Environmental control system, Shading devices, Radiation, Thermal comfort, and Energy efficiency*

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Background to the Study

For effective heating and cooling loads in buildings, principal concern should be paid to non-mechanical or passive means of providing environmental control. Perhaps it is more appropriate to call the system architectural means of environmental control, these methods do not consume energy in their operations even though energy is probably consumed in their construction. The need for proper analysis of the potential heat loss and heat gain in buildings must be underscored, this is because it not only indicates the heating and cooling loads that will exist, it also provides information that is necessary in creating functional architectural designs. An understanding of the thermal performance of buildings, helps the architect and other environmental engineers in providing efficient massing and also in developing environmental responsive fenestration designs. It necessitates therefore the proper options for sustainable materials and supports efficient construction process, and The systems used to control the interior thermal environment are logically called Environmental Control System (ECS). These systems are generally assumed to be technical or mechanical systems that entail some form of energy consumption for them to provide Heating, Ventilation and Air conditioning (HVAC). Architecture belongs to these systems known as environmental control system.

Therefore, it should be acceptable then that environmental design is the principal umbrella that encompasses both architecture and mechanical systems. In clearer terms, environmental design is concerned with the modification of the physical environment in order to support habitation. This modification which should be done in a sustainable, manner should be both responsive to and expressive of the nature of the habitation to be accommodated. The basic design of ECS includes the modification of the physical environments integral architectural components and an understanding of how the structure of the building fulfills the need of thermally modifying the physical environment. It also explains the effects of employing non mechanical devices in the control of the environment.

Shading is a non-mechanical Environmental Control Systems (ECS) component; this paper therefore reviews the potentials of shading devices as environmental control systems (ECS) component, which is employed in achieving indoor thermal comfort in buildings, and in the reduction of cooling and heating cost in buildings.

Most buildings in the tropical environments gain heat during summer. Heat gain into the interior of buildings increases the indoor temperature, and creates discomfort (Alozie, 2014). The discomfort resulting from the heat gain in return requires cooling and as rightly noted by Botkin and Keller (1998), cooling and heating spaces require energy, which is scarce and expensive. Heat gain into buildings is in form of radiation, that passes through openings such as windows. Radiation is part of the science of thermo-dynamics which Bradshaw (2006) defined as the study of the branch of science that deals with the relationship between heat and other forms of energy including heat transfer and psychometrics.

In radiation which is heat transfer, the internal energy or molecules of vibrations set-up electromagnetic waves that emanate from warm objects and carry energy to all bodies within a direct line of site, then the electromagnetic waves excite the molecules of the receiving bodies and thereby increase their internal energy. Familiar examples of radiant heat transfer are the sun's rays and hot coals of fire. (Bradshaw, 2006). According to Alozie (2014) one way we experience radiation is when sunshine travels through space and through our atmosphere. Alozie (2004) However noted that in solar gain into buildings, that it is radiation that causes the increase in indoor temperature due to the heat gain especially during summer and clearly stated that to remove or reduce the heat gained requires money.

Alozie (2014) is rightly supported by noted by Bradshaw (2006) who inferred that solar radiation through glazed envelope of a building may have serious effect on thermal comfort in the indoor spaces. They all confirmed that solar radiation heats up the interior spaces in our buildings and, thus contribute significantly to the cooling load especially during summer, but have positive effect in winter. Glazed facades facing south-west are vulnerable to overheating and causing discomfort (Alozie, Odim and Alozie 2016). This situation therefore requires suitable shading strategy to help reduce the cooling load. (Bunning and Crawford 2016). Hee, Alghol, Bakhtyar Elayeb, Shameri, Alrubaish and Sopian (2015) however underscored the adoption of smart dynamic glazing as a strategy to control solar gain in buildings, Accordingly Hee et al, (2015) explained the term smart as glass that can switch its optical properties when needed triggered by voltage pulse (electromagnetic glazing) or a high temperature (thermochronic glazing). This allows the building shell to be adaptive to climate that is, to admit solar energy only if there is a heating or daylight demand. (Baetens, Jelle and Gustaren 2010). Smart glasses can prevent thermal discomfort and provide huge energy saving for space cooling. (Costanzo, Erola and Marletta 2016). Although this technology is beautiful, it is however, and mechanically driven, that means it consumes energy and expensive.

This paper prefers passive strategies as an option to smart dynamic glazing, not only because of the cost of its procurement, and operation, but also due to the fact that a static reflected glazing can reduce solar gains, but cannot modify its properties when more oncoming radiation is needed as noted by Costanzo et al, (2016).

This paper reviewed literature of the keywords such as shading devices, thermal comfort, energy efficiency, radiation as environmental control system component to uncover the effectiveness of shading devices in enhancing thermal comfort in buildings.

Shading and Shading Devices

Shading in buildings is the practice of limiting or stopping completely the sun radiation from evading and increasing the temperature of indoor spaces of buildings (Alozie, 2014). This is necessary because when radiation gains entrance into the indoor environment of buildings, it increases the temperature thereby causing discomfort especially during summer. Appropriate shading helps in reducing unwanted heat gain, especially through unprotected glass, which are the greatest source of heat entering into indoor spaces in buildings. Shading can be in form of fixed or movable devices. Shading devices include roof eaves, awnings, fins, blinds, trees in vegetation and reflective glass. Shading is of very vital importance in building for reasons that include preventing the infiltration of sun rays into the building interior to which causes thermal discomfort to protection of the body from skin cancer which is caused by UV radiations. UV radiations unlike infrared rays are invincible to the eyes and cannot be physically felt. (Thursfield and Farrugai 2015). Both inferred that most cases of skin cancer are preventable and that shading is one of the best and easiest ways to protect against UV radiations. According to Parson et al, (1998) good quality shade can reduce UV exposure by 75%. Accordingly, National Heart Foundation of Australia recommends the provision of shades as an important component in the design and creation of safe and healthy communities. UV radiation gains admittance into building's interior through windows, and similar openings on the walls of the building facades. Shading therefore comes handy in removing this unwanted admission.

Types of Shading Devices

1. **External**

External shading device is any shading application that takes place outside the building, and not inside. External shading devices such as roof eaves, awning, verandahs, trees in the vegetation, fins, overhangs and reflective glass play critical role in reducing unwanted solar heat gain, especially in cooling dominant climates during summer. Shading devices work firstly by restricting unwanted direct heating of walls. External shading devices are the most effective way to control solar heat gain, into building spaces. (Alozie, 2014)

Passive architectural design practices in heating dominant climate zones relies on maximizing solar heat gain from north, east and west facades to block out unwanted heat in summer. For north facing facades, shading can successfully be achieved with eaves or fixed horizontal overhangs at the top of the wall or windows. The short eaves block out the sunlight in summer due to its more vertical angle of incidence.

The eastern and western facades of a building receive large amounts of sunlight in the early morning and late afternoon respectively, and therefore are more suited to adjustable shading devices such as awning, roller shutters, and louvers. In like manner heating dominant climates adjustable shading also allow for full solar gain on eastern and western windows during winter, while in cooling dominant climates, at low latitudes, (tropical and hot and dry) full shading, where practical where possible is require on all sides of building facades to minimize heat gain at all times. This could be achieved with, verandahs, deep overhangs and fixed awnings. External shading devices provide the following benefits;(i) Reduces peak cooling requirements, with annual cooling energy savings of about 15%. (ii)Reduces glare and improves visual comfort which leads to increased satisfaction and productivity.

2. **Sun Breakers**

Sun breaker system, is highly efficient external shading system, which can serve a decorative part of the building. Sun breakers are mobile system with a blade rotation range from 0 to 90 degrees. It can be fixed both horizontally and vertically. It is a perfect way of making a building more architecturally attractive and for reducing energy consumption from air conditioning. Using sun breakers can significantly improve the energy balance of the building. Optimally designed solutions allow the stoppage of 80% of sunlight, thereby allowing reduction of energy consumption from air conditioning even up to 30%.

Solar control and shading can be provided by a wide range of building components installed outside the building and may include, External elements such as overhangs or vertical fins. Landscape features, such as mature trees, hedges, lawns, low shading coefficient (SC) glass and horizontal reflecting surfaces called light shelves.

3. Vegetation (trees, lawns and hedge)

The vegetation is an intermediate layer between the surface of the earth and the atmosphere above. It gives protection against solar radiation and glare. Heating of earth's surface around a building due to solar radiation can be checked to some extent by planning suitable lawns and other kinds of vegetation. Foliage trees planted around a building should be in such a manner that the required shade at required time is obtained with minimum obstruction to the circulation of air. Also they should provide shade in summer and should not obstruct the sun's ray in winter. Deciduous trees also known as broad leaved trees serve this purpose well as their leaves fall in autumn and new ones appear in spring season. Such trees can be provided on west and south sides of the building, on which the solar radiation is more. (Rao 2007). Carefully selected trees can cool an area by reducing the air temperature in summer by 30%.

The subject of shading in buildings may keep unfolding new ideas especially with the trending sensitive topics of global warming and climate change. However, the contributions of scholars like Palomo and Bano (1998), and, Lechner (1991), Chandra, Fairey and Houston (1983). Chandra et al, (1983), in support of others authors on the same subject of shading, fancies the use of trees, climbers, high shrubs and pergolas. Both noted that trees, climbers and high shrubs could provide effective shading for the buildings walls and windows, and that ground cover plants also reduces reflected solar radiation and long wave radiation emitted towards buildings, thus reduces solar and longwave heat gains They concluded that the average temperature of the shaded area could be reduced by 5- 15 degrees less than that of un shaded area. Lechner (1991), and Parker (1995), recommended that the use of roof garden in helping to the indoor attain temperature of 10 – 30 degrees Celsius below that of an exposed roof surface depending on the roof construction, planting details and surrounding conditions. Both authors agree that to compliment indoor comfort in buildings quantitative planting principle should be developed to help optimize the cooling effect of vegetation especially when used in conjunction with, and in place of conventional shading devices and insulation, however both warned that attention be paid to balancing the benefits from temperature reduction with adverse effects from increased humidity due to the evaporation process, especially that when plants are grown near ventilation inlets, that optimization of local plants be explored.

Thermal comfort

Alozie, Odim and Ehibudu (2016) believes the need for thermal comfort studies is evidenced in various styles of shelter and their building materials of various traditions around the earth. In defining thermal comfort the trio adopted both ISO 7730 standard and American Society for Heating, Refrigerating and Air conditioning Engineers. ASHRAE (2004) definitions. ISO 7730 standard defined thermal comfort as that condition of mind which expresses satisfaction with the thermal environment. ASHRAE (2004) however appear more detailed having provided a measurement for evaluation. ASHRAE (2004) defined thermal comfort as the express satisfaction within the thermal environment, in which at least 80% of sedentary or slightly active persons find their environment thermally acceptable.

Thermal comfort is necessarily an issue of concern to all, because studies have unveiled salient reasons for clothing and shelter in response to attainment of thermal comfort equilibrium between human body and ambient air temperature. This quest by the human body philosophy (thermoregulatory mechanism) is influenced by several factors such as air temperature, the mean radiant temperature, the air velocity, relative humidity, the intrinsic clothing and activity rate. The survival of the human body will depend on tolerable range of acceptable limit of temperature (thermal balance) between the body temperature, skin temperature and ambient air temperature. Where this is not achieved, physiological fatigue, fainting, and eventually death will occur (Alozie, et al 2016).

Among the principal causes of discomfort in buildings is radiation. Radiation in buildings increases the indoor temperature and this brings about discomfort. Shading of appropriately radiation rays reduces or removes completely this unwanted heating of the building indoor spaces.

Energy Efficiency

Efficient energy use, also known as energy efficiency is the goal to reduce the amount of energy required to provide products and services. For example, insulating a home allows a building to use less heating and cooling energy to achieve and maintain a comfortable temperature. Installing LED lighting, fluorescent lighting, or natural skylight window reduces the amount of required energy to attain the same level of illumination compared to using traditional incandescent light bulbs. Improvement in energy efficiency are generally achieved by adopting a more efficient technology or production process by application of commonly accepted methods to reduce losses (Alozie, Odim and Ehibudu 2016)

There are many motivations to improve energy efficiency. Reducing energy use reduces energy cost and may result in a financial cost saving to consumers. Reducing energy use is also seen as a solution to the problem of reducing greenhouse gas emissions. According to International Energy Agency IEA, improved energy efficiency in buildings, industrial process and transportation could reduce the world's energy needs in 2050 by one third, and help control global emission of greenhouse gases (Botkin and Keller 1998). Another important solution is to remove government – led energy subsidies that promote high energy consumption and inefficient energy use in more than half of the countries in the world. (Botkin and Keller 1998). Energy efficiency and renewable energy are said to be the twin pillars of sustainable energy policy. (Spence 2004) and are high priorities in the sustainable energy hierarchy. In many countries energy efficiency is also seen to have a national security benefit because it can be used to reduce the level of energy imports from foreign countries and may also slow down the at which domestic energy resources are depleted. Energy efficiency is indeed the first fuel to sustainable global energy system, as it can mitigate climate change, and improve energy security and grow economies, while delivering environmental and social benefits. (Spence 2004).

Most energy need in tropical homes is for cooling, a situational need prompted the influx of sun rays in form of radiation into building interiors. Radiation on entering the building interior, raises its temperature and since radiation travels through known medium and routes, it becomes easy to block, limit or redirect its routes. Shading with devices could be an integral of the Environmental Control System to addressing the problem of radiation into building's interior.

Understanding how Shading Devices work

It becomes necessary at this point in study to understand that the success attained in the employment of shading devices as a component of environmental control system lies on its application. In order to ascertain success in the application of shading devices therefore it is pertinent that the paper outlines how to do this, and at the same time pin down the advantages and disadvantages if any of applying shading devices in pursuit of thermal comfort in buildings.

Window Shading for Cooling

Shading windows in the summer to prevent excessive solar gain can greatly reduce overheating in buildings and cut air conditioning bills, or even eliminate the need for air conditioning in some climates. A window opening with an area of 100 square feet facing east can gain over 100,000 BTU on a sunny summer day, this is like running the furnace for couple of hours, which obviously results in overheating, high air-conditioning bills and high greenhouse gas emission. https://builditsolar.com/Projects/Cooling/Shading/Shading.htm.

In practice windows that faces south could be shared with overhangs, this will block the higher summer sun, but in winter climates, allows the low winter sun to shine in and provide passive solar heating when desired. Overhangs do not work for east or west facing windows, since the sun is low in the sky when shinning on the east and faces the house. External shading devices work best for east and west exposures. Inside shading devices are not as effective as external shading, but could still be helpful. Internal shades that are reflective on the outside surface will be most effective as they reflect some of the sun right back, out the window http://builitsolar.com/Project/Cooling/Shading/Shading.htm.For some areas that have hot days but somewhat cooler nights, a combination of reduction in heat gain during the day coupled with ventilation at night can reduce or even eliminate the need for air conditioning. Shading can be a big part of reducing the daytime heat gains.

Overhangs

Awell designed overhang can shade south facing windows from the high summer sun, while still allowing the low winter sun to shine in and provide welcome solar heating. Overhangs are not effective on the east or west facing windows because the sun is too low in the morning and afternoon. For an overhang to provide any effective shade, the overhang for south facing windows can be incorporated in the eaves overhang, or be a separate overhang or awning just over the window areas. It should be noted that overhangs on south facing windows are only effective in blocking direct sun. Overhangs are quite helpful however they still allow about 50%

of the solar radiation. This implies that that another design which makes use of sun blocking solar screens or trellis or landscaping may become effective than overhangs. A combination of the two may however produce better results.

Trellis

An exterior vertical trellis works well for shading east or west facing windows, and preventing excessive solar gain. These windows cannot be shaded by overhangs because the sun is low in the sky when shinning on east and west sides of the building. Plants growing on the trellis can provide some additional shading in the summer and allow more sun during the winter when it is desirable. A large trellis can cool an entire wall and windows and still reduce heat gain.

Trees

Trees work well to provide shading for windows on all exposures. In most climates, the leaves fall off in winter to provide welcome sunshine and solar gain. Large trees can also shade full walls, which can reduce the outside wall temperature from 60 degrees' Celsius range to a temperature that is more like air temperature, the heat transmission through the wall, which depends on the difference between the inside and outside wall temperatures is correspondingly reduced. Reflective walls can also help. Evergreen trees can also provide wind protection from cold winter winds.

Landscaping

Landscaping is an effective and pleasant means of providing shading for buildings. An effectively planned landscape will block out the hot summer sun, encourage warming sun to enter into buildings in winter, deflect the cold winter winds and channel breezes for cooling summer. An ideal landscape will plan for trees to be planted the east and west of the buildings to provide summer shading, with the south left relatively clear in order to allow solar heating in winter. Trees will be most effective if they shade east and west windows, where most heat enter, but shading east and west walls and the roof is also important. Even trees which do not directly shade the building, such as those planted to its north are valuable because they reduce the temperature of the air surrounding the building.

External Shades

External rollup shades made from a shade cloth material (as is used in green houses) can block a high percentage of the sunlight while allowing some useful daylight to enter the room. Such shade cloth can be ordered in various grades that block different amounts of sunlight. Awnings either fixed or movable are also very effective for blocking unwanted sun.

Inside Shading and Reflective Window Films

Inside shades are the least effective way to block unwanted solar gain through windows, since the sun has already penetrated the window before it gets to the shade, but they can still be effective. To be most effective the face of the blind that faces out should be as reflective as possible to reflect as much as possible back to the window. Blinds that fit fairly tightly and minimize air circulation behind blind are also more effective. Reflective window films can be applied to inside pane of glass. These films reflect and / or absorb some of the solar energy, resulting in less heat gain into the building.

Windows

Windows can be designed to absorb a high fraction of solar energy, and this helps to reduce solar heat gain. The SHGC (Solar Heat Gain Coefficient) is the fraction of solar heat transmitted through the window. For new windows, the Solar Heat Gain Coefficient (SHGC) will be marked on the window. For climates where heating bills are low and cooling bills high, windows with low SHGC's are preferred to cut down on summer solar heat gain. The low SHGC does not have the negative effect of reducing winter time passive solar heating.

Conclusion

The system used to control the thermal environment is known as Environmental Control System, (ECS). This system is generally assumed to be mechanical or technical, that is, entails some form of energy for them to provide Heating, Ventilation, and Air conditioning (HVAC). This process covers architectural production. As a matter of fact, architecture is said to be the first amongst the process. ECS also explains the effects of employing non mechanical devices in the control of the environment.

For effective heating and cooling loads in buildings, the principal concern of the architect and developers, should be non-mechanical or passive environmental control system means. Shading is a non-mechanical, energy efficient environmental control system tool, in the hands of the architect, with which he could effectively employ in enhancing thermal comfort in buildings. Amongst the principal causes for shading in buildings is heat gain from radiation. Radiation which is heat transfer into buildings, increase the temperature in the building spaces. This gained temperature requires cooling to get back to the comfort zone. (Bradshaw, 2006, Alozie, 2014).

The architect need to understand the thermal performance of buildings in order to design responsively to control the excesses that climate might impose on him. A major means by which the architect can enhance thermal comfort in his buildings is underscoring the need to accommodate the nature of heat transfer in his environment

In view of the need for the architect to accommodate the nature of heat transfer in his environments, and in the content of energy efficiency it becomes pertinent that the architect embraces the potentials of passive architectural design or non-mechanical option of achieving thermal comfort. Shading as earlier projected in Alozie, (2014), as the practice of blocking off unwanted sun rays from entering into the interior of buildings presents the passive architectural solutions to that challenge Passive energy measures have are zero energy measures, which is the energy required to enhance thermal comfort in buildings.

Thermal comfort, which earlier has been defined in ASHRAE (2004), as the express satisfaction within the thermal environment, in which at least 80% of the sedentary or slightly active persons find their environment thermally acceptable.

One factor that can prevent attainment of thermal comfort in any environment, especially during summer or radiation. Radiation has been severally linked with energy loads and cooling cost. The energy employed in cooling spaces which gained heat by radiation, as well be saved through the application of energy efficient architectural designs. Shading remains a major option and component of energy efficient architecture that could be applied to help enhance thermal comfort in our buildings.

Energy efficient building has been defined as the goal to reduce the amount of energy required to provide products and services, for example insulating a home allows a building to use less heating and cooling to achieve and maintain a comfortable temperature, just like installing LED lighting, fluorescent lighting or natural sky lighting window reduces the amount of required energy to attain the same level of illumination compared to using traditional incandescent light bulbs. Shading devices, work exactly like sky lighting windows, they provide services need for comfort at a zero energy cost. Therefore, shading is an integral part of energy efficient architecture.

One of the mechanical version of shading devices is the, Smart Dynamic Glazing. This technology is used in controlling solar gains, into buildings, although not popular due to its cost, it also has an inability to modify its properties when more incoming radiation is needed. Smart Dynamic Glazing has the ability of switching its optical properties when needed, and it is usually triggered by voltage pulse (elecomagnetic glazing) or high temperature (thermochronic glazing). This allows the building shell to be adaptive to climate that is to admit solar energy only if there is a heating need or day lighting demand. Although literature did not discuss the shading potentials of this technology if any, it still cannot be a part of recommendation of this review since the technology is energy driven.

The paper reviewed environmental control system, with interest on shading and how it could be employed to enhance thermal comfort in buildings. The paper traced the heat gain in building as resulting from radiation. Radiation brings thermal discomfort, cooling cost, UV radiation could cause skin cancer.

Among reasons for shading, are reduction or elimination of cooling loads, prevention of skin cancer and elimination of thermal discomfort. Radiation gain entry into buildings through unprotected glass and other openings on the wall of buildings and shading devices employed in controlling radiation may be fixed or movable.
Shading devices include, roof eaves, awnings, fins, blinds, or curtains, vegetation (trees, lawns and hedges), verandahs, sun breakers, and reflective glass.

It is interesting to know that shading could stop 75% of UVrays, reduce 15% of cooling energy load in buildings, reduce glare and improve satisfaction and productivity. Some shading devices, such as sun breakers also double as decorative objects for building facades. Depending on its design, sun breakers could block 80% of sunlight from gaining entrance into building interior and create a reduction of 30% c cooling cost of air conditioners.

Trees in landscape could reduce the air temperature by 30%. Nayak (1999) Palomo and Bano (1998) and Lechner (1991) in separate experimental results noted the difference in the temperature of building walls shaded by trees and the ones un shaded to be lower in the range of 5 to 15 degrees Celsius. Nayak (1999) also observed that the temperature of the building with roof garden was lower by a range of 10 to 30 degrees Celsius.

The paper established from literature, that the south need shading more than the south, strong recommendations from literature on planting trees on all sides of the buildings however exist. This is because trees do more than shading in the environment, they act as air filters.

In conclusion, the paper recommends that architects and all individuals, especially building developers, understand the prevailing climate in order to enable them design from inception the nature of shading and the kind of shading devices that will be best in enabling the enhancement of thermal comfort in buildings.

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