

IMPLEMENTING VERTICAL GREENERY ON OFFICE FAÇADE OPENING TO IMPROVE INDOOR LIGHT QUALITY

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ABSTRACT

In medium-rise office buildings in tropical climates, façade fenestration is mostly dominated by a glass curtain wall. In this case, an effort should be done to control the daylight penetration and to shade glare of low sun angle, especially from a west orientation. The idea is to utilize the vertical greenery system (VGS) on facade opening, how it performs as glare limitation as well as accommodating view. Firstly, the variable of artificial shading to a light parameter is studied. Then, the previous research on VGS was explored, to find its influential variables. The last step was to develop a recommendation for VGS implementation on office facade opening to improve light quality. Finding from the study, the most influential variables are the plant species suitable to the climate condition, its canopy leave area as a light variable, and the placement; integration of the plants' construction system with other facade elements which consider light angles of incidence and viewer's sightlines.

Keywords: Office building facade; vertical greenery system; indoor light quality.

INTRODUCTION

In tropical climates, the building facade usually has a role to filter the unexpected external climate element such as high air temperature, high intensity of solar radiation, and high luminance reflections from daylight that bring up discomfort glare indoors (Mahdavi, 2013; Hirning, 2016). Facade opening has an important role from controlling daylight penetration to glare limitation, as well as accommodating view. In medium-rise office buildings in the tropical climate, since facade fenestration is mostly dominated by unshaded glass curtain walls (Dinapradipta, 2015), an effort should be done to shade the low sun angle that brought unacceptable glare for office workers. (Dinapradipta, 2015; Lim, 2010). Visual activities such as reading, writing, and working on visual display terminals/VDT-based devices such as desktop computers and laptops are the main activities in an office building. In this case, a good lighting environment especially adequate daylight that penetrates through the fenestration with no excessive brightness is beneficial for maintaining daily visual comfort besides reducing energy.

Office Building Facades for Daylight Utilization and Visual Comfort Problem

From climatic data of tropical regions, the outdoor light level from overcast sky conditions is approximately 10,000 lux; but the highest level can reach 100,000 lux on a clear day (Rahim, 2009). In the

indoor area closest to windows, the light level may be reduced to approximately 1,000 lux; but this light level is still high since the DF requirement for office works was 2-5% or equal to 250-500 lux (CIBSE, 1999; SNI 03-6197-2001). This level may increase according to office work requirements (Design builder, 2008). Therefore, due to the high luminance near the glass area, wide-span offices seek to increase daylight uniformity with light pipes. (Elsiana et.al, 2015). Even combining light pipe with fixed external shading e.g. the light shelf is indicated to reduce glare to an imperceptible level. (Elsiana et.al., 2021). A horizontal illuminance above 1500 lux usually brings visual discomfort (Lim, 2011; Lim, 2012; Mahdavi, 2013). Visual activities usually have been done in hours, that's why the office worker brought eyestrain that needs to be relieved by looking out the window to see the view outside. Unfortunately, the glass façade is usually very bright because the intermediate sky patches reflect by this surface. This brings up direct glare, especially when the window luminance is higher than 5600 cd/m² (Shin, 2012). For achieving visual comfort for office users, view is very important as it is needed for relieving eye fatigue, reducing stress, and improving satisfaction in the office environment and workability (Hahn, 2021; Lottrup, 2015). From research by Shin, 2012, luminance level 5600 cd/m² felt just uncomfortable by 62% of users, while luminance 10000 cd/m² felt uncomfortable by 95% of the user. Measurement of glass opening from Kim, 2012 the window luminance ranged above to lower position from >15000 until 700 cd/m². So, the above position of the

glass facade is a potential glare and brings visual discomfort that needs shading devices.

In medium and high-rise office buildings more than 25 meters high, the facade is usually wider than the roof; that's why the facade design is crucial in determining better occupant's visual comfort. In this case, understanding the geometry and mechanism of shading devices on opening, toward sun position and daylight at days along the year are the key elements to get illuminance sufficiency without glare, as well as accommodating view.

Facade Elements and VGS as Potential Shading Devices

The facade fenestration elements are glazing material, external and internal shading (Knaack, 2007). Santamouris and Asimakopoulos, 1996, classified shading as fixed shading elements and adjustable

shading elements. Fixed external shading such as overhang, vertical fins, egg-crate, and balcony; whilst tents, awning, blinds, pergola, as well as deciduous plants, trees, and vines are adjustable ones (Lechner, 2009). For internal shading, the adjustable ones are curtains, rollers, and venetian blinds; whilst light shelves are fixed.

VGS is potential sustainable shading since it is a biotic sun tracker with a natural aesthetic that brings psychological relieves for humans, as an advantage compared to artificial shading elements that are abiotic (Ehleringer, 1981; Montacchini, 2017; Radic, 2019). Besides, it has the advantage of supporting the sustainability and biodiversity of nature. Table 1 lists research results on the benefit of VGS. But some disadvantages for VGS implementation as façade elements usually are its maintenance and uncontrolled life cycle as a response to climate conditions since it is biotic (Otelle, 2011; Bustami, 2018).

Table 1. VGS Benefit

Topic / Variabel	Researcher/year/location/method/ VGS type (LW=Living wall, GF=Green Façade)	Result
Thermal	N.H. Wong et al/ 2010/Singapore/ experiment/GF & LW of 8 species	Surface temperature reduction for LW=11.58°C, GF = 4.36°C
	S.C.M. Hui, Z. Zhao/2013/ Hongkong/mathematical model/ LW	Thermal reduction by heat absorption of VGS and lower humidity by evaporation and evapotranspiration process
	H. Yin, et al./2017/ Nanjing China/Observation/GF	In linear, the denser the higher temperature reduction. Vegetation enclosure influence cooling linearly; whilst foliage thickness, density and volume influence exponentially to cooling performance. Orientation influences the plant growth and solar irradiance it received.
Design	L. Bianco, V. Serra, F. Larcher, M. Perino/2017/Italy/Design LW	Modular LW using prefabricated and light material for easy installation and maintenance; patented as <i>felt-pocket living wall system</i> . This system with substrate can lower the thermal transmission to 40%.
	M. Manso, J.P. Castro-Gomes/ 2016/Mediterranean/Experiment/Green wall & green roof	The use of recycle material as Geogreen, a mixing of geopolymer waste and corkboard as LW modular give cooling and can be implemented as VGS or green roof.
Vegetation	L. Jørgensen, D.B. Dresbøll, K. Thorup-Kristensen, /Denmark/ 2014/Experiment/LW	Perennial plant is more recommended to minimize maintenance cost and reduce water. A heat resistance, good toleration to salt and local vegetation is more suggested. Edible local plant can be used as LW.
	L.-M. Mårtensson, A.-M. Fransson, T. Emilsson/2016/ Scandinavian/Experiment/LW	LAI=3.5–4, give 34% saver energy. This saving depends mostly to GF orientation.
Phytoremediation	G. Perez, J. Coma, S. Sol, L.F. Cabeza/2017/Spain/n.a./GF	VGS acted as <i>carbon-sequestration</i> . Averagely 0.44–3.18 kg CO ₂ eq/m ² absorb by VGS per year. The result different from tropical climate, which give only 2-33.6% absorption of the Mediterranean result, because of infertile plant.
	M. Marchi, et al. /2015/ Mediterranean/ Dynamic simulation model/ Perennial Mediterranean shrubs	
Economy	S. Charoenkit, S. Yiemwattana/ 2017/Thailand/Experiment/LW	VGS benefit are energy saving, building property value, CO ₂ reduction, and air quality improvement; compared to installation cost, maintenance, and disposal. <i>Payback period</i> ranging from 16-25 years for direct GF, 16-42 years for indirect GF and more than 50 years for modular LW.
	K. Perini, P. Rosasco/2013/Italy/Lifecycle and Benefit-Cost Analysis/GF & LW	
Acoustic	N.H. Wong, A.Y. Kwang Tan, P.Y. Tan, K. Chiang, N.C. Wong /2010 / Singapore/ Experiment / 8 species GF and LW	Substrate absorption reduce sound on low frequency and middle frequency; but plant dispersion reduces slightly on high frequency. Sound absorption increase as far as the plant density. GF and LW increase acoustic insulation property of building.
Social study	A. Magliocco, K. Perini/2015/Italy/Survey	VGS and biophilic infrastructure associated to human welfare. Opinion on VGS can be different among every user. From environment study, trees on outdoor are preferred than VGS.
	M. Asgarzadeh, T. Koga, N. Yoshizawa, J. Munakata, K. Hirate/2010/Tokyo/Experiment	

Until the 2022 year, more than 30 research on greenery facades, or Vertical Greenery System (VGS) in tropical climate has been done (science direct.com). But research on greenery for indoor lighting environments was still scarcely done. This preliminary review paper will explore the geometry and mechanism of artificial shading and the VGS for light variables. At the end of this review, will recommend VGS implementation as shading to improve office light quality.

METHODOLOGY

Fenestration elements which are the glazing and shading; and the VGS are the materials to be reviewed here. The methods consist of three steps. The first step was studying the geometry and mechanism of internal and external shading that is usually used as shading devices on office façades, and its impact to the indoor light environment. Then, the previous research on VGS on light was studied, to find its influential variables. The last step was developing a recommendation on implementing VGS to improve visual comfort.

Step 1a: Glazing Technology, Light and Shade

Office building facade commonly consists of a combination of opaque walls and or fully glazed, curtain walls. This is aimed at supporting the principal activity of office work with lighting as the main requirement, besides the need for a view outside the building. But at certain orientations and times, not only lighting required are being fulfilled but high brightness caused glare for workers. That's why, glazing technology develop from the single, double, and even triple glazing; tinted and reflective for better daylight shade; and the latest is the semi-transparent PV window and electrochromic glass with dynamic tint technology (Piccolo, 2009; Kapsis, 2015; Jamrozik, 2019).

In selecting glass material as curtain wall, electrochromic (EC) glass is the most excellent invention both in energy savings and visual comfort. Experimental research from Piccolo, 2009 was carried out as a function of weather conditions, orientation of cell-test, time, and strategy switching. Using a small test cell equipped with a small area double glazing unit, with one layer of clear float glass with VT=90%, and the other an EC device with visible transmittance (VT) ranging from 6.2 to 68.1%; found that this kind of glass did not always effective for all orientation. For windows in south orientation and under the prevailed climatic conditions, EC glazing with a dynamic control strategy can reduce discomfort glare caused by high window brightness effectively, but still, need shading for reducing the glare of high brightness especially from west orientation with low sun angle.

Kapsis, 2015 reported daylighting performance of semi-transparent photovoltaic (STPV) façade configurations examined by Daysim simulation. STPV module with effective visible transmittance of 30% (STPV30%) which is integrated as the outer glass layer of a double-glazed Low-E window, provides daylight sufficiency within the perimeter office throughout the year, resulting in sDA 300 lux/ 50% = 1. STPV higher than 30% was not recommended, as it will result in undesirable solar gains that reduce annual PV electricity yield. It is also revealed, that a three-section façade configuration with Si-based spaced PV cells on the daylight section and thin-film PV on the view section of the façade gives maximum daylight utilization and view to outdoors. From simulation on DGP, glare occurs when the solar penetration is high when solar altitude is low, during the fall and winter seasons (October to March, from 11:00-14:00). With the Si-based spaced cells STPV module on the daylight section, perceptible glare ($0.35 \leq DGP < 0.40$) was only reduced by 6.5%; whilst disturbing glare ($0.40 \leq DGP < 0.45$) was only reduced by 3.5% along the year. It was caused by the non-uniform luminance distribution between opaque PV cells and the light penetration through the space between the cells.

Research on office workers from Jamrozik, 2019 using glass with dynamic tint technology for view and daylight requirements, found that Tint 1 was the highest percentage of the workday, chosen by most office workers. This tint is balanced between the color of the view outside, and the illuminance inside and reduces glare so that it makes a good lighting environment. But since this kind of glass is costly, other alternatives using shading can be more useful.

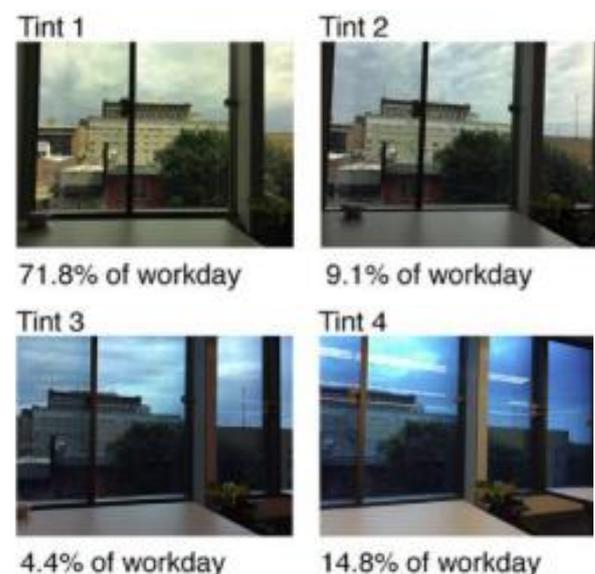


Fig. 1. Glass with dynamic tint technology (Jamrozik, 2019)

Step 1b: External and Internal Shading for Energy Saving and Visual Comfort Improvement

A preliminary analysis for dynamic shading device optimization using venetian blind for tropical climate in the open-plan office has been done by Primanti, et al., 2019. The investigated shading parameters are blind angle and blind covering area. The performance indicators include Spatial Daylight Autonomy (sDA), Daylight Glare Probability Simplified (DGPs), and Energy Use Intensity (EUI). The method for sensitivity analysis is the standardized regression coefficient (SRC). By comparing the magnitude of SRC, the most significant parameter can be defined. For the DGPs indicator, the results when the blind is tilted upward to 80° or downward to -80°, DGPs values are decreasing because direct sunlight is not reflected to the observer. It has also been observed that the SRC values of EUI for Lighting and sDA are contradictory for both shading parameters. When indoor daylight illuminance values are high, lighting energy will decrease. As the blind is tilted, less daylight enters the space, therefore the illuminance decreases, and more lighting fixtures switch on. Comparing the two inputs, the blind angle has a more significant impact than the blind covering area. SRC values are also higher for blind angle than for blind covering area since the blind angle is better for directing sunlight. Based on the result, the SRC for the blind angle is higher than the blind covering area for EUI lighting, sDA, and DGPs with 0.78, 0.704, and 0.702, respectively. It can be concluded that blind angle is a more influencing parameter than blind covering area. Meanwhile, both blind angle and blind covering area do not significantly affect EUI cooling since the SRC is around 0.03. However, with the combination of these parameters, daylight is more likely to be controlled to increase building performance.

More detailed research on the impact of louvre angle on Daylight Factor (DF) has been done (Gutierrez, et al., 2019). All the louvres sections were assessed for Madrid (40°N latitude) at 12.00 noon, with the louvres oriented south. The louvres slat configuration and spacing were designed considering the winter and summer solstices. During summer days at solar noon, the angle of the sunrays with the horizontal plane will lie in the interval 50° and 73°; in the winter it will lie in the interval 27° and 50°. The lighting performance of each louvre's geometry was assessed in the range of 15°–50°, using 5° intervals. The designs were produced to take advantage of the high intensity of direct sunlight which is four to seven times greater than a diffuse skylight. This design results in more diffuse sun rays to an indoor light environment compared to base conditions, a usual flat slat as well as venetian blind. A slight alteration of the optimized profile would be necessary for other latitudes design.

Perforated metal screens are another common shading. Some types of perforated shadings with similar transparencies, depending on geometry and openness factor were investigated (Mainini et al., 2014). The measurements using integrating spheres were collected to obtain spectral optical properties of the shading devices. The optical properties were measured for angles of incidence between normal and 60°, with a step of 15°. The collected data were integrated in accordance with ISO 9050, to obtain visible and solar transmittance values. The comparison between the two perforated metal sheets with the same openness factor, but with different hole dimensions and spacing: the first R2T3 sample with a smaller hole and spacing, has solar and light values that greatly decrease from 39% to 15% toward an increase of incident angles. The other sample, R4T6 with two times bigger hole and spacing has a similar behavior but with a

Table 2. Geometry and Mechanism of Artificial Shading for Office Visual Comfort

Types		Artificial shading			
Shading component	Geometry	<i>Venetian blind</i> (Primanti, 2019)	<i>Louvers</i> (Gutierrez, 2019)	<i>Perforated metal</i> (Mainini, 2014)	<i>Combined glass and roller blind</i> (Dinapradipta, 2015)
	Mechanism	Blind angle; Blind covering area	Slat angle; Slat spacing	% Opening to total area; Thickness	Glass as permanent component; roller blind as flexible one
Office Visual Comfort Parameter	Illuminance	√	√	√	√
		Depend on blind angle arrangement to spatial Daylight Autonomy	Setting of slat spacing and slat angle according to <i>cut off angle</i>	Setting of hole diameter and spacing to sun position	Depend on Visible transmittance of glass type
	Glare reduction	√	X	X	√
		Depend on blind angle arrangement to Daylight Glare Probability	Not examined	Not examined	Dynamic roller blind for better distribution and glare control
	View	X	X	X	√
		Not examined	Not examined	Not examined	Glass opening with dynamic roller blind

smaller transmittance coefficient decrease, which varies from 40% to 32% at 60°. This difference is due to higher inter-reflections in the denser mesh (R2T3) so the different results between the two samples are a consequence of their geometry. Both samples have the same thickness, but the ratio between average hole diameter and thickness is an important parameter to define the angular optical performance of the perforated metal sheet.

Research from Dinapradipta, 2015 on roller blinds combined with a tinted and reflective glass of office buildings found that reflective glass was better than tinted glass in decreasing daylight penetration, but for better distribution & glare control, dynamic roller blind addition was useful.

Step 2: VGS Variables for Light Quality

Quantitative variables

Pérez et al., 2011a, monitored for a year an existing double-skin green façade of a climber plant, *Wisteria Sinensis*. This research has been done at a location close to Lleida (Spain), under the Mediterranean continental climate. The light transmission factor is the ratio between the intermediate space illuminance and the exterior illuminance. This value ranged from 0.04 in July to 0.37 in April, during the season with the dense foliage.

Then, a simple experiment was carried out to determine the transmission capacity of different plant species suitable to this climate (Perez et al., 2011a). The species chosen were ivy (*Hedera helix*) and honeysuckle (*Lonicera japonica*), as perennial plants; others were Virginia creeper (*Parthenocissus quinquefolia*) and clematis (*Clematis* sp.), as deciduous plants. The results of this experiment showed light transmission factor values of 0.15 for Virginia creeper, 0.14 for clematis, 0.18 for honeysuckle, and 0.20 for ivy plants. These values, as occur in the other work (Perez G., et al, 2011b), are comparable to the best values of the shading coefficient that can be obtained using artificial barriers for the south orientation.

Studies deal with the shadow effect produced by green curtains, either making an attempt to calculate directly the ability of interception of solar radiation by plants or using the Leaf Area Index (LAI), which has been traditionally used in agriculture to measure the density of crops and it is linked to aspects such as the growth and yield of crops (Wolter, et al., 2009; Ong, 2003; Wolter, et al., 2012). Ong, 2003 proposed a “green plot ratio” index, based on LAI, as a tool to make urban planning more sustainable.

Research by Kristanto, 2020 with climbing ivy found that even a low LAI ≤ 1 , can reduce indoor illuminance by 30-50%. Vegetation impacts on light were determined by its orientation, depth, and surface area it covered. It was very effective to reduce excessive sunlight since it grew toward the sunlight. Another research with denser *Shibataea Kumasasa* with LAI > 3 , gives the highest daylight reduction until 70-90% for north and west orientation from noon to the afternoon. In this case, the vegetation was too dense so the illuminance was too low for visual activities in the design studio (Widigdo, 2019).

Qualitative variables

Research from Tuaycharoen, 2007 with an experiment conducted on different sky conditions of 20 high-rise office building users, bring the result that natural views with greeneries were chosen by most respondents. Glare sensation is categorized in distance parameter and natural or manmade view, to discover how the view from a window and increase in luminance range can be associated with discomfort glare. This research concluded that glare decrease when interest in natural view increase.

According to Sadek, 2013; people tend to give more attention to the unusual color condition. Moreover, the plant colors are required for a specific situation. Dark green brings a more relaxing room, the green-yellowish and light green makes a cheerful ambiance, giving strength and spirit. While red plants can improve concentration and bring luxury to the environment. Koga and Iwasaki, 2013 with an experiment on tactile stimuli of some different materials such as fabric, metal, and artificial and real leaves of photos plants, found that people feel a hard and cold for metal, and soft and pleasant stimuli of fabric and artificial and real leaves. The difference between real and artificial leaves was in a physiological calm and relaxing sense when touching the real plants. Jeong and Park (2021) experiment looked at 4 kinds of visual stimuli which were the real plants, the artificial plants, the plant's picture, and no plants at all; revealed that the real plants give the most relaxing, comfortable, and natural score; which meant positive mood conditions. That's why natural plants are needed as an important element for the human environment.

In another research from Widigdo, 2019 with students on architectural design studios as respondents; after implementing the VGS on façade opening, 83.8% said that solar radiation was not interfering, 58% had expectations for natural elements as plants for the studio; 41,6 % stated that vegetation affects visual comfort and 7.9 % said that VGS was useful as view.

But they also expected that the vegetation was not too dense, to fulfill the requirement for visual activities of the design studio.

Latter discussion tries to develop some recommendations for implementation of VGS as shading in the case of office building's light quality.

RESULTS AND DISCUSSION

Implementing VGS to improve visual comfort must consider its variables which are the plant species that are suitable for tropical climates. This variable will influence its light variables which depend on plants' canopy leaves area. Another variable is the placement that considers the integration of the façade element, orientation to sun and daylight penetration, as well as user sightlines for improving the light quality indoors.

Plant Species vs Tropical Climate

Climatic conditions influence VGS operation because climate directly affects the specific aspects of plants such as the species to be used, their foliage thickness, their growth rate, their evapo- transpiration, their lifecycle, etc. (Paine, et al. 2012; Hui and Zhao, 2013; Staggemeier, et al., 2019)

Tropical climate near the equator which warm and humid conditions for almost the year characterized by two seasons, the dry and the rainy season. In the dry season from March to October, the air temperature tends to high from 28-35°C in an open outdoor area, with rather dry air at about 50-75% RH. In this season, the plants with flowers were blooming, usually in April-May; but because of the heat and the drier air, the number of leaves of all plants decreases, and even some plant species shed their leaves to decrease the need for water for living. In the wet/rainy season from October to March, the air temperature is usually lower at about 26-31°C but the RH increases until 85-90%; that's why the condition felt warmer because of the higher humidity, even though the air temperature was slightly lower. In this season, because of the high water supply from the rain, the leaves of all plants grow densely. But because of cloudy weather with lower sun exposure, usually, no flowers bloom.

From previous research for Green Façades in the tropical region, climbing plants are usually used, which can be evergreen or deciduous, such as *hedera helix*, *Parthenocissus tricuspidata*, etc. For Green/living walls, modular systems, planter boxes, and hanging plants, such species as *Nephrolepis exaltata/boston fern*, *urechites lutea*, *ophiopogon japonicus*, *tradescantia spathaceae* were recommended. (Wong, 2010; Perez et al., 2014). This recommendation with energy reduction as a goal so that the denser plants all year, the better. But for better daylight requirements, the ideal

would be plants that grow densely in the summer / dry season to exclude high brightness from the sun and have the fallen leaves in the winter/rainy season to let the light enter the room optimally. For this reason, evergreen plant species such as *hedera helix* and *vernonia elliptica* are more recommended than deciduous plants.

According to Sinoquet and Andrieu, 1993, the ability of VGS to filter high solar and daylight penetration or canopy radiation interception depends on its quantitative variables which are, the *leaf area index* that represents foliage thickness per unit area (m²) or *leaf area density* for an area in m³, *leaf area dispersion* which represents how the leaves spacing inside the canopy filter the incident light; whilst *leaf angles* toward the sun will influence how many lights it is transformed/reflected. These 3 variables can be measured for any kind of vegetation; to get a comparable result of its efficiency. But other variables such as the color, the form, and dimension of leaves and foliage canopy, the texture, etc. are other factors that may influence qualitatively. That's why a preliminary study regarding these qualitative variables should be taken before implementing it in an office environment.

Placement

The construction of VGS broke down into 2 big categories, the Green Facades and Green/Living Walls. The green facades can be divided to double skin green facade, grid system, cable wire system, and mesh system; whereas the living walls, can be divided into the pocket system, geotextile felt system, modular system/frame boxes modular, carrier system, substrate cell system, landscape system, moss wall, trough planters, and plug-in system. (Radic et al. 2019).

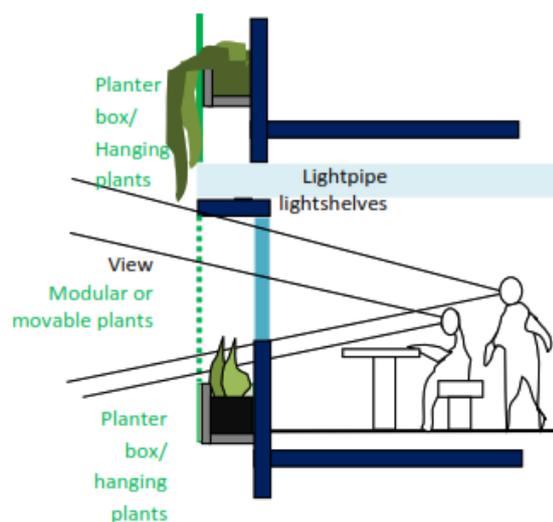


Fig. 2. Recommendation of VGS Placement vs Viewer Position

In practice, this system can be classified as a hanging, creeping/climbing, planter boxing, modular and movable system. Then for integration, the light angles of incidence upon orientation and the viewer’s sightlines need to be considered. Since the facade opening can be divided into three parts vertically, which are: the bottom section, the middle section; and the top/daylight section (Kapsis, 2015), and considering the viewer sightlines as well as integration with other facade elements, so the placement of the VGS can be implemented as Figure 2. The hanging is an effective shading for the top section, the movable or modular will suit the middle section as it operable for shading as well as a view to the outside environment, whilst the planter boxing for the bottom section to shade the lower sun angle.

CONCLUSION

Besides having advantages for its thermal properties for energy reduction, aesthetic impact, biodiversity, and sustainability value; in tropical climates with excessive daylight, VGS has opportunities for improving the visual comfort as well. In application,

some variables to consider for implementing VGS for light quality on office building facades are:

PLANT SPECIES; local plant recommendations that are suitable for the climatic condition. For tropical climates, the evergreen plants especially the species that need full sunlight exposure and grow throughout the year will be more suitable than deciduous ones that have fallen leaves in the dry season. The capabilities of VGS to improve light quality depend on its quantitative variables which are the leaf area index, leaf dispersion, and leaf angles of plants that influence illuminance vs luminance contrast produces. Whilst its color, form, and texture are the qualitative variables that give advantages as a view to relieving eyestrain and relaxing sense.

PLACEMENT/Position on Building Façade; integration the plants construction system with wall and facade element which consider light angles of incidence and viewer’s sightlines

The recommendation in this paper still needs to be proved by later experimental research on VGS along the plant life cycle to get illuminance, luminance data, view, and glare sensation of building user, how its impacts to indoor light environment.

Table 3. Comparison of Artificial Shading and VGS as Biotic Shading for Office Visual Comfort

Types		Artificial shading				Biotic shading
Shading component	Geometry	<i>Venetian blind</i>	<i>Louvres</i>	<i>Perforated metal</i>	<i>Combined glass and roller blind</i>	Vertical greenery system (VGS)
	Mechanism	Blind angle Blind spacing	Slat angle Slat spacing	% Opening to total area Thickness	Glass as permanent component; roller blind as flexible one	
Visual Comfort Parameter	Illuminance	Depend on blind angle arrangement to spatial Daylight Autonomy	Setting of slat spacing and slat angle according to <i>cut off angle</i>	Setting of hole diameter and spacing to sun position	Depend on Visible transmittance of glass type	Leaf area, Leaf dispersion, Leaf angle
	Glare reduction	Depend on blind angle arrangement to Daylight Glare Probability	Not examined	Not examined	Dynamic roller blind for better distribution and glare control	Arrangement of leaf area, leaf dispersion, leaf angle
	View	Not examined	Not examined	Not examined	Glass opening with dynamic roller blind	View to vegetation can reduce glare
						Form, color and texture of VGS enhance view

Table 4. Implementation of VGS on Office Façade to Improve Light Quality

Facade element	Types	Character of light	Recommendation
Glazing	Clear	High brightness	VGS with high LAI (>3)
	Tinted	Medium brightness	VGS with medium LAI (1-3)
	Reflective	Medium brightness	VGS with low LAI (< 1)
	Electrochromic	Disadvantage from low sun angle	VGS addition only at low sun angle orientation
	STPV window	Disadvantage for light uniformity	VGS addition for better light uniformity
External shading	Overhang	Sun blocker	Hanging/planter box VGS
	Lightpipe	Sun collector & forwarder	No VGS
	Perforated metal	Sun filter module	Modular VGS can be accommodated
Internal shading	Roller/venetian blind	Sun filter	Movable VGS as alternatives
	Louvres	Sun filter	Movable VGS as alternatives
Combined	Window and opaque wall	Daylight and solar penetration balance	VGS applied for WWR > 35%

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