Framework for Heat Gain Minimization through Recessed Window Shading Façade

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ABSTRACT

External Sun shading strategy provide an opportunity for the architect to control natural lighting, ventilation, and solar gain, all of which provide a benefit to the overall building performance. The intensity of solar radiation on a building façade called for the use of strategies that will intercept its devastating effect before reaching the interior of the building. Due to some challenges encountered by some exterior shading devices, recessed window is confirmed to be one of the best form of shading as it is a form of self-shaded strategies. As the building's biggest heat directing surface, the façade which housed window has the greatest influence in minimizing the building's energy utilization. It is on this premise that this framework aimed at assessing the potentials of recessed window façade for heat gain reduction in the tropical buildings. The methodology used in this study focuses on an intensive review of previous studies and literatures. The paper verified from previous studies that the use of recessed window façade is preferred to other forms of external shading devices because of the problem of thermal bridges, thermal mass, etc. encouraged by most shading devices. It also finds out that, the dimensionless “depth” to which the window is recessed, \( R = r / L \) and is a very crucial formula amongst orders that determine the heat transfer rate in recessed window shadings.

INTRODUCTION

Global attention is now steering towards sustainability in building design and development. Efficient energy use is therefore one among the pedestals of a sustainable energy strategy [1, 2 & 3]. Energy efficiency in many countries is observed to have benefit in national security, because it can be used to minimize the level of energy import from other countries. Efficient energy consumption, aims at reducing the quantity of energy needed to produce goods and provide services. For instance, provision of insulation in a building helps to minimize the demand for heating or cooling of the building’s interior energy to achieve and maintain an acceptable thermal environment. The achievement of high energy efficiency can be generally adopted on one hand, by a more efficient technology or by processes of production [4]. On the other hand, by application of commonly accepted methods of minimising loss of energy [5]. One of the strategies for achieving energy efficiency in buildings is the minimization of heat gain using façade configurations [6] and visual comfort can still be achieved with optimizing recessed window [7]. Façade in architecture is one of the most crucial aspects in the beginning of a design, as it sets the tone for the rest of the building. From the engineering point of view, façade in the building is very much important because of its influence on energy efficiency [8 & 9]. The word façade emanated from the French word façade, from the face which means face or frontage. Dictionary defined façade as an exterior side of a building usually, but not limited to, the approach or front view. Façade can also serve as a side view or elevation of any building with its detail outlook. Previous study revealed that local zoning regulations or other laws highly restrict or even prohibit the alteration of façade because of the importance and historic nature of it.

The façade of a building is an aspect of the architectural idea behind a building which is perceived at first, and which, therefore, plays an important part in the architectural design [9].
Fig. 1: A typical high-rise recessed window facade office Building.

Fig. 2: Types of facade Shading Device as illustrated by Courseware Design tools NORMA are zero (0) to (3):
0 – None 1 - Recessed window 2 - Side Fins 3 - Overhang

Background:
In most industrialized nations, building structures is in charge of about 40—45% of the national overall energy utilization. Up to 2/3 of this energy is utilized for thermal controls: heating and air conditioning. The measure of energy required for HVAC depends all that much of the building's design, its thermal performance, its climatic suitability. An extra partition is required for lighting. Quite a bit of this energy needed can be minimized by proper design of openings, including solar control and shading devices. The two most essential climatic elements that impact the thermal conductivity of a building are air temperature and solar radiation (in spite of the fact that winds and humidity additionally have an impact). Solar radiation can bring about serious overheating in summer (now and again, even in winter), or it can increase the load on air conditioning, whilst it can be helpful in winter, decreasing the thermal necessity or possibly even dispose of the requirement for using so as to heat conventional types of energy. One of the first undertakings of an architect is to focus when sunlight based heat is important and when sun oriented radiation is to be avoided. The following step will then be to give the suitable solar control.

To achieve comfort in the interior of a building, it is necessary to either cool or heat the enclosure depending on the climate type, weather of the day, personal preferences and the season. There is a possibility to store excess heat in a building starting with one time. Then onto the next and consequently reduces its heating and/or cooling requests and, in the meantime, the indoor temperature varieties. How a significant part of the
surplus heat that can put away depends, also to other things, upon the warmth stockpiling limit of the building. The warmth limit of the indoor air is far not exactly the warmth limit of the material on the encompassing floor, dividers and roof. In this manner, the indoor air temperature changes more quickly than the temperature of the encompassing surfaces. The distinction in temperature will create a warm exchange that will hose the quick change of the indoor temperature. In structures, there is regularly an overflow of heat amid daytime because of sunlight based lighting, family machines and human movement. The indoor temperature increases because of the excess heat and hence the temperature of the building structure will likewise rise. Amid the night, the overflow of heat will be less, and the indoor temperature will diminish. The diminishing in indoor temperature will neutralize due to temperature of the building structure has now been higher than the indoor temperature. Heat exchanged from the building structure to the indoor air. Although View windows on façade could generate heat, but are important to façade [10].

Problems Statement:

Sustainable design is the biggest challenge facing the building and architectural industry today. Because of this, what the world is clamoring for now is an architectural-led sustainability invention and creativity in a variety of several dimensions [11].

Exterior shading devices are chosen as the best shading system because of their first hand blockage of direct solar heat radiation on buildings. However, significant numbers of these devices encounter serious challenges as they causes thermal bridging, negative thermal mass in the tropical climate, aesthetic façade distortion, structural failure due to wind load, etc. The best option for this challenge is to design the buildings to shade itself (Bülow-Hübe, & Lundgren, 2005, Elmroth, 2009, Heier, & Österbring, 2012). That is, the form of the building itself can be used for external shading. Among these self-shaded alternatives, are the use of deeply recessed windows to make the entire wall around the opening an effective shading device, minimizing solar heat gains without reducing natural light and view figure 3. Others are, a cantilevered floor can be used to shade windows on the level below it, Windows on the east and west facades can be oriented north or south for sun control (Wallentén, et al., 2000, Bülow-Hübe, 2001, Wall, et al.,2001) (figure 4.) and the use of inclined glass is effective in controlling the penetration of the solar radiation into the building by reducing the area of glass exposed to the sun. among these self-shaded

![Image](Fig. 3: deeply recessed windows of Students’ Center Building, Strathmore University, Nairobi Source: UN-Habitat / Jerusha Ngungai)
Strategies enumerated above, many studies have been carried out except the recessed window strategy whose study is not in-depth despite its contributions towards energy efficient buildings. This is why this study is exploring literatures, observations, figures and/or photographs to see the extent of contribution of recessed window shading façade and its parameters that enhances energy efficient buildings.

**AIM:**

The main goal of this research is to explore the existing studies on recessed window façade and the potentials of this shading strategy for heat gain reduction in the tropical buildings.

**Significance of The Study:**

The study will add to the existing body of knowledge that features and factors in a building design that relate to façade shadings. It will also inform how window recess shading devices affects heat gain, in this period of sustainable development. It will as well inform us on the design based type for heat gain and shading device of a building. Configured façade could be used to establish the concept of sustainability and green building.

**Method:**

The knowledge about past researches is very vital as it gives a guide for further studies (Webster & Watson, 2002). Therefore, the method adopted here is the use of a structured literature review that would enable identification of facts about the current study. Literature reviewed in this study can be classified as a scoping study (Arksey & O’malley, 2005), seeking for how far works has been carried out in the area of heat gain minimization through recessed window.

The searching design of literature is such that the keywords used in searching include: Recessed window AND thermal performance, shading AND devices, Heat transfer in buildings, SHGC and U-factor, Building AND tropical climate and finally Winter AND summer heat gain. The database used in this searching are: Elsevier Science Direct Scopus which is the second largest Database Scopus after SciVers Scopus Database (Merschbrock, & Munkvold, 2012) and Google Scholar. All the articles were assessed within the months of October and November, 2015 where 57 relevant articles and books were collected and only few that were not cited gave an inspiration of writing this piece of work.

The methodology limitation was the restrictions to publications from Database whose articles are in English Language only leaving other vital articles published in other languages. The conduct of this review include

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**Fig. 4:** Windows are deeply recessed and oriented north to prevent direct solar radiation Coca-Cola Building, Nairobi. Source: UN-Habitat / Jerusha Ngungui
Books and Journal articles that represents the area of this research. The complete articles and books are exported to a mendeley library for accurate and easy citations and references. In conclusion, the review of literature indicated that even though much works have been done in external shading strategies, little was specifically done in recessed window shading façade.

Result:

Tropical Climate:

The climates whose primary problem are heat is the tropical climate, where for most of the year structures serve to keep the tenants cool, instead of warmth. Where the yearly mean temperature is at least 20°C since a generous piece of the Sun's warmth is spent in dissipation and downpour arrangement, temperatures in the tropics once in a while surpass 35°C. A daytime greatest of 32°C is more basic. Around evening time, the inexhaustible shady confines heat misfortune, and least temperatures fall no lower than around 22°C. This abnormal state of temperature is kept up with a little variety as the year progressed. As the seasons exist, they are recognized not as warm and cool periods, but rather by variety of precipitation and shadiness. Most noteworthy precipitation happens when the Sun at late morning is overhead. This occurred two times annually on the equator in March and September, and in this way there are two wet and two dry seasons. Further far from the equator, the two blustery seasons converge into one, and the atmosphere turns out to be more monsoonal, with one wet season and one dry season. In the Northern Hemisphere, the rainy season happens from May to July, in the Southern Hemisphere from November to February.

The Building façade:

Building façade has an extreme impact on the thermal performance of the room. Customarily, confronting south was the ideal building introduction with a patio to give shade in the summer, while eastern and western dividers are outlined without windows, or connected with adjoining structures. Be that as it may, now with the common tower outline, an individual flat is prone to face simply one yet any single headings. Additionally, to give a view to the tenants, vast, arched molded windows have turned out to be extremely prevalent and are seen as the extra market esteem by both domain designers and potential purchasers. Subsequently, sun based warmth increases are getting to be a predominant ventilating burden. It creates the impression that the route forward is to give compelling flexible outside shading. The customizability may provide a tradeoff between holding the charming view and diminishing sun powered warmth pick up when needed. Samples are the canny façade as tested in the European examination initially imagined for office applications. Different innovations like keen glasses may be helpful, yet their expense adequacy may need further exhibition [12].

Passive Design:

The design approach that deals with the utilization of natural resources such as the sun and wind to produce heat, light, or cool in a building is termed passive design [13, 14 & 15]. Passive solar or passive cooling architecture use the opportunity of the solar energy from the sun to optimize heating or cooling due to building’s solar exposure and the natural prevailing wind situation. Employing passive design strategy requires minimal maintenance and reduction in energy demand by reducing or eradicating active cooling systems adapted to control interior lighting and temperature.

The passive design system can involve the physical feature of the building in question. It includes the orientation of the building, placement of window, installation of skylight, insulation and building materials. Specific components of a building, which include fenestrations and window shades, are inclusive. In zero carbon building (ZCB), the several passive design strategies result to 20% savings in energy compared to the same building of the present design standard.

Principles of Heat Transfer:

The condition of being hot is referring to as heat. Transfer of energy from the region of higher temperature to the area of lower temperature is known as heat transfer. Heat is transferred to and from objects -- such as you and your home -- via three processes: conduction, radiation, and convection.

Conduction is heat traveling through a solid material. On hot days, heat is conducted into your home through the roof, walls, and windows. Heat-reflecting roofs, insulation, and energy efficient windows will help to reduce that heat conduction.

Radiation is heat traveling in the form of visible and non-visible light. Sunlight is an obvious source of heat for homes. In addition, low-wavelength, non-visible infrared radiation can carry heat directly from warm objects to cooler objects. Infrared radiation is why you can feel the heat of a hot burner element on a stovetop, even from across the room. Older windows will allow infrared radiation coming from warm objects outside to radiate into your home; shades can help to block this radiation. Newer windows have low-e coatings that block infrared radiation. Infrared radiation will also carry the heat of your walls and ceiling directly to your body.
Convection is another means for the heat from your walls and ceiling to reach you. Hot air naturally rises, carrying heat away from your walls and causing it to circulate throughout your home. As the hot air circulates past your skin (and you breathe it in), it warms you.

Window Performance Rating:

Windows are rated by the National Fenestration Rating Council (NFRC) based on these measured properties and rated according to the following energy performance characteristics:

Solar Heat Gain Coefficient (SHGC):
The fraction of solar radiation admitted through a window or skylight, both directly transmitted and absorbed, and subsequently released inward. The solar heat gain coefficient has replaced the shading coefficient as the standard indicator of a window's shading ability. It is expressed as a number between 0 and 1. The lower a window's solar heat gain coefficient, the less solar heat it transmits, and the greater its shading ability. SHGC can be expressed in terms of the glass alone or can refer to the entire window assembly. For near-normal incidence only, \( \text{SHGC} = 0.86 \times \text{SC} \). See also Shading Coefficient (SC) (Seifert, 2004, Jori, 2010, Slovak, et al., 2010, Singer, & Simon, 2013, Dall’O’, & Dall’O’, 2013, Marchand, 2014).

<table>
<thead>
<tr>
<th>Projection/Recessed depth Factor</th>
<th>SHGC multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equal or greater than 1.0</td>
<td>0.00</td>
</tr>
<tr>
<td>Equal or greater than 0.50 and less than 1.0</td>
<td>0.625</td>
</tr>
<tr>
<td>Equal or greater than 0.25 and less than 0.50</td>
<td>0.75</td>
</tr>
<tr>
<td>Less than 0.25</td>
<td>1.00</td>
</tr>
</tbody>
</table>

U-factor (U-value):
A measure of the rate of non-solar heat loss or gain through a material or assembly. It is expressed in units of Btu/hr-sq ft-°F (US) or W/sq m-°K (European metric). Values are normally given for NFRC/ASHRAE winter conditions of 0° F (18° C) outdoor temperature, 70° F (21° C) indoor temperature, 15 mph wind, and no solar load. The U-factor may be expressed for the glass alone or the entire window, which includes the effect of the frame and the spacer materials. The lower the U-factor, the greater a window's resistance to heat flow and the better its insulating value in the template climate. However, higher U-factor favours the tropical climate table 2.

To convert the U-factor from US (imperial/IP) to European (metric/SI), multiply the imperial number by 5.678. For example, If \( U = 0.35 \) Btu/hr-sq ft-°F in imperial units, then \( 0.35 \times 5.678 = 1.9873 \). The U-factor in metric units will be 1.9873 W/sq m-°K.

<table>
<thead>
<tr>
<th>Typical Window Type U Factor Ratings</th>
<th>Btu/hr*ft2</th>
<th>W/m2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old metal casement window 1.3</td>
<td>1.30</td>
<td>7.38</td>
</tr>
<tr>
<td>Good quality single-pane window 1.0</td>
<td>1.00</td>
<td>5.68</td>
</tr>
<tr>
<td>Good single-pane with storm window .6</td>
<td>0.60</td>
<td>3.41</td>
</tr>
<tr>
<td>Double-pane with low-E glass .4</td>
<td>0.40</td>
<td>2.27</td>
</tr>
<tr>
<td>Triple-pane with low-E glass .25</td>
<td>0.25</td>
<td>1.42</td>
</tr>
</tbody>
</table>

Benefits of good window design:
Windows are a vital part of any home—they allow natural light into the home providing views and fresh air. Well-planned and protected windows improve comfort year-round and reduce the need for heating in winter and cooling in summer. Window size, orientation, glazing treatment, shading and internal coverings can have a significant impact on energy efficiency and comfort. Designing north windows for maximum solar access can reduce winter heating bills by up to 25%. External shading can block up to 80% of summer heat gain through windows. Internal window coverings and double glazing can reduce winter heat losses by around 40%. Window design and shading principles

The three main principles of energy smart window design are listed below.
1. Maximise winter heat gain by orientating windows to the north and sizing windows to suit the amount of thermal mass in the dwelling.
2. Minimise winter heat loss through appropriate window sizing, together with double glazing and/or close-fitting internal coverings such as drapes with pelmets.
3. Minimise summer heat gain by protecting windows with external shading devices, and through appropriate sizing and positioning of windows. The same principles apply to other types of glazing, such as glass doors, roof windows and skylights. Wherever the term ‘window’ is used, it encompasses all forms of glazing.
**Theoretical Framework:**

The fundamental principle behind heat gain or transfer inquisitive in buildings was rooted from the importance attached to thermal comfort condition in buildings. Therefore, theories supporting this condition are taken into consideration.

Solar control through shading devices is most effective when designed specifically for each façade, since time and duration of solar radiation vary with the sun’s position in the sky - its altitude and azimuth (Shen, & Tzempelikos, 2012, Athienitis, & Santamouris, 2013, Lechner, 2014). Solar shading devices can substantially reduce the cooling load of buildings. According to a recent literature review (Dubois, 1997), this reduction is between 23-89% depending on the type of shading device used, the building orientation, the climate, etc.

In order to save energy, shading devices should be integrated to a building’s façade at an early design stage. This can be achieved using "traditional" design tools like solar path diagrams and shading masks or special computer programs that automatically "generate" the optimum shading device geometry as a function of a set of input parameters (e.g. orientation, latitude) (Dubois, 2000).

The work of Oosthuizen, and Jane (2011) revealed in their result that one of the parameters in the convective heat transfer rate from a window covered by a room blind is the dimensionless “depth” to which the window is recessed, \( R = r / L \), where \( r \) is the window recessed depth and \( L \) is the overall height of the window figure 5. This signify that how deep a window is recessed and it height will affect the heat transfer through the window.

![Fig. 5: situation considered in the work of Oosthuizen, and Jane (2011)](image_url)

**Discussion:**

Façade is the demarcation of the building envelop that distinguish the outdoor environment from the indoor space of buildings. It is the exterior walls that protect the buildings from the harsh weather condition such as temperature, rain, sunlight, wind, etc. and serves as the security of lives and properties. Previous studies revealed facts about the significance of solar heat gain in buildings, most especially office buildings. The essence of thermal comfort in office buildings can not only tied to the fact that it provides a conducive
atmosphere for the occupants and save energy, but also enhances employees’ job performance among others. Thermal comfort is also one of the major components of green building that sustain building development as it reduces the mere quest for mechanical cooling demand thereby increases energy efficiency in buildings. Heat gain into building causes thermal discomfort, and its minimisation can be optimized by reducing the heat transmission. In addition, the reduction of direct solar radiation from the outdoor into the interior of the building through shading strategy is very vital. Façade design is one of these strategies that can be applied to reduce heat gain into building hence, thermal comfort realization. Façade configurations can be used in all types of climate, as it can optimize and minimize heat gain into buildings. For the purpose of reducing heat gain in the building, many studies were conducted, among them, is the work of [16]. The assumption of his study is that the configuration of façade using shading strategy to intercept with the direct sunlight that accompanies with heat radiation that causes heat gain into buildings will be minimized. This strategy reduces the overall thermal transfer value (OTTV) thereby; improve the thermal performance of the room most especially the tropical climate of Malaysia. While in another study [17] shows that effective shading devices reduce the cooling load of the building hence conserving energy, a building’s structure or an element of it is designed to prevent solar heat from penetrating, so as to keep its internal temperature low.

Conclusion:

External shading devices have been identified as the best shading strategy to reduce the intensity of solar radiation in buildings. Although, some of these devices have been faulted due to some challenges faced by them. Best shading option recognized is the self-shaded building form, in which recessed window shading strategy was recommended as it reduces the heat without much affecting daylighting. The crucial recessed parameter to be considered is the dimensionless “Depth” (R) which depends on the recess depth (r) and the height of the window (L). These parameters will evaluate the Solar Heat Gain Coefficient (SHGC) which will in turn determine the shading ability of the recessed window. Solar heat gain coefficient ranges from 0 – 1, and the lower its value the more the shading ability of the window. In considering thermal performance of windows in tropical or summer period of the season, SHGC is preferred to U-factor or U-value because the later deals with the heat flow that consider the rate of escape of heat from the room or it conservation to reduce the heating load in temperate or during winter season.

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